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DATABASE MANAGEMENT SYSTEM MODELING FOR CONSTRUCTION PROJECT COST AND TIME DATA PROCESS

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DATABASE MANAGEMENT SYSTEM MODELING FOR CONSTRUCTION PROJECT COST AND TIME DATA PROCESS

By

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ABSTRACT

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By

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In order to successfully manage a construction project, cost and time controls are two important project management functions and their related information usually draws more concern from project managers. A database management system can be designed to collect, store and manage these data throughout the construction process to satisfy information needs for decision making.

The critical part of designing a database management system is the abstraction of the conceptual data model from reality. The primary objective of this research was to develop a formal conceptual database model for construction project cost and time related data. This conceptual model was developed using the entity-relationship database modeling method. A construction company's business process was analyzed to identify the project construction processes and events. Data generated in these processes was recorded around these events with what (resources) and who (agents) are involved. A prototyping database structure based on this conceptual model was implemented into the MS Access environment. Two case studies were conducted to evaluate the model application in construction practice.

To my Parents and Sister,

And to my Uncle Dr. Shun Ku

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A/E/C: Architecture/Engineering/Construction

CAD: Computer-Aided-Design

CBS: Cost Breakdown Structure

CM: Construction Management

COMBINE: Computer Models for the Building Industry in Europe

CPM: Critical Path Method

CSI: Construction Specifications Institute

DBMS: Database Management System

DFD: Data Flow Diagrams

ER: Entity Relationship

HVAC: Heating, Ventilating, and Air Conditioning

IS: Information System

OBS: Organization Breakdown Structure

QBE: Query by Example

REA: Resource-Event-Agent

STEP: the international STandard for the Exchange of Product data

SQL: Structured Query Language

WBS: Work Breakdown Structure

Chapter 1

Overview and Introduction

1.1 Overview

Construction projects are time-consuming undertakings and each project usually involves much more investment of money than a typical manufactured product. The development of a project normally consists of several phases including planning and definition, design, procurement and construction (Clough and Sears, 1991). Management of a construction project is one of the most challenging management assignments in the industrial world. In a short period of time after contract award, the field manager must finalize the preliminary project plans developed during the pre-bid or proposal phase, order materials and construction equipment, erect construction support facilities, and recruit and mobilize a construction force (CII, Project Control, 1987). Of course, the primary objective during the construction process is completing the project on time and within the budget while meeting established quality requirements and other specifications. To achieve this goal, a well-designed project management system must be implemented. Construction project management, applied to a given project, is a process to monitor the field operations according to the plan, find the deviations, and take timely corrective action. The construction process starts with the onset of construction. At this point, a comprehensive construction budget and a detailed time schedule of operations have been prepared and serve as the base plan for project control. After the project has been started, the reporting system provides progress information to monitor and measure the actual construction process. Deviations from the plan are identified and management action is needed to revise it. Project control is established this way (Clough and Sears, 1991). During the construction process, many data are generated. One of the important parts during the control process is to collect, store, and manage data throughout the construction process to draw progress information used in the monitoring and reporting system in a timely fashion. In the meantime this information can be used as a basis for planning future projects.

A well-designed information system should be applied as part of an efficient project management system. The information system is usually composed of people, computer hardware, software programs, and database(s). It provides a mechanism for data collection, storage, and retrieval. It also facilitates the transformation of data into information and the management of both data and information. Information plays a key role in construction project management. For a construction project to be well managed, data generated during the project construction process must be readily available. As an important component of an information system, database technology is an important tool for managing the enormous amount of data generated throughout the project construction process, and is one of the areas that can be improved to benefit project management. The term database refers to a shared, integrated computer structure that houses a collection of data (Rob and Cornel, 1997). Database management systems (DBMS) are programs to manage the database. Through an efficient DBMS, data from the project at hand is available for management on a timely basis and also available for further project use.

Cost and time management is the key functions in a project management system, since they are the two major criteria to measure the success of a project. Cost and time-related information has usually drawn more attention from project managers than other issues. Project cost and time management are based on cost and time plans developed for the project and on an information system that will provide data for comparing planned performance with actual performance (Clough and Sears, 1991). So the major concern of a database management system (DBMS) in this research is for the collection, storage, management and retrieval of the cost and time-related data to facilitate project cost and time management.

Computer and information technologies have been employed in many business processes and have made previously impossible things, possible. The fast development of CPU speed, the memory capacity and hard disk space has physically improved the database management ability in PC based computers. The construction industry can also benefit much from this technology improvement. During the construction process large amounts of data are generated, a well-designed computer-based project database management system can provides a central data storage pool and help to achieve automatic information processing and retrieval.

1.2 Problem Area

Construction project management begins from a project plan, which sets up the budget and target for operation. After initiating the construction, the project-controlling phase begins. Successful cost and time control are key parts for project success. Effective control is dependent on a good information system. This system provides feedback information to measure, evaluate, and report job progress, comparing it with the planned performance. Information must be timely with little delay between field work and management review of performance. This timely transfer of information gives the project manager a chance to evaluate alternatives and take corrective action while an opportunity still exists to rectify problem areas (Clough and Sears, 1991). This need for rapid and efficient information transfer raises the requirement of an efficient information system for timely retrieval of useful information for management. As essential components of an information system, database provides the basic structure and pool to collect, store and retrieve data into information. The problem is how to design and implement such a database management system (DBMS) for construction project data, especially cost and time data.

Traditionally, a construction project cost system is designed to control the construction costs within the established control budget and to develop information for estimating future work. Cost data are stored and processed in the job cost system. Along with the construction progress, time data are entered in the schedule system to update the preset schedule. Each type of data collection has traditionally become independent from the other and maintained separately. Managers are dependent on information from both systems, which reduces the efficiency of obtaining meaningful information and making prompt and fully informed decisions (Abudayyeh and Rasdorf, 1991b). Sometimes they are misdirected by different types of information related to one object. A DBMS for time and cost control functions must be able to collect, manage, and use both types of data in an integral and timely way. When the time data can be stored and managed in the cost system, the integration of both the functions in one system can be realized. Basic to a project management information system is identifying specific packages of work referred to as work items (Adrian, 1979). These work items serve as a means of integrating the project time management function in the cost system as an integrated system. So the first problem to be solved in building a project DBMS for cost and time data is to define the work items as the basic data storage units. There are many ways to define specific work items for a given project. The broader the scale of a work item and the fewer work items you have for a project, the less accuracy will be provided for determining the project's work performance. The way a project manager defines the work items also reflects the detail level in the operation that will be planned, monitored and evaluated. A well-known breakdown structure is the Master Format published by the Construction Specification Institute (CSI). It also provides a standard for numbering and classifying sections to organize both estimates and schedules by the same numbering system, which can then be used for the control budget and schedule (Barrie and Paulson, 1992). Some researchers have proposed to use work packages which are based on the work breakdown structure to divide a project into manageable work packages that have well-defined scopes of work. Each work package represents the actual tasks that will be used in the project's network and is suggested as a control account against which both cost and time data are acquired and accumulated (Rasdorf and Abudayyeh, 1991a). This means that work must be scheduled and estimated in accordance with the control account in the plan stage. In the operation phase, data will be collected and stored in these accounts for project monitoring, reporting and controlling. The work package and CSI code system can be integrated to provide the basic numbering data storage unit for the modeling of project DBMS in this research.

The availability of DBMS makes it possible to deal with more sophisticated uses of the project data resource, if the DBMS is designed to make use of that availability. The data structures and the extent of the relationships among them play a powerful role in determining how effective a DBMS is. Therefore, design of a database management system is very crucial. Only a well-designed database can facilitate data management and become a valuable information generator. Researchers have focused on the process of designing databases to support numerous complex applications. The database development begins from the procedure to determine the information needs of the end users. Then system designers use a conceptual model to derive a formal representation of the information elements obtained in the requirement survey. This conceptual model is transferred into a computational DBMS logic model suitable for implementation in the computerized environment. Finally, the model is applied to a specific hardware and software environment. In the development process, conceptual design for a conceptual database model is very import. It is emphasis on an understanding of the structural properties of data that is independent of implementation details (Batini, et. al., 1992). It represents the domain reality in an abstraction level. Using conceptual models, one can build a description of reality that is easy to understand and interpret (Batini, et. al., 1992). In the case of project construction, as shown in Figure 1.1. Labor, material and equipment are resources that make a project. Superintendents are involved in the construction process to be in charge of the process. Parts of the project work are subcontracted to subcontractors. This typical picture of project construction is illustrated in the upper part of Figure 1.1. All these components and activities have related cost and/or time data. In the middle of Figure 1.1 a conceptual database model represents this picture and summarizes the data in an abstraction level. When data are presented in their logic view in the conceptual model they can be applied in a computerized environment for information processing to get the demand information for managers. The process of data abstraction from reality to computerized information processing is shown in Figure 1.1.

As a conceptual database model is critical in database design, the problem here is how to develop such a model. Model development requires the use of tools. The Entity-Relationship (ER) model method is widely used in the relational database environment, which is also the database environment used in this research. Several conferences have been organized on the applications of the ER model to database design and to software design in general. In 1988 American National Standards Institute chose the ER model as the standard model for Information Resource Dictionary Systems (Batini, et. al., 1992). In this model data elements are organized around the basic notions of entities, relationships and attributes. More explanation about this model will be given in chapter 3. These notions can be furthered by the "real-world" objects that will represent the system. In an accounting information system these would include: economic resources (such as raw material) controlled by an enterprise, economic events (such as issues and purchases of raw material) affecting the resources, and economic agents (such as foremen and buyers) participating in these events (McCarthy, Rockwell and Armitage, 1994). This Resource-Event-Agent (REA) representation and relations consist of the REA template in the relational database environment. REA was introduced by McCarthy(1982) as a domain-specific theory for the design of accounting information systems, and its use has gradually been expanded to the modeling of economic phenomena in general (Geerts and McCarthy, 1994). This concept will be explained more in chapter 5.

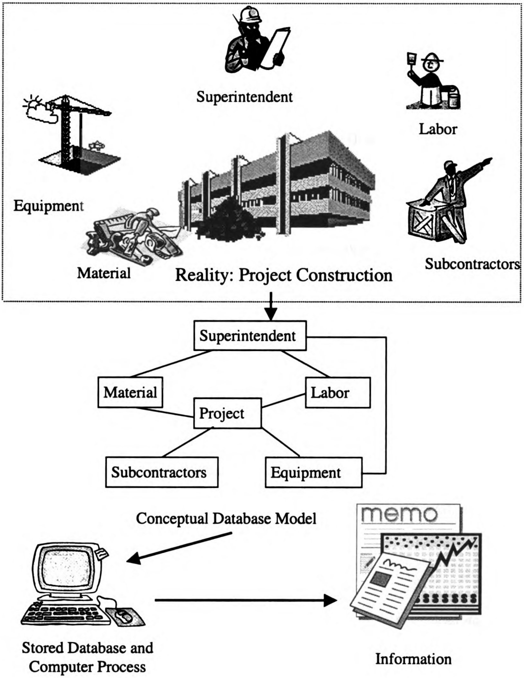

Figure 1.1 Conceptual database model abstraction and information processing

Database and information system design also requires a good understanding of the business process of its domain. The value chain concept provides a systematic method for examining all activities for which a company is responsible and how they interact. Then it is viewed as an input and output process in which resources are entered as inputs and some value added-outputs are produced through the production process. A typical manufacturing company might include product and service flow through (1) research and development; (2) engineering; (3) production and manufacturing; (4) marketing; (5) sales and distribution and (6) service. Each step can be considered as a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer (Geerts and McCarthy, 1994). From a construction company point of view, the project construction phase can be considered as the production and manufacturing cycle. Labor, material and equipment are inputs to the process. Through the construction activities, a new facility is the output that will be passed on to the customer (owner). The value chain concept and REA template can be used to analyze business processes where economic exchanges are evaluated from a database perspective. These concepts will be applied in this research to analyze the construction business in a database environment.

1.3 Research Objectives

The primary objective of this research is to develop a formal conceptual database model for construction project cost and time related data.

The purpose of this model is to present data elements of a domain system in an organized and abstract representation via standard modeling. The domain system, which is the part of reality being represented in a database system, is the integrated project cost system. An integrated system means that data processed here are not just cost data, but some time related data for schedule control are also considered here. Based on this model a database management system (DBMS) can be built to facilitate project information processing. This research explores database design development issues and highlights conceptual database modeling.

The specific objectives of the research are:

(1) To review the issue of integrating time related data to the cost system and to establish a framework which defines basic control items for data storage and control purposes. After time data have been collected and stored in the cost system, this system becomes an integrated cost system which can perform some time control functions;

(2) To investigate issues about information systems and the database development life cycle. The database development process for the integrated cost system is outlined;

(3) To develop a conceptual data model for the integrated cost system. This conceptual model represents a project integrated cost system in a database view. It can also be transferred into a logical model tailored to specific DBMS software.

(4) To build a prototyping database structure in MS Access. These examples will demonstrate how data can be processed in the database system that is built from the conceptual model to prove the concepts explained in the model.

A database reflects an efficient way of storing, accessing, and managing end user data. A theoretical database development process is needed to produce an efficient database. Conceptual design is the most critical phase of database design within this process (Batini, et.al., 1992). Pursuing the above objectives will place emphasis on the phase that includes information requirement analysis and conceptual model development. The fulfillment of these objectives will give the author some specific knowledge of database development for construction project data. It will also help integrating information system concepts in the construction field to accomplish effective project management.

The domain projects that are studied in this research will be projects that vary from one million to one hundred million-dollar values. When a job value is in this range, a detailed, complex reporting and information system is required to serve project management needs. Then the cost of implementing this system can be justified by the value of management data that it provides. A simpler and less elaborate information system is sufficient for smaller and simpler projects.

1.4 Research Methodology

1.4.1 Literature Review

The first step of this research is a comprehensive review of literature. This review includes the areas related to construction project management, integration of cost and time control, information system and database management system design, ER data modeling, relational database software study, value chain and REA business process analysis.

1.4.2 Integration of Cost and Time Control

The next phase is to study the project construction process and the project management system focusing on the cost and time control subsystems. Information requirements and flow in project cost system will be studied. Data elements and their characteristics will be discovered and classified from analyzing documents in this system. The issue of how to integrate the time control function into the cost system will be raised. Basic data storage units for project cost and time data will be identified.

1.4.3 Conceptual Model of Project Database Management System Development

A conceptual model of project database management system will be developed. This model will be a formal representation of the cost and time related data elements generated in the construction process. There are several research tasks involved in developing the model. The value chain analysis tool will be used to study the business process of the construction company. Inputs and outputs during the project construction cycle will be analyzed. The information requirements of a project manager for cost and time management will be examined. The data elements related to this requirement will be organized in terms of entities, relationships, and attributes. The REA pattern will be used to as a template to represent the entities and relationships that are summarized from the real-world objects. Using this method, a conceptual model of the project database system will be developed. This model will provide a logical view of the data that meet the information requirements of the project manager.

1.4.4 A Prototyping Database Structure Implemented in Relational Database Software

In this phase, the author will build sample data tables based on the conceptual model in a relational database software environment. Microsoft Access[1] will be selected as the implementation software. The conceptual model will be transferred to be a particular MS Access relational database model. Data tables will be developed. Some sample data will be entered into Access to show how information can be derived from the database by Structured Query Language (SQL) tool.

1.5 Expected Output

This research study is intended to integrate relational database management technology with construction project management systems. This research will focus on using ER modeling tools and REA templates to develop a conceptual model for the design of a DBMS which will store and manage project time and cost data to facilitate effective cost and time control. It will follow the system approach of the DBMS development process. The DBMS will be built upon the integrated cost and time control systems. By determining the information requirements of project managers and information flow in this system, data elements will be organized in an R(resource) - E(event) - A(agent) template and the relationships among entities will be defined. The DBMS conceptual model will be generated using the ER model. This conceptual model should not be limited to a particular database software application. Based on this model, a

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

project DBMS can be developed. This DBMS will store, manage and retrieve the project cost and time data. In this research, data tables will be built base on this model in Microsoft Access. Sample data will be input to show information processing procedure in DBMS.

1.6 Organization of the Thesis:

This thesis is organized as follows:

- Chapter 2 provides the research and literature review. It describes the existing research work and defines the difference of this research and the goal.
- Chapter 3 outlines the development process for the project database model. It introduces some basic concepts in information and database systems and provides the overview of their development process. The specific model development process for the project cost and time data is described.
- Chapter 4 presents the information requirements analysis in the domain system. It analyzes objectives and functions of project management. The basic storage unit for cost and time data will be defined. Through the common data unit, some time control function is integrated in the project cost system. The information requirements and flow in the cost system are examined. Data elements will be identified and grouped based on the natural logic relationships among them.
- Chapter 5 focuses on the conceptual model development and explanation. To design the cost information system in a database view, the business process of a construction company is examined into cycles and events by value chain analysis. Business events trigger the information process. In an ER modeling environment, REA organizes

resource and agent involved around the event to provide an information process model template. A prototyping database structure is built in MS Access to implement the conceptual model.

- Chapter 6 is the case study. Through the case study, the proposed database view integrated cost system will be compared with the real practice of construction company. The proposed system will be used to try to solve some problems of the reality.
- Chapter 7 completes the thesis by discussing the conclusion and the future research in this area.

Chapter 2

Literature Review

This chapter describes the existing research and literature in the topics of project cost and schedule control system integration, and database modeling in construction management.

2.1 Cost and Schedule Control System Integration

Traditionally project cost and schedule control systems have been used independently. Both a Cost Breakdown Structure (CBS) and a Work Breakdown Structure (WBS) are used in the planning and controlling of construction. The CBS is a breakdown of all cost elements within a project, both direct and indirect. It's used in the estimating process and the cost control system (Construction Industry Institute, 1987). The WBS is a breakdown of the project into tasks which progress is tracked. Based on a WBS the project schedule is generated to serve as the baseline for time control. Since these two systems are closely related, research was conducted focusing on the integration of cost and schedule control systems in order to achieve efficient project management.

2.1.1 Cost/Schedule Integration Problems and Methods

The problem of integration between money and time is a problem of compatibility, because the cost items are associated with the physical elements of the project. The schedule, on the other hand, is a plan of what is to be done and how, and in what sequence it will proceed. These two types of data are sometimes incompatible and the relationship between them can be: one to one; one to many; many to many (Navon, 1994). On the one hand, a given schedule item may relate to only one cost item. On the other hand, and more often, a cost item is related to more than one schedule item and those schedule items can be associated with more than one cost item. Methods to solve the compatibility problem in this research included manually specifying the resources associated with each activity; dividing each cost item equally, or proportionally, among the activities with which it is associated; and assigning each cost item's resources to the appropriate activity automatically by storing each activity's resource information in an embedded database (Navon, 1996).

2.1.2 CPM/COST: An Integrated Approach

In "CPM/COST: An Integrated Approach," Sears defined an activity as a unit of work which takes place in a specific location and has a finite time duration and a cost account is related to functional items of work such as formwork, excavation, and site drainage. He summarized six ways that cost accounts were matched to activities. It included: (1) one-to-one relationships of activities to cost accounts, with distribution being uniform; (2) two or more activities to one cost account with a uniform distribution; (3) two or more cost accounts to one activity with a uniform distribution; (4) any combination of 2 or 3 above; (5) any predefined non-uniform relationship between activities and cost accounts; (6) any discontinuous or undefined relationship through field evaluation of progress.

The simplest form of CPM/COST integration is that of an activity which involves only one cost account and where the cost account is unique to that activity. Because of the requirement of a large number of cost accounts and the bookkeeping burden, a more beneficial approach is to allow numerous activities to makeup one cost account. Each actual resource cost was recorded under a single cost account. The important point was that the activity cost can be forecast for cash flows and cost projections since the relationships of activity and cost account have been established, and the actual cost for each cost account is recorded for historical purposes. It is also possible for one activity to have more than one cost account.

Information such as estimated and actual quantities and costs was stored in CPM/COST files. The format of these files was that of a variable length computer record, which stored data including estimated quantity of work, estimated unit costs for labor, equipment, materials, and subcontracts, as well as actual costs to date, actual quantity, and activity number. Records were organized by the cost account numbers. This file was used to produce reports for cost status, cost-forecast, progress cash forecasting, and time-cost tradeoff (Sears, 1981)

2.1.3 Project Breakdown Model for Integrated Cost and Time Control

To improve the effectiveness of cost and schedule control, researchers are concerned with the quality, integrity, and timeliness of data that flow through these control systems. A number of project breakdown models have been proposed to integrate cost- and schedule-control functions.

In Rasdorf and Abudayyeh's research, They summarized several research in the topic of breakdown project to small unit to integrate cost and time data (Rasdorf and Abudayyeh, 1991a). The first one is a mapping mechanism between the CBS and the

WBS, which the cost in a given cost account from CBS is allocated to one or more activities (tasks) that relate to that account in WBS by percent allocation.

