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INTEGRATED SYSTEM FOR PROJECT PLANNING AND PROJECT CONTROLS USING REA MODELING TECHNIQUE

VOLUME I

By

Yogesh Prabhakar Joshi

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ABSTRACT

INTEGRATED SYSTEM FOR PROJECT PLANNING AND PROJECT CONTROLS USING REA MODELING TECHNIQUE

By

Yogesh Prabhakar Joshi

The goal of this research effort is to develop an integrated system for project planning and project controls, which consists of data model and a process model. The integrated system is developed using the REA modeling technique, adopted from the Accounting Information System design. The targeted construction domain for this research is Construction Management (CM) environment with the focus on scheduling and project controls. For any CM firm, it is important to capture, store, and process the real time data. The quantity and quality of data to be captured varies as the project progresses. Thus there is need to have an information system that will capture accurate and timely information to help decision-making. The proposed integrated system is an application of information system for information management. The thesis methodology includes, developing REA models, the generalized framework for the computer implementation of REA models, developing an information system, and developing the proof of concept. The author believes that the proposed research will lead to a data model for standardizing the integration process between scheduling and project controls and will lay down a framework for developing an integrated system for the construction management domain. The proof of concept will analyze the application of the proposed integrated system in real life construction projects under the construction management domain.

Dedicated to my spiritual Guru-Rev. Asoke Da, my Mother, and hence to my Lord!

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LIST OF ABBREVIATIONS

AEC	**Architect engineer contractor**
AM	**Accounts manager**
A/R	**Accounts receivable**
ARCM	**At risk construction management**
C	**Contractor**
CAD	**Computer aided design**
CAE	**Computer aided engineering**
CIC	**Computer integrated construction**
CM	**Construction Management**
CPA	**Construction planning agent**
CPCA	**Construction project controls agent**
CPM	**Critical path method**
CSI	**Construction specification institute**
D	**Designer**
E	**Estimator**
E-R	**Entity-relationship**
ERP	**Enterprise resource planning**
GC	**General contractor**
GMP	**Gross margin profit**
IBP	**Integrated building process**
ID	**Identity**

IT	**Information technology**
KBS	**Knowledge based system REA**
LAN	**Local area network**
MIS	**Management information system**
O	**Owner**
ODBC	**Open database connectivity**
OOPS	**Object oriented programming system**
PCs	**Prime contractors**
PC	**Personnel computer**
PCM	**Professional construction management**
PD	**Project director**
PM	**Project manager**
P3	**Primavera project planner**
REA	**Resource Event Agent**
Resp	**Responsibility**
S	**Scheduler**
SQL	**Structured query language**
TGIF	**Timberline gold interface**
UML	**Uniform modeling language**
VB	**Visual basic**
WAN	**Wide area network**
WBS	**Work breakdown structure**

Chapter 1: Introduction

1.1 Abstract

The goal of this research effort is to develop an integrated system for project planning and project controls. The integrated system will be developed using the REA modeling technique. The REA modeling technique was introduced and used for the "Accounting Information System"- design (David 1998; McCarthy 1982). REA stands for "Resource-Event-Agent," which contributes to any transaction processing system like accounting. The targeted construction domain for this research is the Construction Management (CM) environment with the focus on scheduling and project controls.

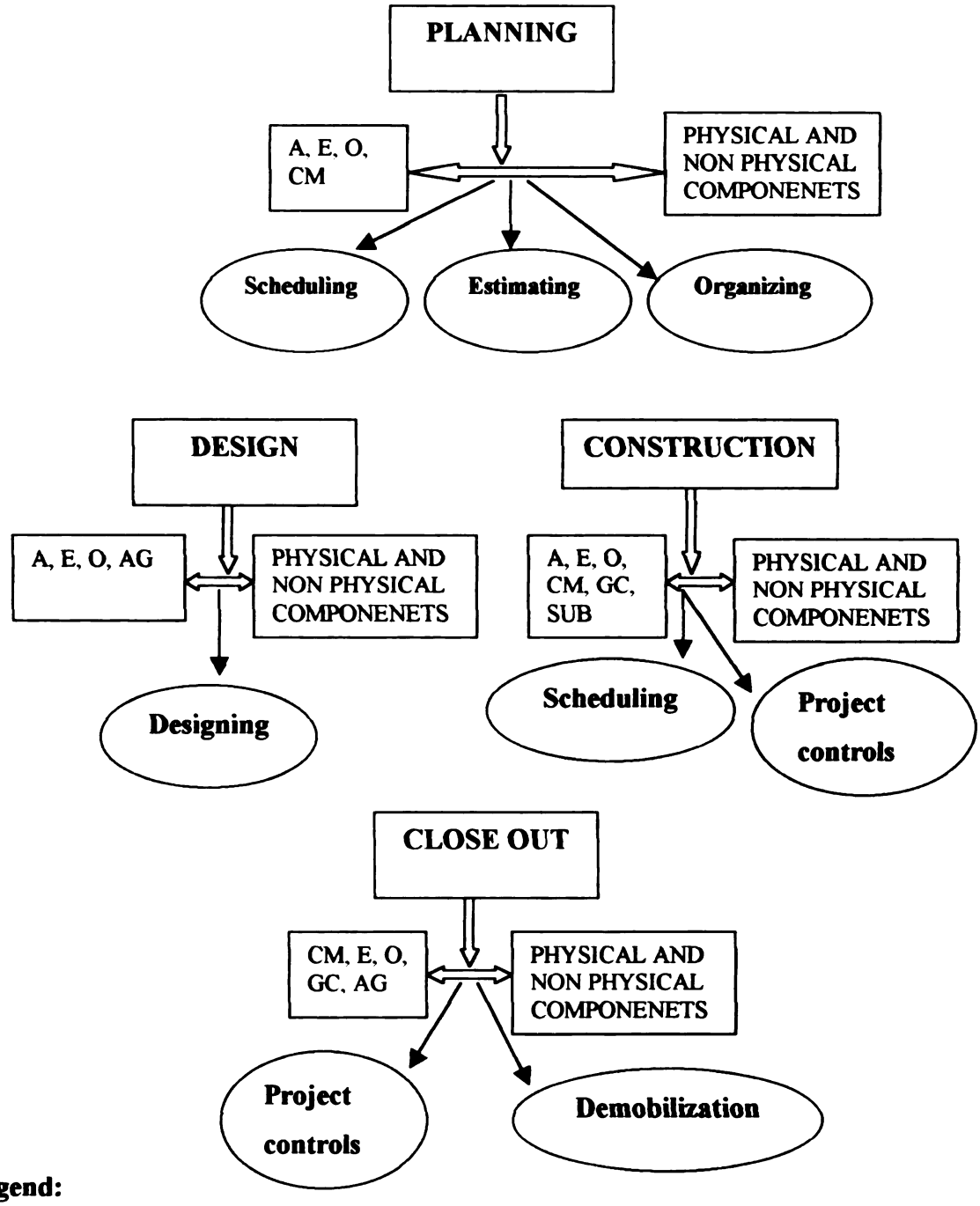
1.1.1 Nature of construction projects

A construction project is mainly completed through the four phases of design, planning, construction, and closeout (Clough and Sears 1998). The planning phase involves estimating and scheduling to a great extent, while the construction and closeout phases involve more scheduling, and project controls (Syal 1992). Each project is a complex set of physical components such as labor, material, equipment etc. and nonphysical components such as methods, schedules, budgets, codes, and regulatory requirements. There are various project participants like architects, owners, engineers, general contractors, sub contractors, project managers, and construction managers that contribute to the development and completion of such complex projects (Anderson 1997; Fischer and Aalami 1996; Kang and Paulson 1998; Miyatake and Kanagari 1993). Depending on the type of contractual agreement such as Design-Build, Build-Operate and Transfer,

Turn Key, General Contract, Sub Contract, Construction Management, each project has different components and participants. The project participants act on different project components to generate various project processes, during each phase of the project life cycle (Clough and Sears 1998; Fischer and Aalami 1996; Fischer and Kunz 1995; Miyatake and Kanagari 1993), as shown in Figure 1.1. The quantity and quality of information and data generated at each point is different. To summarize, any project can be considered as a system in itself involving system phases, components, participants, processes, data, and information. The whole system can be represented as shown in Figure 1.2.

1.1.2 Construction management environment

In the construction management environment, the focus is on the "project delivery" method in which the goal of the management team is to ensure the within time and budget delivery of the project to the owner by the contractor (as per author's experience during his internship with CRSS constructors Inc.). The construction manager usually enters during the final stage of planning and supports the project throughout the construction and the closeout phases. The final stage of planning involves various activities like identifying and finalizing all the requirements, organizing the team of project participants, defining the means and methods for the project, setting up project budgets and schedules, and setting up project control formats (Clough and Sears 1998; Fischer and Aalami 1996; Syal 1992). The construction manager is the key participant who coordinates between different project participants and acts as a system facilitator.



Legend:

A: Architect E: Engineer O: Owner CM: Construction Manager
AG: Testing/ inspection agency GC: General Contractor
SUB: Sub contractor

Figure 1.1: Project Life Cycle (Fischer and Aalami 1996; Syal 1992)

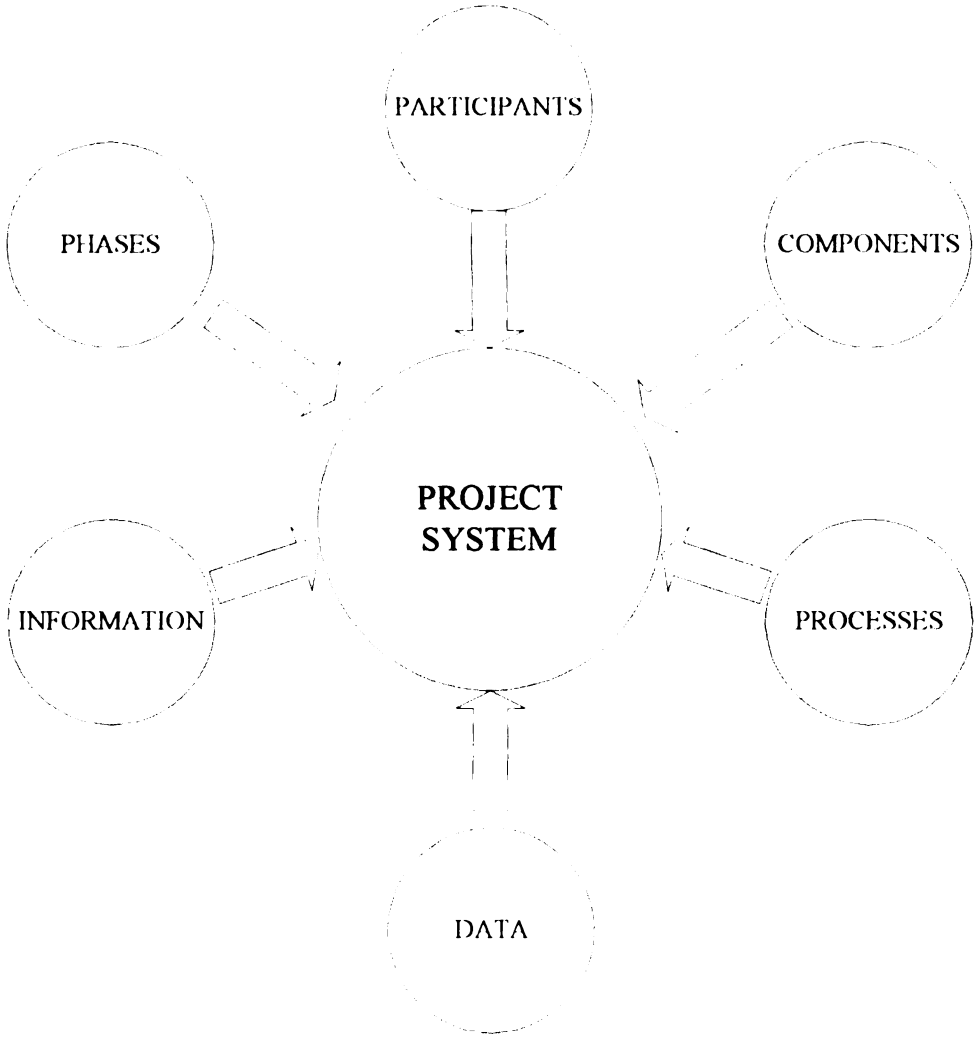


Figure 1.2: Project System (Fischer and Kunz 1995; Miyatake and Kanagri 1993)

Again, there are two possible types of construction management environments. One is the Professional Construction Management (PCM) and the other, more recent, is the At Risk Construction Management (ARCM). The basic difference between the two is that, in the PCM system, the firm will usually participate from the final stages of planning and manage the project until its completion through various project control techniques and strategies. Whereas in the ARCM system, the firm accepts the responsibilities from the design phase and acts as the owner's representative throughout the project lifecycle to its completion. According to the researcher's industry experience in the CM environment, PCM has been the most common business practice over the years but ARCM business is becoming more popular and competitor in the construction management industry.

1.1.3 Information system in the construction management environment

The complex nature of the construction project and its magnitude demand a timely acquisition and analysis of information in order to be successful. As described earlier, there is a continuous generation and flow of formal and informal information across various project components and participants (Anderson 1996; Fischer and Aalami 1996; Kang and Paulson 1998). Formal information consists of facts and figures like cost, budget, material quantity etc. Informal information is more like the historical records, experience, knowledge, and expertise of the people. A common term used in this aspect is the Management Information System (MIS). It is an information system application that provides for management oriented reporting, usually in a predetermined, fixed format, and is a tool to determine the progress of a management team on a particular project (Whitten and Bentley 1998). The goal of any information system is to manage the

huge volume of data generated during the entire lifecycle of any project and MIS application simply uses the information system set up to generate various reports for managerial purposes. For any Construction Management (PCM or ARCM) organization, the efficient and effective management of bulk information is very important. Incomplete information leads to wrong conclusions and incorrect decisions that cause delays or even failure of projects during any phase (Paulson et. al, 1998; Rezgui et. al, 1998; Zaplac et. al, 1994). Typically in the PCM and ARCM environments the major focus is on scheduling and project controls that form the backbone of the project from its planning to completion. Estimating is typically done in the beginning to set the project budget whereas scheduling and project controls are continuous processes that involve updating, modifications and changes to a greater extent (Syal 1992, Paulson et. al, 1998). Therefore, the goal of an information system is to manage the information during scheduling and project controls processes.

1.1.4 Information technology applications in construction

Information technology has become a part of our life and an integral part of construction management business. There is an increasing use of electronic communication through emails, video conferencing and satellite communications. The project managers are able to get information in their office about projects from almost any location because of the Internet and intranets. Use of laptops is becoming more common with field managers. More and more hardware resources and software packages are being developed and introduced into the market to meet the needs of the construction industry (Fischer 1995, Miyatake 1993, Rao 1997). Companies like Primavera, Timberline, and Meridian Project

Systems are investing more time and money towards development of construction-software packages. Some common software applications in use are, Primavera Project Planner (P3) for scheduling, Precision Estimation for estimating, Precision Gold collection for job cost accounting, Auto CAD for designing, Expedition and Prolog Manager for project controls, administration and management (Expedition 1998; Primavera Project Planner 1998; Prolog Manager 1998; Timberline 1998). All of these software packages support independent PCs as well as network environments. Furthermore, there are "integrator" software or modules that translate and transfer the information between the various individual software applications. The complete circle of integration across different applications is shown in Figure 1.3. The circle is developed based on the researcher's knowledge and experience in the use of these applications and reference to the software application manuals. The researcher believes that with time, the circle will get bigger and bigger due to the addition of new software applications.

1.1.5 Construction domain and parameters

The construction domain selected for this thesis is Construction Management (referred hence forth as CM). The selected size for the CM domain is a medium to large size company that handles individual projects of a minimum value of $ 100 million, spanning over a minimum of two years duration. The type of contract is professional construction management (PCM), in which the construction manager coordinates with different project participants and is mainly responsible for the within time and budget delivery of the project to the owner (Clough and Sears 1998). Under this domain, the focus systems are scheduling and project controls. The goal of the scheduling system is to develop a

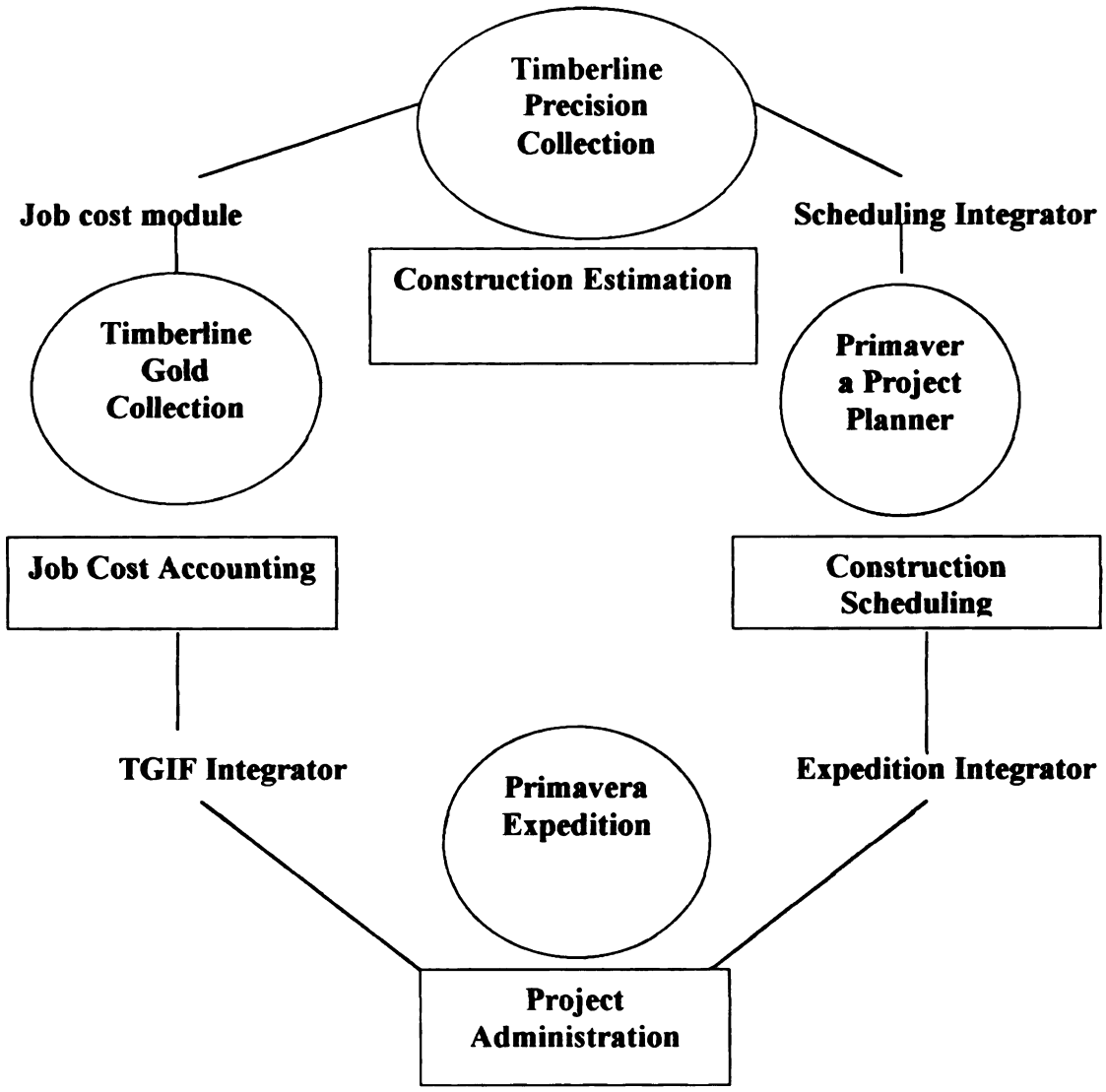


Figure 1.3: Circle of Integration

(Fischer and Kunz 1995; Miyatake and Kanagri 1993)

working schedule by generating the activities and the logic, based on selected means and methods and availability of resources. The project control on other hand, is directed towards the measuring and monitoring of the project progress, comparing it with the planned, and taking corrective actions as required (Syal 1992). As discussed earlier, the business-goal of any CM firm is to manage the project successfully by monitoring and controlling the cost and time factor. The duration of the project is set during the scheduling, and the cost is set during the estimating systems. The monitoring of duration and cost is achieved in project controls through various project control techniques.

1.1.6 Time and cost management

The time required to complete the project is calculated in the scheduling during the final stages of planning. A detailed schedule is developed that gives the duration of all the activities involved in the project. The cost for the entire project is also finalized in the estimating process, during the final stages of planing. The overall budget for the project, including the cost for different work items in the project, is set before the project starts (Clough and Sears 1998; Fischer and Aalami 1996; Paulson et. al, 1998). As the project progresses, there is continuous updating of project schedules depending on the actual progress compared to the "planned" project progress. As the schedule changes, there is a change in the duration associated with each activity and thus overall duration of project. This leads to a change in the direct and indirect cost associated with the activities and the project as a whole, which leads to further updating of work item costs, and overall activity costs. Thus time and cost management is based on schedules and estimates developed during the project planning and the subsequent information system developed

at the beginning of project controls. This provides the data for comparing the actual with expected or planned performance (Sanvido and Paulson 1992; Russell et. al, 1997). Thus, time and cost management are inter-related procedures. The project control techniques like developing time -cost envelopes, project progress curves, cost loaded schedules, cost forecasts, and cash flow analysis are used for cost management. However different scheduling techniques such as bar charts, Program Evaluation Review Techniques (PERT), process flowcharts, CPM are used for time management (Clough and Sears 1998; Russell et. al, 1997; Zapalac et. al, 1994). The information system set up between time and cost management, generates various reports and graphs that help the management at different levels to identify the problem and take corrective actions. The proposed work consists of developing such an information system, which serves as an integrated system between scheduling and project control for time and cost management.

1.2 Problem statement

As a construction management firm, the company has to coordinate with the Architects, Owners, General Contractors, Sub Contractors, and Regulatory Agencies in order to manage the project. There is huge volume of data and information that flows across all these entities and in different magnitudes during the life cycle of the construction project (Anderson 1997; Fischer and Kunz 1995; Rezgui et. al, 1998). It becomes very difficult to store, process, and manage such a huge volume of data and to ensure the data integrity and originality. Further, it is difficult to track and use all the informal information available during the life cycle of any construction project (Sanvido and Paulson 1992;

Zapalac et. al, 1994). Many construction projects run over budget and over time due to poor management of information.

As discussed in an earlier section, information technology has a major influence on the construction business. A complete circle of integration across the different software applications is shown in Figure 1.3. Primavera is the commonly used software for scheduling, while Prolog Manager, and Expedition are commonly used for project management and controls (Expedition 1998; Primavera 1998; Prolog Manager 1998). These software and integration tools are not necessarily developed by construction professionals but by software developers. Thus, they are designed based on the current hardware and software technology and current market trends rather than on the construction processes, components and participants that are at the core of such an integrated system (Rao et. al, 1997; Stumf et. al, 1996). Each of these software and the integrators have their own system setup and hardware and software requirements. It also means that each of them has the cost associated with their purchase, customization, user training, and maintenance (Expedition 1998; Primavera 1998; Prolog Manager 1998). Therefore, the design and operational aspects of any stand-alone or integrated set of software needs to be defined for the particular nature of business and the end user.

The software applications available may not support the business needs. This is because during the project life cycle, the information generated varies across different phases. Depending up on the nature of the contracts whether PCM or ARCM, the data responsibility, generation, and processing will also vary from project to project. This leads to a unique information set up for every project. The scheduling and project control processes for a home building project differ greatly from the one for commercial type of

projects. Thus, the type of project also determines the software application requirements (Fischer and Aalami 1996; Rao et. al, 1997; Rezgui et. al, 1998).

Each company has its own set up and style of business. Many factors influence the development and operational mode for any CM Company. Many times the need of the client is the governing factor in deciding the use of a particular software application. If an organization has projects at various geographical locations, then network technology needs to be used to transfer data across different applications and participants (Miyatake and Kanagari 1993; Whitten and Bentley 1998). The nature of the business and the type of contract also dictates the need of particular software and the degree of integration required (if any) to generate the different reports and transfer the information between different software applications.

1.3 Need of an integrated system

The need of an integrated system, between scheduling and project controls, is analyzed based on the discussions in the previous sections and from the perspectives of research, present technology and the nature of business in the construction industry.

There is a great amount of data flow between scheduling and project controls. The time and cost management as discussed in the earlier section, demands a highly efficient and dynamic information system between the two. There is a huge volume of information generated in terms of progress reports and cost and schedule updates, during the lifecycle of the project. Further, the nature of the information required (i.e. reports generated) differs at each management level (Fischer and Aalami 1996; Miyatake and Kanagari 1993; Syal et. al, 1993). To ensure that the new information is reflected across all project

components and participants there is a need to have a dynamic integrated system between the two processes. Again, pertaining to the increasing complexity of the projects, the management of information and processes between these two become increasingly critical. A dynamic integrated system between the two will help manage the data and information, smoothly and efficiently (Zapalac et. al, 1994; Fischer and Aalami 1996; Miyatake and Kanagri 1993).

A lot of research effort is being made successfully in the field of estimating, scheduling, and integration between these two (Paulson 1998). Much research deals with the data modeling aspect of these two systems. Various data modeling techniques have been also proposed by different authors for the modeling of different processes involved in construction (Paulson 1998; Fischer and Aalami 1996; Rao et. al, 1997; Sanvido et. al, 1989; Stumf et. al, 1996; Syal 1992). Quite a few research papers propose an information system framework for different types of projects and contractual agreements (Ganeshan et. al, 1994; Paulson et. al, 1998; Rezgui et. al, 1998; Sanvido and Paulson 1992; Zaplac et. al, 1994). However, considering the importance of scheduling and project controls process for the construction management business, there is a need to model the two processes to help develop the integrated system between the two.

There is a need to understand the different processes, underlying data and flow of information that affects the decision making process for time and cost management. To generate the reports that act as tools to help the management take corrective actions, it is necessary to know the quantity and quality of the data to be generated. The data consists of time and cost related parameters such as man hours spent, amount of money spent, amount of work in place, percent complete, earned construction hours etc. (Clough and

Sears 1998; Russell et. al, 1997; Sanvido and Paulson 1992). A list of parameters is included in chapter 3. Further, it is important to know where this data originates and how it needs to be reflected over the whole project. In order to keep track of the time and cost related data during the construction phase, there is a need to develop a model that depicts the project processes in the simplest form. The author believes that the REA modeling technique can be used to model the construction processes as the REA technique breaks down the complex project systems into the simplest processes, events, agents and data and helps in information management (David 1998; Greets and McCarthy 1998; McCarthy 1982; Whitten and Bentley 1998).

As discussed earlier, the technology currently exists that integrates scheduling and project controls in some aspects, such as generating project progress report from the schedule (Primavera Project Planner 1998; Expedition 1998, Prolog Manager 1998). Further, more of the business is being done over the Internet using World Wide Web technology. For the companies that plan to do business on the Internet, an integrated system in place is always easier to manage than the individual systems in place (Khedro 1995; Miyatake and Kangari 1993; Rao et. al, 1997). There is also a great increase in the "At Risk" nature of business where the whole project is built under a single roof starting from its planning to its completion (based on author's knowledge and limited experience). The integrated system will definitely be a need in such circumstances where all the information generated needs to be efficiently managed from a single location.

For any CM firm, it is important to capture, store, and process the data at the right time. Again, the quantity and quality of data to be captured varies as the project progresses. Thus there is a need to have an information system that will capture the data and produce

accurate and timely information to help in decision-making (Sanvido and Paulson 1992). The proposed integrated system is an application of the information system that manages all the data and information produced during scheduling and projects controls. The integrated system has the greatest advantage for the multiproject programs or projects of repetitive nature, mass construction etc., where the CM firm has to deal with almost the same set of information at regular intervals as the project progresses.

Time and cost management are interrelated and interdependent processes carried out in scheduling and project controls, as explained earlier. In order to successfully merge the time and cost aspects, we need a common interface between the two. The interface should not be technology dependent but should depend more on underlying business process and data that is at the core of the management. The proposed integrated system is such an interface that will serve the needs of time and cost management through various scheduling and project control techniques and is independent of the technology.

1.4 Research objectives

The focus area for this thesis is the integration between scheduling and project controls for the CM nature of business. The goal is to develop an integrated system model, which consists of a data model and a process model, and can achieve the best possible integration between scheduling and project controls. The same model will be used to analyze the capabilities of commercially available integrating tools. The objectives include:

1. To develop the REA model for scheduling and project controls for a PCM environment: This model will provide the understanding of data, processes, and information in scheduling and the project controls system. The model will depict the flow of information across the two and identify the components and participants that affect the decision making process (McCarthy 1982; David 1998). The output of this model will be identification of the data that needs to be used to produce the different reports that are used for scheduling and project control techniques.
2. To develop a generalized framework for computer implementation of the REA model: The framework will generalize the various components of the REA model (discussed in detailed in section 4.3, chapter 4), identify the technology and tools available and suggest the quality and quantity of data to be integrated to achieve the best possible integration.
3. To develop the information system that will make use of the REA model and the generalized framework. The design components of the proposed information system are the decision support system; the project control cycle; and the data warehouse (developed in detailed in section 4.4, chapter 4).
4. To use the REA model developed above to prove the concept: This involves analyzing the business set up and mode of operation for the case study companies, and studying the application of the proposed integrated system for their business processes. Any recommendations and/or changes, which benefit the case study companies, will be suggested in this research work.

1.5 Methodology

The present literature available on modeling and information systems will be studied. Also, the author's knowledge of REA modeling will be used to develop the REA model for scheduling and project controls. At this point, the author also proposes to select the construction domain as CM, based largely on the feedback from the construction management professionals and his limited experience. The thesis will be accomplished through the five steps described below, and shown in Figure 1.4.

1. Explain the REA modeling: Different types of modeling techniques are used to model various construction processes. The REA modeling technique is widely used for the design of the information system and the transaction processing system like Accounting (McCarthy 1982; David 1998). At this point, the focus will be on explaining the concept of REA modeling as related to scheduling, project controls processes, and show the advantages of the same from data modeling perspective. The REA modeling concepts are discussed in detailed in section 4.3.3, chapter 4.

2. Develop the REA model for scheduling and project controls: The REA modeling concept as explained in the first step, will be used to develop the REA model for scheduling and project controls processes performed during the final stages of the planning up to the close out phase of the project. This model will depict the process of scheduling and project controls done independently as well as inter-dependently.

Focus of the REA Model: The parameters selected under scheduling are activity duration and sequencing. The REA model will depict the processes, internal and external agents involved, and any constraints in determining the activity duration and logic. Similarly, in modeling the project controls process, the main focus is on the time and cost aspect of the

project as the project control process involves monitoring and updating the estimate and schedule with reference to the budgeted cost and duration established during the final stages of planning (Clough and Sears 1998; Syal 1992).

The REA models for scheduling and project controls and the integrated REA model is developed in section 4.3.3, chapter 4.

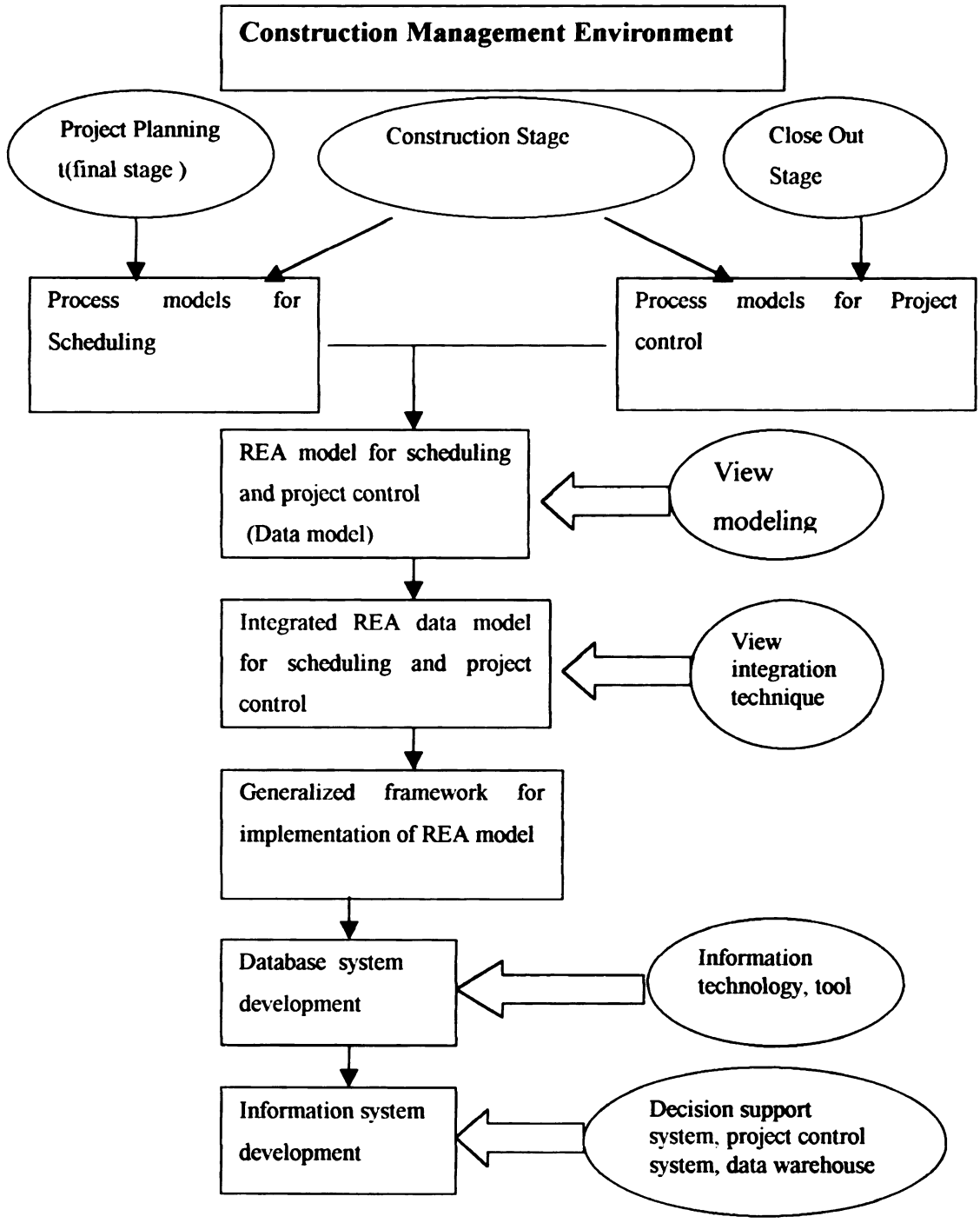


Figure 1.4: Conceptual model of the proposed research

3. Develop a generalized REA framework for computer implementation of the REA model: The framework is essentially a model whose focus is on depicting where the data is, how it flows, and how it is processed. This model generalizes all the components of the REA model i.e. resource, event, and agent, and develops a framework for the computer implementation of the integrated REA model between scheduling and project controls. The output of this step is a database system used to implement the REA models. (McCarthy 1982; Rao et. al, 1997; Fischer and Kunz 1995, have made some recommendations in this regard).

The generalized framework and computer implementation of the REA models is discussed in section 4.3.4, chapter 4.

4. Develop the information system: The information system makes use of the data from the integrated REA model, for project controls and decision-making. The proposed information system is made up of the following components: the data warehouse, the decision support system, and the project control system. These components further include sub components, all of which are developed in section 4.4, chapter 4.

5. Develop a proof of concept for the proposed integrated system: At this level, the focus is on using the concepts developed in this research work in the case-study companies. The application of the proposed REA model, database system, and the information system will be analyzed for the business needs of three case-study companies. The key individuals, such as the project manager in each company, will be interviewed for the purpose of data collection. Data will be collected about the set-up and mode of operation of the company, the scheduling, the project control process, and the present information system set up. The data collection will be followed by the analysis of how the data

gathered from the companies fits into the proposed REA model and the proposed information system in this research work. Finally, any changes or recommendations will be made for the case-study company. The human subjects, i.e. the key participants, who were interviewed for the data collection purposes, will review these recommendations.

It is believed that the proposed research will lead to a data model for standardizing the integration process between scheduling and project controls and will lay down a framework for developing an integrated system for a CM nature of business. The project will also provide guidelines to effectively use the REA modeling technique in designing the integrated system and modeling the existing business processes in a particular type of construction business like CM. The final stage of this thesis, which is developing a proof of concept of a proposed REA model, will also lead to suggesting the use of particular software applications for the implementation of REA models and also for the overall functioning of the proposed integrated system between scheduling and project controls.

1.6 Summary

The proposed research work is focused on developing an integrated system framework consisting of an REA model, and a computer implementation model between scheduling and project controls in the Construction Management environment. It also develops an information system, which will make use of the data from REA models, for project control purposes. The proposed concepts can be further applied, by potential researchers and construction professionals, to different processes like designing, estimating, job cost accounting, as well as in different construction environments like Design build, Turn key

and General Contractor. To summarize, any integrated system should be designed based on a current information system set up and future system requirements. In addition, great importance should be given to the particular construction environment and stage of the construction project. At implementation level, the efficiency, accuracy, user friendliness and technology play a major role in deciding the final implementation tool.

1.7 Research organization

The proposed research thesis is organized in six different chapters. The first chapter describes in brief about the research concept, problem area, need of the research work, the research thesis methodology, and the output and deliverables. The second chapter is dedicated to the review of existing research work and computer applications in construction. This chapter recognizes the research work done in the area of modeling, computer applications, and the information system in the construction field. It brings about the advantages and disadvantages of the available tools and techniques used. Further, this chapter also points out how the researcher proposes to use, and further develop the existing research concepts and the technology. The third chapter explains building blocks of this research work and the concepts utilized in developing the model in chapter four. The fourth chapter is the main output that deals with developing REA models for scheduling and project controls, developing framework for implementation of the REA model, and developing an information system. The fifth chapter is dedicated to developing proof of the concept. This chapter includes discussion about three case-study companies, and the application of the proposed REA model and integrated system concepts to case-study companies. The sixth chapter, is the last chapter of this research

work, and will discuss in detailed about the deliverables and future area of research. The Appendix section of this research includes references, and research review by the CM Companies.

Chapter 2: Existing research and software applications

2.1 Introduction

This chapter summarizes the existing research work and the capabilities of commercially available software for the construction industry. The existing research work is sub-divided into modeling in construction industry; information system applications (MIS) and information technology in construction; project scheduling and controls; and computer applications in construction industry. The work recognized in the following sections include the construction industry domain in the broad sense but is still applicable to the construction management domain. Each section includes a detailed summary of the research papers that are published in the related areas. A separate section is devoted to work done in scheduling and project control aspects of construction, which is the focus area of this thesis.

2.2 Information modeling in construction

The information modeling for the Architect / Engineering / Construction (AEC) industry includes product, process, and project models. The product model deals with the components or parts of the buildings. The process model describes the various construction processes, and the project model integrates the product and process model. All of them are discussed in the following sections.

2.2.1 Product model

The product model is a description of physical components and real objects in the construction. Gielinh (1998) developed the general AEC reference model, which specifies the structure of a product model, based on product definition units, functional units and their technical solutions. Bjork (1989) proposed the RATAS model, which organizes the building product model based on composition / decomposition relationships of building components. Researchers have worked on STEP / PDES (NIPDE 1995), which attempts to standardize computer interpretable representations and exchange of product data.