Noticing that a cost account may relate to one or more activities, and at the same time an activity may relate to one or more cost accounts, some researchers proposed using a work-elements concept for integration. A work element was a control account defined by a matrix of work packages from the WBS and cost accounts from the CBS, as shown in Figure 2.1. A work element provides a link between the WBS and the CBS, where a cost account may relate to one or more activities from the WBS, and at the same time an activity may relate to one or more cost accounts from CBS. Examples are shown in the work element matrix table in Figure 2.2. The 30cm walls on the first floor are a work element from the integration of the first floor walls activity and 30 cm walls cost account. In this model the authors recognized the need for a common denominator for acquiring and maintaining data for effective project control.

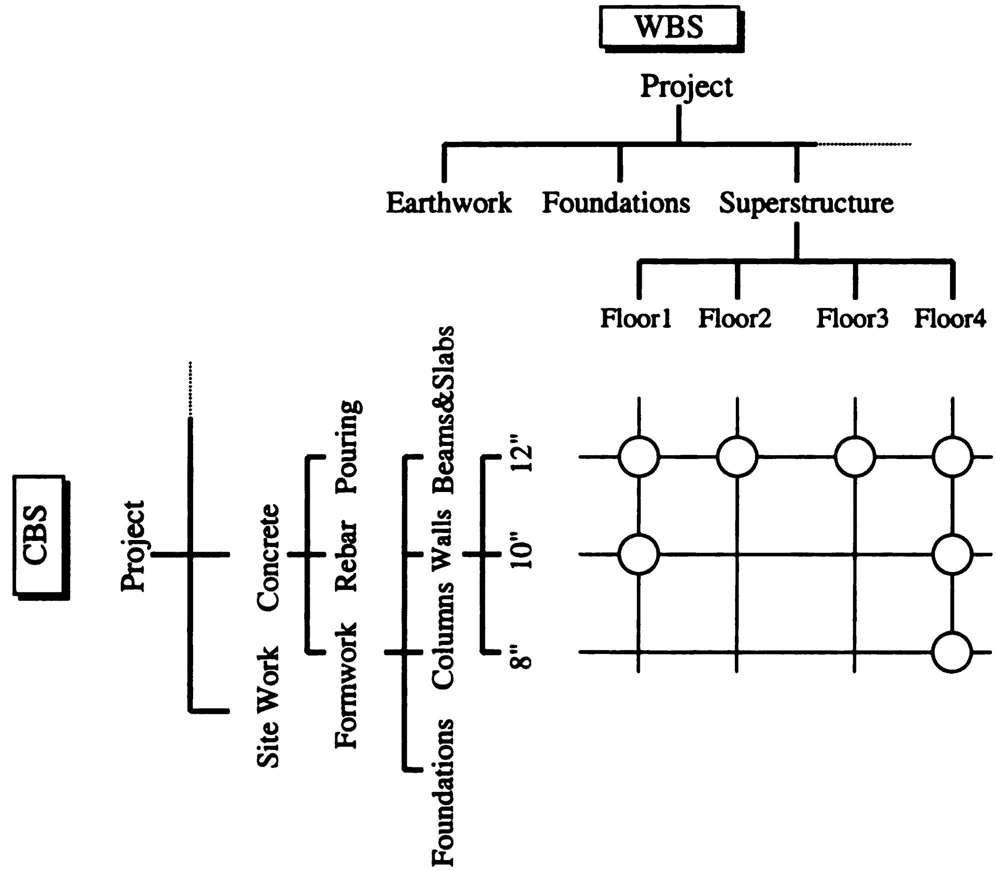

Figure 2.1 Work element model
(Source: Rasdorf and Abudayyeh, 1991a)

		Activities			
		First Floor	Second Floor	Third Floor	Fourth Floor
Cost Accounts	30cm Walls	X	X	X	X
	25cm Walls	X			X
	20cm Walls				X

X: work element

Figure 2.2 Work element matrix table
(Source: Rasdorf and Abudayyeh, 1991a)

In Rasdorf and Abudayyeh's research, they also described another approach developed by Ibbs and Kim (Rasdorf and Abudayyeh, 1991a). Ibbs and Kim (Kim, 1989) defined a new element called the basic construction operation required by a design object (BOD), which is the lowest-level construction task needed to build a specific design object. Thus, a BOD is an object that provides a linking mechanism between a design object and its corresponding construction operation control functions, such as estimating and scheduling. A BOD links to three dimensions: a work package on the WBS, a cost account on the CBS, and a design object on a drawing. For example, the following five BODs can be generated for an 20-cm (8-inch) concrete wall object of area A on the fourth floor: "fabricate formwork", "erect formwork", "place rebars", "pour concrete", and "strip formwork". Each BOD is then linked to one cost account on the CBS and one work package on the WBS. Relevant cost accounts for this example may include "labor cost for 8-in. walls formwork fabrication", "labor cost for 8-in. walls formwork erection", "labor cost for 8-in walls formwork stripping", and others for material and labor costs of placing rebars and pouring concrete. Relevant work packages may include "formwork for 8-inch wall of area A — fourth floor", "rebar work for 8-in. wall of area A — fourth floor", and "concrete work for 8-in. wall of area A — fourth floor", and "concrete work for 8-in. wall of area A — fourth floor". This BOD approach ignored data acquisition support since each BOD is defined at such a refined level that it brings the difficulty of data acquisition.

Summarized from their work described above, Rasdorf and Abudayyeh proposed a work-package model based on a project WBS, where a package on the WBS may exist at a higher level than the actual activity level and serve as a basis for project control functions. Another breakdown structure, the contractor's organization breakdown structure (OBS), was also recognized by the work-packaging model. This structure assigns organizational functional responsibilities to each control account established at the desired level of detail on the WBS (Rasdorf and Abudayyeh,1991a).

2.2 Information Management and Relational Database Integrated in Construction Management

Information technology (IT) has played a big role in today's business operations. It has also drawn the attention of researchers in the construction industry (Abudayyeh, 1991, 1993; Betts, 1993; Gibson, 1992; Kartan, 1997; Rasdorf, 1991, 1992; Talonpoika, at. el. 1995). From construction process modeling to database concept integration, researchers have made efforts to use IT to better represent and communicate project information to achieve the goals of rapid production of high-quality design, fast and cost effective construction of facility and effective facility management.

2.2.1 COMBINE2 (Computer Models for the Building Industry in Europe) - Subproject Building HVAC Component Database

COMBINE is a research project focused on developing an operational computer-based Integrated Building Design System (IBDS). It began with the development of new methods designed to enhance data-sharing between a number of design applications in the fields of energy efficiency and building services engineering. This project will enable better and more efficient building designs, especially from energy conservation, building quality, and heating and ventilation perspectives. COMBINE2 was the second phase of the COMBINE project. In the COMBINE2 project, the developments concentrated on establishing a data structure and tools for managing the information exchange in a building design team. New data exchange methods were developed based on the international STandard for the Exchange of Product data (STEP) and have been tested. The objective was to access the architecture CAD, the HVAC-CAD, several thermal simulation tools, the daylight simulation tool, the costing tool, and two component databases with the STEP data exchange link to each component and to the common design database. In the building HVAC component database subproject, the HVAC component database prototype was implemented. It had a more generic database structure, which was able to store and manage any kind of component data and integrate these databases to building design systems. Researchers developed the HVAC component data model and implemented it with the Access 1.0 relational database. The browser of the HVAC database was programmed with the Microsoft Visual C++. The browser allows a user to browse, create, edit, delete, search, and export component data. It enabled links between any components to different kinds of documents such as text, graphics and CAD. Selection of one of these links opened the document with the original software used for making the document. The objective of this project was to build a generic component data management and storage structures for integration of different manufacturer's and supplier's databases to facilitate building design practices (Talonpoika, at. el. 1995).

2.2.2 Integrated Database Systems

In his research, Gibson (1992) declared that there was a need in the construction industry for more efficient methods of transferring data between various computer systems and/or project or corporate entities. Data-transfer strategies were defined falling into two categories, external and internal. External strategies involve improving data flow by performing translations or format modifications on the data to permit transfer to some dissimilar hardware or software environment. Internal data transfer strategies involve the use of central databases that can be accessed by a wide range of project or corporate users. This researcher proposed an Integrated Database System (IDS) concept to effectively combine graphical Computer-Aided-Design (CAD) data and traditional nongraphical data that are utilized for estimating, scheduling, materials management, cost accounting, and other project-management functions. This research focused on integrating a 3-D CAD system and relational database systems. Data were captured during the design phase and were used for different departments within the construction firm. The data were captured from 3-D model components, which were converted from a 2-D CAD drawing. Takeoff information was generated electronically and used for material requisitioning, purchasing, expediting, and inventory management (Gibson, 1992).

2.2.3 Integrating Safety and Health Performance into Construction CPM

Kartan (1997) developed a database management system that solicited project-specific data from the user and provided, as output, applicable safety and health standards and recommendations. Then this database was integrated into a Critical Path Method

(CPM) project scheduling process. This safety database was developed using a relational database management system (SuperBase) and hypermedia techniques[2]. Combining the capabilities of database with hypermedia techniques provides alternative means of presenting information. This database was linked to scheduling software such as Primavera Project Planner, making it possible to automatically transfer safety information to specific project activities in a CPM schedule. Hypermedia techniques permit dynamic linkage of separate text or graphic files or other forms of computer data and provide a different view of safety information. This integrated database/CPM safety system presented an effective tool to improve project safety control (Kartan, 1997).

2.2.4 An Entity Relationship (E-R) Model of Construction Project Bid Data

Betts (1993) developed a conceptual database model for project bid data. A database was implemented using a relational database management system and data from a recent tender. A primary result of the work was an entity-relationship model for construction tender data. Another result of using a database was the measured improvements in the flexibility of information retrieval. The range of information included in this research was that which a building contractor uses and produces while preparing a tender. This researcher concluded that relational databases offer obvious and significant improvements in the flexibility with which construction project information can be retrieved and presented. The conceptual database is appropriate to the dynamic and

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[2] Hypermedia: Technique used in multimedia presentations that allows the user to quickly move among screens to related subject areas, such as pictures, sounds, animation, or maps in computerized encyclopedias (Shelly, et. al., 1996).

diverse data represented by a construction project tender and that a database in this area can result in a worthwhile information system (Betts, 1993).

2.2.5 Related Work in Project Control Area: Design of Construction Industry Information Management Systems

Abudayyeh and Rasdorf have made a research effort focusing on building an efficient project information management system. Their research identified work packages on the project Work Breakdown Structure (WBS) combined with a contractor's Organization Breakdown Structure (OBS) as the basic structure to establish a common-denominator control account. Organizational functional responsibilities were assigned to each control account established at the desired level of detail on the WBS. A schedule and budget were developed based on work packages. Each account was a depository of control data that describe the work involved in it.

This research also proposed use of automating data acquisition to improve the quality of data by eliminating error-prone tasks and processes subject to human errors. Bar-coding technology was used as an automated data-acquisition tool for identifying and tracking a variety of information on a construction job site. Bar-coded data items are provided to the foreman on a sheet. The data sheets were scanned by a hand-held scanner, and these data were directly entered into the computer.

The process of designing and developing an information management system in this research was considered to be similar to the development of engineering systems. The process consisted of four steps including problem definition, conceptual modeling, computational modeling, and computer modeling. Step one involved identifying the required data items, and describing the behavior of the engineering system with respect to the methods and mechanisms used in acquiring, storing, and processing data. It was accomplished by analyzing the work packaging model and the data-collection forms developed by R. S. Means Company. In step two, the Nijissen information analysis methodology (NIAM)[3] was used to formally represent the problem formalized by step one to get the conceptual model. Then the conceptual database model was transformed into a relational data model. The normalization process to reduce data redundancies was applied in this step. Finally, the relational data model was mapped onto a relational database management system.

Their conceptual data model was transformed into data tables. Data about budgets, definition of WBS and OBS, resource and time consumption are stored in these data tables. Relational tables that deal with the creation of historical data for future planning are also created in this database. (Rasdorf and Abudayyeh, 1991a, 1991b, 1992, 1993)

2.3 Chapter Summary

Time and cost management are two important functions within construction project management. Researchers worked on the integration of these two functions to achieve more effective management. It's important to know the information reflecting these two aspects related to one measurable unit of the project breakdown structure. Researchers analyzed the two sets of project breakdown approaches, cost breakdown structure (CBS) and work breakdown structure (WBS). They identified the integration problems and the

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[3] NIAM is a natural approach to semantic modeling that produces a conceptual data-base schema design that is independent of, and can be mapped to, any data-base model. Semantic modeling involves identifying a set of semantic concepts that can be used to formally model the real world and to represent the meanings of data (Rasdorf, 1992).

relationships between cost accounts based on a CBS and schedule activities based on a WBS. A work-packaging model was proposed to integrate the CBS and WBS. In this thesis research, the author will follow this approach to establish the basic units for data management within a database model. Also, a CSI Master format numbering system will be integrated in the project breakdown approach in this research.

Database management systems have been applied in the construction field in various areas. At the bidding stage of projects, a database system improves information availability and flexibility in retrieving information (Betts, 1993). From the project plan point of view, an integrated database system where data were taken directly from a 3-D CAD system facilitated the data transfer to different applications of planning such as estimating, scheduling, material purchasing (Gibson, 1992). The integration of a safety and health database with CPM scheduling can effectively improve project safety planning and control (Kartan, 1997). From the designer's point of view, a more generic database, which is able to store, and manage any kinds of Heating, Ventilating, and Air Conditioning (HVAC) component data, can facilitate the designer's practice (COMBINE, 1995). Structured systems analysis and ER modeling for the database design was used in the contractor's tendering system (Betts, 1993), but not in the area of project management systems pertaining to cost and time control systems. Abudayyeh and Rasdorf used the engineering system development approach to design a project information system. They see the construction project as an example of an engineering system. In this system they modeled project material, labor, equipment usage and time consuming by using NIAM data modeling methodology (Rasdorf and Abudayyeh, 1991a, 1991b, 1992, 1993).

The subject of this research is conceptual database modeling based on the project cost system, which is also integrated with some time control functions. The basic idea here is to perform an information-processing function in the integrated cost system through a centralized database. Files, documents and procedures for information processing in the cost system will be redesigned into a database environment. The database system will be built via a database conceptual model. Conceptual models are tools for representing reality at a high level of abstraction (Batini, et. al., 1992). So it is important to abstract the description of all data components and their logical structure of the integrated cost system in a conceptual database model. Besides resource and time consuming, all the cost components such as subcontracting expense need to be included in this data model. No such database model which covered all the cost components has been found in this literature review.

A cost system is a subsystem of a project management system as well as one process within the construction company's business processes. From the literature review no research regarding analysis of construction companies' business process for database management system design has been found. In this research, value chain and Resource-Event-Agent (REA) concepts will be used as tools in a business process analysis for the information system and database design. These two concepts are developed in the general business management field and will be explained in more details in chapter 5. They have never been applied in the construction management field in analyzing business process of a construction company for database system design. The Entity-Relationship modeling method will be used as the database modeling tool because its readability and simplicity format is well recognized, and more available in both computer science and information system literature. In this research, a system approach of the information system and database development process established by both information systems and computer science researchers will be used to describe the development process of the conceptual model. It is described in the next chapter to outline the development process of a database model.

Chapter 3

Systems Approach of Database Design

Since database technology began to replace file systems in the mid-1960s, database design has become a subject studied by researchers both in the computer science and information systems disciplines. Computer people tend to be concerned with developing better ways of representing, storing, and processing data by machines. Information researchers are more concerned about applying computer-based information systems to the organization to improve productivity and achieve efficient management. They emphasize the understanding of the structural properties of data that are independent of implementation details. They study the data modeling aspects of database management systems, that is, the ways in which data can be organized so they represent the real-world domain of interest as closely as possible and yet they are still processed by computer. The systems approach was developed by information researchers for database design and implementation. This approach will be used in this research for the database modeling of the project cost and time data. An explanation of this approach will be given in this chapter to outline the conceptual database model development process for project cost and time data. System analysis and model development will be presented in the following chapters.

3.1 Computer-based Information System and Database

3.1.1 Computer-based Information System Overview

A system is a group of interrelated components working together toward a common goal by accepting inputs and producing outputs in an organized transformation process. An information system (IS) is a set of people, procedures, and resources that collects, transforms, and disseminates information in an organization (O'Brien, 1994). The IS of an enterprise consists of a collection of activities that regulate the sharing and distribution of information and the storage of data that are relevant to the management of the enterprise (Batini, et. al., 1992). Its basic purpose is to make information available for the right person in the organization. Computer-based information systems use a variety of computer systems to accomplish the information processing activities. Its basic components include people, computer hardware, software and data resources (O'Brien, 1994).

People in the IS can be grouped into two different categories: IS end users and IS specialists. End users are people who use the system in their daily work to produce information for the business functional operations. IS specialists are people who develop and maintain the system. They can be categorized into system analyst, computer programmer, and system administrator. An information system is designed to support the realization and management of the organizational processes and activities. It builds upon the business system which has the demand for information. System analysts begin to analyze the object system from the user view and abstract it to get a logic model of the system which represents the function of the system in the way a computer can process. Programmers code the programs for information processing based on output from system analysts. System administrators will take care of system maintenance after the implementation.

Information systems could be operated manually before the computer age. People used pen and paper to collect, store, and process data generated during the business operation to produce information for management needs. Since computers entered into the daily life of business, no IS can function well without computer hardware and software. Hardware identifies all the system's physical devices. It includes computers (microcomputer, minicomputer, or mainframe) and all their peripherals, which are the physical devices that control computer inputs and outputs. Peripherals also include any electronic devices that are used to connect two or more computers, thereby producing a computer network. Software refers to the collection of programs that instruct the machine how to work, and procedures that instruct people how to work with computers.

Data are raw facts about physical phenomena or business transactions. Within the computer-based information system, people use hardware (machines, media, and network), and software (programs and procedures), to perform inputs, processing, outputs, storage, and control activities that convert data resources into information products. Data, programs and procedures work together performing business functions and activities to produce meaningful information for management.

3.1.2 Database System

3.1.2.1 File System in Information Processing

To generate relevant information efficiently, quick access to the data from which the required information is produced is needed. Data management, which focuses on data collection, storage, and retrieval, constitutes a core activity for any organization (Rob and Coronel, 1997). Prior to the use of database management systems (DBMS), data were kept in computer files on physically large disk drives or magnetic tapes. File processing systems were used, in which data are organized, stored, and processed in independent files of data records. For many years, the orientation of information systems had been file processing (O'Brien, 1994). For instance, in the construction management (CM) field, project estimates and schedules are kept in estimating and scheduling files. Labor, material, and equipment usage data are kept in labor and equipment time cards, material purchase orders and material requisition slips. The quantities of work performed are kept in progress sheets. Data were stored in these independent data files. The project updating process consisted of using separate computer programs that updated these independent data files and used them to produce the documents and reports required by each separated user application. The independent data file system has limitations in efficiency and effectiveness for end user applications due to their several major problems. Data duplication in separated files causes problems in updating and maintenance. Lack of data integration requires special computer programs to be written to retrieve data from each independent file. Data dependence requires all data access programs to be changed when any of the file's data characteristics are changed.

3.1.2.2 Database Management System

The concepts of database and database management were developed to solve the problems of file processing systems. In the database management approach, files are consolidated into a common pool of records available to many different application programs. A database is an integrated collection of logically related records and files in a computer system (O'Brien, 1994). A database represents a change in the way end user data are stored, accessed, and managed. A database management system (DBMS) is a collection of programs that manages the database structure and controls access to the data stored in the database (Rob and Coronel, 1997). A DBMS serves as a software interface between users and databases. This system helps users easily access the records in a database, and allows the user to create, maintain, and report the data. In the CM field, if data about a project schedule, estimate, resource usage, and work progress are stored in one database, information-processing tasks will be performed in a more efficient and effective way.

3.1.2.3 Entity Relationship Database Modeling

A conceptual database model is an important concept in a database system. It describes the structure of a database in a conceptual schema, independent of the particular DBMS. A typical database model shows all data and their relationships. If the models are not logically sound, the database designs derived from them will not deliver the database system's promise of effective information draw from an efficient database (Rob and Coronel, 1997).

An Entity-relationship (ER)[4] approach for conceptual database modeling was introduced in 1976 and has become more and more popular; several conferences have been organized on the applications of an ER model to database design and to software

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[4] For more about ER model concepts please refer to Rob and Coronel, 1997; Teby, 1994 and Batini, Ceri, Navathe, 1992.

design in general (Batini, et. al., 1992). The basic concepts provided by an ER model are entities, relationships, and attributes.

- Entities represent classes of real-world objects. They are the principal data objects about which information is to be collected (Teorey, 1994). A particular occurrence of an entity is called an entity instance. An entity is represented by a rectangle containing the entity's name in an ER model (Figure 3.1).
- Relationships represent real-world associations among one or more entities, and as such, have no physical or conceptual existence other than that which is inherited from their entity associations (Teorey, 1994). Relationships are represented by diamond-shaped symbols (Figure 3.1). A particular occurrence of a relationship is called a relationship instance or, relationship occurrence.
- Attributes represent elementary properties of entities or relationships (Batini, et. al., 1992). There are two types of attributes: identifiers and descriptors. An identifier (or key) is used to uniquely determine an instance of an entity; a descriptor (or nonkey attribute) is used to specify a non-unique characteristic of a particular entity instance. They are usually represented by a line and a cycle connecting to the entity box or relationship diamond symbol in ER diagram.