2.2.2 Process model

The process model represents important steps throughout the project life cycle. Sanvido (1990) developed the integrated building process model (IBP), a reference model for project processes. The key functions and information flows are identified by dividing the life cycle of the facility into five processes, manage; plan; design; construct and operate the facility. Fischer and Yin (1992) introduced the general data flow model based on data flow from a construction contractor's viewpoint.

2.2.3 Project model

The project model provides a framework for system integration of the product, process and organizational aspects of AEC projects to provide richer semantics for project management. The Unified Approach Model (Bjork 1992), GenCOM (Froese 1992), BPM

(Luiten 1992), and IRMA (Luiten et al. 1993) are among the project models for the AEC Industry.

2.2.4 Summary of selected research publications

The following research and journal papers are discussed in detail have a valuable input and influence over this thesis work. The general focus of all these papers is modeling in construction and the level of detail varies for each of the models.

2.2.4.1 "A top down approach to integrating the building process," (Sanvido et al., 1989).

This paper discusses the need to develop the information architecture, and to integrate the processes and subsequent software used throughout the life of a building. It defines the process model by the functions required to provide a facility to the end user, namely: managing, planning, designing, constructing, and operating the facility. Finally a knowledge- based approach to implementing the information architecture is proposed.

The paper discusses in detail about the present information system set up and its drawbacks. It shows that the industry lacks a unified framework for representing construction processes, as well as a common open architecture for the representation, classification, capture, and real time retrieval of data. The process model developed in this paper is the Integrated Building Process model (IBP), which is "a top-down approach," to modeling various processes in the construction industry. IDEF modeling was selected as the most appropriate modeling tool, which has components of input, output, function, control and mechanism. The IBP model involves an overall model

called "provide facility" and another model with five sub processes under provide facility, which are very detailed models. Provide facility is an F level model, which defines the boundary of the model in general terms. The five sub processes are as follows:

- Mange facility: includes all business functions and management process required to support provision of the facility from planning through operations.
- Plan facility: includes all the functions required to define the owner's needs and the methods to achieve these needs.
- Design facility: comprises of all the functions required to define and communicate the owner's needs to builders.
- Construct facility: includes all the functions required to assemble the facility so that it can be operated.
- Operate facility: consists of all the activities required to provide the user with an operational facility.

The model provides a generic top-down view that holds true for any facility and the functional models remain the same for any project delivery process.

2.2.4.2 "Object Oriented Model for Integrating Construction Product and Process Information," (Stumf et. al, 1996).

This paper presents an object-oriented model that integrates product and process information to support collaboration among design and construction agents and two prototype construction agents for construction planning and monitoring project progress.

The model is intended to bridging a gap between product and process model and to support the life cycle of information management. Three main types of models can be identified in the project life cycle:

Product model: organizes and communicates building product information

Process model: represents various steps throughout the project life cycle

Project model: provides the framework for system integration of products, processes and organizational aspects of AEC projects.

The model developed in the paper is the ICIM model, which is an integrated model between product and process that defines the relationship between design components and construction processes. It includes data abstraction, encapsulation, inheritance and relationship between objects. The ICIM model is the best example of an E-R or REA model. It explains all object oriented modeling concepts like aggregation, typification, etc., (Figure 2.1).

The paper has developed two prototype agents, one for project planning (CPA), and another for construction project controls (CPCA). The objective of CPA is to support the generation of a preliminary cost estimate, and schedule for facility design. It is based more or less on the OARPLAN concept. The model identifies the following different project planning activities and methods:

Planning activities:

- Organizational level activities: identifying only key project activities that need to be monitored for timely completion of the project.
- Project level: identifying key activities related to a particular project.
- Process level: identifying more detail activities, processes and relationships.

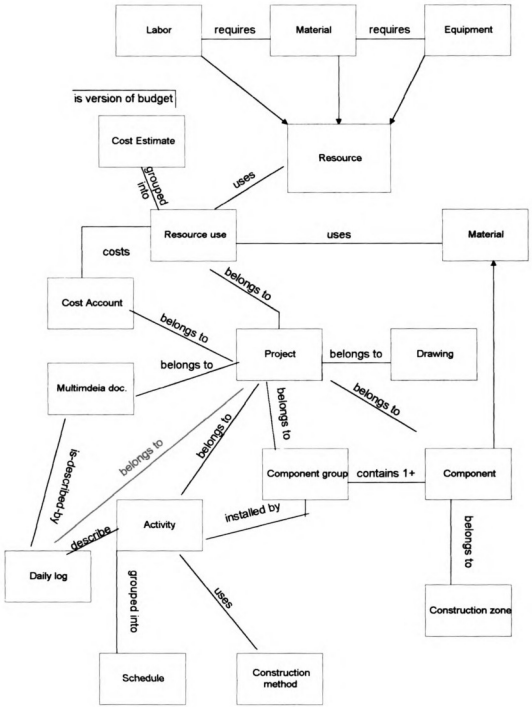


Figure 2.1: Integrated Construction Information Model (ICIM) (source: Stumf et. al, 1996)

Construction methods activities: assigning resources and computing activity duration

Sequencing construction activities: activity sequencing for single type of installation, which is usually the same among different projects, and activity sequencing, rising out of spatial and functional relationships between components, which varies from project to project.

The construction planning process underlying the CPA model is shown in Figure 2.2.

The goal of the CPCA agent is to manage the progress information, update the activities in the schedule, and maintain the multimedia record of construction. The variables considered for developing CPCA are the relationship between design components and construction processes, construction methods, activities, resources, and cost. The paper proves that a more powerful and semantically rich information framework can be created from integrating the product and process model. The CPA and CPCA agent and other components of an agent collaborative environment are shown in Figure 2.3.

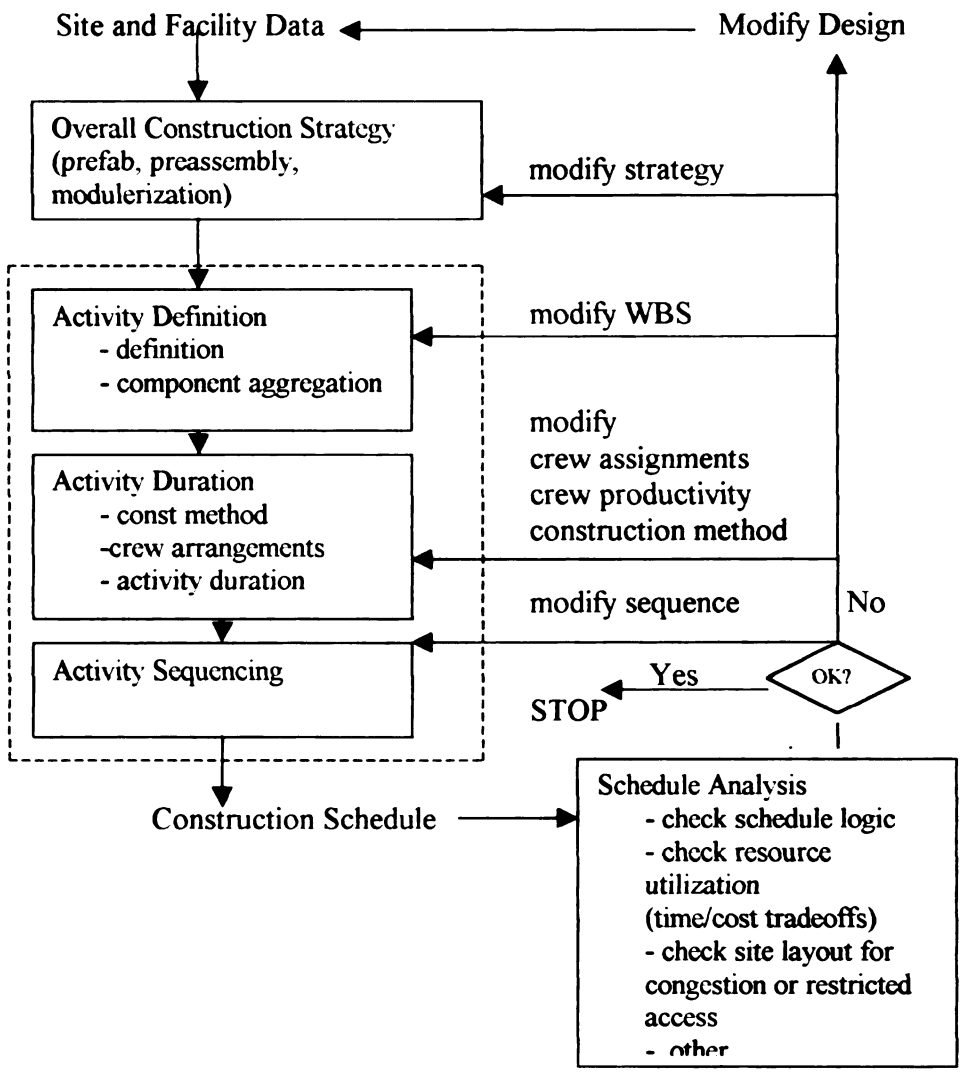


Figure 2.2: Construction Planning Process (source: Stumf et. al, 1996)

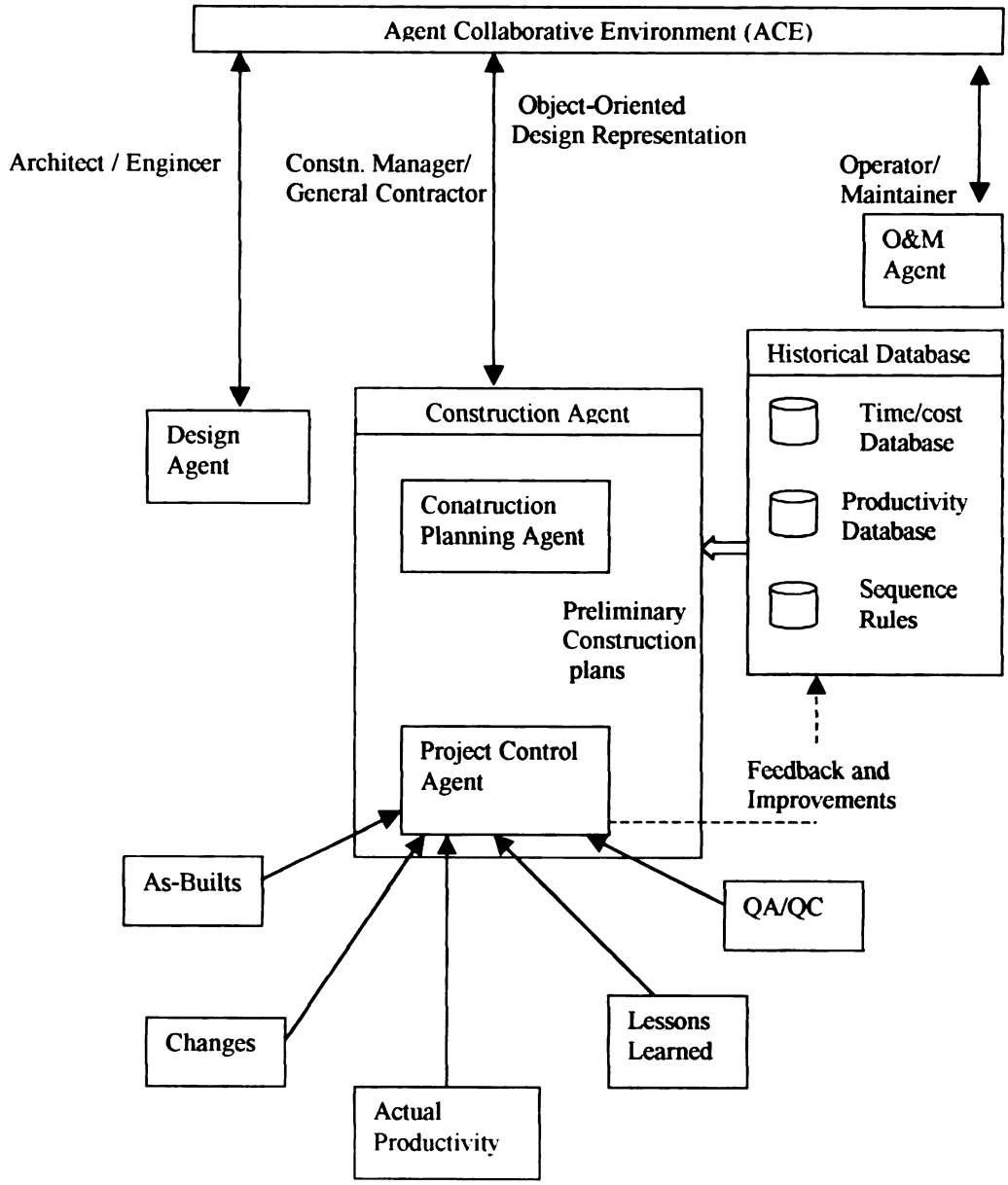


Figure 2.3: Agent Collaborative Environment (source: Stumf et. al, 1996)

2.2.4.3 "Scheduling with Computer Interpretable Construction Method Models," (Fischer, M. and Florian, A. 1996).

This paper presents computer-interpretable models for the representation of construction methods as one of the integration mechanisms to translate design information into the schedule and cost views of the project. These models support the automated generation of realistic construction schedules. The methods elaborate higher-level activities into appropriate lower level activities to link schedules of various levels of detail. The paper identifies the following five attributes to define any construction method: domain, constituting activities, activity sequencing, constituting objects and resource requirements. The construction method models can act as templates to capture production and scheduling knowledge specific to firms and projects. The model implementation is demonstrated through an example of the construction of masonry structure.

The process of schedule generation is shown in Figure 2.4. The input to the scheduling process is in the form of a three dimensional (3D) CAD model. The CAD model is interpreted and linked to a building product model that is instantiated for the particular project. Systems such as Semantic Modeling Extension (SME) and Design++ provide this link. Via activities, the components in the product model are then linked to construction method models. These models generate and sequence necessary activities and determine resource requirements. Once activities and their sequence relationships have been made explicit in the process model, they can be visualized as an activity network and displayed as a four-dimensional (4D) model.

The research team of this project feels that the model developed above will serve as the best tool for project managers and also construction managers who can make decisions

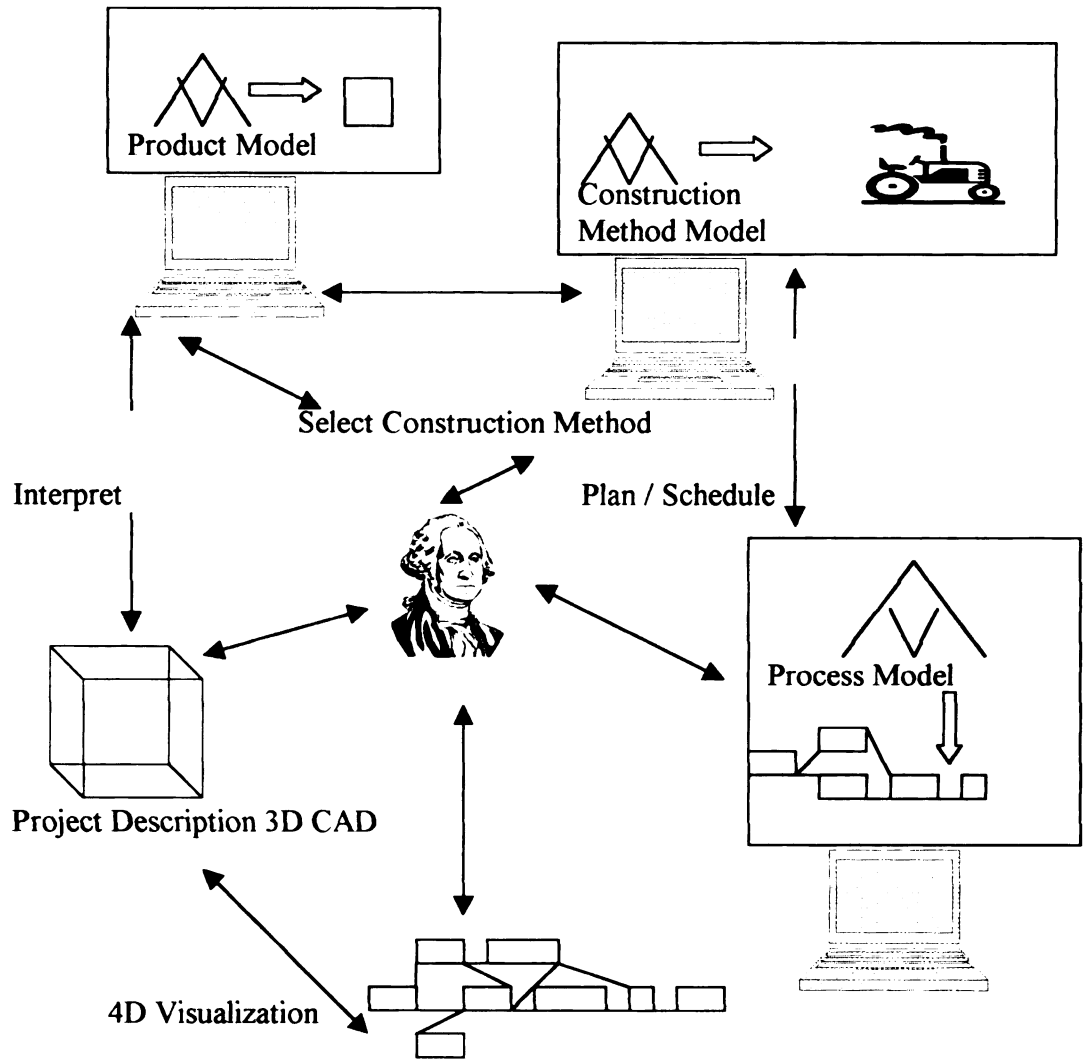


Figure 2.4:Models for Construction Methods Support an Integrative, Dynamic Scheduling Environment (Fischer, M. and Florian, A. 1996).

about the construction method selection, which is the very assumption underlying this project, that the end user of this model is one who can make such decision.

2.2.4.4 Information Management in Collaborative Multi actor Environment (COMMIT Approach) (Rezgui et al., 1998).

This paper deals with mechanisms to improve information management and support decision-making in collaborative projects. The paper also describes the central model underlying the COMMIT project. The paper develops a prototype model called CIMM. It is an object- oriented model that tackles the problem of information structuring and representation through a conceptual framework consisting of four levels of abstraction and functionality. The primary purpose of CIMM is to dynamically capture the process by which information is acted upon by the project actors through their respective roles. In addition, CIMM addresses the problem of decision representation. It describes what objects are relevant to decision, which factors influence a decision, who initiates the decision, how information is being used and processed and how the decision affects the information base. The CIMM uses six different models:

The main elements of the UML (Object Oriented language) class diagram, versioned objects and object implementation in CIMM; versioning and schema evolution in CIMM; rights and responsibilities in CIMM; change notification and propagation in CIMM and decisions and interdependencies in CIMM.

Finally the paper provides a real life example of implementing the CIMM prototype to handle a modification request from a project architect.

2.3 Information system and information technology applications in construction

The complex nature of construction project and its magnitude demand a timely acquisition and analysis of information in order to be successful. The goal of any MIS is to manage the information during the life cycle of any project. Information technology, on the other hand, plays a major role in acquisition of information and generating various reports out of the processed information, to be used for decision making. Thus the information system and information technology, together, form the back-bone of a project management system.

2.3.1 Information system applications (MIS)

The use of information system applications started becoming more prominent in the late 80's in construction industry. Due to growing boundaries of construction projects and increasing complexity, it became necessary to have an information system to manage the projects. The management information system (MIS) is an application of an information system that provides the scoreboard to determine how the project team progresses towards the project goals (Schei 1990). Information management in collaborative environments has been addressed by various research projects including COMBINE (Computer Models for Building Industry in Europe; Dubois et al. 1995) and ATLAS (Bohms et al. 1994). Other research tackled various aspects that fall within the scope of information management, including change notification and propagation (Khedro 1996) and versioning support (Kartz 1990; Law and Krishnamurthy 1996). The COMMIT Project (Rezgui et al. July 1998) is the most recent information management research done in collaborative project management. Zaplaac et.al. (1994) explains the process of

MIS development for a management team headed by a construction manager / program manager in mutiproject programs. Sadri et.al. (1993) has described the requirements of an information system and system development phases and activities.