An example of an ER diagram is shown in Figure 3.1. Relationships in entity-relationship models are described in terms of degree, connectibity, and cardinality.

- Degree of a relationship indicates the number of entities associated in a relationship (Teorey, 1994). A unary relationship exists when an association is maintained within a single entity. A binary relationship exists when two entities are associated. A ternary relationship exists when three entities are associated.

- Connectivity is used to describe the relationship classification. It includes one-to-one, one-to-many and many-to-many relationships between entities (Rob and Coronel, 1997).
- Cardinality expresses the specific number of entity occurrences associated with one occurrence of the related entity (Rob and Coronel, 1997). It describes the number of instances within an entity that are related through a relationship. Cardinality is represented in the ER model by numbers in the parentheses.

These concepts are illustrated below in Figure 3.1. Material and actual material usage are two entities. Material no., material description and budget unit cost are attributes of material entity. Charge no., date, and quantity are attributes for actual material usage. Material no. and Charge no. are key attributes for Material entity and Actual Material Usage entity. Their relationship is "issue to" which means material is issued to a project as material actual usage. It's a binary relationship and has one-to-many connectivity. Cardinality of this relationship is shown in two parentheses. On the material side, 0 means one kind of material can still be in storage and not be used in the project; n means material can be issued many times to be used in the project. On the actual material usage side, the two ones mean that each record of the material usage can only record one kind of material.

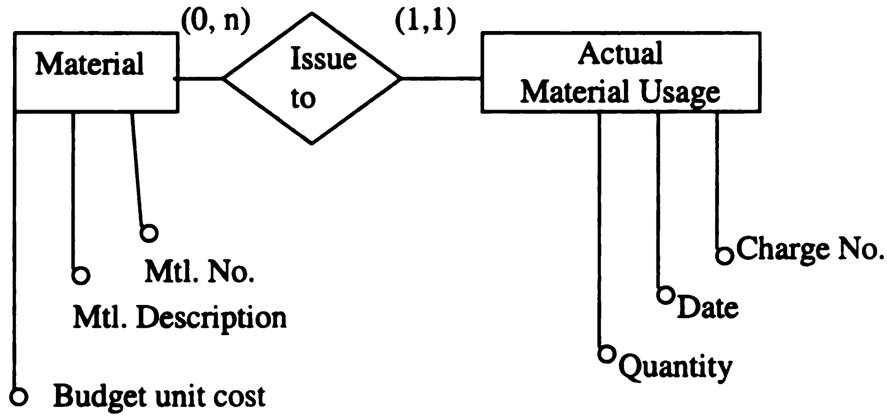


Figure 3.1 Example of ER diagram

3.2 Information System Development Life Cycle:

The information system development life cycle represents the history (life cycle) of an information system. Database design takes place within the scope of an information system life cycle. It's difficult to separate database design from the system development cycle. The process of creating an information system is known as systems development (Rob and Coronel, 1997). Applying this systems approach, an information system's development cycle can be summarized as a step-by-step process, with major stages including: (1) investigation, (2) analysis, (3) detailed systems design, (4) implementation, and (5) maintenance.

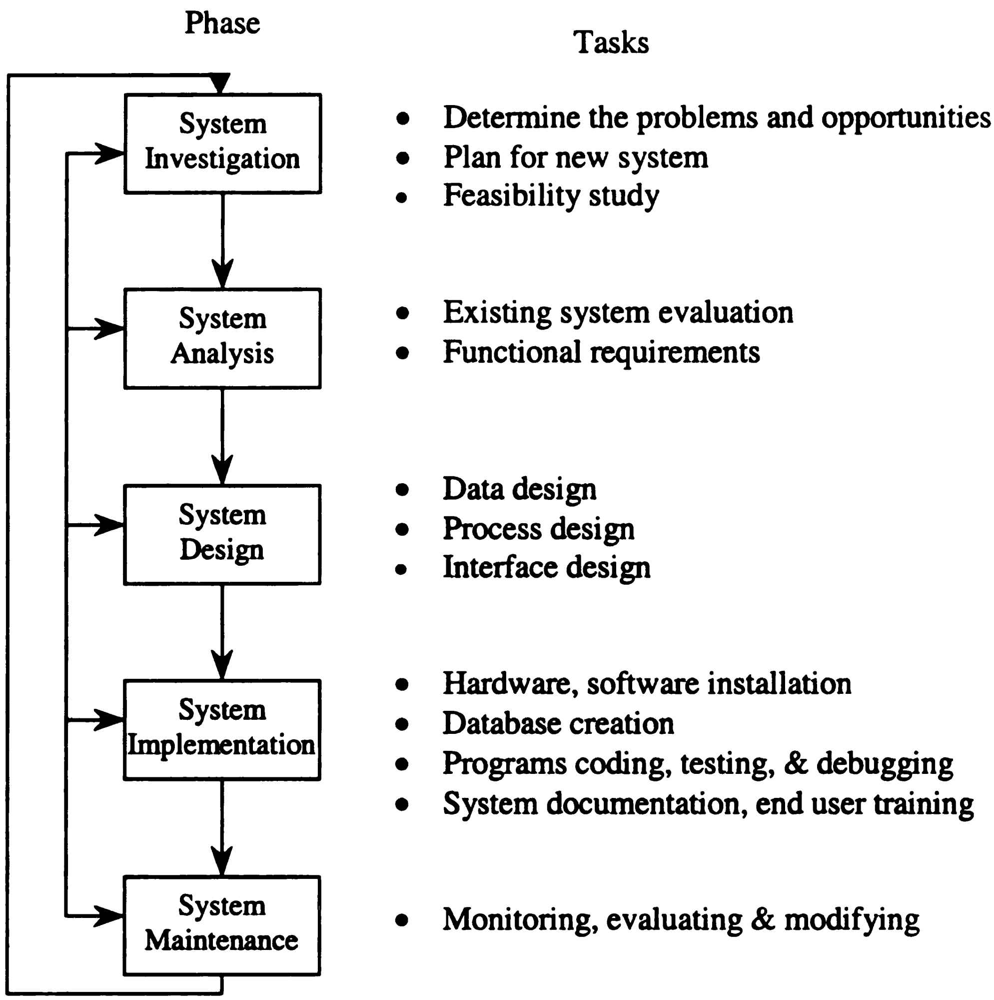


Figure 3.2 The information system development life cycle
Source: Modified from Coronel, 1997

As shown in figure 3.2, several tasks are involved in each phase. The items in the right column represent the tasks which need to be completed to accomplish each phase. In the first step, system investigation is an overview of the company and its objectives. System analysts examine the existing systems to find out the problems and opportunities. The requirement of a new information system is planned to improve the business functionality and to contribute to the achievement of the company's objectives. Then a feasibility study is conducted. It determines the technical aspects of hardware and software requirements, costs, benefits, and feasibility of the proposed system. Problems defined during the planning phase are examined in greater details during the system analysis phase. The existing system is also studied to determine how the system activities of input, processing, output, storage, and control are accomplished. All data flow and current processes are described and documented, using systems analysis tools such as data flow diagrams (DFD). More explanation about DFD is given in section 3.3.1.1 and in appendix A. The result of system analysis should be a better understanding of the system's functional areas, actual and potential problems, and opportunities. Functional requirements of a new system are developed, including user interface requirements, processing requirements, and data storage requirements. Based on the functional requirements, a systems design specifies how the system will accomplish these objectives. The data design activity focuses on the design of the database structure and the files to be used by a proposed information system. System analysts use a methodology such as entity relationship (ER) diagrams to draw a conceptual data model for the proposed database. Process design focuses on the design of data transformation and processes within the database environment. A user interface design focuses on building the interactions between end users and computer systems. Designers concentrate on input-output methods and the conversion of data and information between human-readable and machine-readable forms.

During the implementation phase, the hardware, database management system (DBMS) software, and application programs are installed. The data model is applied into a particular DBMS environment, and the actual database is created. Process and interface programs are coded, tested, and debugged until the system is ready to be delivered. After testing is concluded, the final documentation is reviewed and printed, and end users are trained. The system is full in operation at the end of this phase.

Once the system is fully implemented and operated by end users, the maintenance function begins. Maintenance is the monitoring, evaluating, and modifying of operational information systems to make improvements.

3.3 Database Development Process:

Within the large picture of an information system the database is also subject to a development process. Research has been committed to this area. Researchers in both computer science and information systems have focused attention on the process of designing databases capable of supporting numerous complex applications. They have noticed the need to design and use conceptual models in the early stage as part of a well-developed design methodology for the entire database development process.

3.3.1 Two Approaches of Database Design

Much has been written about database design methods, and basically there are two methodology approaches: one is data-driven, one is process-driven (Maciaszek, 1990; Raymond, 1987; Nijssen, 1989; Olle, et al, 1986). These two approaches also reflect the design philosophy of information system design.

3.3.1.1 Process-driven Design

The process-driven design is concerned with how the processes or activities are performed in the application area. It focuses on applications rather than data. The processes (business functions) are described first. The direction of data flow, which may physically be contained in a letter, an invoice, or a report passing between processes and other components, is also made clear. Data storage locations in the whole process are also considered. Often, a complex process is refined into several subprocesses. A data flow diagram (DFD) is usually used as a graphic-diagramming tool to represent the logical view of the flow of data in a system without specifying the physical devices. Appendix A shows the symbols used in DFD and a typical DFD. DFDs are usually drawn in increasing levels of detail, starting with a summary high-level view and proceeding to more detailed lower level views. Data elements from the data flows and data storage locations are documented in a data dictionary. The initial database structures are derived from data flow and data storage locations in the flow.

3.3.1.2 Data-driven Design

The data-driven approach focuses on what kinds of data are stored in the database, as well as what constraints and relationships between data are applied. The principal design task is to build a data representation or model of the objective system. The entire focus is placed on data and their properties. Once the data are identified and structured, data capture and storage procedures are elaborated so that the resulting database can be kept up-to-date. Finally, data access and processing procedures can be designed on demand to allow decision makers to obtain information in various forms (reports, terminal displays, graphics) and analyze this information (costing, scheduling, performance evaluation) (Raymond, 1987). ER modeling is a widely accepted technique in the design of conceptual data base models, which is also to be used in this research.

3.3.1.3 Comparison of Data-driven and Process-driven Approach

Comparing these two approaches, a mixed design environment is sometimes necessary. If the design starts with processes and derives initial database structures from the processes, then the method is process-driven. Alternatively, if the design starts with the determination of data structures that satisfy some desirable properties and refines such structures once the processes are specified, then the approach is data-driven (Maciaszek, 1990). The data-driven approach builds the data structure on the basis of the general semantics of information used in the business. If user requirements and business processes were significantly changed, the redesign of a database derived by the process-driven methodology is likely to be required earlier than in the case of the database derived in a data-driven fashion. The database modeling and design for project cost and time data are considered to be a data-driven approach since the design starts with the determination of the data requirements, and concern about the data content in a conceptual database model. The database in which the project data are stored and managed is the center of the project information system. Data processing programs and procedures are applied to this database. The data-driven approach is also chosen in this thesis research because data can be represented in a more generic model without specifying the particular processes.

3.3.2 Database Design Process

Although different terminology is used, the database design process for research efforts can be outlined and summarized as four separate but dependent phases: (1) information requirements analysis, (2) conceptual design as view modeling and integration, (3) logic design, and (4) physical design (Ceri, 1983; McCarthy, et al., 1994; Rob and Coronel, 1997; Teorey, 1994). In the design of a database for project cost and time data, the four phases can also be applied as a generic rule. These four phases will be described in the following sections.

3.3.2.1 Information Requirements Analysis

Information requirements analysis can be simply defined as a procedure which attempts to determine the present and future information needs of the user community (McCarthy, at. el., 1994). In this phase, objectives of the database system are identified. The scope, which is defined as the extent of the proposed database based on operational requirements, is determined. The existing information system is analyzed to find the end user data views and identify data and their characteristics. The designer examines the input/output forms and files in order to discover the data characteristics. Business rules that act upon the data are also reviewed. In this research, a project cost system is analyzed to define the function and operation rules. Common data storage units for cost and time data are constructed to provide information for some schedule control functions in the cost system. Data elements are discovered and classified by analyzing documents, forms, record formats within the existing system.

3.3.2.2 View Modeling and Integration

The purpose of conceptual design is to describe the information content of the database rather than the storage structures that will be required to manage this information (Batini, at. el., 1992). In this phase, information elements obtained from the first phase are transformed into a formal representation using standard modeling methodology. By definition from Batini, a data model is a collection of concepts that can be used to describe a set of data and operations to manipulate the data. When a data model describes a set of concepts from a given reality, it is a conceptual data model. When used in database design, it is a conceptual database model. This model embodies a clear understanding of the business and its functional areas. Also, it is software- and hardware-independent.

Conceptual database model development is accomplished using conceptual modeling techniques, particularly the entity-relationship (ER) model. A basic task here is to construct a graphic diagram in which raw data from the business operations are captured in a logical way. Compared with other modeling methods, ER is the most popular and standard data model, which can be found in most available literature both in computer science and information system fields. Its simplicity and readability feature also helps easy communication between database designer and end user. In this research, an ER model will be used as the modeling methodology for the project cost and time data conceptual model development. This model presents data in the integrated project cost system at an abstraction level, and it provides a central storage mechanism for data. It also reflects a new way to perform information process functions in the integrated cost system.

When the information process in a project cost system is redesigned, value chain analysis provides a way to examine all activities that a construction company performs. It decomposes the business process into cycles and events. These events trigger the information process. REA which represents Resource-Entity-Agent, was first introduced as a framework to present the accounting information system in a database view (McCarthy, 1982). In a database environment REA serves as a template to describe the event information by identifying what happened (event), what resources are involved, and who (agent) performed the roles. The REA concepts applied here in the model development process help to identify and implement the business roles in the model.

When the database design is large, and more than one person and one function area are involved, multiple views of data and relationships result. Integration is a concept consolidating these views into a single global view to eliminate redundancy and inconsistency from the model. View integration requires the use of ER semantic tools such as identification of synonyms, aggregation, and generalization. An example can be two possible views of a material/equipment database to be merged into a single global view based on common data about work items in process which consume material and equipment.

3.3.2.3 Logic Design

Logic design encompasses activities which translate a DBMS-independent conceptual model into the internal model for a selected database management system (DBMS); such as DBASE, ORACLE, MS Access. For the relational DBMS, the logical design includes the design of tables, views, and access authorities. In short, the logical design translates the software-independent conceptual model into a software-dependent model by defining the appropriate domain definitions, the required tables, and the necessary access restrictions (Rob and Coronel, 1997). Other output from this phase would include physical design specifications, program design directions, and guidelines for the database administrative staff regarding the database security, recovery, consistency and performance.

In this research, a prototyping database structure including sample tables and queries based on the conceptual model were set up. But issues regarding the database administration were not considered since the research purpose here is to analyze the construction project system and construction business to develop a conceptual data model for project cost and time data, which is the blueprint of the information generator for project managers.

3.3.2.4 Physical Design

Physical design is the process of selecting the data storage and data access characteristics of a database. It decides the location of the data in the storage devices and the performance of the system. It is not only software-dependent but also hardware-dependent. Several issues are considered here, including data storage in a single platform or in a client/server platform, data distribution in different locations, and networking configurations. Database interface design, application programming for data retrieval, and integration with other software application are other tasks involved here.

Physical design in the database development process is described as a very technical job, more typical in the mini and mainframe world than of the personal computer (PC).

Even in the more complex mini and mainframe computer environments, modern database software has assumed much of the burden of the physical portion of the design and its implementation (Rob and Coronel, 1997). The hardware environment for the prototyping database structure is the IBM PC. Since this research emphasizes database modeling, most issues in the physical design part are not included here.

Figure 3.3 summarizes the development process of a project cost and time database model. The left column shows step-by-step phases in database design process. In the middle column, tasks that need to be taken in each phase are described. Particular methods used in this research for project data modeling are illustrated in the right column.

3.4 Chapter Summary

This chapter provides an overview of the concepts of databases and information systems and their development life cycle. The emphasis of this chapter is on the description of the database development process. The project cost and time database design is considered following in the same process. The purpose is to delineate the step-by-step process of the project cost and time data model development. The following chapters will follow the outline here to develop the model.

Database design process	Tasks	Methods used in project data modeling
Information Requirements Analysis	• Objective & scope • Business model development • Define data & business rules	• Cost and schedule control system analysis • Form analysis
View Modeling & Integration	• Conceptual data model development	• E-R modeling • Value chain analysis • REA template
Implementation Design	• Translate the conceptual model into definitions for tables, and views.	• Prototyping database structure setup in MS Access
Physical Design	• Define storage structures, location and access paths • Interface programming	• Sample MS Access tables applied in IBM PC hardware environment

Figure 3.3 Project cost and time data model development process

Chapter 4

Information Requirements Analysis in an Integrated Project Cost System

This thesis explores database-modeling issues for project cost and time related data generated during construction. The purpose is to redesign the data storage system for cost control and time control to improve the information retrieval for project management. This research focuses on the information requirements during the project construction of a typical construction company. This sample company is fully responsible for all perspectives of the construction. Contractual relationships can be varied, and this company can be a general contractor which performs parts of the project by its own forces and subcontracts the other parts. In an alternative way, the company can serve as a construction management firm to coordinate subcontractors. This database system will provide an organized and efficient means of measuring, collecting, storing, and processing data reflecting the progress and status of operations on the project with respect to cost, resources, and schedule. The conceptual database model represents the data and operation rules of the project cost system at a high level abstraction. It must embody a clear understanding of the business and its functional areas. So information requirements analysis is the important first step to build the conceptual model.

This chapter analyzes the project management system to identify the information requirements for cost control and time control functions. It starts from a project management overview. Project management is the process and system applied to construction projects to accomplish the project effectively. There are several functional areas within the project management system including cost, schedule, quality, and safety.

The emphases of this chapter are to examine information requirements and to discover the data element characteristics within the integrated cost system in which time related data are also considered. Basic data storage units for cost and time data will be proposed for cost and schedule control integration. Data elements and their characteristics will be identified by analyzing source documents and the traditional information process in a cost system.

4.1 Project Management System Overview

A construction project is usually a one-time job upon contract award to finalize the design under budget and on schedule while meeting the quality specifications. The primary purpose of project construction is to deliver the project according to the design under budget and within a specified time frame. Project management refers to how best to implement the construction process which would include proper scheduling, coordination, and controlled flow of materials and equipment to the job site (Levy, 1994).

Project management usually includes time management, cost engineering, quality control, resource and safety management. It is implemented by a planning and control system. The plan provides the baseline and standards against which performance is measured. The control system monitors the project status and determines where the project is with respect to the plan, and initiates corrective action if there is a significant discrepancy. So the project management system is a repeated process of planning, operation, feedback, and controlling. Before construction, a plan is set according to the design, the company's historical information, and the project's external factors. When the operations get underway, the plans become reference standards. As operations continue, external factors such as weather, design changes, labor disputes, and material delays may cause the course of operations to differ from the plan. Data generated in the operations are processed to provide information for management about work in place, time, money, or resources expended. This information processing system includes collection, storage, analysis, and reporting. Decision-makers use the information adjusted by outside condition to modify the plan and take action for managing and controlling the operations. This is a feedback control system, and it operates continuously throughout the life of a project.

Project cost control is one of the key responsibilities for all members of the project team, and it provides the analytical methods and procedures for monitoring, analyzing, forecasting, and controlling costs on a construction project. It also can be expanded to aid in performing several project management functions, especially the schedule control system.

4.2 Project Cost System

Controlling the project costs is a concern of every participant in a project. The objective is to keep project costs within budget and provide information for estimating the cost of future work. A functioning and reliable cost system plays a vital role in proper management of a construction project (Clough and Sears, 1991). It is a process of planning, operation, monitoring, information feedback, and taking actions. Planning establishes standards of performance. As the work proceeds in the field, cost accounting methods are applied to determine the actual costs of production. Data are processed into information to provide the basis for management decisions that are essential to get an action leading to improvements in performance. Resources and production information are also derived for future estimating.

Traditionally, data are recorded in different source documents such as time cards, and purchase orders; and are generalized in the job cost accounting system. A database provides a more efficient way for information processing. A database model outlines the blueprint upon which to build a project database. In order to develop a database model for a project cost system, the basic data storage unit needs to be considered. To the simpler and smaller construction projects, field data can be collected and stored into one unit — the project itself. Usually, a project needs to be broken down into small measurable units for planning, controlling and managing data. When time-related data and cost-related data are collected into the same unit, the cost system is integrated with the time control system.

4.2.1 Work Breakdown Structure (WBS) and Data Capture Units

4.2.1.1 Work Breakdown Structure

A WBS is a tree hierarchy of the required work to be performed in accomplishing the end project. Through this hierarchy, a construction project is divided into succeedingly lower levels of detail, and the bottom level has measurable units in which tasks can be identified. This management technique is widely used in construction project management since construction products are totally different from other manufactured products. Most factory products are produced in clear, visible units such as computers, cars or lamps, and management emphasizes planning, monitoring and controlling the production process based on these measurable units. On the contrary, each construction product is usually too broad to be a measurable unit. Each construction project takes considerable time to complete and is unique as to its design and required construction methods. A WBS serves as the analysis tool breaking the project into the level where work can be managed by providing a formal structure which identifies all products and relates all of the work effort required to meet project objectives (Department of Energy, 1981). The WBS is structured in accordance with the way work will be performed and reflects the way in which project costs and data will be summarized (Department of Energy, 1979).

In the project cost and time database, the hierarchy of a project provides a structure for project data summary and collection. During the planning stage, a time schedule and cost estimate are developed according to the project WBS. As work progresses on tasks and resources are employed, management control is applied. Actual project data are captured based on the planning format and then summarized to provide successive levels of management with the appropriate report on current and predicted status of the work for which they are responsible.

4.2.1.2 Cost Coding and Data Capture Unit

Cost coding provides the basic framework upon which a cost system is built. It's a numbering system of the cost items within a project. Cost items are coded in the cost coding system which serves as the basic data capture unit in the cost system. A project is decomposed into units where costs can be calculated and collected. It is also referred to as a cost breakdown structure (CBS). Actually, a CBS is also one kind of WBS, but it has a different emphasis and approach for project breakdown into activities for a schedule. A schedule WBS focuses on a breakdown of the project into activities that need to be performed and progress is tracked. A CBS emphases the elements of a project for calculating costs. In separated cost and schedule systems, cost and schedule data are calculated, collected, and maintained separately in cost items and activities. But if these two kinds of data are managed in one database, the basic data storage unit needs to be established.

Sometimes the cost items and activities are not compatible. If an estimator has prepared an estimate for a building project by functional elements, it may be a formidable task to determine the estimated quantities and costs for each activity. For example, the functional element superstructure includes such items as concrete formwork, structural steel, precast concrete, and miscellaneous iron. If only a total cost figure is given for the functional element, it will be difficult to distribute this cost over activities. To solve this problem, estimating and scheduling must follow the same WBS structure at the beginning stage. Then the consideration is to identify specific packages of work referred to as work packages for cost and schedule control and data collection. These work packages are at a higher level than the activity and cost items in the WBS. The work-package creates a unified view of project data by merging the WBS and CBS. It accomplishes the need for a common denominator in the hierarchy for acquiring and maintaining data for effective project control (Rasdorf and Abudayyeh, 1992). Each work package is assigned to one cost account. All aspects of the contractor's management control systems come together at the cost account including budgets, estimates, schedules, work assignments, cost collection, progress assessment, problem identification, and corrective actions (Department of energy, 1981).

The Master Format, shown in Appendix B, published by the Construction Specification Institute is a standard for numbering and classifying sections of a project. Combining this numbering system with project work packages can provide a standard numbering project breakdown system where on the bottom level project data can be collected and recorded. The number for each work item will have 9 digits. First the project is divided according to the 16 divisions of the Master Format. The second level is the subsections under each division as shown in Appendix B. These two levels will take the first five digits. Then the project is continued to be broken down by locations. The next two digits are for numbering the locations. The next level of the project breakdown is the work packages named as work items divided according to project elements. Two-digit number will be used to code this level.

A sample building project was broken down by this method as an example shown in Figure 4.1. This is actually a numbering project WBS based on the master format. The project was broken down and each level was numbered according to the master format. The first level is in accordance with sections of master format, and the second level is subsections. Then the project was divided by the locations (floors) and function elements (slab and beam, walls and columns). The numbers in each level are coded according to Master Format numbering system. As shown in the example, the code for the cast-in-place concrete wall work item on floor one is 0330001002. This coding system provides a numbering system for the project breakdown units as well as their identification in the computerized information processing environment. Work items which serve as cost control accounts and basic data capture units are at the bottom level. Each item may include several activities and different kinds of cost resources. In the example of cast-in-place concrete wall item on the first floor, it includes "pour concrete", "finish concrete", and "cure concrete" activities, and all cost resources associated with these activities such as concrete material, labor and equipment. When cost and time data can be captured in the same unit, the cost system is integrated with the schedule control system. In the integrated cost system, scheduling plan and estimating budget are required to be done according to these preset work item units in the early stage of project planning.

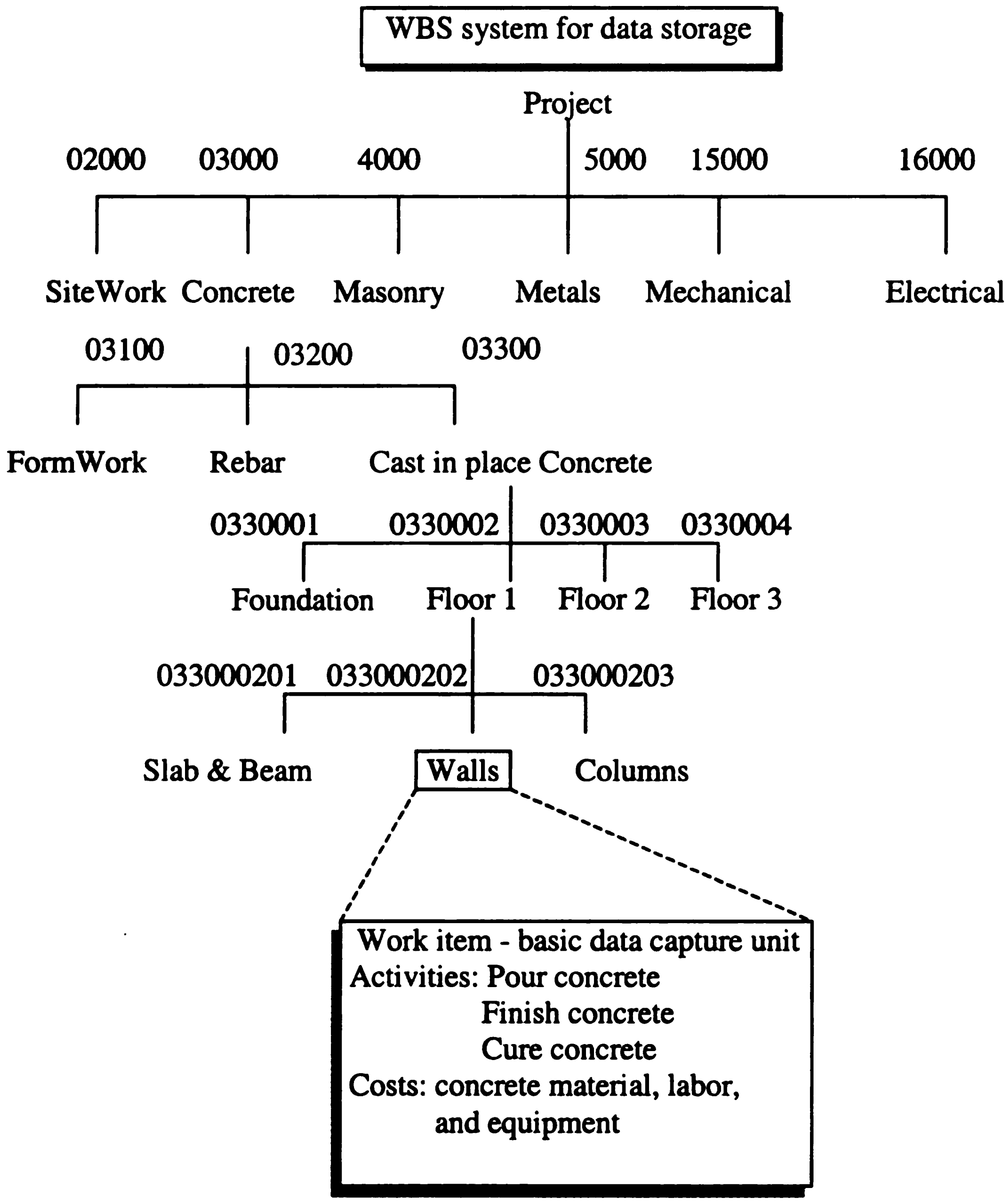


Figure 4.1 WBS numbering system of data storage units

4.2.2 Cost Plan

For control of project costs, there must be a cost plan against which cost performance is measured. The cost plan may be considered to consist of two major divisions: schedule and estimate. Since the cost system here is the cost/time integrated system, the schedule is considered as one part of the cost plan.

4.2.2.1 Schedule

Usually a construction project has a fixed time frame, in which project managers need to manipulate large numbers of operations to complete the project. The planning techniques of the Critical Path Method (CPM) draw all operations of the project in a network diagram based on job logic and restraints. Once the network has been developed, the time element is introduced into the planning diagram to form a work schedule. This project schedule is a projected timetable of construction operations that will serve as the principal guideline for project execution (Clough and Sears, 1991). Schedule development involves a series of steps. The major steps include identifying activities, developing the logic relationships, determining a time duration for each activity, and calculating critical path time. The scheduling progress begins by dividing the project into several different detail levels according to project WBS. Basic schedule activities are identified and then the project time data of these activities will be generated. These major data items include planned duration, starting time, finishing time, and float time. They reflect the planned project time information. These schedule activities and their associated time data can be summarized to the higher level units which become work items for data storage.

4.2.2.2 Estimate

A project estimate establishes the cost projection and control baseline for construction. Along with the design-construction processes, development of estimates proceeds from a conceptual view to more detailed information. A conceptual estimate is a prediction of the total anticipated cost to the owner. An estimate generated in the detailed design stage is an aid to predicting the project bid price. The most detailed estimate is prepared by the general contractor. In the integrated cost/time control system, work items are the basic units on which quantity take off and prices are based. The contractor uses this estimate in preparing a bid. Once the bid has been accepted, the estimate serves as a budget which sets realistic goals for company personnel to accomplish. Quantities, manhours, unit costs, direct dollars, and other resource expenditures to perform the work are defined by the unit of work items. Major data items in the budget are quantity, productivity, resource budget usage and unit costs.

4.2.3 Cost Control

4.2.3.1 Project Job Cost Accounting

The primary objective of a project cost system is to keep the construction costs of the project within the established control budget. As the work proceeds in the field, cost accounting methods are applied to determine the actual costs of production. The costs as they actually occur are compared with the budget. This is the way to find problems and take actions. Project job cost accounting is the key ingredient in the project cost system. It provides the basic data required for both cost control and estimating (Clough and Sears, 1991). It performs the function of information processing.

A project job cost system is the set of forms, procedures, and communication channels used to document project information, process it, and then structure it for project management decisions (Adrian, 1979). It's part of an accounting system, but differs substantially from financial accounting. Financial accounting is concerned with tracking accounts receivable, accounts payable, generating payroll, and maintaining good bookkeeping. Its structure is in accordance with accepted rules and procedures of accounting and outside requirements. Its objective is, in great part, preparing a financial statement. Job cost accounting belongs to managerial accounting, which is more concerned about cost control and how to allocate costs to the specific product produced. Cost accounting involves the continuous determination of productivity and cost data, the analysis of this information, and the presentation of results in summary form. As part of the accounting system, a job-cost ledger is kept to record usage of labor, material, equipment and other resources, and to record indirect cost expenditures.

Construction cost accounting is concerned not only with costs, but also with man-hours, equipment-hours, and the amounts of work accomplished (Clough and Sears, 1991). These data are collected and analyzed for cost control and estimating. Figure 4.2 illustrates the data collection and information process procedures in a job costing system. In the first rounded rectangle, the project estimating process sets up the budget baseline for field construction. During the construction process shown in the top dotted line rectangle, field data are collected through a set of forms and procedures of a job cost system. Direct labor, direct material and other direct costs are identified and posted to job-cost ledgers. The source document for assessing a project's labor cost is the timecard. The material purchase invoices are the source documents for identifying material costs.

Besides cost data, quantity of work performed by work item is recorded periodically in progress sheets to reflect the project progress. Then these field data are processed in a cost and productivity analysis and compared with the budget. Information generated from this process is summarized to provide management reports for control and feedback for future estimating. These analysis and feedback processes are shown by the other two rounded rectangles and arrows in Figure 4.2. In the mean time, cost data are collected from the job cost ledger to the expense accounts in the financial accounting system.

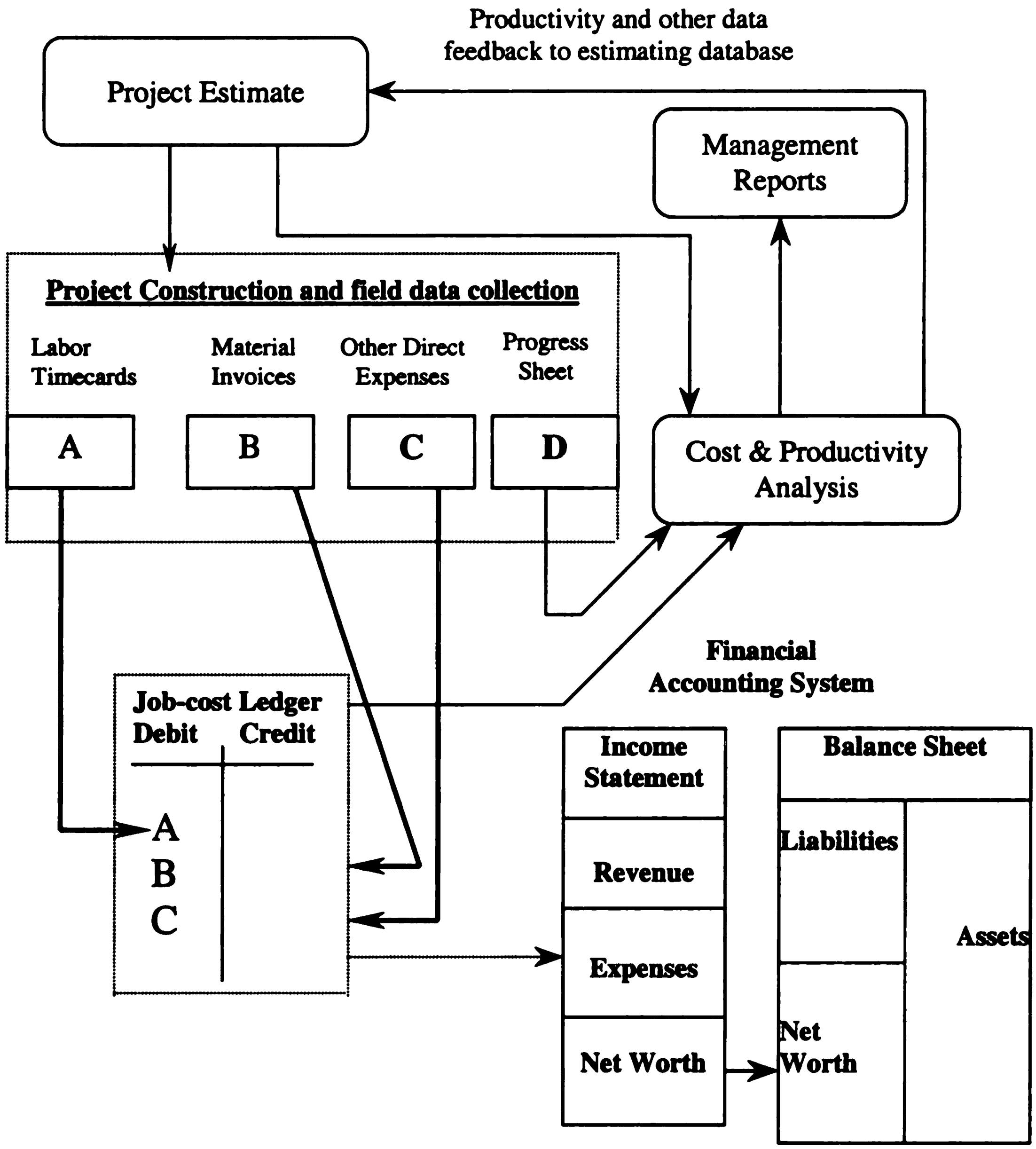


Figure 4.2 Data collection and information processes in a job cost system

4.2.3.2 Source Documents for Data Recording

As mentioned above in section 4.3.3.1, job cost accounting has the set of forms and procedures to document project data. Management reports are produced from these documents to give information feedback to project managers for their decisions. Job cost accounting serves as a data recording and information processing system in the project system. No matter whether the information process within this system is manual or partially computerized by some computer software, it is still a file system. Data are entered into a series of forms and then stored in forms, reports and other documents. Data requirements are expressed with a variety of formats. To design a database system based on this file system, data requirements need to be examined from these documents. These basic documents include progress sheets, manhour time cards, warehouse requisition slips, equipment timecards, and subcontract progress payment claim sheets. These documents are forms which are predefined paper modules used to collect data, and to exchange data among users (Batini, et. al., 1992). So the data requirement analysis begins from the form analysis to identify and classify data elements.

4.3 Information Requirements from Form Analysis

The first task in form analysis is to understand the structure and meaning of each form. Information expressed in forms is obtained by subdividing forms into areas. An area is simply a portion of the form that deals with data items closely related to one another (Batini, et. al., 1992). Each form is partitioned into pieces of similar complexity. Data elements are discovered from forms and classified by areas. Entities in the ER model can be abstracted from these areas. So form analysis represents the first step toward a conceptual model for database design. Analysis of the basic forms in a cost system is presented in the following sections. Data elements in each example form are grouped into areas. These areas are used to derive abstraction level entities for the ER model.

4.3.1 Progress Sheet

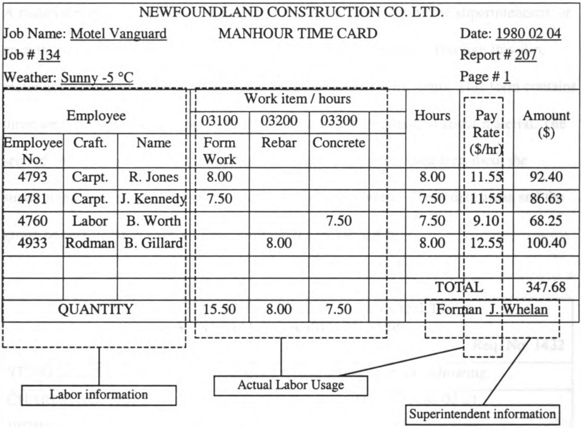
Progress is one of the most important components of successful cost control. A project that runs ahead of schedule may be over budget and lacking in quality. On the other hand, where costs run below the estimate the project may be behind schedule. Only when the progress on a project is on schedule and within the estimated cost for the work done is the project performing satisfactorily. Progress information is periodically collected from the site and recorded in the progress sheet. Table 4.1 shows a typical progress sheet used by a construction company. In this sheet, project name and recording data are presented in the title part. Quantity of work performed is recorded daily in each work item. Work item descriptions are under the column titled by work item. The work item codes are presented in the second row. This progress sheet provides data on a daily basis to document actual work which has been performed.

NEWFOUNDLAND CONSTRUCTION CO.LTD.							
PROJECT: Motel Vanguard							DATE: 1980 03 01
DAILY PROGRESS SHEET							
Work Item	Quantity of work performed by work item code						
	BB 03100	BB 03200	BB 03300				Remarks
Formwork (m^2)	83.4						
Rebar (tonnes)		1.58					
Concrete (m^3)			45.9				

Table 4.1 Job progress sheet
(Source: Ahuja, 1980)

4.3.2 Manhour time card

Labor cost forms a major portion of the total cost for many projects and is one of the most sensitive costs to manage. A day-to-day reporting system provides a measure of performance to compare with the estimate. One of the basic reports in the traditional file system is the time card. A typical time card is shown in Table 4.2. The time card is used for a foreman to report his manpower allocation in a standard uncomplicated format. This format uses predefined numbered work items. Manhours are allocated to each work item daily. Manhour time cards, together with the progress sheets, can provide information about productivity analysis, unit labor cost, and manhour status. The time card contains three areas which contain closely related data items to describe similar information. The first area is a group of data items about actual labor usage. The second one is an area about labor information including employee number, name, craft, and hourly wage rate. The other one is an area indicating the information about the superintendent who is in charge of these workers. These areas and their correspond data items are shown in Table 4.3.



NEWFOUNDLAND CONSTRUCTION CO. LTD.

MANHOUR TIME CARD

Job Name: Motel Vanguard | Date: 1980 02 04

Job # 134 | Report # 207

Weather: Sunny -5 °C | Page # 1

Employee			Work item / hours				Hours	Pay Rate ($/hr)	Amount ($)
Employee No.	Craft.	Name	03100 Form Work	03200 Rebar	03300 Concrete				
4793	Carpt.	R. Jones	8.00				8.00	11.55	92.40
4781	Carpt.	J. Kennedy	7.50				7.50	11.55	86.63
4760	Labor	B. Worth			7.50		7.50	9.10	68.25
4933	Rodman	B. Gillard		8.00			8.00	12.55	100.40
							TOTAL		347.68
QUANTITY			15.50	8.00	7.50		Forman J. Whelan		

Table 4.2 Manhour time card
(Source: Ahuja, 1980)

Area	Data items recorded
Labor	Employee no., Craft, Name,
Actual labor usage	Actual hours, Date, Actual rate
Superintendent	Name

Table 4.3 Data areas and their items derived from manhour time card

4.3.3 Material Requisition Slip

Material cost is one of the most important elements making up the total project cost. A material requisition slip as indicated in Table 4.4 is filled out by the superintendent, or an authorized individual, before the material is used in the project. Through this slip, material is issued to the project and recorded according to work items. This form contains three areas grouping related data items. The first area is information about material. The second area is about material actual usage. The third one is the data area about the superintendent who is authorized to receive the material items. These data areas and the group of data items in each area are summarized in Table 4.5.