2.3.2 Information technology (IT) applications in construction

Application of information technology in the construction industry is addressed by many researchers, most of them coming from construction industry background as consultants or project managers. Terry (1993), focused on issues such as strategic planning of IT resources for contruction. Kostem (1993), has focused on issues involved in transferring data across different work platforms and operating systems. Some work is done in usage of IT resources and procedures for better management of projects (Pixley 1992). Other research work like Najafi (1991), has investigated the legal aspects of software usage. The issue of in-house development has been addressed by Brown (1980).

2.3.3 Information technology (IT) applications in construction

The following research and journal papers are discussed in detail that have a valuable input and influence over this thesis work. It is interesting to note that the journal papers related to information systems also emphasize the structure and the importance of information technology. On the other hand, the research papers related to information technology recommend an information system set up as a framework to use information technology. Thus the two fields are thus closely related.

2.3.3.1 "Establishing a management information system for multi project programs,"

(Zapalac et. al, 1994).

This paper includes a detailed discussion about the system requirements of large programs or mega- projects and makes general recommendations on assessing the program needs, developing the schedules and monitoring cost and funding.

The goal of any MIS is to provide reliable and timely controled data to the management team members. When developing MIS for a large program, the project management group (PMG) has to address following issues:

- What information is critical, how information will be collected, reported, and distributed.
- Who will receive reports and information and how it will affect the program goals.
- The actual system to be used.
- The end user's perspective, the level of details required at each level of management.
- Who should participate in data generation and the final presentation of data and mechanics of the system.

2.3.3.2 "Site level construction information system (SCIS)," (Sanvido and Paulson 1992).

This paper defines the information requirements to support the decision-making needs of site level personnel constructing a facility. It focuses on information required to drive the

processes rather than technical information for design related problems. SCIS consists of a four step process: establishing the matrix of key project decisions; defining the project control system for the given project; establishing methods to select the decision making mechanism, collecting information and implementing decisions; and proposing a method of monitoring the site information system. The domain area of this paper is site management, however the author feels that the concept could be also applied over the other phases or stages of the project life cycle.

2.3.3.3 "Information management to integrate cost and schedule for civil engineering projects," (Kang and Paulson 1998).

This research work proposes a tentative construction information classification system (CICS) for civil engineering projects that permits regulation of a project with common information both for cost estimating and for schedule planning. This CICS has four facets with mnemonics in a notation system. Facility and space facets are grouped by the classified items for the management in upper levels through construction phases, while element and operation facets re classified to apply to the management in lower levels.

2.3.3.4 "Decision models and expert systems in construction management," (Warszawski 1985).

The goal of this paper is to survey the domain of construction management decisions and the applicability of various decision tools to different construction instances.

Construction Management decisions: A typical domain is a construction company, which simultaneously operates several projects at different locations. The construction process

involves interaction between the following entities such as projects under construction or to be constructed; a company's pool of resources; the outside world that includes clients, suppliers, the vendors; and the management which involves bidding, contracts etc. The physical flow diagram (Figure 2.5), best describes the decision making process for the CM environment.

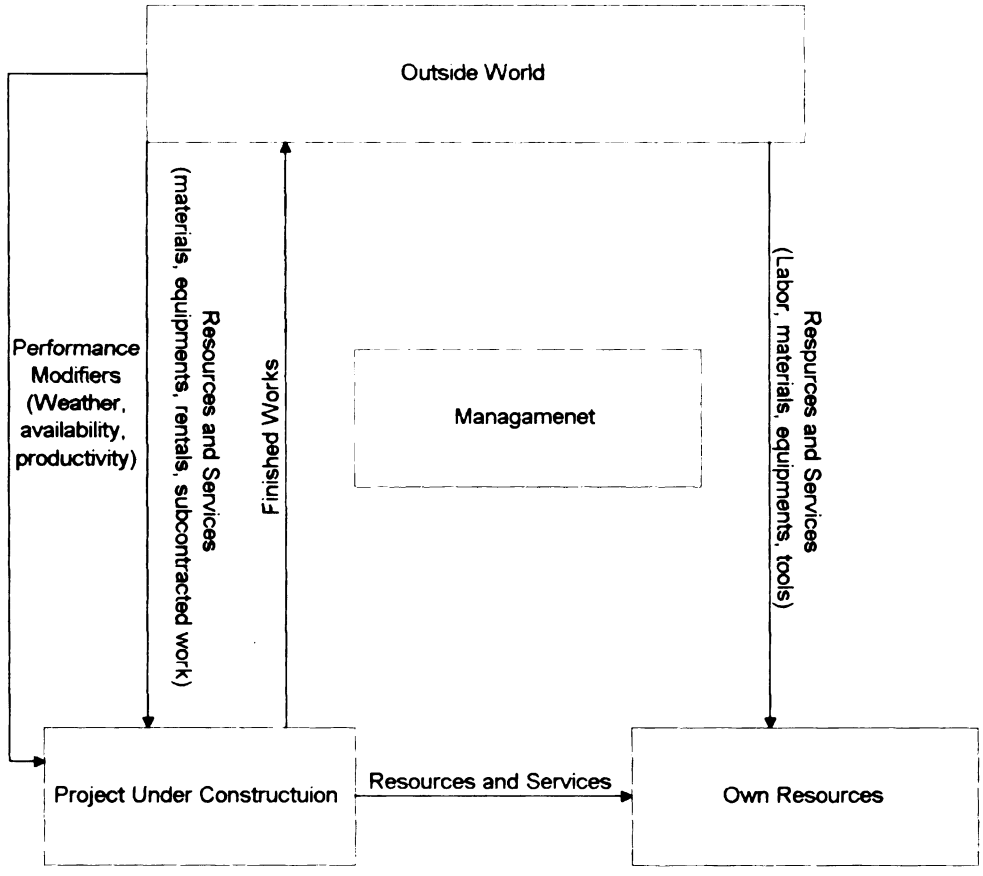


Figure 2.5: Physical flow in construction (source: Warszawski 1985)

The decision process is aided by information storage, which consists of current information and knowledge base. Current information is mainly used for project controls while the knowledge base is used for future planning. The decision and information flow diagram is a good representation of the decision- making process (Figure 2.6).

Decision tools / models:

Analog models: these are graphs, charts or diagrams represent, in graphical manner, the main attributes of the project and their effect on schedule and budget. The various tools include bar charts, s curves, cash flow diagrams, crew balancing charts, precedence networks, flow lines or line of balance, process flow charts, and spread -sheets.

Optimization models: these are mathematical models, which through the manipulation of relationships between the project attributes indicate optimal allocation solutions in terms of cost or profit. They are used for bidding, pricing, investment, evaluation, and other types of managerial decisions. A typical model includes the following elements:

- Objective function: describes the relationship between decision variables and parameters
- Constraint on manipulation of decision variables
- Search procedures for manipulation of decision variables

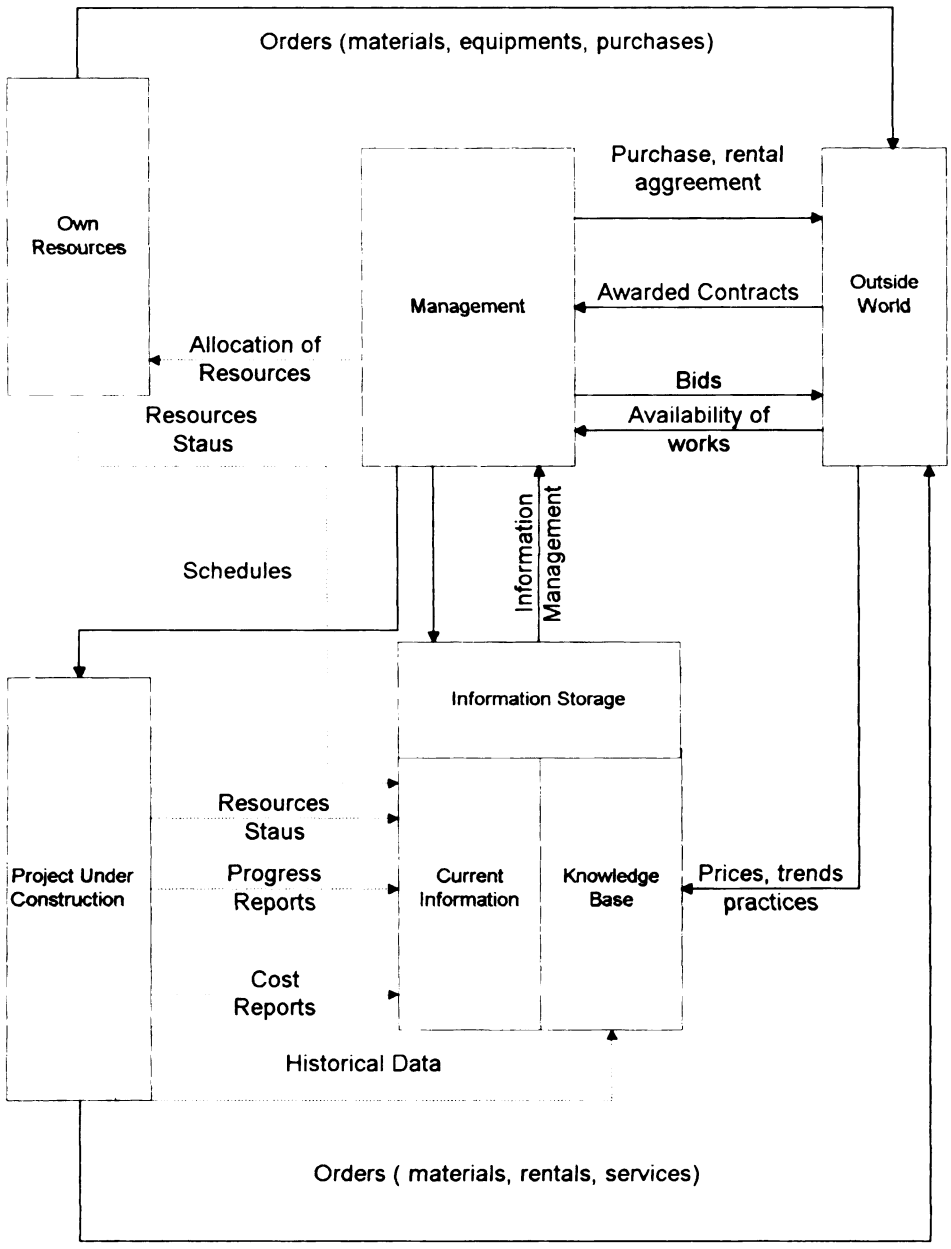


Figure 2.6: Decision and Information Flow (source: Warszawski 1985)

2.3.3.5 "Time for an integrated approach to facility management," (Scarponicini 1996).

This editorial article written by Scarponicini points out the importance of the integrated system approach and compares the dream to the reality.

Reality vs. Dream

The researchers envision object oriented database management systems, but in reality engineers have yet to exploit the relational models. The researchers exploit neural networks and OOPS, while industry is still struggling with C and FORTRAN. The heterogeneous database has become reality but engineers still use sneaker netted DXF file systems. The researchers continue to concentrate on highly focused technology without clear understanding of how this technology could be applied to the engineering process, whereas engineering firms focus on business process re engineering. The article recognizes the efforts we need to make to match the dreams and reality to the best possible extent.

What we need to do:

- Increase the overall awareness of practicing engineering community.
- Raise the expectations of the facility owner.
- Rethink our academic and research programs.
- Prove the long-term benefits over the short-term gain.

The article finally concludes that it is the time to accept the paradigm shift for the way we design, construct and maintain the facilities.

2.3.3.6 "Information technology philosophy in an A/E practice," (Anderson 1997).

This editorial article written by Anderson, expresses the author's views on IT philosophy in AE industry. According to the author the computer should become a regular tool available to the architect or engineer on his desktop. IT tools should be used to achieve better communication between clients and contractors. The article recognizes the following responsibilities for any IT staff of the company:

- Support for office infrastructure
- Training of the staff
- Integration of new technologies into day to day work
- R & D of new technologies
- Participation in any reengineering effort

The author of this article feels that the IT consultants could prove to be the best asset as they bring in better value added processes to the business and provide higher quality and flexibility in reengineering. To get the best out of them the IT department should work hand in hand with them for any integrated system development.

2.4 Project scheduling and controls

Integration of project schedule and cost controls has been a main objective of project control systems since the late 1970s. Several authors have presented methods for construction project controls (Neil 1982; Bernstein 1983; Murthy 1983; Riggs 1987; Singh 1991). Control automation relationships of project control to project integrated databases have been explored (Abudayyeh and Rasdorf 1991). The Construction

Industry Institute, in Austin, Texas has issued guides for engineering and construction (Project Controls 1986,87). Abu –Hijleh (1991) described detailed cost and schedule integration with a focus on exception reporting.

Previous research into automating the planning process includes: Construction PLANEX (Zozoya-Gorostiza et al. 1989), OARPLAN (Darwiche et al. 1989), CASCH (Echeverry 1990), Integrating construction scheduling with cost estimating (Yau 1992) and Know Plan (Ayman 1992). GHOST (Navinchandra et al. 1988) applies critic-based planning. Other efforts to integrate construction cost and schedule for project control include Grobler (1988) and Rasdorf and Abudayyeh (1991). Other research focused on controlling construction projects and managing as-built information during construction (Liu et al. 1994; Ganeshan et al.1994; and Chin et al. 1995)

2.4.1 Summary of selected research publications

The following research and journal papers discussed in detail, have a valuable input and influence over this thesis work. The papers discussed here refer to the project controls for a specific project environment or type such as: site level controls, multi project programs etc. However, the project control techniques discussed are recommended to be used by the project managers or CM companies; thus of the relevance to this thesis.

2.4.1.1 "Establishing management information system for multi project programs," (Zapalac et. al, 1994).

This paper recommends the following strategies or techniques in developing schedules for large programs:

- Complex schedules should not be built for individual projects. Typically 25-30 activities for each schedule are sufficient.
- Minimal / necessary amount of activity logic to be shown.
- Schedules should be sufficient for monitoring and reporting required by PMG.
- Critical path information may or may not be relevant.
- Cost and fund loading for schedules should be spread over different activities
- PMG schedule does not need manpower and equipment loading but PMG should ask the designers and the contractors to load their schedules with the same
- Selection of project management software is critical, and software like Primavera and Primavision can be used.

Particularly from a project scheduling controls point of view, the following recommendations are made towards setting up the working project schedule:

- Use of intelligent activity ID structure.
- Use of various codes in the schedule.
- Use of generic logic models.
- Customization to be achieved through batch processing (Figure 2.7).
- Loading the schedule with fixed limit of resources.
- Resource loading to be used by the designers and constructors for detailed scheduling.

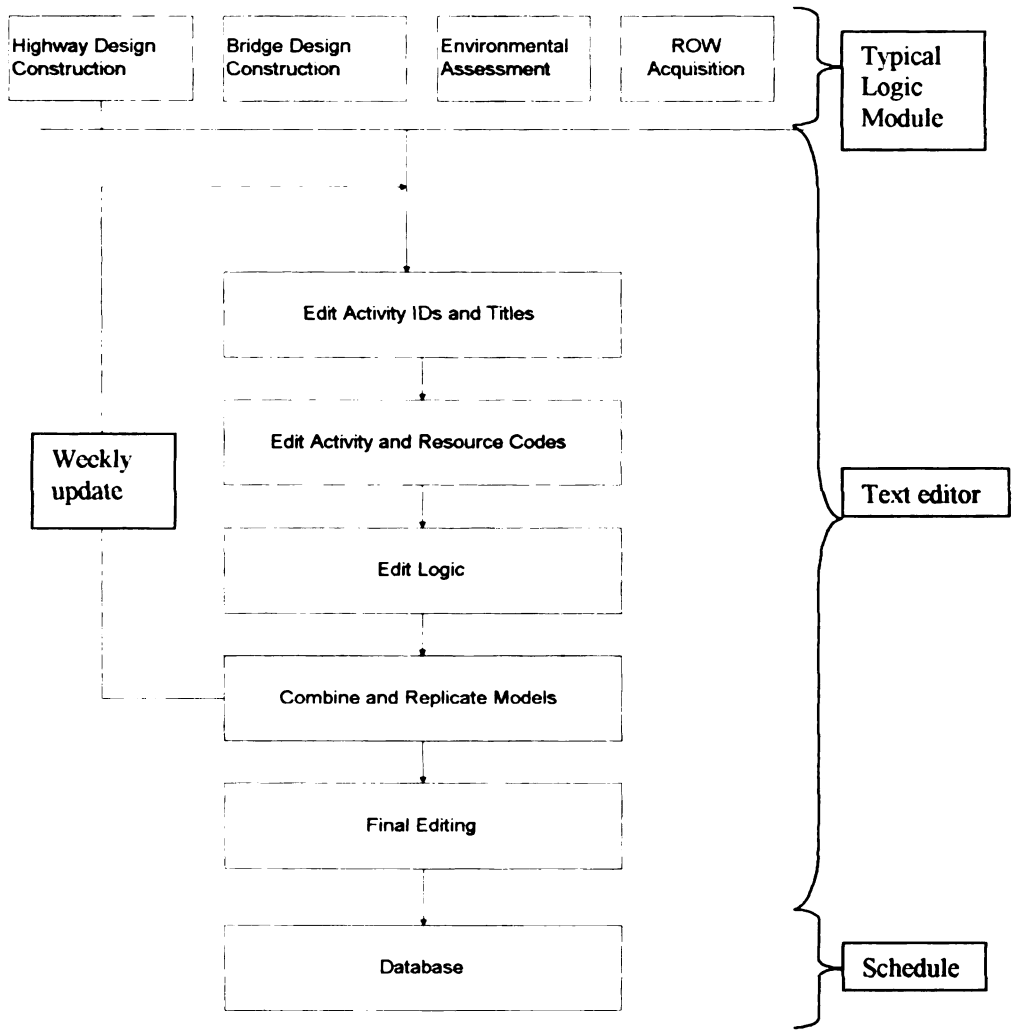


Figure: 2.7: Batch Processing (source: Zapalac et. al, 1994)

Again, from project cost control perspective, the following methodology is recommended in this research paper:

A cost loaded schedule should be developed to know the outgoing funds, whereas fund loaded schedules tell us about incoming funds. Both should be later combined to develop the overlapping envelope that identifies the key points for strategic planning and decision making. Further, the merging of both schedules provides a successful cash flow analysis tool. Usually both schedules will be updated in their own software packages and then exported to a spreadsheet to be merged and manipulated (Figure 2.8).

Overall for any project control system, a major consideration is the logistics of updating schedules and budgets. It include deciding on when and how to update the information and who will update it, comparing the costs for maintaining against updating etc. Typically, detailed updating is to be done at lower levels and then automated updating at higher levels. The Batch process is highly recommended.

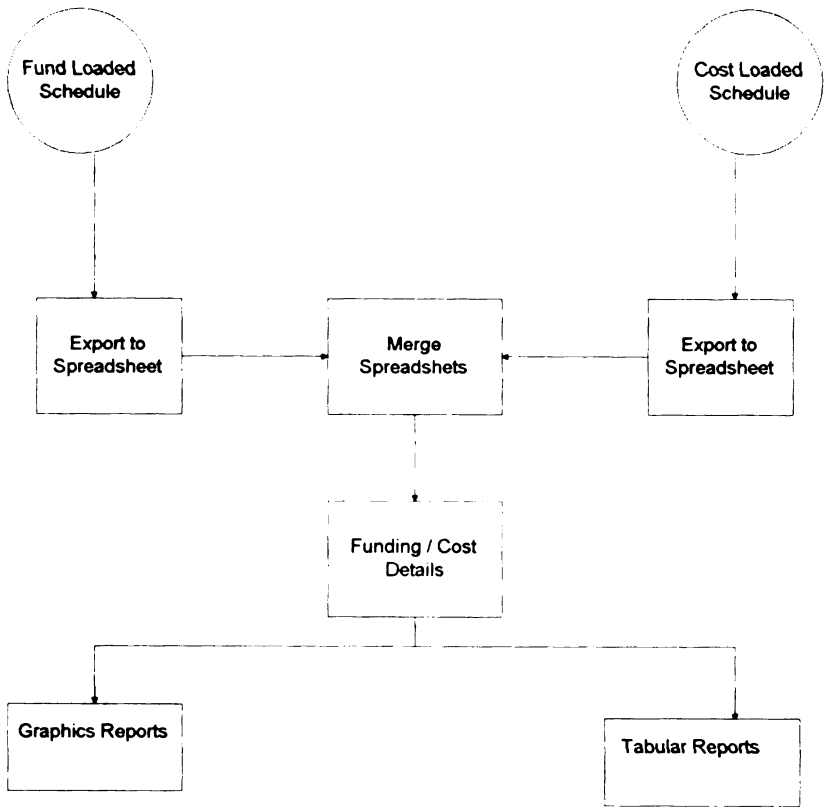


Figure 2.8: Cash Flow Analysis (source: Zapalac et. al, 1994)

2.4.1.2 "Site level construction information system (SCIS)," (Sanvido and Paulson 1992).

This paper brings out the following drawbacks of traditional project control systems:

- Excessive reliance on cost and schedule reports.
- The project budgets reflect the best estimate of probable project costs but the system can't identify poor planning and poor resource utilization for activity running under budget or within schedule.
- Lack of important information not captured by traditional systems: the time for resource acquisition and the approval cycle; the time for the resource to get crafts after approval of the cycle; time for the resource to be repaired; appropriate control level for a resource on site; and the method of distributing resource to the crafts.

The paper includes a very detail discussion about the decision-making process and the method to use it for project controls. According to this paper any generic decision making process involves three phases: intelligence phase, deign phase, and choice phase. Furthermore, there are three levels of planning and control such as strategic planing, management control and operational control. The whole decision-making process is structured under programmed decisions and un-programmed decisions. This structure is used to develop the methodology for project controls as given below:

Establish the decision matrix.

Define the project control system

Select the decision- making mechanism

Develop the information flow chart

The flow chart is an excellent template for the project controls process (Figure 2.9).

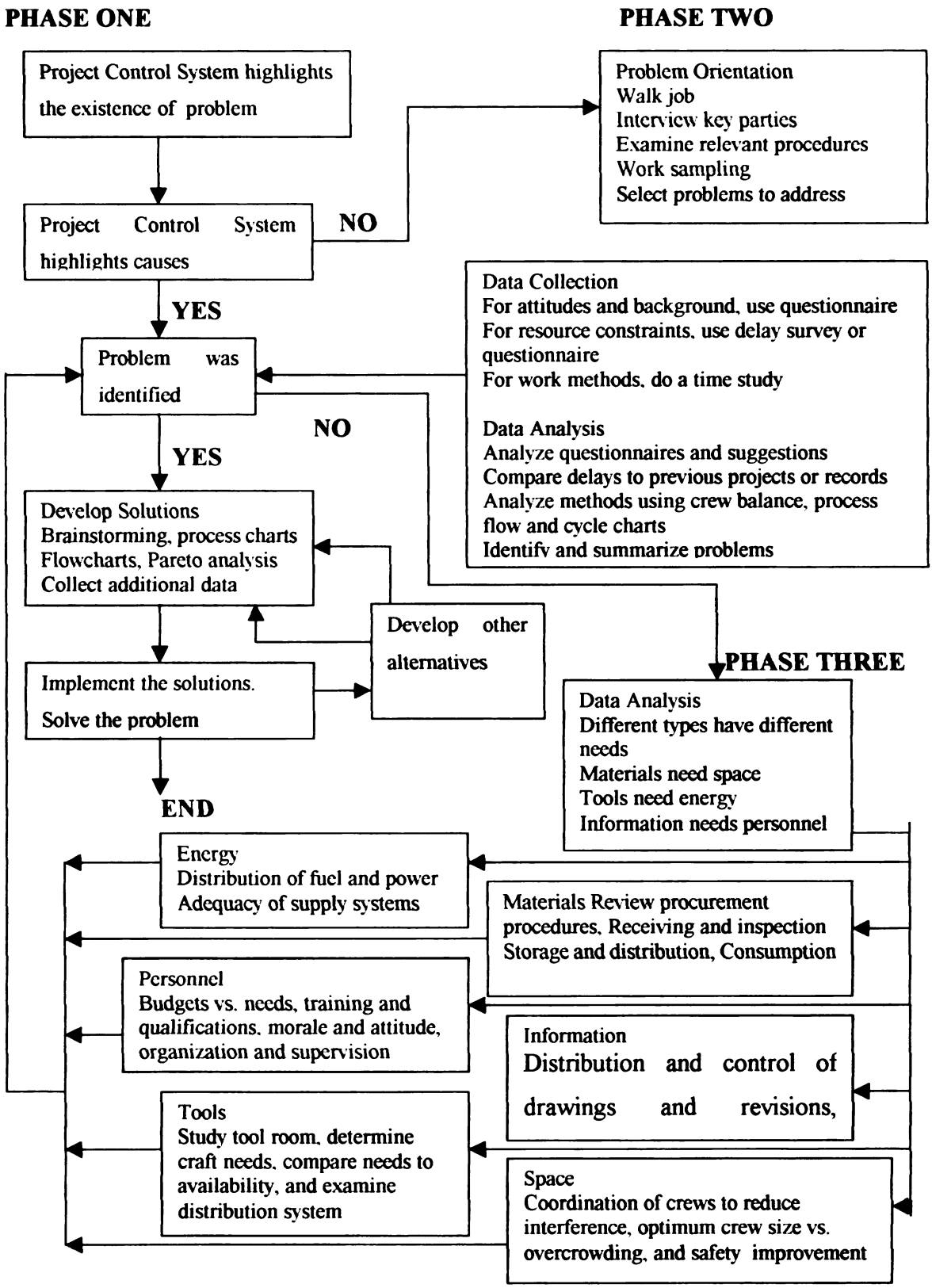


Figure 2.9: Information Flow Chart (source: Sanvido and Paulson 1992)

2.4.1.3 "Continuous assessment of project performance," (Russell et. al, 1997).

The goal of this research paper is to describe a process whereby project managers can use continuous or time dependent variables to predict project cost and schedule outcomes from the start of detailed design through construction completion. The paper involved a lot of data collection and information gathering upfront and project variables from 54-continuous projects were collected. S curves were developed for two project categories: successful and less than successful.

The project variables consist of a list of 76 variables that determine the future of any ongoing project. The variables are organized under the following main categories of owner expenditures; contractor construction effort hours expended; invoices paid by the contractor; total commitments for material and equipment; cost of owner project commitments and contractor project commitments and designer project costs.

The whole data collection process involved use of "Data tool" which is a 41 page questionnaire that was sent out to the participating firms. The data tool consisted of data definitions, general information and continuous variables. A total of 54 projects (45 successful, 9 less than successful) were provided by 17 companies of different types. This enabled the use of continuous variables as predictors of project cost and schedule outcomes. The author proposes making use of the variables from the list, as these variables are obtained from the best sources and reliable means and methods.

The data collected was analyzed using a CAPP computer program that includes modules like data input, data normalization, statistical analysis and graphical report generation. The modules also provided the perspectives of project type, project size, organization

type and contract strategy. The actual CAPP can be used with the necessary changes for the implementation of the REA model developed in this thesis.

Results:

S-curves were plotted for selected project variables for different types of projects and different stages of projects. It was found that a variable's predictive capability depended on project parameters selected and the project phase. The variables responsible for significant deviation in the nature of S-curves were identified as project control variables. Using these variables, the real time control charts were created. These charts are the graphs, or curves, that combine only those S-curve portions of project, which have significant deviation, thus eliminating unnecessary curve information.

The S-curves and the real time control charts can be developed from the integrated REA model, developed further in chapter 4.

2.5 Computer applications in construction

The computer applications in construction can be classified into integrated system applications; three dimensional modeling (3D); simulation techniques; and other areas such as knowledge based system (KBS), neural networks and robotics. Various companies are using the integrated system applications, 3D modeling, and simulation techniques. However, KBS, neural networks and robotics are still in their preliminary stages of applications.

2.5.1 Evolution

Computer applications began evolving in the larger construction companies in the late 1950s, a little more than a decade after the first electronic computer was built and almost as soon as commercially supported programming languages become available. The next two decades saw a steady progress particularly in home office applications such as accounting and finance. Project oriented applications such as CPM scheduling, estimating and simulation continued to evolve with enhancement such as graphical plotter outputs. In 1980s microcomputers became widespread and rapidly decreased in cost and easy to use software applications increased the number of users enormously (Paulson 1992).

2.5.2 Integrated system applications

Integrated applications in construction, introduced in 1970s and 1980s, involved developing mainframe and microcomputer databases to integrate construction applications. However, they met with limited success. Now with regular use of Windows technology, software packages like Primavera, Precision collection, Expedition, Auto CAD have developed integrated modules to be used with other databse applications. The short summary of integration across the commercially available software packages (excluding AutoCAD) is enclosed under software applications.

2.5.3 Three dimensional (3D) electronic modeling, and simulation techniques

In the recent times, as early as 1990, 3D modeling and simulation techniques are used by advanced construction companies like Bechtel's Construction CAE (Simmons 1988) and Jacobus Technology's Simulation Session Manager (Jacobus 1991). Some systems also

interface with CAD software such as Intergraph's IGDS and Mc Donnell Automation's GDS; Primavera to relational databse like Oracle and Informix (Paulson 1992).

2.5.4 Other areas

Other areas of computer applications that are evolving and still in the primary stages of applications are bar coding applications in construction, knowledge based systems (KBS) or expert systems, neural networks, robotics and fully integrated systems like ERP packages.

2.5.5 Summary of selected research publications

The following research and journal papers, discussed in detail, have a valuable input and influence over this thesis work. Some of these papers are of a technical nature and recommend various programming techniques, tools, network structures and data transmission techniques to be used. Others discuss the needs of computer applications and the factors like organizational behavior etc., and analyze the future of computer applications in construction industry.

2.5.5.1 "Experiencing Computer Integrated Construction," (Miyatake and Kangari 1993).

This paper describes the experiences gained in CIC implementation from a Japanese construction company viewpoint and presents a prototype model for CIC. This could be very well used as lessons learned in implementing a computer-integrated construction and serves to alarm the researchers of possible problems and difficulties.

As defined by this paper, the role of CIC is seen as a strategy for linking existing and emerging technologies and people in order to optimize marketing, sales, accounting, planning, management, engineering, design, procurement, contracting, construction, operation and maintenance and support functions. Any CIC typically involves integrated information flow, application of computers and high level automation. The backbone of CIC tool is a communication technology that transfers information from one machine/person to another. The different modeling components of any CIC application include:

Physical modeling: visible aspects, hw /sw issues and tools required

Functional: construction processes and operations

Informational: the structure of CIC needed to integrate planning, design and construction

Simulation: simulating construction processes using dynamic, 3-D animation / graphical systems

Organization: people, interaction and interface

The author proposes to identify these modeling components in the REA models developed further in this thesis.

The lessons learned in this project are summarized below and are representative for any effort in computer integrated construction.

- The main problem faced by the management in implementing CIC is a lack of methodology.
- Any integrated system application is less beneficial without automation.
- CIC should include all activities in addition to design and construction.

- Move towards CIC essentially means change in the philosophy and method of organization.
- It is very important to develop a strategy for CIC implementation and to assess the operational benefits in the beginning.

2.5.5.2 "The Circle: Architecture for integrating software," (Fischer and Kunz 1995).

The goal of this paper is to propose "circle integration" as a simple, testable approach to structure the integration of AEC software applications. The basic intent behind a circular integration is to support integrated multidisciplinary analysis of project alternatives, resulting in saving in a significant amount of time and money during the project-planning phase.

The paper identifies two phases of integration. The organizational integration involves discussion among the client and various discipline specialists within the project teams or integrated design build organizations during the planning stage. The technical integration links the software application that supports the discipline specialist. The technical integration is further divided into multipoint and circle integration. The basic difference between the two is that the multipoint integration, like LAN, has a "smart" central node that also has a knowledge base and communicates data from one application to all different applications. The circle integration structure looks like a circle or a ring in which each user node is a "smart" user node and decides the data to be passed on to other applications. The paper compares multipoint and circle integration and selects circle integration for implementation and testing. The circle integration structure (Figure 2.10)

is similar to the basic circular integration diagram (Figure 1.3, chapter 1), used in this research work.

This paper recommends various technologies such as shared database systems, agent oriented programming, black board systems, and object oriented programming tools. The two most basic architectures for technical integration are automation of current organizational integration and simplification of data integration. A rule of thumb is "simplify and then automate." However, there is a need to create and maintain knowledge about behavior and the capability of each application at the central node, which is a difficult task.

The author recognizes the following implementation and testing considerations, as pointed out by this paper, to be used for the implementation part of the REA model developed. The minimum considerations are adaptability, clarity of versions, ease of using various types of software, speed issue, stability of solutions, consistency, and support for evolutionary development.

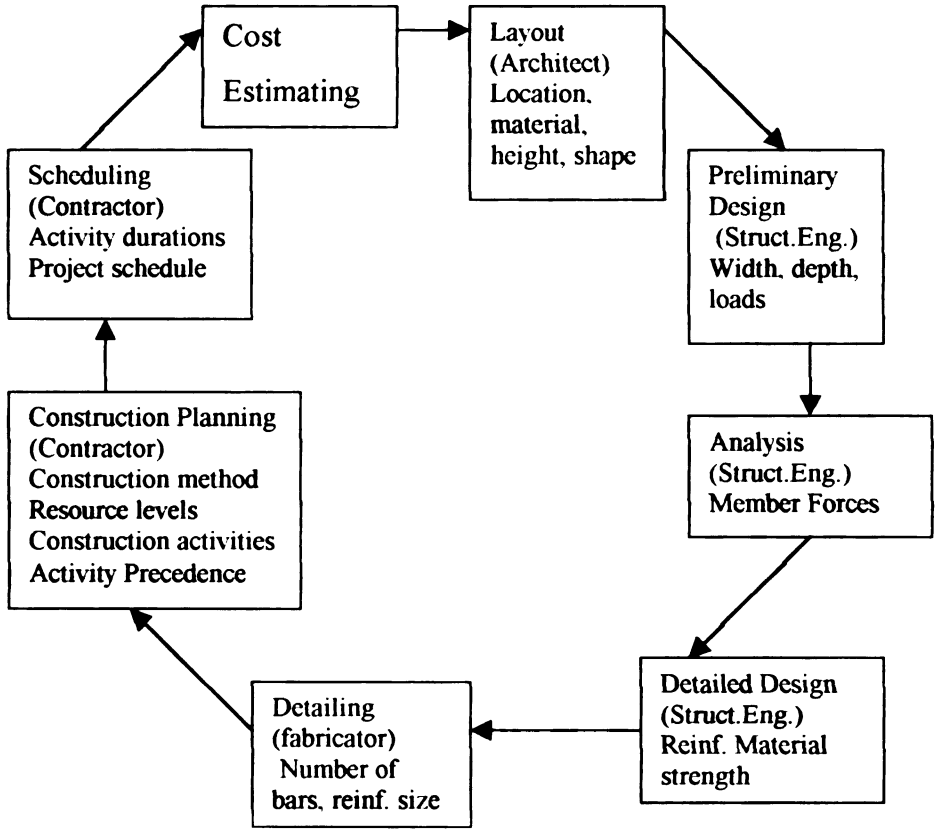


Figure 2.10: Circle Integration (source: Fischer and Kunz 1995)

2.5.5.3 "Inter connected applications (ICA) for AEC software development," (Rao et. al, 1997).

The aim of this research paper is to acquaint the AEC community with ICA and to provide an overview of its merits and potential. The problem areas identified by this paper are specific to AEC industry and are summarized as follows:

- Ad hoc query structure in the software requires computer professionals.
- Often discontinuity crated by the present AEC working methodology hampers the very purpose of the software, which is to maintain the data integrity.
- AEC professionals either lack computer skills required or don't have time for software development.
- The attitude problem of the AEC industry towards the software applications.

The author of this thesis recognizes the following recommendations made by the above research paper in using the technology and system architecture for developing ICAs. The author feels that ODBC and DDE and OLE could be used as the communication technology for the software implementation (out of the scope of the thesis) of the thesis work in future.

Suggested communication technologies include:

- MAPI: Messaging Application Programming Interface, like email
- TAPI: Telephony Application Programming Interface, like telephone
- ODBC: Open Database Connectivity, i.e. communication with different databases that are SQL compliant.
- DDE: Communication between client –server using cold or hot links
- OLE: Object linking and embedding, the final application on top of all.

Communication Architecture and Model:

- Client server, LAN, WAN, Internet, Intranet
- Visual Basic, C++, COBOL, CORBA, ACL, Open Doc.
- Components, hybrid and glue.

This paper provides the guidelines for laying down a framework for developing ICAs and could be used for developing a framework for the proposed integrated system in this thesis. The framework has two stages, building and implementation. The factors considered under each stage are described below:

ICA building (key planning, designing)

- Planning: problem identification, scope definition and development strategy selection

Design and Implementation:

- Key capabilities of different components.
- Type of communication desired (broad cast/relay, request/supply, one way/ two way, cold link / hot link)
- Where is data and how it is processed?
- Format of the exchange of information

2.5.5.4 "Computer integrated design drawings and construction project plans," (Parfitt et. al, 1993).

This paper provides one approach to the processes involved in the CPP stage to aid in the integrated creation of construction cost and time plans. It points out the need for better methods of data handling relative to current design practice and the importance of an integrated information flow process. The research identifies the specific problems related

to developing integrated software for transferring design data to the planning stage. The following major problem areas are identified:

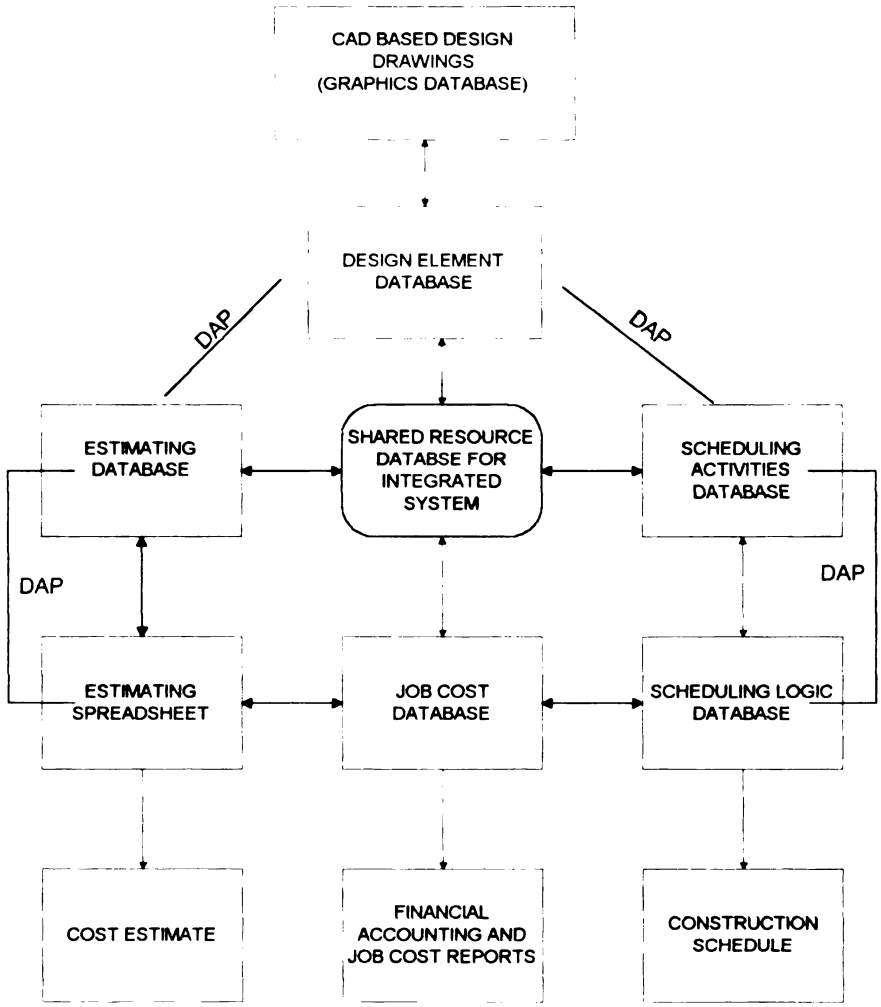
- Most modern software is first deigned to be a stand-alone module rather than a component in an integrate system.
- There is no general consensus of the exact form of a comprehensive building database.
- AEC- CAD integration solutions vary widely in operation and data structure.
- Software that addresses some of the issues of CAD, scheduling and estimating, are not considered to be cost effective by many firms.