NEWFOUNDLAND CONSTRUCTION CO. LTD. MATERIAL REQUISITION SLIP Req. No. 1432				
STOREKEEPER: Please Furnish Mooney Construction with the following:				
CHARGE NO. 15332 WORK ITEM: BA03110		DATE: 1980 02 21 Dept. Construction		
Quantity	Articles	Stock No.	Unit Cost	Amount
200	Timber 5cm x 10cm x 3m	201	$1.50	$300.00
300	Timber 2.5cm x 15cm x 6m	468	$2.00	$600.00
ENTERED ON Ledger 293	ENTER ON Stock Ledger 154		STORE KEEPER R. Gorman	RECIPIENT L. Vivian

Actual Material usage

Material data area

Superintendent

Table 4.4 Material requisition slip
(Source: Ahuja, 1980)

Area	Data items recorded
Material	Material stock no., Unit cost, Description
Actual material usage	Charge No., Quantity, Date
Superintendent	Recipient name

Table 4.5 Data areas and their items derived from material requisition slip

4.3.4 Equipment Time Card

Equipment usage in a project usually depends on the type of project and the methods of construction that are adopted. The information required on the use of equipment is in a format very similar to that required for manpower. An equipment time card is the basic form to record data. It normally contains machine description and/or number, hourly rates, total dollars, and special conditions (breakdown or idle). Actual working hours are classified by work items. An example of a typical equipment time card is shown in Table 4.6. Three groups of data items can be identified from this form. One is equipment information, the other one is equipment actual usage by work items. And the third one is the project information. These areas and the data items are summarized in Table 4.7.

Area	Data item
Project	Project No., Project name
Equipment	Machine no., Machine name, Standard rate, Overtime rate, Idle/Repair rate
Actual equipment usage	Actual hours, Date, Actual cost

Table 4.7 Data areas and their items derived from equipment time card

Project general information

Equipment information

WEST AMERICA CONSTRUCTION COMPANY, INC.
WEEKLY EQUIPMENT TIME CARD

Project: Mountaintown Warehouse
Week Ending: Aug. 23, 1980 Project No.: 83WH04

Machine: CAT977
Machine No.: L-5 Rate ST $84.80/hr.
Idle/Repair: $32.40/hr. OT $69.20/hr.

Day	Standard Time(ST) / Over Time(OT)	Work item F10-02220	Work item S01-02222	Work item	Total Hours ST.	Total Hours OT.	Total Hours Repair	Total Hours Idle	Total Cost	Weather & Comments
Mon.	ST	8			8				678.4	Clear, 85
	OT									
Tue.	ST	6			6		2		573.6	Clear, 80
	OT									
Wed.	ST	8			8				678.4	Cloudy, 70
	OT									
Thu.	ST		8		8				678.4	75, Light wind
	OT									
Fri.	ST		8		8				816.8	80, clear
	OT		2			2				
Sat. Sun.	OT									
Total Hours		22	18		38	2	2			Prepared by: B.C. Paulson
Total Cost		1865.6	1495					42	3425.6	

Equipment Actual usage

Table 4.6 Equipment time card
(Source: Modified by Barrie and Paulson, 1992)

4.3.5 Subcontract costs

Subcontracts cost — similar to manhours, materials, and equipment cost — form a varying percentage of project costs, depending on the type and complexity of the construction and the prime contractor's preferences. Subcontractors' progress payments, subject to approval of the contractor's authorized field person, are recorded and maintained to control expenditure spending for subcontractors. An example of a subcontractor's progress payment claim is shown in Table 4.8. Three groups of data items can be classified as areas. The first area is subcontract information. The second one is data items about change orders for the subcontractor. The third area is information about the subcontractor's progress payment. Table 4.9 shows these areas and their data items.

Area	Data items
Subcontractor	Subcontractor name, Work description, Contractor price
Sub's progress payment	Claim no., Date, For period, Amount, Work description
Sub's change order	Change order no., date, change amount

Table 4.9 Data areas and their items derived from subcontractor progress payment claim

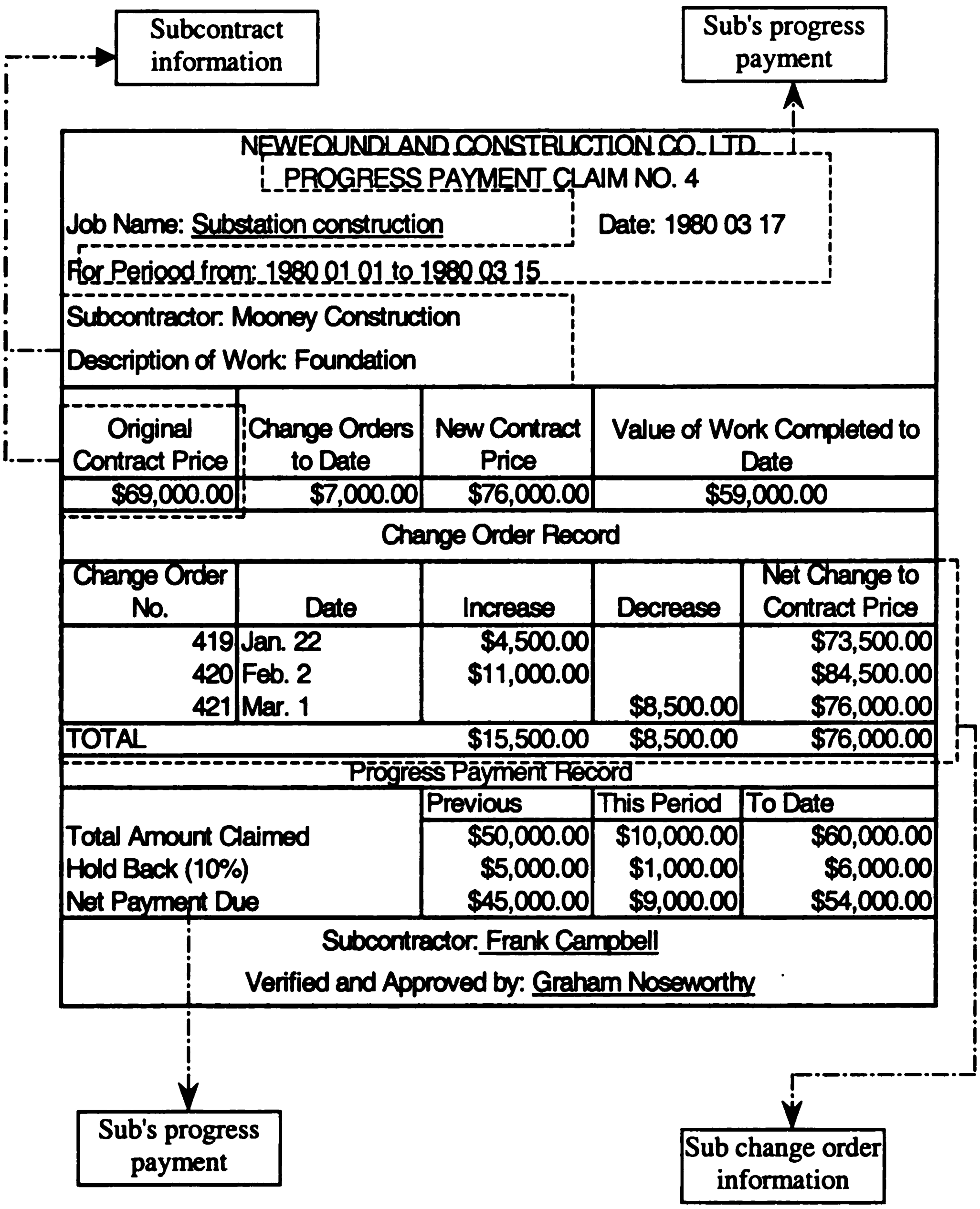


Table 4.8 Subcontractor progress payment claim
(Source: Ahuja, 1980)

From the above analysis, data element groups are classified from forms as areas. These areas reflect an abstraction level of data elements. They could serve as candidates to be used as entities in an ER model diagram.

4.4 Chapter Summary

In this chapter, a project cost system was analyzed. Numbering data storage units based on work packages derived from a project WBS and master format was proposed. Each work item served as a data capture unit to collect both cost data and time related data. Through the common data capture unit, the cost system was extended to perform some schedule control functions. Data collection and information process in a cost system were analyzed. Then information requirements in this integrated system were examined from form analysis for the database design. Data elements in each form were identified and classified by dividing form structure into areas. This classification of areas as data element groups established the approach toward the abstraction of entities for the conceptual database model development. In the next chapter, the conceptual database model for project cost and time data is formalized.

Chapter 5

REA Database Model for Project Cost and Time Data

Information requirements in a project integrated cost system was analyzed in Chapter 4. Work items were coded according to a project WBS and proposed as cost and time data storage units. These units also provide an integrated point for time data to store in a cost system. After data elements are identified and classified in an integrated cost system, the next step is database model development for cost and time data. In this chapter, the database model is developed and explained.

Entity-Relationship (ER) is used as the database modeling method to develop the conceptual model for project data. It organizes data elements identified in chapter 4 in terms of entity, relationship and attribute. It is critical to fully understand the business process of a company in order to evaluate and reengineer an information system. First, a construction company's activities are examined from the value-chain point of view. Project construction is viewed as a conversion cycle in which resources are converted into goods and services for sale. Within each cycle, business events trigger the need for an information process to record, store, analyze and retrieve event data. A database of the project data is built to satisfy this need. In the database environment, REA as a generalized entity-relationship representation, which consists of sets of resources, events, and agents and which serves as a template in the modeling process. From a business event as the beginning point, an REA pattern considers what (resource) and who (agent) are involved in the event. It identifies and represents the essential data characteristics of business processes and events in a set of events, resources and agents within a database environment. After the database model has been developed, sample tables and queries in an MS Access DBMS are built to reflect the idea of a database view integrated cost system.

5.1 A Construction Company and Value Chain

5.1.1 Value Chain Concept

The Value chain concept was first introduced by Porter, 1985. It provides a systematic way of examining all activities that a firm performs and how they interact in analyzing the sources of the company's competitive advantage. Later this concept has been extended to be used in business reengineering for Architecture/Engineering/ Construction (A/E/C) industry and information system analysis (Choi, 1994; Hollander, et. al., 1993). In Porter's original definition "every firm is a collection of activities that are performed to design, produce, market, deliver, and support its product." All these activities are represented using a generic value chain, shown in Figure 5.1. These activities are divided into two categories, primary activities and support activities. Within each category, activities are further classified into different groups. Primary activities are directly related to product production and sale. They can be grouped further into groups such as operations, logistics, marketing and sales and service for operations. The other category includes activities that do not directly contribute to product production and sale but they are also one important part of a firm's daily business to provide support functions. They can be separated into firm infrastructure, human resource management, technology development, and procurement groups. After all activities are classified within the generic value chain, they can be examined into details to find the added value to the products and thus its value margin to the firm.

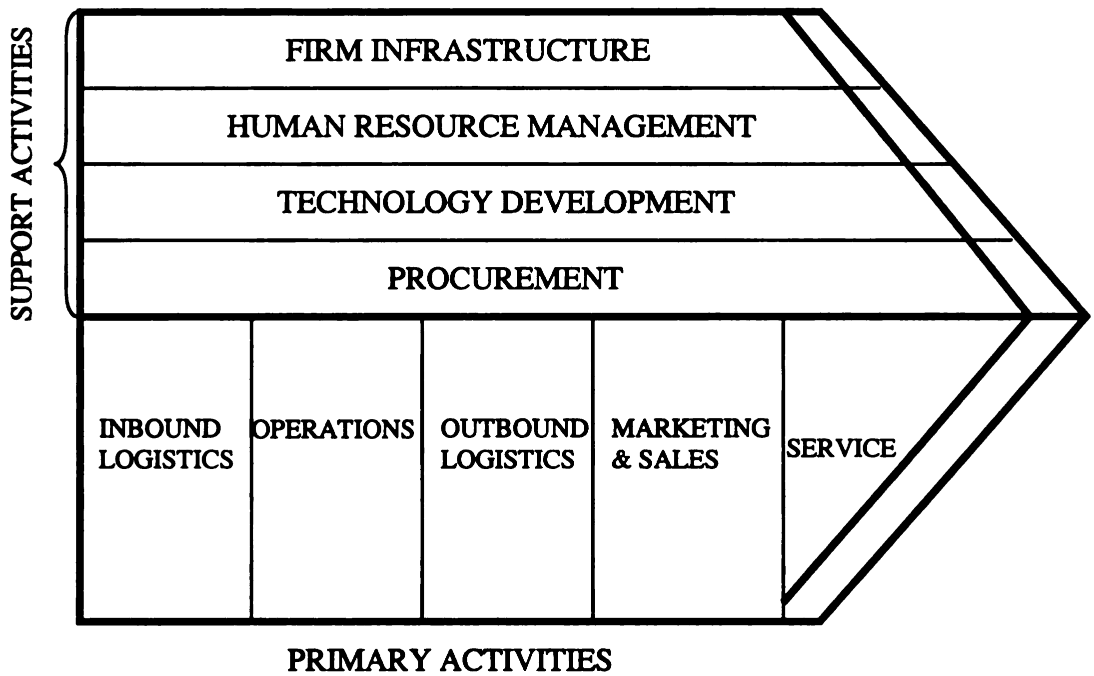


Figure 5.1 The generic value chain
(Source: Porter, 1985)

5.1.2 A Construction Company's Value Chain

In the later extension (Hollander, et. al., 1993), the value chain concept has been used in business process analysis for information system design. The business processes define how an organization creates value. They are the activities associated with providing goods and services to customers. Regardless of the type of goods or services provided, each organization has three types of business processes:

1. Acquisition/payment process — acquiring, maintaining, and paying for resources needed by the organization to provide goods and services.

2. Conversion process — converting the acquired resources into goods and services for customers.
3. Sales/collection process — delivering goods and services to customers and collecting payments (Hollander, at. el., 1996).

Furthermore, a business process is divided into a discrete, related series of business events. When business events are executed, they trigger the need for an information process to record business event data.

Business, in general, has been decomposed into acquisition/payment, conversion, and sales/collection processes. When applied to the construction industry, the basic process will be similar, but the events within each process and the methods used to convert resources into goods and services for customers differ significantly. The goods and services delivered in the construction industry are facilities, such as buildings, roads, power plants, airports, and dams. The generic value chain process of a construction company is shown in Figure 5.2. Three business processes of a construction company are shown in the circles. Besides acquiring human resources, financing, property, and plants, a construction company will also acquire labor, material, equipment and subcontract services. These acquired services and resources are inputs in the construction process. Each construction project is a conversion process for one or a group of facilities. Project management in construction is the process to organize, plan, control and deliver a facility. The sale and collection process in a construction company is completed by the way of period progress payments during the construction. Outside the company, customers and suppliers are also involved in the company's business process. In the construction industry, these outside participants are facility owners, suppliers and subcontractors.

Suppliers and subcontractors participate in the company's business by providing resources and services and by getting paid. Owners are involved in the process by receiving their facility and paying for it. The arrows in Figure 5.2 illustrate money, resources, and products flowing through the company's process and its outside participants.

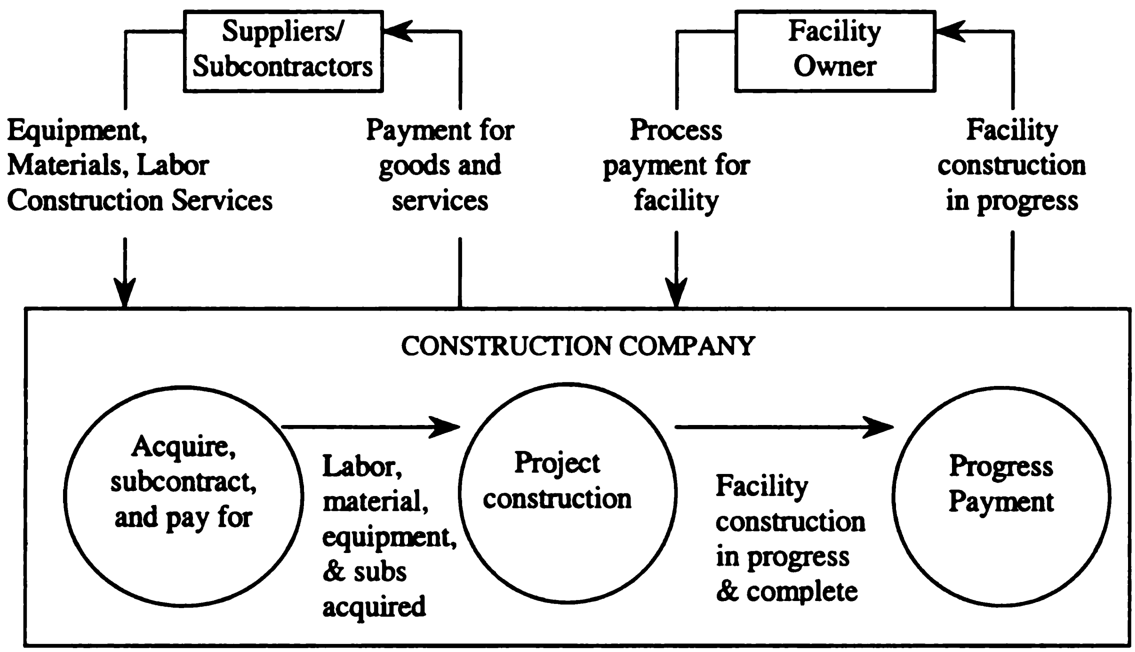


Figure 5.2 Business process in a construction company
(Modified from Hollander, et. al., 1996)

Information processes are shaped by an organization's business and management processes (Hollander, et. al., 1996). A value chain provides a way to decompose an organization into processes and events. Each event triggers a recording process. Record maintenance creates the need for a repository of data that documents and describes an organization's business processes, including the events, people and resources associated with the processes. This data repository which is a collection of data, is used to generate output for information customers. For example, subcontracting parts of the project's work is an example of a business event; recording data about the subcontract is an information process. Installation of the formwork of the first floor wall is an example of event; while recording the actual data about start and finish times for this installation is an information process.

A value chain analyzes the business processes within an organization into separated cycles (processes) and down to events. It provides a business model on which a database system can be built. Data generated in the business process are identified and recorded and then associated with the events analyzed from the value chain.

5.2 REA Concept for Integrated Cost System Redesign

As described in Chapter 4, a job cost accounting system records and processes project cost data. It is part of a traditional accounting information system serving the cost control function, and providing information for future project planning. In the process of design of an accounting information system integrating with computer database technology, REA framework as an 'occurrence template' was developed using database modeling for accounting transactions (Geerts and McCarthy, 1991). When referring to accounting as the language of business, REA provides an alternative model language to organize business data. It organizes entities and relationships of the data model into a template of three elements that are resource, event and agent.

- Economic resources are defined to be objects that are scarce and have utility and are under the control of an enterprise.

- Economic events are defined as a class of phenomena which reflect changes in scarce means (economic resources) resulting from production, exchange, consumption, and distribution.
- Economic agents include persons and agencies who participate in the economic events of an enterprise or who are responsible for subordinates' participation. (McCarthy, 1982)

Stock-flow relationships connect the economic resource and events. Resource stock flows to economic events and is consumed there. In the mean time, events are controlled by agents. A duality relationship links events when one event is increasing the resources of an enterprise and the other is a corresponding event involved with resource decrement (McCarthy, 1982). A typical example to reflect the duality relationship concept is the relationship between "purchase" and "cash disbursement". "Purchase" fills the increment role which increases a company's raw material, supplied parts and other resources. "Cash disbursement" decreases the company's money resource. These relationships and the resource-event-agent (REA) elements are shown in a simplified REA template in Figure 5.3. The symbols used here have the same meaning as they do in an ER model. Examples are given for resource, event, and agent in the entity rectangles. It is a simplified REA pattern because duality relationship is not illustrated in this pattern. Duality relationship in the conversion cycle of project construction is presented by the relationship between "actual resource usage" and "actual work item in progress" events. Actual resource usage reflects the decrement of resource owned by a company. Actual work item in progress is an event representing actual work done in the field. What the work has done in a project is the increment of the construction product (project), which can be viewed as a company's resource also.

After the data elements concerned within the integrated cost system are identified, development of a data model would continue by trying to characterize those items in semantic terms (that is, in terms of entities and relationships). With the REA as a template, this characterization process would proceed to identify economic events, resources, agents, and their data attributes. An REA provides a template to help system designers think about the information process of a company. Events are considered as critical information elements and as base elements of the conceptual schema (McCarthy, 1982). Then, what and who are involved in this event are considered as resource and agent. Data generated during a business process are recorded around an event, resource and agent template.