The author feels that the flowchart developed in this paper for the current integration process in modern commercial level software packages, could be best used as the base template for adding new component or software module in the entire integrated system cycle. The author also believes that the problems identified by the above research work in deigning and implementation of an integrated system (as given below) are the representative obstacles for any such effort. The problems identified are:

- Implementation and operational restraints
- Hardware issues and communication difficulties.
- Variation between documentation and program operation.
- HW /SW limitations.
- Operating systems, program installation problems.
- Incomplete resource details in estimating database.
- Individual software learning curves.

Finally, the author also recognizes the recommendations made by the research team of this paper in designing an integrated system that are summarized below:

- An ideal integrated system should have the format of a centralized or nuclear database.
- Use of distributed database applications in conjunction with centralized data integrator.
- The multi application integrated system framework (Figure 2.11) can be further developed and used in this research work.



↔ Represents "Hot link" between Applications and Database

DAP = Distributed Application Databases

Figure 2.11: Two-Way Multiapplication Integration Framework with Shared-Resource database (source: Parfitt et. al, 1993)

2.5.5.5 "Decision models and expert systems in construction management," (Warszawski 1985).

Expert systems: These are computer based decision tools that can manipulate the available data, use mathematical algorithms for solutions and also employ unstructured decision rules based on expert's opinions. These models will be identified in REA models, as areas of future research.

Any expert system usually consists of the following components:

1) A knowledge base of facts and attributes and action rules in the problem domain

2) The context that stores the current data and also keeps track of current state of its solution

3) An interface procedure that activates the pertinent information or rules from knowledge base.

The high-level expert systems includes knowledge acquisition facility and explanation facility, in addition to the above components

The expert systems could be sued in the following areas of CM business:

Estimating

Construction planning

Site planning

Construction financing

Other applications

2.6 Existing software applications

The existing software application in the construction industry owes its success mainly to the windows technology and graphical user interface, used by these applications. The most commonly used software are those developed by companies like Microsoft, Primavera Project Systems, Timberline Inc., Meridian Project Systems Inc. The commonly used software applications are the Microsoft office suite (which includes word, excel, powerpoint, project, access), Primavera Project Planner (P3), Precision Estimation Collection, Precision Gold Collection, Prolog Manager, Expedition, Auto CAD and MC Square. The software applications are selected based on the type and nature of project and also the cost associated in use and maintenance of each of them. Almost all of them have an open database connectivity (ODBC), which allows them to communicate and share information with other applications. Over time the software companies have been making use of this ODBC feature to develop integration modules and integrated system application packages. A short summary of integration across various software applications that are commonly used is included in the following sections. This summary is based on the available information through software manuals and use guides and the Author's own experience with using them. To get the latest information about any of them the reader is strongly advised to visit the respective web-sites of the companies.

2.7 Summary

The literature review describes the work done in different aspects of construction industry and serves as the background for developing this thesis. It is difficult to allocate this

thesis effort to a particular research or work done but wherever any model or strategy is adopted from a particular work, the author has recognized the same in the sectional summaries and also referenced the material used. It is very clear that great work is done in the areas of modeling; information system and information technology applications; and computer applications in the construction industry. However, comparatively, the work done in the areas of project controls is very less as pointed out by Carr (1993). The use of the REA modeling technique in this thesis is among a few of such related efforts made in the history of the construction industry.

Section 1: Integration between Estimating and Scheduling

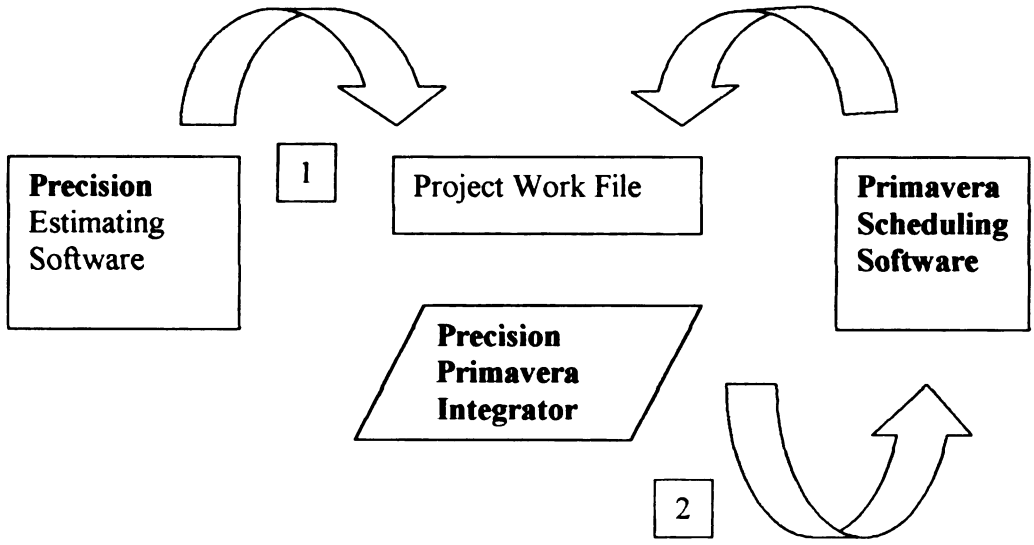
(Software: Precision Estimating Extended Edition (3.0) for Estimating, Primavera Project Planner (2.0 b) for Scheduling)

Different approaches towards using integrator:

1. **Creating activities in Primavera Integrator:** You can create the activities directly in the integrator using estimation information and then transferring the completed activities to primavera scheduling software, where you can assign the logic.
2. **Pre building activities in Primavera:** You can create the activities and / or the logic in primavera first, and then use the integrator to load and update these activities with the estimate information.
3. **Combined approach:** Combine the above two scenarios to meet your specific needs. This means pre building some of the activities in primavera and building others in the integrator using estimating information. Then export all of the data to primavera software.

Automating the above process: You can automate the process of building activities using estimation codes such as phase, location, or user defined WBS codes. In this case the integrator will automatically build activities for each WBS code value in the estimate. Each activity will have items designated with that particular WBS code value. Again you can, if you wish, modify these activities in the integrator or automate the export process to primavera scheduling software.

The integration process thus works in either direction, and regardless of any approach towards the integration, the transfer of information between Estimation and Scheduling can be shown as in the Figure 2.12.



(Steps 1 and 2, can be automated.)

Figure 2.12: Integration between Estimating and Scheduling

Section 2: Integration between Scheduling and Documentation Control

(Software: Primavera Project Planner (2.0 b) for Scheduling, Expedition (6.3) for Documentation Control)

1) Exchanging Expedition data with Primavera Schedule

You can review dates from the Primavera Project schedule from within Expedition to see the impact of schedule delays or other factors. Once you specify the project schedule to link to the Expedition project, you can use the early and actual activity dates from the schedule to update start and finish dates in Expedition. In addition, the export reports enable you to create or update the activities in P3 based on Expedition activity data.

2) Expedition Documents Linked to Activities

You can export data from Expedition to create and update activities in Primavera like Change Orders, Contacts / Purchase Orders, Daily Reports, Punch-lists, Delivery etc.

Similarly, you can associate and update dates for the following Expedition documents with P3 activities, like Change Management, Change Orders, Contracts and Purchase Orders, Daily reports, Submittals etc.

The exchange of data takes place through ODBC (Open Database Connectivity) technology, which is commonly used.

In simple, ODBC allows different databases to talk to each other and is usually a set of instructions in any programming language.

Section 3: Integration between Documentation Control and Project Cost Accounting

(Software: Timberline Gold Collection (3.0) for Project Cost Accounting and Expedition (6.3) for Documentation control)

Timberline Software's Gold Collection is the single tool needed to manage project accounting for the Construction industry. With complete, integrated accounting management, Gold helps you make better-informed decisions, increase productivity and improve profits. The Gold Collection includes the following integrated applications:

Accounts Payable, Accounts Receivable & Contracts, Advanced Retail Billing, Equipment Cost, General Ledger, Information Assistant, Inquiry Designer, Job Cost, Payroll, Property Management

Integration:

Expedition and Gold together form a complementary solution. With just enough overlap to make data integration straightforward, each system has been designed to handle different jobs within project-oriented companies.

Expedition TGIF (Timberline Gold Interface) is a Primavera-built interface that allows customers to have the best of both worlds by giving them a quick and easy way to synchronize data. Relevant fields, including cost codes and titles, contacts, contracts, purchase orders, change orders, and labor costs, are transferred between the two systems with just a few mouse clicks. Expedition TGIF reduces administrative costs and eliminates data entry errors.

Expedition to Timberline: The interface transfers information from Expedition to Gold. For example, change orders issued by project managers in Expedition can be uploaded into Gold, giving finance managers a fast and accurate way to stay on top of the latest project changes.

Timberline to Expedition: The interface helps project managers by linking information from Gold to Expedition. For example, labor information from Gold can be downloaded to Expedition, giving project managers timely access to current payroll costs.

Integration Architecture:

The integration between Timberline, Primavera and Expedition is possible on a stand alone (PC) as well as on client-server architecture. So for the companies having their LAN set up, integration over the network is the best solution for its high speed, ease of operations and relatively low cost of purchasing licenses. Again, all the recent products of the above three software, support "in the office" as well as "on the road" operations. Also, its windows based operations allow use of mouse and drag and drop feature. One Timberline license will support integration with only one license of Primavera, which in turn, will support integration with one license of Expedition.

Chapter 3: Building blocks of the integrated system

This chapter is aimed at defining the concepts or building blocks, used in developing the integrated REA model for scheduling and project controls. The building blocks are identified in the following narrative section that describes the functional style of a CM Company. The building blocks are then explained in the sub-sequent sections.

3.1 Functional style of a construction management (CM) company

The company has its own organizational structure defining the roles and responsibilities of an individual. An organization chart for a medium to large size CM Company usually looks like the one shown in Figure 3.1 (Clough and Sears 1998). This company set up is based on the assumption that the company is hired by the owner to manage different projects, which are constructed by the General Contracting (GC) firm. In this set up, the CM is responsible for the overall management of the project for the owner and acts as the owner's representative. All the individuals inside the company and also outside the company, play an important role in project completion, but the functional and operational style and responsibilities for all of them are different. These individuals further define the decision hierarchy levels (Fischer and Aalami 1996).

According to the researcher's experience in the construction industry, during the final stages of planning, a detailed schedule and budget is developed for the whole project. The schedules and budgets define the boundary lines for the project in terms of cost and duration and serve as the blackboard for the project controlling process during construction (Clough and Sears 1998). The general contractor (GC) develops his own

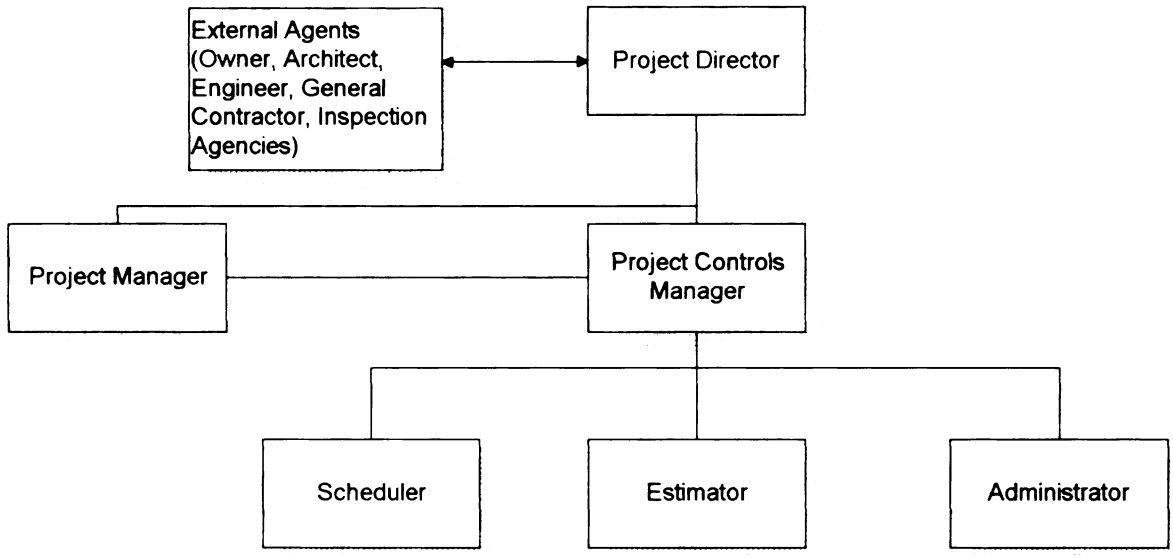


Figure 3.1. Organization Chart for a Construction Management (CM) Firm (Clough and Sears 1998)

schedules and budgets for the construction of the projects. The CM firm, develops its own budgets and schedules, to manage the project. The process of developing final schedules and budgets is a very rigorous process that requires great effort by the CM company to communicate and interact with various project participants like the owner, engineer, architect, general contractor, sub contractors, and suppliers etc. during the project planning phase (Fischer and Aalami 1996).

During the various project meetings, decisions are made regarding means, methods, technology, duration and cost aspect of the project, which are converted into detailed schedules and budgets. The schedules and budgets used by the PM or senior management greatly differ from the one used by the field supervisor or subcontractors (Fischer and Aalami 1996; Clough and Sears 1998).

In other words, these schedules are individual specific, and also as the project progresses to its completion, there is a continuous revision and updating done to reflect the present stage of the project and also to predict it's future. This is where the project controlling techniques are used to identify the problem areas and take corrective action to ensure the successful completion of project. The goal of the project controls system is to measure the project progress, compare it with what was planned and use the data to make necessary decisions, through the decision-making cycle (Syal 1992; Russell et. al, 1997). The decision making cycle is a part of the decision support system, which uses a set of procedures or decision making mechanism to take corrective actions (Sanvido and Paulson 1992). The quality and quantity of the data that is input into the project controls cycle varies according to the phase of the project. The information system manages this huge volume of data. The information system has, at its core, a data warehouse where the

past and present data for any phase of the project is stored, processed and made available for decision-making process (Sanvido and Paulson 1992; Russell et. al, 1997; Zapalac et. al, 1994). It is further required to transfer this data across different project participants and store it in the knowledge base. The data generated by various project participants because of various construction processes, and as a result of decision-making process, is managed by the information system (Sanvido and Paulson 1992). To ensure the data integrity and smooth data transfer across all project participants and various project levels, an integrated system is required. In order to understand the functioning of a CM firm and to design an information system, one needs to first model the different construction processes under the CM domain. Among the various CM processes, scheduling and project controls are the key processes.

Based on the above narrative and the, the following building blocks are identified

- Scheduling
- Project controls
- Decision support system
- Project control-information system
- Information Access or Data Warehousing

For this research work, the REA modeling technique is proposed, to model the scheduling and project controls processes. The REA modeling technique has been successfully used in the transaction processing systems like Accounting, and also for the design of an information system (David 1998). The output of the REA models will be the identification of data elements that are required to flow through the scheduling and project controls system. These data elements are then used by the decision support system

and project control system. Therefore, before developing the above building blocks, the following concepts need to be discussed in detail:

- REA modeling concept as used in the accounting system
- REA modeling concept as applied to the construction

These concepts are explained in the following sections and the remaining building blocks are then developed in the sub-sequent sections.

3.2 REA modeling concept as used in accounting

The analysis of a firm's Resource, Events and Agents, known as REA theory of accounting, was originally presented by McCarthy (1979 and 1982) for capturing information about accounting phenomenon. Since that time, many research studies have been published that describe the implementations of REA, rigorous applications of REA, comprehensive applications of REA, implementation platforms and empirical analyses (David 1998).

As identified by researchers, REA methodology, which incorporates different levels of analysis, is not only a useful tool in developing rich, integrated databases, but also can be used as a methodology to support enterprise-wide system implementations. The REA methodology is a flexible tool for understanding business and guiding new system design projects (David 1998).

3.2.1 REA model

The REA model consists of resource, events and agents. These three entities are the main components of any REA model, but depending upon the underlying business processes,

their values change (David 1998; McCarthy 1979, 1982). These components will be defined in the next section. The event, as defined by McCarthy (1982), is a class of phenomena, which reflects changes in scarce means (i.e. resource) resulting from production, exchange, consumption, and distribution. The resources, as defined by Ijiri (1975), are objects that are scarce and have utility and are under the control of enterprise. The agents are the employees of the company (internal agent) and the customer (outside agent). The resources and the agents for a particular enterprise are well defined and fixed. However, the events can vary depending on business processes, and are a result of such processes or transactions (David 1998). Three major types of events can be recognized for any business. These are economic events, business events and information events. All of them are discussed in detail in the following sub sections.

A typical REA model template for business process is shown in Figure 3.2. Starting from the left side, the resources are shown in the rectangle. The events are shown again using the rectangle in the center. The agents are of two types, internal and external agent, shown using rectangular boxes on the right side. The relationship between resource and event, and event and agent is shown using diamond shapes (David 1998).

3.2.1.1 Economic events

Economic events are those which change the quantity of resource (David 1998). Examples of economic events are SALE, PURCHASE, and CASH RECEIPT. To document an organization's activities, analysts use the events, resources, and agents definitions to create the event-level diagrams. These diagrams are a graphical representation of a firm's processes. These diagrams are also able to document why the

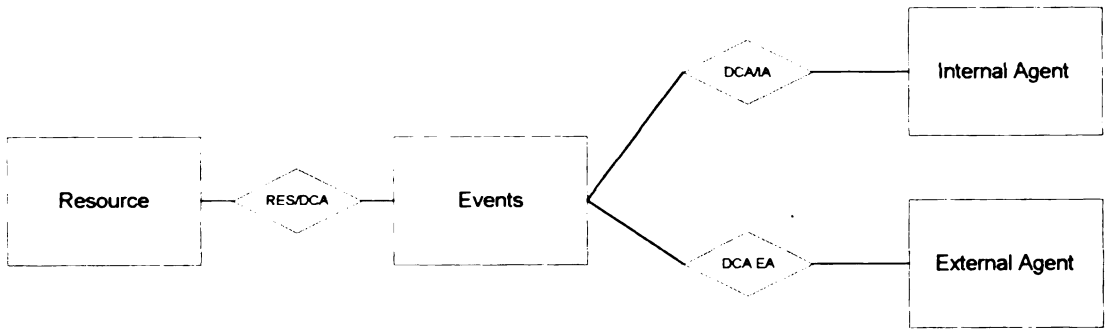


Figure 3.2: The REA model for business process (source: David 1998)

firm is willing to exchange resources with outside agents. Every time the firm uses a resource, the management expects something in return (David 1998; McCarthy 1982). To show this in the REA diagram, every event must be shown as related to at least one other event, which is the other half of the economic exchange (called "duality" relationships). For example, if the analyst begins by documenting SALE as an event that decreases INVENTROY, then the event that increases the resource (money) must be identified as related to SALE. In most cases the related event is CASH RECEIPT. The pair of events, SALE and CASH RECEIPT, results in an exchange between the firm and its CUSTOMER. It is not necessary that the duality relationship mean that two events occur simultaneously but it merely shows the reason why the organization is willing to give the customer INVENTORY. Each exchange is modeled individually and then view integration is performed to consolidate the exchange diagrams into a company wide diagram. The view integration involves connecting the common entities, such as resources and agents between the various REA models (David 1998; McCarthy 1982). The duality event connects to the other half of the exchange event. Figure 3.3 shows an example of exchange events and duality relationship and the view integration process.

If the entire organization is modeled using the REA technique, it becomes apparent that each resource must be related to at least two events: one that increases its quantity, and another that decreases its quantity. While the integrated diagrams can be difficult to develop, business people can understand them easily. These diagrams can be a valuable tool to demonstrate how the current system supports the organization (David 1998).

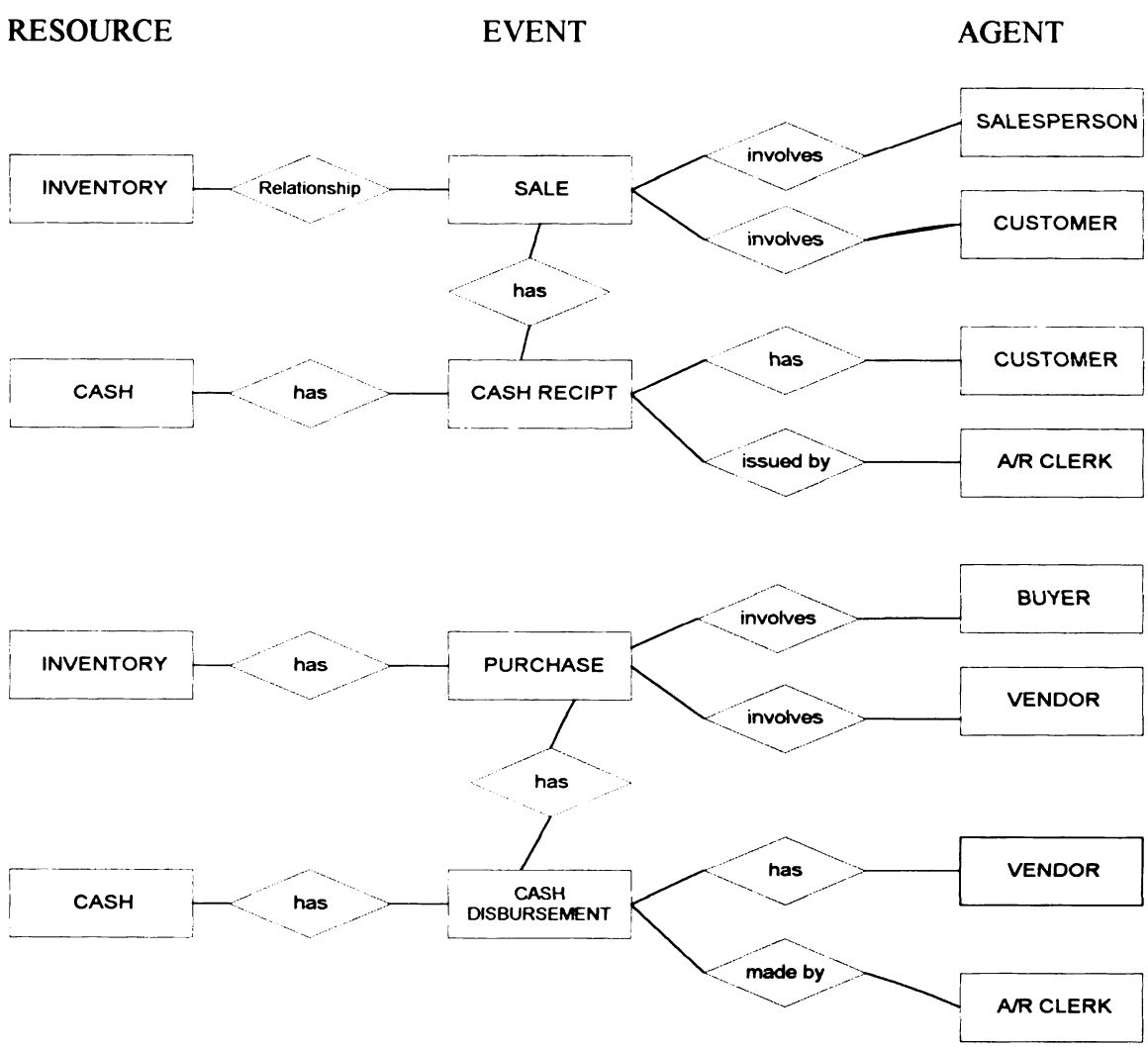


Figure 3.3: Example of REA model for exchange events and view integration process (source: David 1998)

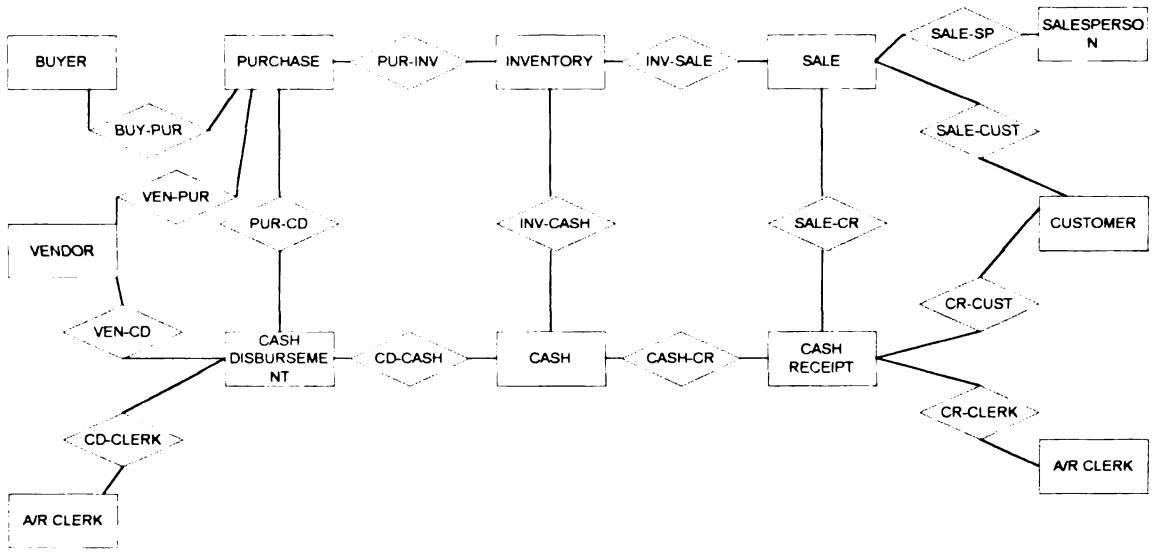


Figure 3.3: Example of REA model for exchange events and view integration process (source: David 1998)

3.2.1.2 Business events

Business events are defined as any business activity that the management wants to plan, monitor and evaluate (David 1998). These events result in changes to the physical world and provide new information to the firm's management. This definition includes all of the economic events in addition to other events, which are necessary for the completion of economic events (David 1998). For example, TAKE CUSTOMER ORDER is a business event, which is performed as a part of a SALE event.

TAKE CUSTOMER ORDER is an event in which the organization and the customer commit to two future events: it is a promise that the organization will provide INVENTORY to the CUSTOMER and that the CUSTOMER will provide a certain amount of CASH for each unit of INVENTORY they receive. No resources are increased or decreased at the time this event occurs, so this is not an economic event. However, this is a business event because once the order is placed, there is new information available which can help the management plan, monitor, and control operations. For example, production schedules may be finalized when orders are received. Staffing decisions may be based on sales volume. Management will have more information about the relationship between budgeted sales and future actual sales. Thus a general relationship between economic events and business events is that, the economic event may take several business events to be completed (David 1998). Therefore, the analysts should first document the firm's economic exchanges. Once that is completed, they can critically evaluate the business events. The relationship between economic and business event is shown in Figure 3.4.

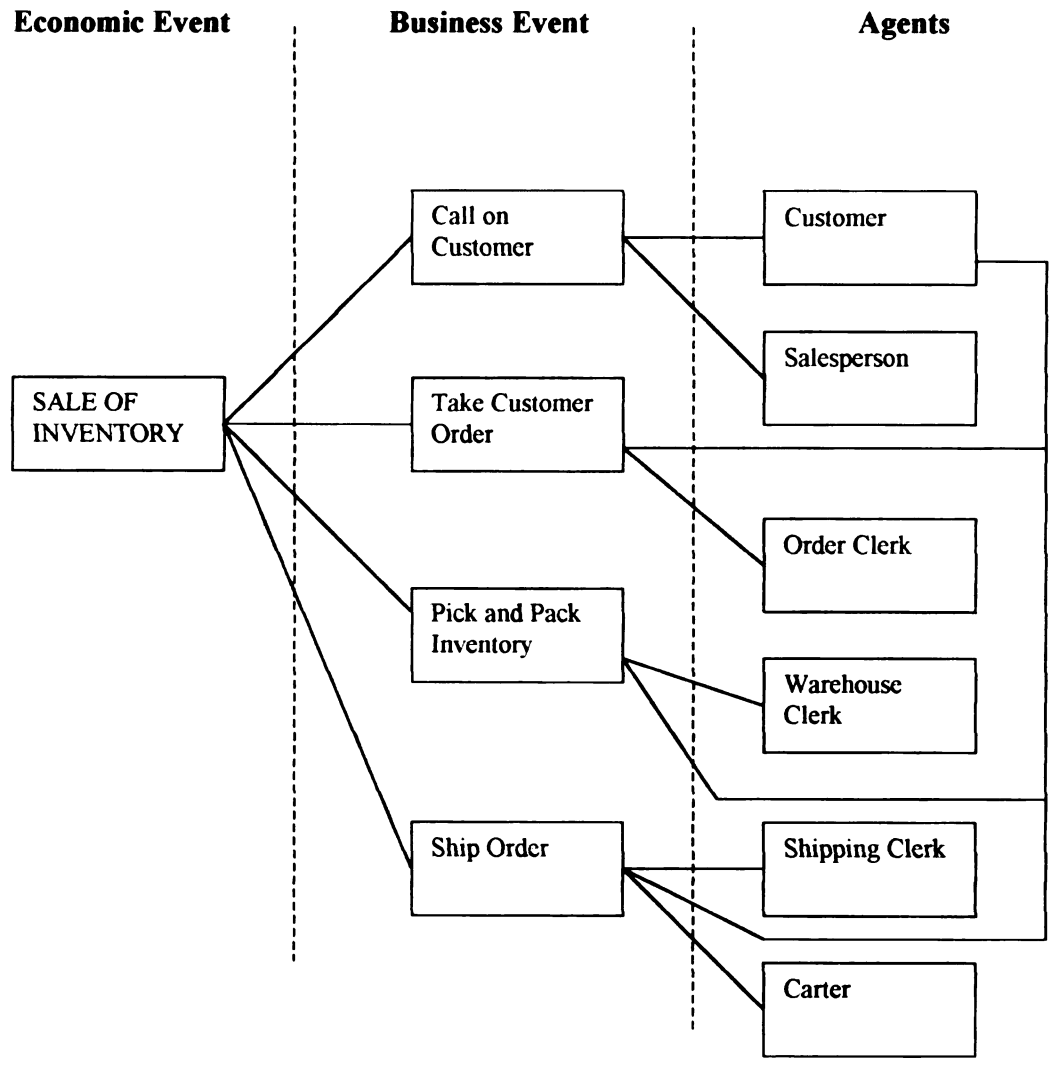


Figure 3.4: Relationship between economic and business events (source: David 1998)

3.2.1.3 Information events

Information events are the third type of events that are encountered in any organization. Information events are a procedure or set of procedures that are performed in organizations to manipulate and communicate information. Thus no new data is created and nothing changes in the real world that the system is describing (David 1998). For example, preparing customer invoices is an information event. It only communicates the information that has already occurred: some quantity of goods has been given to the customer and they are required to pay a certain amount, which was decided at the time of the CUSTOMER ORDER event. The paper document merely confirms the information already known.

As suggested by David (1998), the REA diagrams should not be used to document information processes. Their strength lies in modeling the activities, which occur in the real world, and helping management evaluate these events. Information events on other hand, while perhaps necessary in organization, are merely the processes that use the information captured about the resources, events and agents. They are an implementation issue, rather than a design issue. For example, a systems flowchart could be used to show how the actual information processes are performed and how information is communicated within the organization.

Once the resources, events and agents in the REA model are identified, the next step is to implement the model in a database system. This is explained in the next section.

3.2.2 REA implementation methodology

REA analysis can be followed by data analysis and database implementation to produce an integrated data repository, or system, that is able to produce the required statements and reports to support the programmed and unprogrammed decisions and management needs (David 1998, McCarthy 1982). The following sub sections illustrate the use of REA analysis.

3.2.2.1 Database design

Once the business event-level analysis has been completed, the organization has identified the key business events about which they want to store information. By definition, each of the entities included on this level diagram are important to the management, and once they occur the world has changed and new information is available that could be used to make decisions (David 1998). Therefore, it is necessary to develop a detailed list of attributes that are necessary to store the event. For example, for management to monitor and evaluate the CALL ON CUSTOMER event, they can identify the following important attributes: person contacted, meeting date, start time, end time, discussion summary, and follow up time (David 1998).

Once the attributes have been identified, a database can be created. In general, each entity will become a table in database, with a key attribute to uniquely identify each entity and various other attributes that describe the entity. In addition, the relationship between the entities will be implemented so that the data across tables can be integrated to respond to the management requests (David 1998).

3.2.2.2 Reengineering

Reengineering is defined as "the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance" (Hammer and Champy 1993). One of the most difficult steps in reengineering is the identification of processes that are good candidates for reengineering projects. REA analysis can help guide the reengineering project because a process is simply an economic exchange. By continuing the REA analysis to the business-level events, management is focused to justify each additional business or information event that is added to the process (David 1998).

3.2.3 Consolidation of concepts: REA as design methodology

Once we understand the unique characteristics of economic, business and information events, REA can be used as the foundation of system designs and business process analysis projects. A general framework for this methodology as recommended by David (1998) is presented below: "

1. Identify economic exchange
2. Develop individual E-R diagrams for each exchange following the REA template. Be sure to include all resources, even those that are not traditional accounting systems.
3. Perform view integration of the exchanges:
    a) "Overlay" like entities.
    b) You can have several entities representing the same resource, event or agent if it makes the diagram more manageable.

c) Analyze each event to ensure that the duality links (the relationships between the "gives" and "takes" which make up an exchange) are maintained.

d) Analyze each resource to identify, at minimum, both an increase and decrease.

4. Evaluate each economic event to determine if there are required business events.
    a) Be very critical before adding any business events.
    b) Do NOT include any information events.
5. Replace the economic events in your diagram with the business events.
    a) Make sure that the result of the business events is the same as the original economic event.
    b) The business event may not follow the REA template.
6. Create a system to store the data.
7. Capture the data about transactions as they occur so the data mirrors the activities in the business.
8. Provide users with access to the data.
    a) Create on-line inquiry screens for answers to standard, repetitive questions.
    b) Provide a query generation tool for non-standard question answers.
    c) Create reports only if necessary".

This section described the concept of REA modeling as used in the accounting system. It includes developing REA model for business processes, and then transforming the models into database system using the implementation methodology. The same concept will be applied to the construction system, and the different components of REA model will be identified in the next section.

3.3 REA modeling concept as applied to construction

This section will identify the resource, events, and agents of the REA model for the construction system. The discussion in the following section is along the similar lines as the previous section.

3.3.1 "Event," "Resource," and "Agent" definitions

The event, as related to construction, can be various construction processes that consume resources. The resources can be identified easily as labor, material and equipment. The agent can be project manager, superintendent (internal agent for company) and the owner, architect etc. (external agent). These are described in detail in chapter 4. Again, three types of events are identified i.e. economic event, business event and information event.

3.3.1.1 Economic events

A possible example of an economic event as related to construction is ERECT CONCRETE WALL. This event consumes resources such as formwork, rebar, and

concrete. The possible duality relationship event is GENERATE PAY REQUEST, which increases the resource, such as money.

3.3.1.2 Business events

The possible business events as related to construction are FORM WALL, PLACE REBAR, and POUR CONCRETE. All these events are required to arrive at ERECT CONCRETE WALL event, which is an economic event, as explained earlier. Once the management has information about the formwork, they can plan on placing rebar, or placing concrete. Staffing decisions may be made based on the quantity of concrete that could be poured in the formed area. Management will have more information about budgeted quantity in place and actual quantity in place.

3.3.1.3. Information events

The possible information event as related to construction is SELECT FORMWORK or PUMP CONCRETE. These events don't generate any new information or make change in the real world but simply tell us about the type of formwork to be used and the rate of pumping or type of pump to be used. This information has been already agreed in the contract document by the contractor and the architect.

All the above types of events, as related to scheduling and project controls aspect of construction, will be identified in the next chapter, which is the research output. Again, each phase of the project, i.e. planning, construction and close out, will have different events.

3.3.2 REA implementation methodology for construction

The REA implementation for the construction system involves designing of the database system that supports the information system for the organization. The information system stores all the relevant formal and informal information from scheduling and project controls processes. As explained in previous sections, the business events identification will lead to formation of entities in database tables. In our example, the events FORM WALL, PLACE REBAR and POUR CONCRETE can be converted to the entities. For example the event FORM WALL will have attributes such as wall location, length, width, height, type of formwork used, start date, end date, amount of labor hours spent, name of the supervisor, formwork sub contractor etc.

The actual business events related to scheduling and project controls will be identified in the next chapter. The REA models for these events will be developed and the database system will be designed for implementing the REA models in the research output.

3.3.3 Consolidation of concepts: REA as design methodology for construction

Once the unique characteristics of economic, business and information events as related to scheduling and project controls are identified, REA can be used as the foundation of integrated system design projects. A general framework for this methodology as presented in section 3.2.3, will be used in research methodology.

3.4 Scheduling process in a CM company

The scheduling process starts during the planning stage and a detailed working schedule is prepared at the end of the planning stage (Clough and Sears 1998; Fischer and Aalami

1996). The various processes involved in developing the schedules, during the planning stage, are discussed in the following section.

3.4.1 Planning

The initial stages of planning determine the following aspects of construction (Clough and Sears 1998): 1) determination of activities that need to be performed to successfully complete the project, 2) means and methods used to perform these activities, and 3) the sequence of operations and the overall project schedule and budgets. During the initial planning stage, a preliminary schedule is developed that gives the overall project duration and activity sequence. During the final stages of planning, detailed working schedules are developed, which define all the activities, the duration for each and the sequential relationship or logic among the activities. Also, different types of schedules are generated during this stage, to be used by different project participants (Clough and Sears; Fischer and Aalami 1996).

The steps involved in developing detailed project schedules are discussed in the next section.

3.4.2 Project schedule development

The project schedule is a projected timetable of construction operations that will serve as the principal guidelines for project execution. There are several steps involved in developing and implementing the workable job schedule. The following steps are the recommended (Clough and Sears 1998):

1. "Estimate the time required to carry out each network activity.

2. Using these time estimates, compute the time period required for overall project completion.
3. Establish a time interval within which each activity must start and finish to satisfy the completion date requirement.
4. Identify those activities whose expedient execution is crucial to timely project completion, called as critical activities.
5. If the project duration exceeds the contract duration, shorten the project duration at the least possible cost.
6. Using the surplus or float times that most activities possess, adjust the start and finish times of selected activities to minimize resource conflicts and smooth out demands for manpower and equipment.
7. Make up a working project schedule that shows anticipated calendar dates for the start and finish of each network activity".

The first four steps form the major portion of scheduling activities where as, step 5 onwards focus on managing and controlling the schedules to suit the project needs, which is project control techniques.