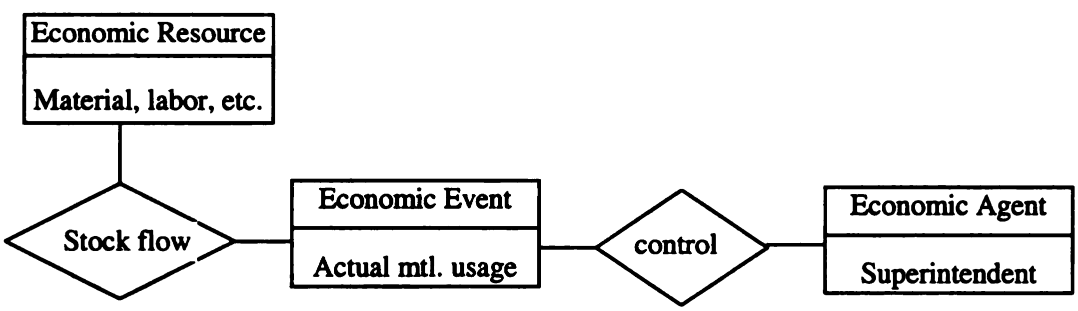


Figure 5.3 A simplified REA example

5.3 REA View for Project Cost and Time Data

What is proposed here is the database view of an integrated cost system. Traditionally, cost data are entered and recorded in a job cost accounting system.

Information that project managers need is derived from cost accounting forms and procedures. Through carefully defined work items, time related data could also be recorded in cost accounting forms. When this system is redesigned in a database view, it reflects a new way to record, manage, and retrieve data. Data are mapped in a conceptual data model to derive the logical structure of the cost system. In the mean time this model can be further processed into a computer storage structure of database management systems. The list of data elements concerned with processing of information required in an integrated cost system have been identified in chapter 4. The conceptual database model is developed here by using the entity relationship (ER) modeling method. It focuses on description of the information content of a database rather than storage structures in a computer. REA provides a template method of discovering an enterprise's business process and events and organizing them into a database environment. Then, the E-R model is built around a major business event. Several events are identified such as actual work items in progress, actual labor usage, actual material usage, actual machine usage and subcontracts.

5.3.1 REA Template to Model Identified Events

5.3.1.1 Material Actual Usage

The REA pattern of material actual usage records actual material use in a project. Material, described by the material entity, is issued to actual usage entity. The superintendent is in charge of the material actual usage. A simplified REA pattern with resource (material) flowing to the actual usage event is shown in Figure 5.4. The superintendent is involved as an agent to be in charge of material actual usage. The cardinality in each relationship which is shown in the parentheses in Figure 5.4 is explained as follows. One kind of material can be used many times in the same project. In the mean time, there is only one kind of material contained in one actual material usage event. One superintendent can issue material usage to the project many times. Actual material usage must be authorized by a superintendent.

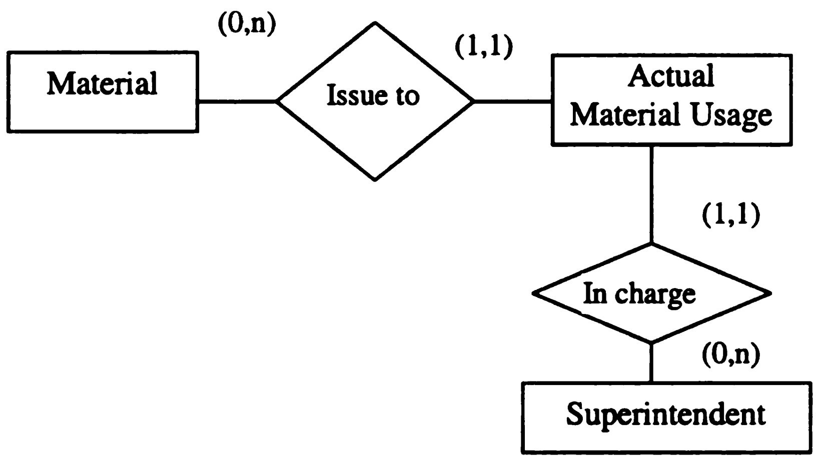


Figure 5.4 Simplified REA pattern of material actual usage

5.3.1.2 Labor Actual Usage

Labor is viewed as an economic resource in the REA template here since it is under control of the company and consumed to the project through labor hours. Labor is not viewed as an agent because it is not responsible for a subordinate's participation. The labor usage process is similar as the pattern of material usage. It is shown in Figure 5.5.

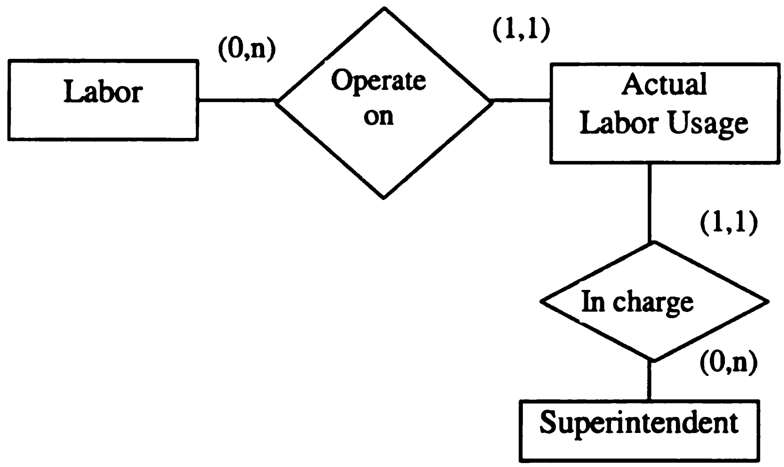


Figure 5.5 Simplified REA pattern of labor actual usage

5.3.1.3 Equipment Actual Usage

The process of equipment usage in a construction project is similar to labor usage. Equipment actual usage is controlled by operators. So operators are involved in this process as agents. As a resource, direct consumption of equipment is calculated by equipment time spent on the project. The simplified REA pattern for equipment is shown in Figure 5.6.

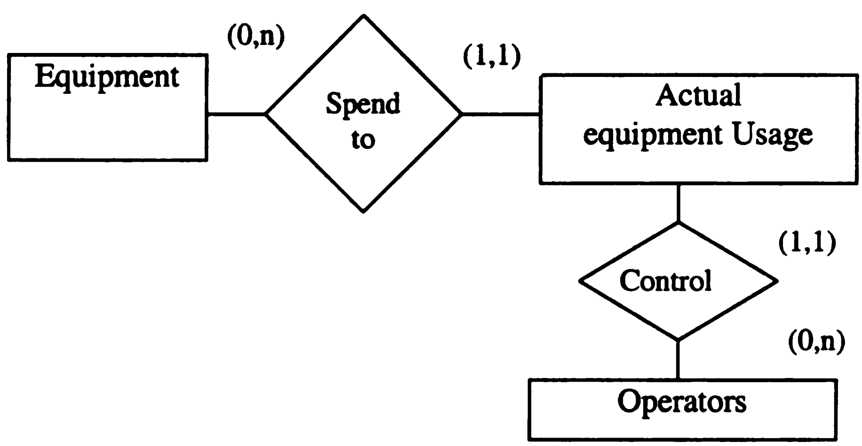


Figure 5.6 Simplified REA pattern of equipment

5.3.1.4 Subcontract

Subcontracts usually form a varying percentage of project work, depending on the type and complexity of the construction and the prime contractor's preferences. So it's also an important event in the project construction process. But the difference is that it is not performed by the company's own forces. It represents the company's outsource process. As an outsource event, subcontractors are external agents involved in this process. The resource here is the progress payments as the money resource flows out to pay for this service. The part of work items of a project done by subcontractors can be seen as the in flow resource that the company gets through the subcontracting event. In the database modeling process, if an entity's existence depends on the existence of one or more other entities, it is said to be existence-dependent (Rob and Coronel, 1997). This concept explains the relationship between subcontracts and sub's change orders. According to the data requirement analysis, data elements about subcontractor's change orders need to be classified in one group to provide information for management during the construction period. This group of data elements can be identified as the change order entity. A subcontractor's change orders refer to its related subcontract. They exist only when the subcontract exists so the subcontractor's change order entity is a dependent entity of a subcontract entity. The subcontractor part of the data model is shown below in figure 5.7.

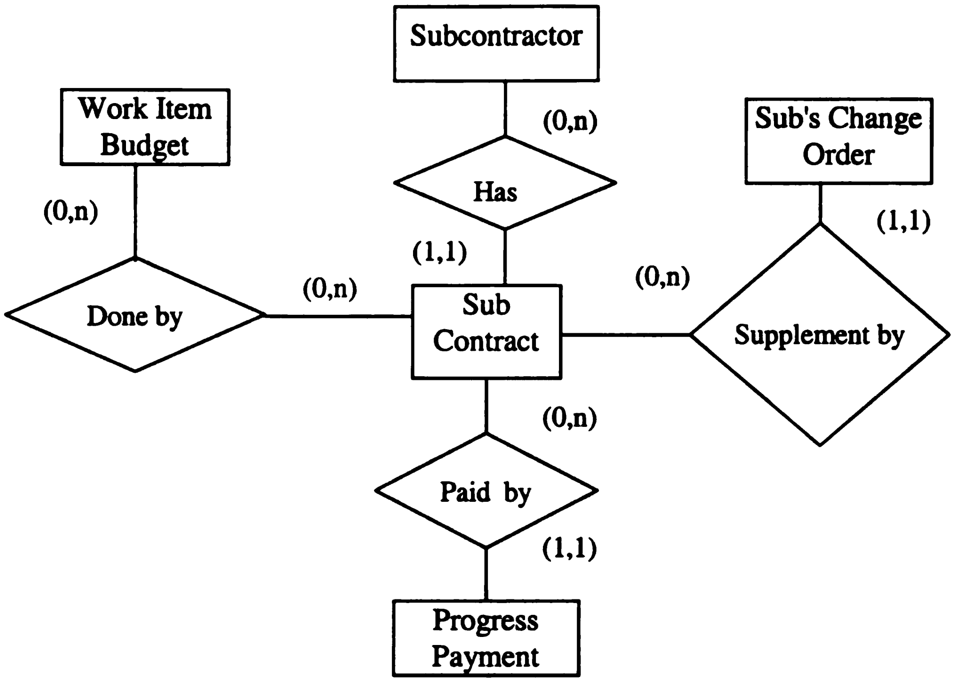


Figure 5.7 Simplified REA pattern for Subcontract

5.3.1.5 Actual Work Item in Progress Aggregation

An abstraction is a mental process that is used to select some characteristics and properties of a set of objects and to exclude other irrelevant characteristics. Aggregation is one type of abstraction concept used in database modeling. It defines a new class from a set of other classes that represent its component parts (Batini, et. al., 1992). Aggregation is described as a "part-of" relationship; for example, wheel, pedal, and handlebar are all parts of a bicycle. The aggregation concept is illustrated by the relation between the actual work item in progress and actual labor, material, and equipment usage. Each work item may have material, labor, and equipment actual usage. Labor, material, and equipment usage are component parts of each work item. This relationship is shown in Figure 5.8. As explained in section 5.2, the relationship between these resources usage entities and the work item in progress entity also reflects the duality concept in an REA pattern. While resources are decreased by consumption in the project, (construction product), a facility is built which is an increment of another kind of resource in the company (products).

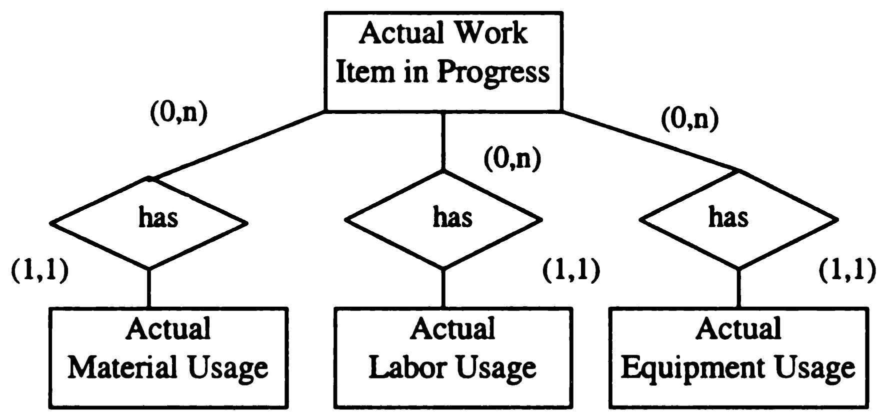


Figure 5.8 Actual work item in progress aggregation

5.3.1.6 Actual Work Item in Progress and Work Item Budget

The entity of an actual work item in progress is for recording work performed in the field. No matter whether these items have been finished or are still in progress, they should correspond to the budget of each item. So there is a relationship between work in progress and its budget. This relationship reflects the items in a project that are performed by a general contractor's own forces. It is modeled by an actual work item in progress and a work item budget with a one-to-many relationship shown in Figure 5.9. It shows each budget work item that is needed to be done in the field and that actual work item in progress data can be recorded several times corresponding to one budget work item.

Figure 5.9 ER model for Work item in progress and budget

5.3.1.7 Work Item Budget and Its Components: Material, Labor and Equipment

Material, labor and equipment are basic cost components of each work item. So relationships exist among labor, material, and work item budgets. Each work item may contain several kinds of material or may consist of only labor and equipment without material consumption. Each kind of material may be used in one work item or in many work items. A many-to-many relationship exists between material and work item budget entities. This relationship has it own attribute to record quantity of each material type for each work item. During the logic design phase, this relationship needs to be transferred into a data table to store this information.

Each worker's personal information such as name and address are recorded as resources in a labor entity. These workers can be further classified according to different craft types. A labor type entity is required for labor type information such as hourly rate, worker availability and number of each craft. Each work item may include several types of crafts to become a crew. For example, placing concrete may include one foreman, one concrete mason, four laborers, one operator, and one carpenter. So the relationship between work item and labor type represents a labor resource component in each work item. This is a many-to-many relationship since each labor type may be included in many work items and each work item may include several kinds of craft. This many-to-many relationship also has its own attribute such as budget hours and number of workers in each craft for each work item. So this relationship must be transferred into a data table when logic design proceeds. Data for equipment cost of each work item are modeled in the same way. Machines are classified into different types and data for machine type are recorded in a machine type entity. Equipment cost information for each work item is represented by the many-to-many relationship between equipment type, and work item budget. The relationships between work item and the corresponding labor, material, and equipment cost are illustrated in Figure 5.10.

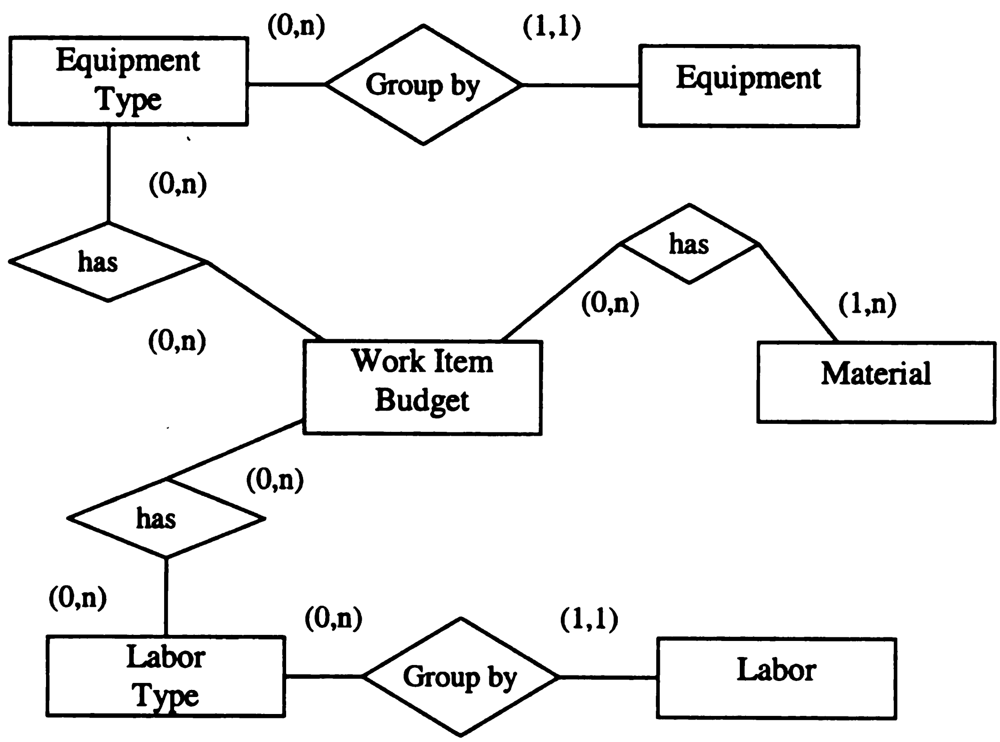


Figure 5.10 Relationship of resource cost and work item budget

5.3.2 Overall Conceptual Model

From the analysis of the different project components, an overall conceptual database model can be derived. Figure 5.11 illustrates the entities and structure of an ER model for project cost and time data. The model is derived by connecting logic relations which were explained above in Figure 5.4 to Figure 5.10. This ER model records actual expenses based on work items. Actual work progress and time are also recorded in work items in progress with actual start times. Work items for completed work also have finish times. Information for resources such as employee name and unit cost is described in material, labor and equipment entities. Workers and machines can also be classified into different types such as labor crafts and machine types to record data elements related to type such as budget rates for different crafts. When resources are spent in a project, the consumption is recorded in actual usage. Material is measured by actual quantity used. Labor and equipment are calculated by hours spent. Then the usage of different kinds of resources is aggregated to the actual work item in a progress entity. The superintendent and operators are involved in the construction process as responsible persons controlling events. Each work item has its budget information recorded in a work item budget entity. After work items have been performed in the field, actual cost and time consumed need to be compared with the budget. This relationship is modeled by a one-to-many relationship between actual work items in progress and work item budget entities.

A project can be separated into two parts, one is performed by a general contractor's own forces, and the other part is subcontracted out. An actual work item in progress reflects the work performed by a contractor's own forces. When parts of the project are subcontracted, subcontractors are involved as agents to perform parts of the project work.

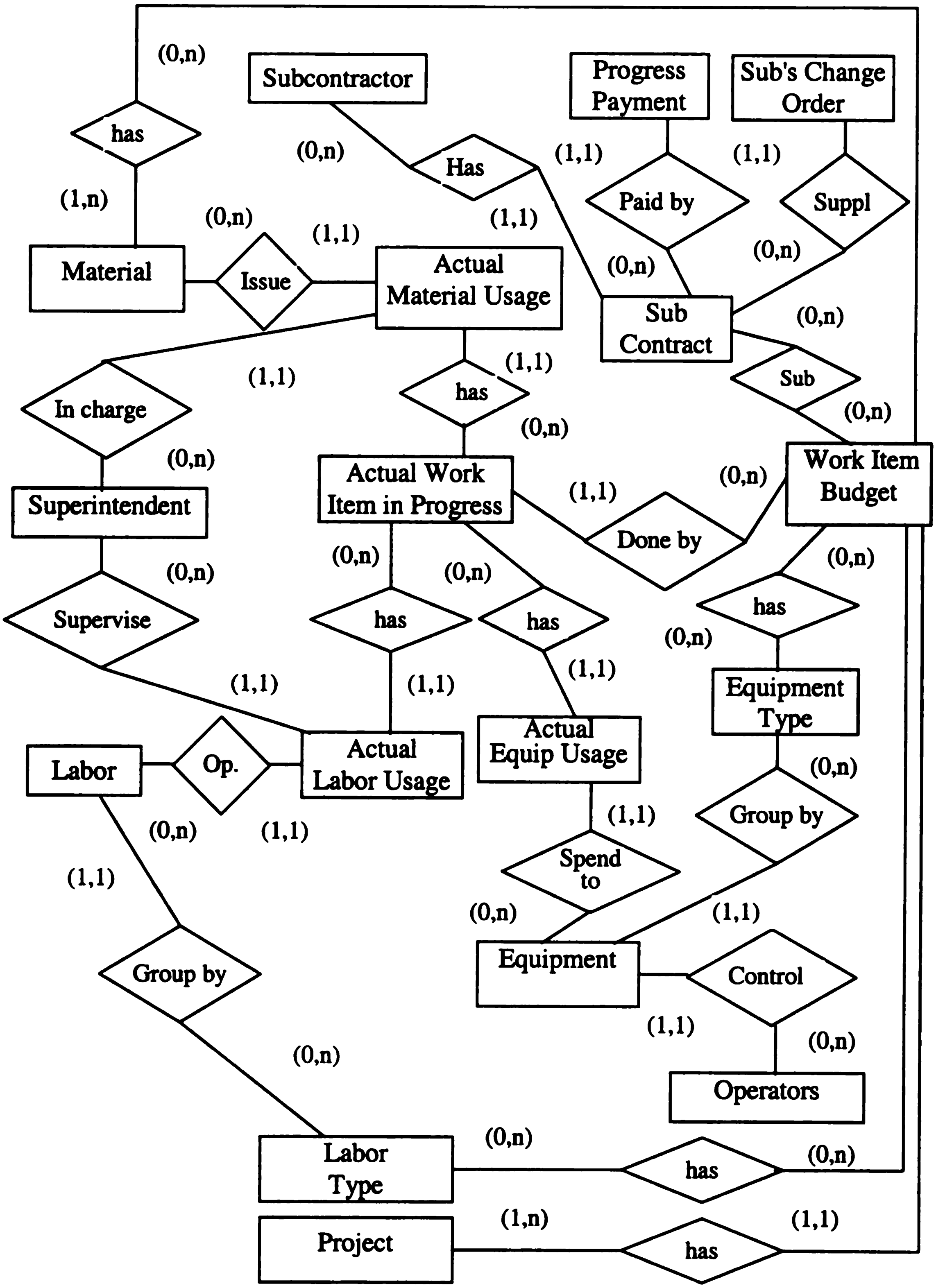


Figure 5.11 Conceptual database model for project cost and time data

Periodic progress payments to subcontractors are the money resource out flow as another important expense in exchange for a service. Subcontractor's change orders are the supplement part to each subcontract to reflect new changes of a project due to the complex situation during construction. These relationships are illustrated in the subcontract part of the ER model. General project information such as project title, location, start date and total price is recorded in the project entity. Each work item reflects one small piece of the project. One project consists of all work items aggregated together.

The conceptual database model represents an abstract picture of an integrated cost system. Project direct expenses are recorded and compared with the budget. Actual cost data are stored and can be used in a future estimate. In addition, time related data are also described in the budget and actual work item entities to provide work progress information for schedule measure and control. Each entity in Figure 5.11 has its attributes to describe the data characteristics of the entity. All entities in Figure 5.11 and their attributes are listed in Table 5.1. The first attribute in each entity is the key attribute to identify every instance in the entity.

Entity Name	Attributes
Project	Project no., Name, Start date, Finish date, Owner, Original contract price, Total value, Location,
Work Item Budget	Work item no., Description, Unit, Quantity, Start time, Finish time, Duration, Material cost, Labor cost, Equipment cost, Total cost
Relationship between Material and Work item budget	Material budget no., Quantity, Material cost
Relationship between Equipment type and Work item budget	Equipment budget use no., Budget hours, Standard rate, Overtime rate
Relationship between Labor type and Work item budget	Labor budget no., Budget labor hours, Budget labor rate,
Actual Work item in progress	Work item work in progress no., Actual quantity, Actual start date, Actual finish date
Material	Material stock no., Description, Budget unit cost, Unit
Labor	Employee Id., Name, Address, Phone no.
Labor Type	Labor type no., Description, Available number, Budget rate
Equipment	Machine Id., Machine name
Equipment Type	Equipment type no., Description, Standard rate, Overtime rate
Subcontract	Subcontract no., Contract price,
Subcontractor	Subcontractor Id., Description, Contact person, Address, Phone no.
Sub Progress Payment	Progress payment no., Period from, To Date, Description, Amount
Sub Change Order	SubChange order no., Date, Change amount
Operator	Employee no., Name, Wage rate
Superintendent	Employee no., Name, Start in charge date, Finish in charge date,

Table 5.1 Entities and their attributes

5.4 Logic Design in MS Access

Logic design translates the conceptual model into a particular database management system (DBMS). In a relational database environment, tables are created using Structured Query Language (SQL). This language is composed of about thirty commands, and is designed to work with any application that requires the manipulation of data stored in a relational database (Rob and Coronel, 1997). By using SQL, table structures can be created within the designated database. Most DBMS now use query by example (QBE) interfaces that allow the attribute names to be typed into a template and the attribute's data type to be selected from pick lists. MS Access supports this kind of template to create tables, queries, and forms.

5.4.1 Table Creation

In this research, all entities represented in a database conceptual model have been implemented into MS Access tables. There are two ways of applying the relationships in the conceptual model to a DBMS. In a one-to-many relationship, the primary key in the one-side entity can be posted to the many-side entity to become a foreign key attribute. In a one-to-one relationship, the primary key of either side entity can be added to the other side entity as a foreign key attribute. Besides a foreign key attribute posting, an additional table can be created to represent the relationships between entities. Primary key attributes are the key attribute from both side entities in a binary relationship. Relationships being transferred into a data table are required when a many-to-many relationship exists or when the relationship has its own attributes such as the relationships among work item budget and its resources as explained in section 5.3.1.7. In this Access implementation, each of the relationships is implemented by creating a table. So the entities and relationships in the conceptual database model in chapter four are become tables in MS Access. Some data table structures of this database are shown in Appendix C. These data tables are built to store cost and time data during a project construction process. They consist of a relational database. Information presented in reports and other formats is draw from these tables by computer procedures. Some sample data are entered into these tables as shown in table 5.3 to table 5.8. These data are from the sample highway bridge project in Clough and Sears' book "Construction Project Management, Second Edition."

5.4.2 Database Operation

The useful power of a database system is that data are logically related and stored in a single data repository. Therefore, they are easy to store, access and manage to produce information by using automatic computer procedures. Based on data tables, some operations such as query and index can be created to manipulate data. A query is a question regarding an information requirement to which a database can provide answers. An index refers to sorting the data in an entity in order. The query capability of relational DBMS by SQL provides a powerful and flexible way to manage data. This capability of data manipulation provides a more flexible way to retrieve information. Different kinds of reports can be produced dependent on how SQL queries are written. Besides query, index and other utility functions provided by a DBMS, application programs could also be written accessing the database to produce useful information.

5.4.3 Weekly Labor and Progress Report Generation

In this research, after the database conceptual model has been transferred into an MS Access database, a weekly progress and labor cost report is generated as an example to illustrate the SQL query procedure. In the project construction process, labor costs and productivity usually attract much concern from project managers. A weekly labor cost report is produced throughout the construction to help monitor labor expenses. Work item's start date and finish date are also drawn from the database to include in this report. These time related data are provided to help project managers in monitoring project progress and controlling the schedule. Data used for this report are stored in several MS Access tables including actual work item in progress, actual labor usage, workers' information, craft type and work item budget tables. These tables are shown in table 5.3 to table 5.8. The sample data are from the sample highway bridge project in Clough and Sears' book "Construction Project Management, Second Edition."

Although data are stored in different tables, they are related to each other by sharing a common entity characteristic, a foreign key attribute. These logic relationships link them together to become a central pool of data. Query is the tool to draw data from the pool to meet the information needs. Based on this principle, a labor expense and progress report is produced to reflect the labor cost and progress statue by using queries and the report utility in MS Access. Its format is shown in Table 5.2. Basically, it compares budget data with actual data and makes forecasts based on work performed. Because of limited data, only one work item's cost and progress status are produced here. Due to the same reason, actual labor usage per day is assumed the same for six days as a week. The work is scheduled to be finished in seven working days. This example shows the possible project information-processing procedures in a database built upon the conceptual model discussed in chapter 4.

WEEKLY LABOR And PROGRESS REPORT

Project: Highway Bridge — Project No 7908-05

Project Ending: July 21 — Prepared By: R.H.C.

Work Item No	Description	Unit	Budget Qty	Actual Qty	Labor Dt Cost
03157	Abutment forms	sf	1,810.00	1448	$1,909.50

To Date Labor Cost	Budget Lb. Unit Cost	To Date Lb Unit Cost	To Date Saving / Loss	Projected Saving / Loss
$1,498.08	1.05497	1.03459	$29.52	$36.90

Budget Start Date	Budget Finish Date	Actual Start Date	Actual Finish Date
7/19/79	7/27/79	7/15/79	7/21/79

Table 5.2 Example of weekly labor and progress report

Work Item WIP No	Actual Quantity	Actual Start Date	Actual Finish Date
A03157-1	1448	7/15/79	7/21/79

Table 5.3 Actual work item in progress data table

Labor Usage No	Date	Actual Hrs	Actual Rate
AL03157-1	7/20/79	8.00	$11.4
AL03157-2	7/20/79	8.00	$11.4
AL03157-3	7/20/79	8.00	$8.41

Table 5.4 Actual labor usage data table

Employee No	Name	Labor Type No (foreign ksy)
132	Kraus, W.R.	0001
143	Whelan, M.D	0003
176	Green, T.T	0002
221	Pierce, J.L.	0001
248	Cordova, J.E.	0003
319	Johnson, S.V.	0003
417	Armstrong, R.D.	0002

Table 5.5 Workers' information data table

Labor Type No	Budget Lbr. Rate	Craft
001	$8.41	Labor
002	$12.60	Foreman
003	$11.53	Concrete
004	$8.41	Labors
005	$11.10	Operator
006	$11.40	Carpenter

Table 5.6 Craft type data table

Labor Type No	Work Item Budget No	Budget Labor Hrs.
001	03311	5.00
002	03157	227.00
002	03311	20.00
004	03311	5.00
005	03311	5.00
006	03311	5.00

Table 5.7 Data table for the relationship between Labor Type Entity and Work Item budget entity

Work Item No.	Description	Qty	Unit	Unit price	St. date	Fn. date	Duration	Mtl. cost	Labor cost	Equip. Cost	Total cost
03157	Abutment forms	1810	Sf	1.92	7/19	7/27	7	145	1909	660	3482
03311	Concrete, footings place	60	cy	44.41	7/12	7/13	1	2236	200	148	2664

Table 5.8 Work item budget data table

5.5 Chapter Summary

A database conceptual model was developed by using the E-R data modeling method. It was derived both from basic concepts involved in the construction process and applications of business information-process analysis techniques. A construction business follows the general business value chain cycles, and project construction is identified as the product conversion process with its own characteristics. The REA concept provides a template for business information systems modeling in the relational database environment. It also fits into the process for construction project data model development. In this chapter, sample table structures based on the conceptual model were also applied in MS Access. Information abstraction procedures from database were explained and illustrated. In the next chapter, two case studies will be described to observe the project cost system in actual construction projects and to evaluate the conceptual model with actual construction practices.

Chapter 6

Case Studies

In Chapter 5, a conceptual database model was developed. This model shows the data content and its logic structure of an integrated project cost system. Data table structures based on this conceptual model were set up in the MS Access database management system. Labor and progress reports were produced as an example to illustrate the information generation process in a database system and to prove the REA concepts applied in the conceptual database model. In this chapter, case studies will be discussed to evaluate the conceptual database model for actual construction projects to find out how information requirements in a cost system can be satisfied by a database as a central data storage and management facility instead of traditional independent file systems. Two projects were used as case studies: one is an institutional construction project and the other one is a prison facility. The cost systems and schedule control functions used in these projects will be analyzed. Through this analysis, some problems that can be solved by applying the database model will be found. The possible changes will be proposed and benefits will be discussed.

6.1 Case One: an Institutional Project

Case one is a new high school construction project. The total project construction value is $31 million, including classroom, auditorium and gymnasium. The construction company was involved in this project since the design phase to help the owner in design, document and price estimating preparation. The company was assigned the contract through negotiation. Then the company is fully responsible for the whole construction process. After the company got the contract, all work was subcontracted out. The company organizes all participants from mobilization to completion, and coordinates design and construction.

6.1.1 Cost System in this Project

The project has been divided into bid packs and subcontracted out based on these bid packs. The total project was divided into bid packs according to the project work breakdown structure (WBS). An estimate for each bid pack was developed as a basis to compare bid prices submitted by subcontractors and also as the budget to control cost during construction. Some estimates for bid packs were prepared from takeoff of blueprints, while some were calculated by the total quantity of the particular work such as square footage of the site work area. The pricing was based on the company's own historical cost data for the same type of work and supplemented by the market prices quoted from subcontractors specialized in a particular kind of work and the local price information known by the estimator. The company's historical data are maintained by cost per square foot of each section according to different type of projects.

The company solicited subcontractors' bids and selected the sub contractor for each bid pack. The major concern of cost control in this project is controlling the subcontractor's costs. The project manager is also the cost control and schedule control person in this project. During the construction process, a spreadsheet is maintained for cost control functions. All the cost data were entered into spreadsheets. The purpose of this spreadsheet is to compare budget with actual cost and to record change orders in order to monitor costs for preventing overrun. The basic cost items for data collection are bid packs. These bid packs were developed according to the project WBS by major process such as site work, concrete, plumbing, and landscape. Each bid pack was assigned to one subcontractor. Major data items in this spreadsheet include original budget, subcontract amount, submittal for changes, approved change orders and amount, and actual payment to subcontractors. The project manager recorded and traced each transaction about income (approved change orders) and expenses (payment) to maintain a margin between budget and actual cost. This margin needs to be a positive figure in order to keep a profit. Reports about the cost status are generated monthly.

A project schedule was developed according to different subcontractors' work sections as milestones for time control. This schedule was developed and maintained using Primavera Project Planner (P3). It is maintained separately from the cost system. The progress of the project is monitored according to this schedule.

6.1.2 Analysis of the Cost System of this Project

Since all work of this project is performed by subcontractors, the company's primary job is to organize the subcontractors' work and maintain their costs within budget. The original budget and expenditure of each bid pack were recorded. After construction was started, changes of the original contract are important items of concern for the project manager. These changes are from several sources including the need to change building design, and field changes from subcontractors. These change orders are submitted to the architects for approval. Before approval, they are recorded in the suspending item in the spreadsheet. If they are approved, they will be listed with the original budget to derive the total amount for controlling the expenditures. So all items including budget, changes, expenses, savings and losses are listed in a spreadsheet. When reports are required, the project manager needs to go through all of the listed data manually to draw information for the report. This process would require much time of the project manager.

The cost system used in this project is not integrated with schedule control functions. No time related data is collected in their cost system. Schedule monitoring and updating are performed in P3.

6.1.3 Recommendation: Database System for Cost Data

The previous two sections described and analyzed the cost and schedule systems used in the first case study project. In this section, some possible changes and benefits by applying the conceptual database model developed in chapter 5 to build a database management system (DBMS) for performing information processes for cost and schedule control will be discussed.

6.1.3.1 System Changes

There will be two changes proposed here as follows:

(1) Using a database to organize, store and manage cost data which is now handled by the spreadsheets. This database can be built based on the conceptual database model of this research. Since all work of this case project is performed by subcontractors, the company does not need to trace the cost to the material, labor, and equipment levels. The database will only include the subcontract part of the

database model and will be easy to develop and maintain. The conceptual database model applied in this project is illustrated in Figure 6.1.

(2) Using basic cost control units the same as the activities for schedule development. In the existing cost system, bid packs are the smallest units for cost control. A schedule is developed in P3 having its own basic units for time control. Here, bid packs are proposed to be divided according to the CSI master format breakdown structure. In the same time, schedule activities are derived from the same structure. The bid packs can serve at the milestone level in schedule control. Time data such as start date, finish data and duration can be summarized for each bid pack and recorded into the cost system.

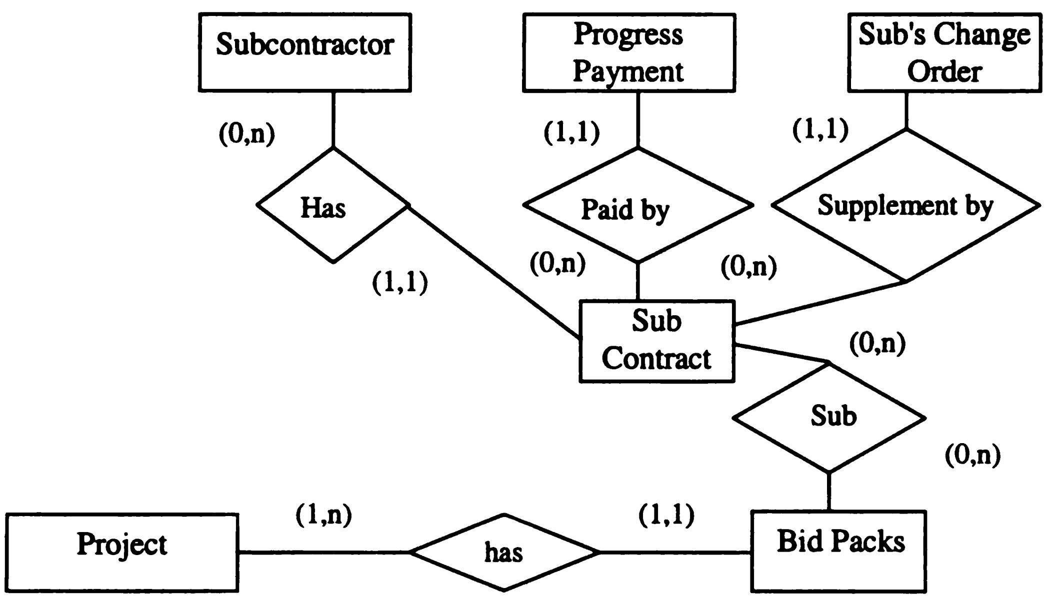


Figure 6.1 Conceptual database model applied for case project one

6.1.3.2 Evaluation of Benefits from these Changes

The following benefits are observed from the changes proposed in section 6.1.3.1.

- **Benefit in report generation:** When cost data are all listed in a spreadsheet, the project manager needs to manually go over all data periodically to draw the necessary data and retype them for period reports. If data are organized in a database, these period reports can be generated automatically by preset queries. This is not difficult to implement in MS Access. It is a one-time setup but can benefit and save time through the construction period. Also, the project manager can have more choices in the report generation. They can organize and manipulate data by using SQL queries and report utility to produce desired information in different reports.
- **Benefit for future planning:** After the cost data are stored in the database instead of several independent spreadsheets, the necessary data for future planning can be derived by queries. Then these data are stored in an easy to use format instead of hiding in different spreadsheet files.
- **Benefit of connection between schedule and cost control:** When time data are entered into the database, they can be presented with the cost data in the same sheet by queries to provide more information about project status.

6.2 Case Two: A Prison Facility

This case project is building a prison facility with four buildings plus seven housing units. The total project value is $49 million. The general contractor (GC) was employed with a lump-sum contract. The GC is responsible for all aspects of the project construction and reports to the owner and architects. The concrete work is performed by the GC's own workforce. Other work is subcontracted to specialty contractors.

6.2.1 The Project Cost System Analysis

Before construction, a project estimate was developed as a budget for cost control. This estimate was developed from the takeoff of the blue prints. One project manager in this project is in charge of the field construction, progress control, cost control, and is also the estimator. So the cost items in this estimated are mainly based on his experience. He selected the detailed units that he wants to allocate costs for control. The pricing is based on the company's historical data and the estimator's experience about market information. After the construction started, spreadsheets are used to record and maintain cost data. The data items in spreadsheets include estimate of costs, actual costs per day, projected costs and variance. For the GC's own labor expenses, cost numbers for each of the above data items are allocated to each labor type of each cost item every day. These numbers come from the labor time cards submitted from the foreman. For the material expenses of the GC, cost is allocated to each building. Since equipment used by the GC is rented, the cost is only traced to the project level. Subcontract cost of this project is traced to each subcontractor.

Spreadsheets are used as the major computer tool to handle the cost data-processing functions in this project. When information is required, the project manager needs to find it manually from all data items in different spreadsheets. It is not an efficient way of data processing.

The project schedule is generated and maintained in Primavera Project Planner (P3). A person is assigned to be in charge of the project schedule. There are two schedules maintained in this project. One is a cost loaded schedule developed by a main office person. Each activity in this schedule has a budget cost assigned to it. The activities are updated with percentage completion when the construction is under way. The actual cost of each activity is calculated by the budgeted cost times percentage of completion. The purpose of this schedule is mainly to generate reports to the owner and architects. Since this schedule was created by the main office person, it is not very detailed and not suitable for all field construction circumstances. Another schedule was created by the project scheduler for the project time control. The problem is that activities in each schedule are not same. The project progress is recorded in the second schedule. These data need to be summarized and transferred to the cost loaded schedule to report to the owner and architects every period. Another problem is that the actual costs associated with each activity in the cost loaded schedule do not reflect the real expenses of construction. It is the budgeted cost for work performed. So for the GC, the relationship between actual costs and actual work progress is still not built.

6.2.2 Possible Changes for the Cost System

The cost and schedule systems in project two were described and analyzed in section 6.2.1. Some problems were observed from this analysis. In this section, a database environment based on the conceptual database model developed in this research is proposed as changes in this project for information processing.

When data are maintained in spreadsheets, it is very time consuming to update and does not allow automatic manipulation of data to produce necessary information. The project manager needs to look through all spreadsheets manually to find the required information. When data are stored in a database, different operations of data can be made for information processing. This database can be built in any selected DBMS software based on the conceptual database model of this research.

When this database is used, a common storage unit for cost and time is required. It requires developing the estimate and schedule in accordance with the CSI Master Format numbering project work breakdown system. Then time and progress data can be summarized from the schedule system and stored in this database. Progress information of a work item associated with its cost can be produced from this database. This arrangement can solve the two-schedule problem. The cost loaded schedule does not need to be maintained since the progress and cost information can be drawn from this database.

6.2.3 Evaluation of Benefits from these Changes

The possible benefits from the changes are as follows:

- **Benefit in information processing:** When data are collected and operated in a database, the necessary information can be produced by SQL queries. These queries can be set one time ahead and used many times when the information is needed. This strategy will save time and reduce errors when information is processed manually. In the mean time, different types of reports can be produced for desired information through the database operation. After project completion, data for future planning can also be summarized from the database as historical information of the company.

- **Benefits in schedule system:** When the same project breakdown structure is used for scheduling and estimating, the connection between time data and cost data can be built. The progress data can be calculated and summarized to the cost database. The progress and cost information can be generated from this database to present in one report for the owner. The problem of maintaining two schedules can be solved this way.

6.3 Feed Back from a Project Manager

The information about using a database to manage data was considered useful by the project manager for the first case study project. The professional accepted the idea of using a database to record and retrieve project data. It is considered to be an efficient way to organize large amounts of data in a project compared with spreadsheets. The project manager realized that a database allows data manipulation, which a spreadsheet can not do. He agreed that by using a database it is easy to sort data, draw specific information, and produce reports for different needs. He agreed that a database is very useful in cost data maintenance and information processing for construction projects. With the author's explanation, he also understood the need of a database model upon which to build the database.

The project manager also pointed out the need for training on using database software and the requirements of easy to use DBMS software. The author suggested windows based MS Access to use in construction projects because of its user-friendly interface.

6.4 Chapter Summary

The case studies were aimed at examining construction practice in cost control and the integration of time data in the cost system. The conceptual database model for project cost and time data was evaluated in the practice. Some possible changes based on this model were proposed. Benefits from these changes were analyzed to solve some real problems for information processes of a construction project.

Chapter 7

Summary, Conclusion and Future Research

7.1 Summary

This thesis centered on applying a database management system (DBMS) in the construction management field to improve the information processes of construction projects. The implementation of a DBMS requires a conceptual database model to represent the data contents and their logic relationships abstracted from real construction projects. The cost system of a construction company within the project management system is the major concern in this research. Since there exists a close relationship between cost control and time control, time-related data was proposed to be entered and managed in the cost system in order to integrate some time control functions in the same system. This was accomplished by using work items as the basic storage units for cost and time data. These work items are generated based on the project work breakdown structure (WBS) according to Construction Specifications Institute (CSI) Master Format system. The job costing performs the information processing function in a cost system. It is a series of forms, documents, procedures, and communication channels to record project data, process it, and structure it in particular formats for project management. This research proposed a design of this traditional information processing system into a database environment. Conceptual database modeling is the critical phase in a database system design. The objective of this research is to develop a conceptual database model for the project cost and time data. Based on this model a database can be built to achieve efficient information processing to facilitate project management. This model was developed by using entity-relationship (ER) database modeling method. In the meantime, the value chain concept and Resource-Event-Agent (REA) pattern were used in the business process analysis for the design of database. Two projects were used as case studies to evaluate the conceptual database model in the construction practice.

This research started from a literature review. It covered the topics about the integration of project cost control and time control functions and the database system application in the Architecture/Engineering/Construction industry. No database model covered all the cost components in a project cost system, which includes material, labor, equipment, and subcontractors' expenses, has been found in this literature review. Analysis of a construction company's business process for database management systems design also has not been found in the previous research. So this research was intended to provide a comprehensive conceptual database model to present the entire picture of a project cost system. In the meantime, a construction company's business process was analyzed to help the database model development.

A system approach for the database management system development was introduced after the literature review. The development process for the conceptual database model of the project cost and time data was described. Followed by this process, an information requirement analysis was conducted next. Work items as the basic data storage units were proposed to integrate time related data in the cost system. Data elements were identified and abstracted into data groups via a form analysis of the forms and documents used for the information process in the cost system.

The value chain concepts were used to examine all activities a construction company performs to find out the events that trigger the information process. In an entity-relationship database environment, an REA pattern was used to record data around those business events with their related resources and participants. A conceptual database model was developed using the ER modeling tool. This database model was also transferred into an MS Access DBMS, and a data table structure was set up. The prototype of information process using structure query language (SQL) was illustrated by producing period labor and progress reports as an example.

Two projects were used as case studies, and the current cost system in these projects was analyzed. The conceptual database model was evaluated in construction practice to find out some possible changes based on the conceptual database model. The possible benefits that can solve some problems in the practice were discussed.

7.2 Conclusions

From the thesis research work it can be concluded that the proposed conceptual database model for the project cost and time data is a feasible model. This model represents the data content and their logic relationships in an integrated project cost system in an abstraction level. Through this research, the following conclusions can be derived.

7.2.1 Conclusions about Time Related Data Integrated in Cost System

Cost data are usually recorded around cost items broken down from the project by a cost person. On the other hand, time data are measured by activities for schedule control. In order to record time data in a cost system, common data storage units need to be built. A work packaging approach is a feasible approach that can be used as a guideline to construct the data units. In this research, work packages in the project work breakdown structure are named as work items. These work items are coded according to CSI Master Format. Cost estimates and time schedules need to be developed based on the same work breakdown structure in order to build a connection between cost data and time data. Planned and actual information needs to be recorded by the same data units, work items.

7.2.2 Conceptual Database Model Development Related Conclusions

- The system approach for information and database system design is very helpful in the database system design for project data. It outlines the step-by-step process of a database system implementation.
- The entity-relationship model was found to be very suitable in the design of database systems in the construction field. Its format simplicity makes it easy to understand and communicate with end users, construction persons. When the conceptual database model is understandable by them with some instruction, the quality of the model can be improved so that the database based on this model will be more effective.
- The value chain concept and REA pattern can also be used to analyze a construction company's business processes and represent these processes in a database system. The REA pattern recognizes business events, its associated agents and consumed resources in an entity-relationship database model. In the mean time, the REA pattern can be combined with other database modeling concepts such as aggregation, and entity dependency to derive a conceptual model.

7.2.3 Conclusions Related to Perform Information-processing Function of the Project Cost System in a Database Environment

Based on the conceptual database model, a database can be built to perform information-processing functions. When the necessary data are stored in a database, information processing can be performed more effectively. Queries can be used to satisfy the information requirement questions. Different types of reports can also be generated automatically using SQL. MS Access can be used as a DBMS software application for construction project data since it is very user-friendly.

7.3 Future Research

The following are directions suggested for future research:

- This thesis research for the conceptual database model was developed using ER modeling in a relational database environment. As an alternative approach, object-oriented (OO) database modeling could be used to model the project cost and time data in an object-oriented database environment. Some features of OO technology can be applied. For instance, data are not only represented in the database but also can have associated programs as methods to perform some desired tasks.
- The database model only covered the cost system within the conversion process of a construction company, although some time related data were proposed to be stored in the database to perform some schedule control functions. The scope of the database model can be expanded to cover all processes of a construction

company. This strategy will provide the foundation to build a central database of a construction company to manage all data of its business processes.

- Some application programs can be written on top of the database which is built from the conceptual data model developed in this research. These programs can perform more information process functions or serve as the interface between the database and other construction software applications.

This thesis explored issues about a database system development and its implementation in the construction management field. The focus is the conceptual database modeling. The conceptual database model developed here is an attempt to facilitate the project information process by taking advantages of the fast improvement of the computer and information technology.

APPENDICES

Appendix A

Concepts of Data Flow Diagram (DFD)

The data flow diagram supports the concepts of process, dataflow, data store, and interface. These concepts are presented by graphic representation shown in Figure A.1. Processes are represented by rectangles with rounded corners, dataflow by directed lines (arrows), data stores by three-sided rectangles, and interfaces by rectangles with right angled corners. Using these concepts, the designer builds a functional schema of the business process.

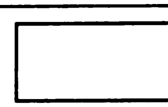
Concept	Diagrammatic Representation
Process: a process represents an activity within the information system. In particular, a process can generate, use, manipulate, or destroy information.	
Dataflow: a dataflow is an exchange of information between processes.	
Data store: a data store is a repository of information. Temporary files, look-up tables, paper forms, electronic forms, and permanent records may all be represented as data stores.	
Interface: an interface is an external user of the information system, who may be the originator and/or the receiver of dataflows or data stores.	

Table A.1 The diagrammatic representation of dataflow diagramming (DFD) concepts (Source: Batini, et. al., 1992)

In Figure A.2, a DFD example applying in construction management field is shown. This DFD illustrates the process of subcontractor's application for progress payment. A progress payment is applied and stored in the progress payment data store. Data about application_amount is flow to the process check amount due. When the application is approved, approved_amount is sent to pay to subcontractor process and store in a file to record approved amount of each subcontractor. After the pay to process, check is sent to subcontractor ending this whole process.

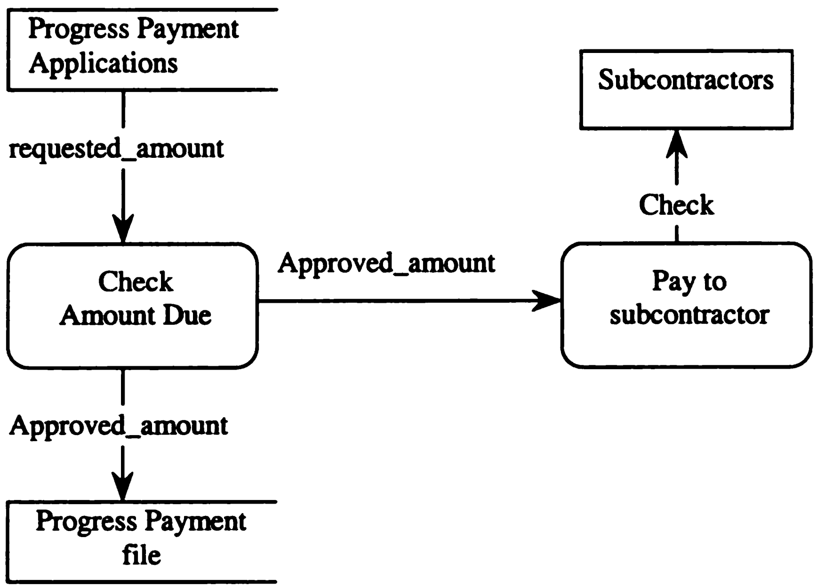


Figure A.1 Subcontractor Progress Payment Process DFD

Appendix B

CSI Master Format — Broadscope Section Titles

This appendix contains the Master Format for construction classifications, as published by the Construction Specifications Institute (CSI), 601 Madison Street, Alexandria, Virginia 22314-1791, in conjunction with Construction Specifications Canada (CSC). It is applicable to organizing specifications sections, drawings, cost codes, materials information, office correspondence and other aspects of design, procurement and construction. (Source: Barrie and Paulson, 1992)

BIDDING REQUIREMENTS, CONTRACT FORMS, AND CONDITIONS OF THE CONTRACT

00010 Pre-Bid Information
00100Instructions to bidders
00200 Information Available to Bidders
00300 Bid Forms
00400 Supplements to Bid Forms
00500 agreement forms
00600 Bonds and Certificates
00700 General Conditions
00800 Supplementary Conditions
00900 Addenda

SPECIFICATIONS

Division 1 — General Requirements

01010 Summary of Work
01020 Allowances
01025 Measurement and Payment
01030 Alternates/Alternatives
01035 Modification Procedures
01040 Coordination
01050 Field Engineering
01060 Regulatory Requirements
01070 Identification Systems
01090 References
01100 Special Project Requires
01200 Project Meetings
01300 Submittals
01400 Quality Control
01500 Construction Facilities and Temporary Controls
01600 material and Equipment
01700 Contract Closeout
01800 Maintenance

Division 2 — Sitework

02010 Subsurface Investigation
02050 Demolition
02100 Site Preparation
02140 Dewatering
02150 Shoring and Underpinning
02160 Excavation Support Systems
02170 Cofferdams
02200 Earthwork
02300 Tunneling
02350 Piles and Caissons
02450 Railroad Work
02480 Marine Work
02500 Paving and Surfacing
02600 Utility Piping Materials
02660 Water Distribution
02680 /fuel and Steam Distribution
02700 Sewerage and Drainage
02760 Restoration of Underground Pipe
02770Ponds and Reservoirs
02780 Power and Communications
02800 Site Improvements
02900 Landscaping

Division 3 — Concrete

03100 Concrete Formwork
03200 Concrete Reinforcement
03250 Concrete Accessories
03300 Cast-in-Place Concrete
03370 Concrete Curing
03400 Precast Concrete
03500 Cementitious Decks and Toppings
03600 Grout
03700 Concrete Restoration and Cleaning
03800 Mass Concrete

Division 4 — Masonry

04100 Mortar and Masonry Grout
04150 Masonry Accessories
04200 Unit Masonry
04400 Stone
04500 Masonry Restoration and Cleaning
04550 Refractories
04560 Corrosion Resistant masonry
04700 Simulated Masonry

Division 5 — Metals

05010 Metal Materials
05030 Metal Coatings
05050 Metal Fastening
05100 Structural Metal Framing
05200 Metal Joists
05300 Metal Decking
05400 Cold Formed Metal Framing
05500 Metal Fabrications
05580 Sheet Metal fabrication

Division 5 — Metals (Continue)
05700 Ornamental Metal
05800 Expansion Control
05900 Hydraulic Structures

Division 6 — Wood and Plastics
06050 Fasteners and Adhesives
06100 Rough Carpentry
06130 Heavy Timber Construction
06150 Wood and Metal Systems
06170 Prefabricated Structural Wood
06200 Finish Carpentry
06300 Wood Treatment
06400 architectural woodwork
06500 Structural Plastics
06600 Plastic fabrications
06650 Solid Polymer Fabrications

Division 7 — Thermal and Moisture Protection
07100 Waterproofing
07150 Dampproofing
07180 Water Repellents
07190 Vapor Retarders
07195 Air Barriers
07200 Insulation
07240 Exterior Insulation and Finish Systems
07250 Firestopping
07300 Shingles and Roofing Riles
07400 Manufactured Roofing and Siding
07500 membrane Roofing
07570 Traffic Coatings
07600 Flashing and Sheet Metal
07700 Roof Specialties and Accessories
07800 Skylights
07900 Joint Sealers

Division 8 — Doors and Windows
08100 Metal Doors and Frames
08200 Wood and Plastic Doors
08250 Door Opening Assemblies
08300 Special Doors
08400 Entrances and Storefronts
08500 Metal Windows
08600 Wood and Plastic Windows
08650 Special Windows
08700 Hardware
08800 Glazing
08900 Glazed Curtain Walls

Division 9 — Finishes
09100 Metal Support Systems
09200 Lath and Plaster
09250 Gypsum Board
09300 Tile
09400 Terrazzo
09450 Stone Facing
09500 Acoustical Treatment
09540 Special Wall Surfaces
09545 Special Ceiling Surfaces
09550 Wood Flooring
09600 Stone Flooring
09630 Unit Masonry Flooring
09650 Resilient Flooring
09680 Carpet
09700 Special Flooring
09780 Floor Treatment
09800 Special Coatings
09900 Painting
09950 Wall Coverings

Division 10 — Specialties
10100 Visual Display Boards
10150 Compartments and Cubicles
10200 Louvers and Vents
10240 grilles and Screens
10250 Service Wall Systems
10260 Wall and Corner Guards
10270 Access Flooring
10290 Pest Control
10300 Fireplaces and Stoves
10340 Manufactured Exterior Specialties
10350 Flagpoles
10400 Identifying Devices
10450 Pedestrian Control Devices
10500 Lockers
10520 Fire Protection Specialties
10530 Protective Covers
10550 Postal Specialties
10600 Partitions
10650 Operable Partitions
10670 Storage Shelving
10700 Exterior Protection Devices for Openings
10750 Telephone Specialties
10800 Toilet and Bath Accessories
10880 Scales
10900 Wardrobe and Closet Specialties

Division 11 — Equipment
11010 Maintenance Equipment
11020 Security and Vault Equipment
11030 Teller and Service Equipment
11040 Ecclesiastical Equipment
11050 Library Equipment
11060 Theater and Stage Equipment
11070 Instrumental Equipment
11080 Registration Equipment
11090 Checkroom Equipment
11100 Mercantile Equipment
11110 Commercial Laundry and Dry Cleaning Equipment
11120 Vending Equipment
11130 Audio-Visual Equipment
11140 Vehicle Service Equipment
11150 Parking Control Equipment
11160 Loading Dock Equipment
11170 Solid Waste Handling Equipment
11190 Detention Equipment
11200 Water Supply and Treatment Equipment
11280 Hydraulic Gates and Valves
11300 Fluid Waste Treatment and Disposal Equipment
11400 Food Service Equipment
11450 Residential Equipment
11460 Unit Kitchens
11470 Darkroom Equipment
11480 Athletic, Recreational, and Therapeutic Equipment
11500 Industrial and Process Equipment
11600 Laboratory Equipment
11650 Planetarium Equipment
11660 Observatory Equipment
11680 Office Equipment
11700 Medical Equipment
11780 Mortuary Equipment
11850 Navigation Equipment
11870 Agricultural Equipment

Division 12 — Furnishings
12050 Fabrics
12100 Artwork
12300 Manufactured Casework
12500 Window Treatment
12600 Furniture and Accessories
12670 Rugs and Mats
12700 Multiple Seating
12800 Interior Plants and Planters

Division 13 — Special Construction
13010 Air Supported Structures
13020 Integrated Assembles
13030 Special Purpose Rooms
13080 Sound, Vibration, and Seismic Control
13100 Nuclear Reactors
13120 Pre-Engineered Structures
13150 Aquatic Facilities
13175 Ice Rinks
13180 Site Constructed Incinerators
13185 kennels and Animal shelters
13200 Liquid and Gas Storage Tanks
13220 Filter Underdrains and Media
13230 Digester Covers and Appurtenances
13240 Oxygenation Systems
13260 Sludge Conditioning Systems
13300 Utility Control Systems
13400 Industrial and Process Control Systems
13500 Recording Instrumentation
13600 Solar Energy Systems
13700 Wind Energy Systems
13750 Cogeneration Systems
13800 Building Automation Systems
13900 Fire Suppression and Supervisory Systems
13950 Special Security Construction

Division 14 — conveying Systems
14100 Dumbwaiters
14200 Elevators
14300 Escalators and Moving Walks
14400 Lifts
14500 Material Handling Systems
14600 Hoists and Cranes
14700 Turntables
14800 Scaffolding
14900 Transportation Systems

Division 15 — Mechanical
15050 Basic mechanical Materials and Methods
15250 Mechanical Insulation
15300 Fire Protection
15400 Plumbing
15500 Heating, Ventilating, and Air Conditioning
15550 Heat generation

Division 15 — Mechanical (Continue)
15650 Refrigeration
15750 Heat Transfer
15850 Air Handling
15880 Air Distribution
15950 Controls
15990 Testing, Adjusting, and Balancing

Division 16 — Electrical
16050 Basic Electrical materials and Methods
16200 power Generation - Built-Up Systems
16300 Medium Voltage Distribution
16400 Service and Distribution
16500 Lighting
16600 Special Systems
16700 Communications
16850 Electric Resistance Heating
16900 Controls
16950 Testing

Appendix C

Data Table Properties

Table C.1 Properties of Entity Data Table in Prototype Database

Table Name	Column	Data Type	Size
Actual Equipment Usage	Equipment Charge No	Text	30
	Date	Date/Time	-
	Actual Hours	Number	Integer
	Actual Cost	Number	Integer
Actual Labor Usage	Labor Usage No	Text	30
	Date	Data/Time	-
	Actual Hrs	Number	Integer
	Actual Rate	Number	Integer
Actual Material Usage	Charge No	Text	Integer
	Date	Date/Time	-
	Quantity	Number	Integer
	Actual Unit Cost	Number	Integer
Actual Work Item In Progress	Work Item WIP No	Text	30
	Actual Quantity	Number	Integer
	Actual Start Date	Data/Time	-
	Actual Finish Date	Date/Time	-
Equipment	Machine No	Text	30
	Machine Name	Text	30
	Standard Rate	Number	Integer
	Overtime Rate	Number	Integer
Workers' Information	Employee No	Text	30
	Name	Text	40
	Address	Text	30
	Phone No	Text	15
Craft Type	Labor Type No	Text	30
	Craft	Text	30
	Available Number	Number	Integer
	Budget Rate	Number	Integer
Material	Material No	Text	30
	Description	Text	50
	Budget Unit Cost	Number	Integer
	Unit	Text	10

Table	Column	Type	Size
Project General Information	Project No	Text	30
	Project Name	Text	40
	Location	Text	40
	Start Date	Date/Time	-
	Finish Date	Date/Time	-
	Owner	Text	40
	Original Contract Value	Number	Integer
	Total Value	Number	Integer
Sub Change Order	SubChange Order No	Text	30
	Date	Date/Time	-
	Change Amount	Number	Integer
Sub Contract	Subcontract No	Text	30
	Contract Price	Number	Integer
Sub Progress Payment	Progress Pmt No	Text	30
	Period From	Date/Time	-
	To Date	Date/Time	-
	Description	Text	50
	Amount	Number	Integer
Subcontractor	Sub No	Text	30
	Description	Text	40
	Contact Person	Text	30
	Address	Text	50
	Phone Number	Text	20
Work Item Budget	Work Item Budget No	Text	30
	Description	Text	40
	Qty	Number	Integer
	Unit	Text	10
	Unit Price	Currency	-
	Start Date	Date/Time	-
	Finish Date	Date/Time	-
	Duration	Number	-
	Matl Cost	Number	-
	Labor Dt Cost	Currency	-
	Labor InDt Cost	Currency	-
	Equipment Cost	Currency	-
	Total Cost	Number	Integer

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