The schedules developed for the various project participants have different details of information. This leads to the formation of a schedule participant matrix, as described in the next section.

3.4.3 Schedule participant matrix

The schedules developed for each level of project participant varies as different individuals have different functional and operational responsibilities (Fischer and Aalami

1996; Sanvido and Paulson 1992). These responsibilities are defined by organizational hierarchy, as shown in Figure 3.1. Thus, for each individual, the data and information provided in the schedules will vary. The schedule participant matrix as shown in Table 3.1 explains the various schedules and details required at each level. The three major types of schedules can be identified according to three functional levels, i.e. strategic schedules, managerial schedules, and operational schedules (Clough and Sears 1998; Sanvido and Paulson 1992). The strategic schedules are overall project schedules and are used for decision-making at the top level of the organization. The managerial schedules are milestone schedules used by the project managers and other project participants, which are the next level in the organizational hierarchy. (Figure 3.1) The operation schedules are more detailed activity oriented schedules, used by general foreman or site superintendent, who are at the bottom level of organization hierarchy. The super schedule, or master schedule, for any project is developed by merging the schedules at different levels, also called fragnets (Sanvido and Paulson 1992).

As the project progresses from planning to close out or completion stage, the schedules used by project participants undergo modifications and changes due to many reasons such as the need to accelerate some activities, changes in methods used affecting the operational sequence, actual progress being different than planned, unaccounted events such as bad weather, labor strike, or material and equipment delays, etc. (Fischer and Aalami 1996; Zapalac et. al, 1994). In this way, the schedules developed during the final stage of project planning, are subjected to changes and modifications, which triggers the project controls process.

	Project Participant		
	Senior management to Project Manager	Site Manager / Site in charge /	Site Supervisor / General Foreman
Schedule control type	Strategic Schedule	Managerial Schedule	Operational Schedule
Schedule type			
Overall schedule	Overall project duration, critical path, milestone dates, key dates, major completion dates, dollars spent, method to be used, procurement and delivery dates etc.		
Key date schedule	Key dates like "start" and "finish" for critical activities, planned manhours, qty. of work in place, payment dates, ispection, testing and submittal dates, etc.	Key dates like "start" and "finish" for critical activities, planned manhours, qty. of work in place, payment dates, ispection, testing and submittal dates, etc	
Milestone schedule		Completion dates for major activities, budgeted qty of work, man hours, constraints for milestones, payment dates, calender dates for admin. activities, etc.	
Major phase schedule		Start and finish dates for major phases such as foundation, external walls, steel structure, framework, enclosures, finishes, roofing, UG Utilities, HVAC, etc.	Start and finish dates for major phases such as foundation, external walls, steel structure, framework, enclosures, finishes, roofing, UG Utilities, HVAC, etc.
Critical activity schedule		Start and finish dates, budgeted qty. of work in-place, budgeted man hours, dollars billed and spent, etc.	Start and finish dates, budgeted qty. of work in-place, budgeted man hours, dollars billed and spent, etc.
Detailed activity schedule			Day to day activity start and finish times, floats, man hours, lags, fabrication time, etc.

Table 3.1: Schedule Participant Matrix (Clough and Sears 1998; Sanvido and Paulson 1992)

The project controls process is a part of project control system. The project control system is described in detail in the following section.

3.5 Project control system

The project control system is aimed at managing the project successfully, within the budget and duration (Clough and Sears 1998; Russell et. al, 1997). The system is designed based on project schedules and budgets that are developed during the final stages of project planning. The various project control tools are developed based on the schedules and budgets. The decision-making process involved in the project controls process makes use of these tools to make decisions and take corrective actions. The components of project control system are discussed next.

3.5.1 Components of project control system

The project control system has two main components such as schedules and budgets. Usually schedules and budgets for the projects are developed independently. However, the schedules are loaded with the budgets to provide a better understanding of the use of funds and the related project progress (Russell et. al, 1997; Zapalac et. al, 1994).

3.5.1.1 Schedule component

The project schedule contains two major components: working schedule and funding schedule. The working schedule is associated with the activities involved in the project and gives the duration for various activities and activity sequencing involved (Clough and Sears 1998; Fischer and Aalami 1992). It also tells us about the means and methods to be

used, the resource requirement and the strategic planning behind it. The funding schedule is associated with pay requests, payroll, fund allocation, and acquisition (Zapalac et. al, 1994).

3.5.1.2 Budget component

The project budget contains two major components: project costs and funding. The project costs are associated with completion of various work items and activities and they draw the funds out. The project funding is associated with various sources and also activities that bring the funds into the project (Clough and Sears 1998; Zapalac et. al, 1994). The working schedule when loaded with the work costs, gives the cost loaded schedule. Similarly, the financial schedule when loaded with funds, gives the funding schedule. The cost loaded schedule tells us about the outgoing funds, whereas fund loaded schedules tell us about incoming funds (Zapalac et. al, 1994). Both schedules should be later combined to develop the overlapping envelope that identifies the key points used for strategic planning and decision-making by the project manager. Further, the merging of both schedules provides a successful cash flow analysis tool (Zapalac et. al, 1994, Russell et. al, 1997). Usually both schedules will be updated in their own software packages and then exported to the spreadsheet to be merged and manipulated as shown in Figure 3.5.

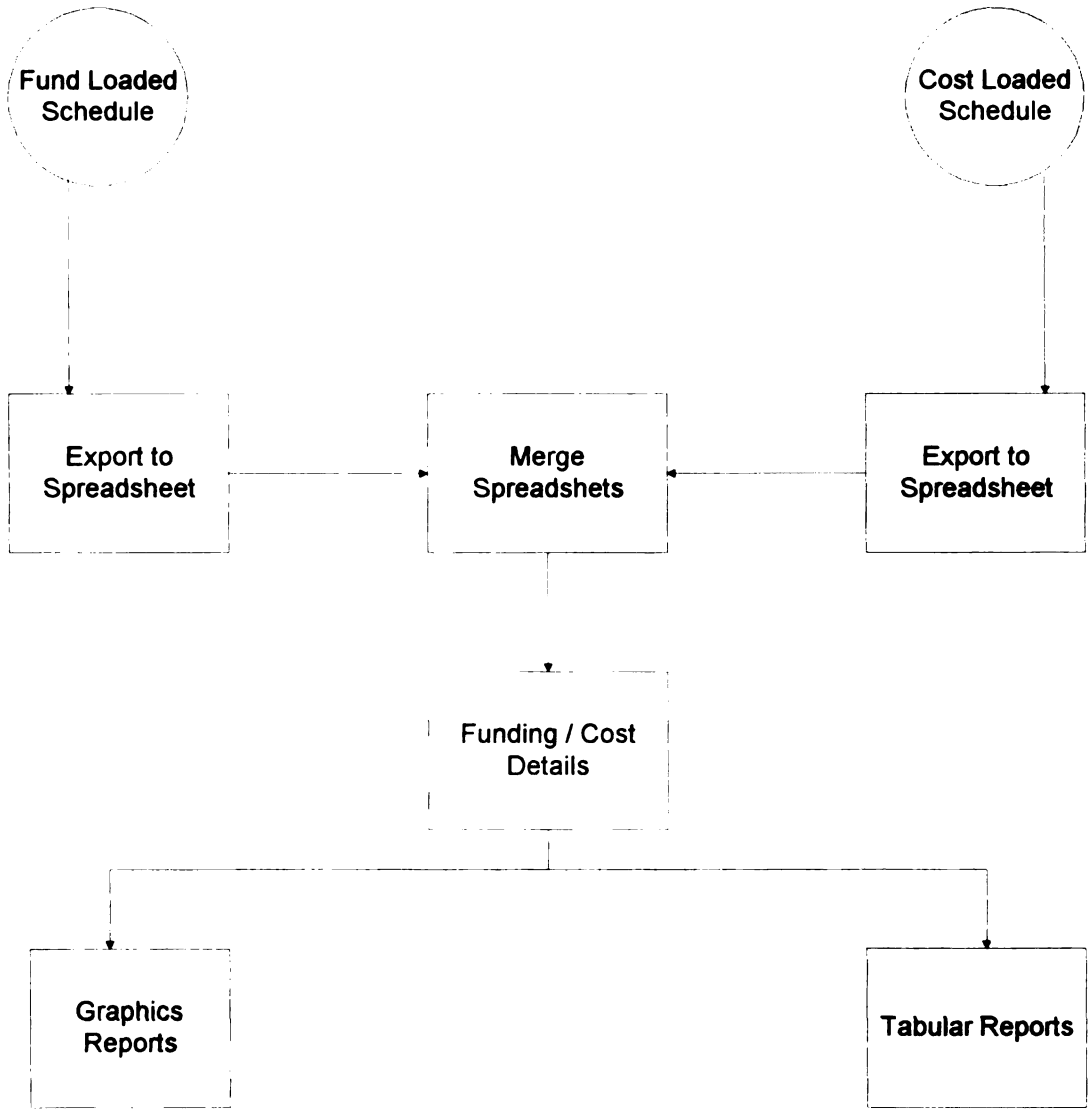


Figure 3.5: Merging cost loaded and fund loaded schedules

(source: Zapalac et al., 1994)

3.5.2 Logistics of schedule and budget updating

Overall for any project control system a major consideration is the logistics of updating schedules and budgets. The logistic of updating consists of answering the questions such as, "when and how to update the information," and "who will update it." (Fischer and Aalami 1992; Zapalc et. al, 1994). The decision hierarchy matrix and schedule and budget participant matrix identifies the person who will act on the data and update the information. The details involved in updating depend on the person who will update it and also on the person who will use the updated schedules and budgets. Typically, detailed updating is to be done at lower levels of hierarchy and then automated updating at higher levels (Zapalac et. al, 1994). The lower levels of hierarchy include the operational schedules that are very detailed, as shown in Table 3.1. Where as the higher level of hierarchy includes overall, or milestone schedules that are comparatively less detailed. Therefore, for operational control detailed updating is done at lower levels, while for strategic control, overall updating is required. Batch processing, as shown in Figure 3.6, is very good method for updating. It involves updating the schedule at different levels with different levels of details and then merging them all in one super-schedule at the higher level for strategic planning and decision –making (Zapalac et. al, 1994). Hence, updating at lower level starts with editing activity IDs and titles and ends at editing the activity logic. This process of updating is replicated across different types of schedules. Once the different schedules are updated, then the master schedule at a higher level is updated. This section described the schedule and budget components of a project control system. The next section will describe the project control tools.

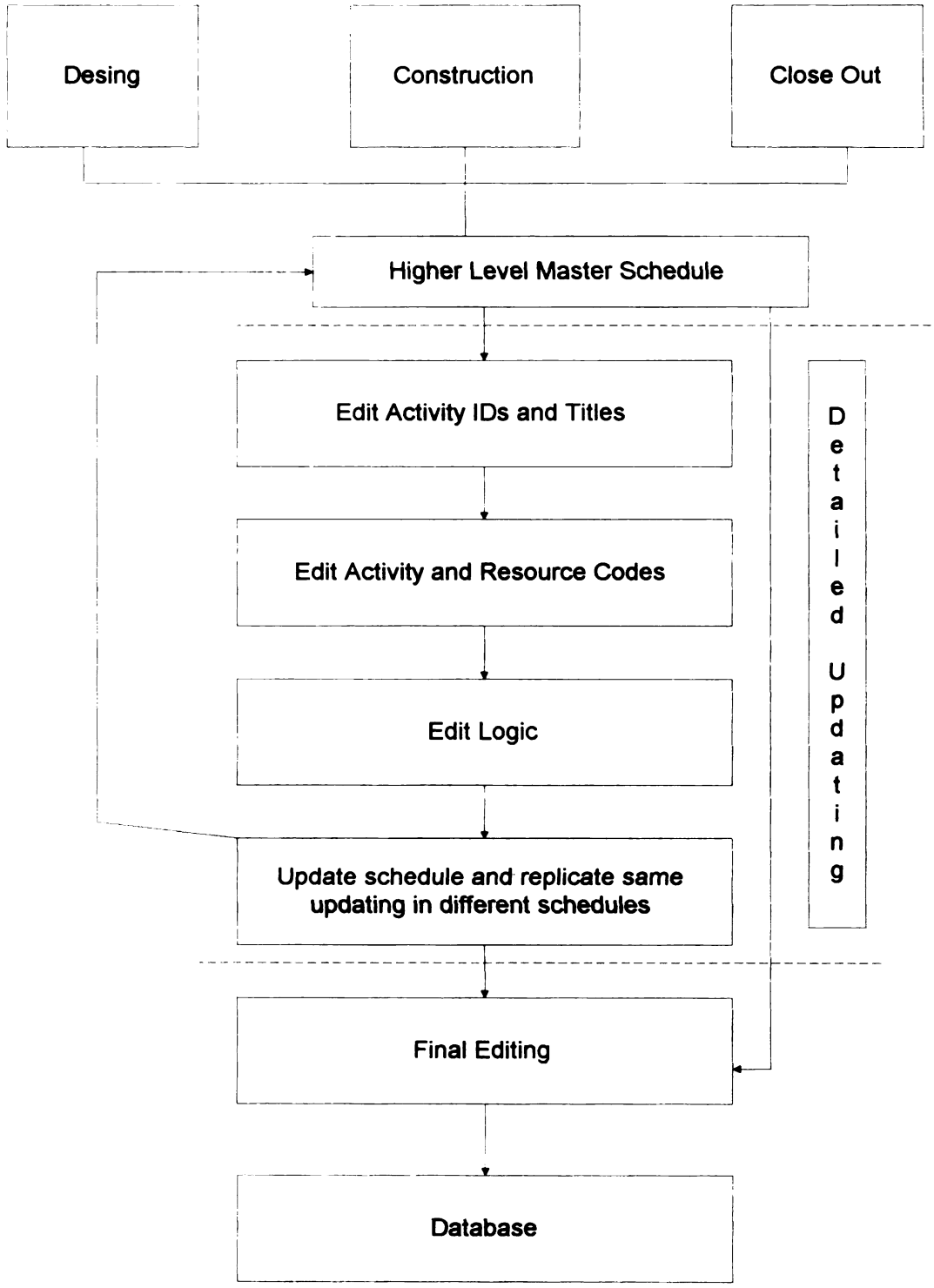


Figure 3.6: Batch Processing (Zapalac et. al, 1994)

3.5.3 Project control tools

Various CM companies use a number of project control tools. These involve time-cost envelopes, line of balance, critical path method (CPM), etc. (Clough and Sears 1998, Russell et. al, 1997; Warszawski 1985). This research work will make use of S-curves, and real time control charts as project control tools. The concept of S-curves and real time control charts is discussed here. However, their use for project controls is discussed in chapter 4.

3.5.3.1 S-curves

S-curves are usually plots of cost vs. time. Here two major categories of S-curves are identified such as "time related" and "cost related" (Clough and Sears 1998; Russell et. al, 1997). The variables that will be used under each category are listed in Table 3.2. Clearly, the time related variables are obtained from schedules and cost related variables are obtained from budgets. For each phase of the project, time and cost S-curves can be plotted. The logic of using these S-curves is as shown in Figure 3.7. The variables responsible for significant deviation in the nature of S-curve can be identified as project control variables (Russell et. al, 1997). Based on the nature of S-curves, the project can be identified as "successful" (meeting or exceeding schedule and budget requirements) and "less than successful" (not meeting the schedule and budget requirements). The project managers can make use of S-curves to keep track of project progress and make sure that it is progressing according to plan or they can even compare the actual S-curves to the S-curves for successful projects of similar nature in historical records (Russell et. al, 1997). As shown in Figure 3.7, the S-curves for the planning phase are

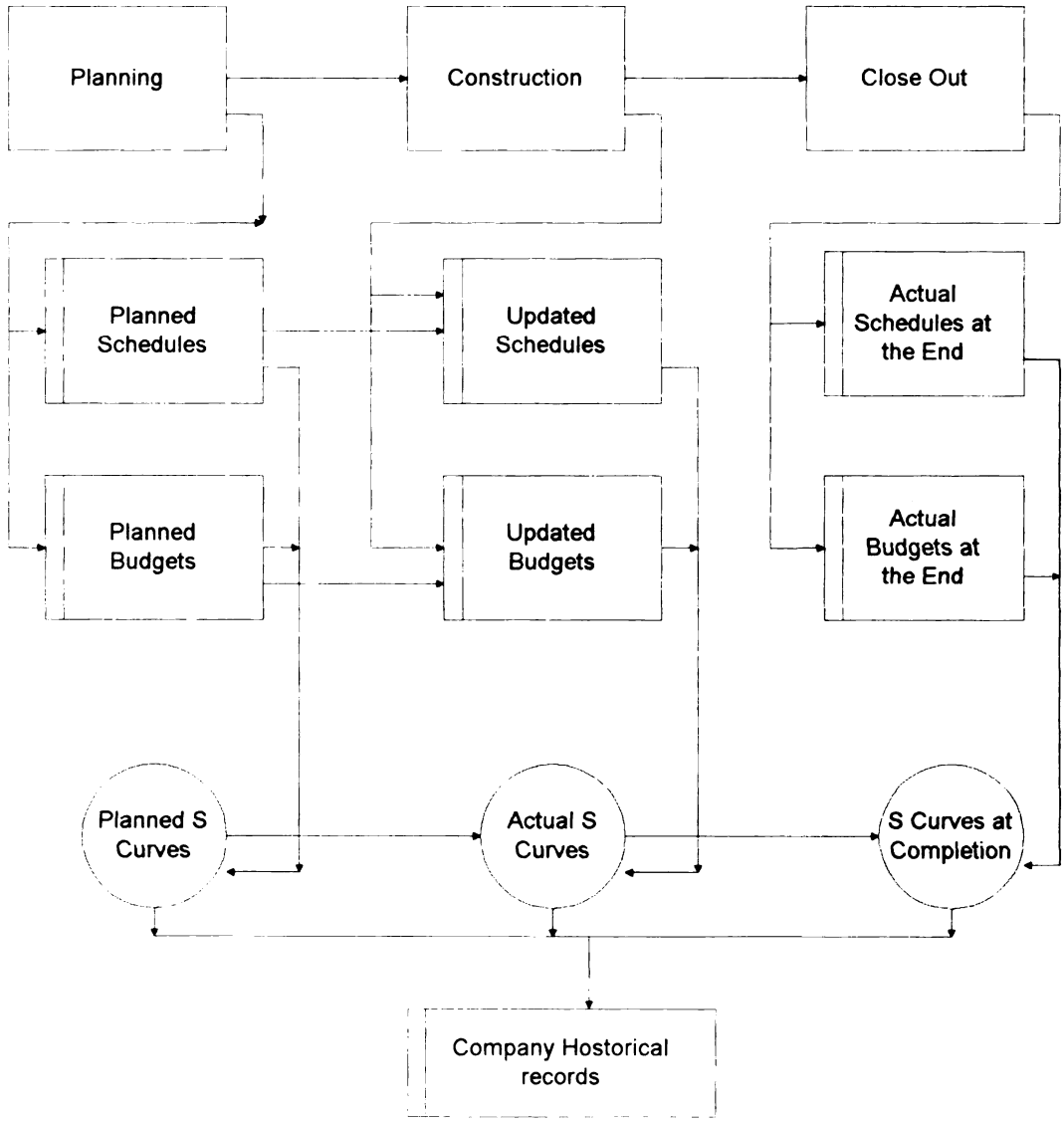


Figure 3.7: Logic of using S curves

	Planning Phase	Construction Phase	Closeout Phase
	Variables	Variables	Variables
Time Related	Budgeted man hours Budgeted construction complete Planned fabrication hours Planned installation hours Planned equipment hours	Actual man hours Actual construction complete Actual fabrication hours Actual installation hours Actual equipment hours	Total man hours Total construction complete Total fabrication hours Total installation hours Total equipment hours
Cost Related	Budgeted money ($) Budgeted labor cost Budgeted material cost Dollars to be billed Budgeted cost of change orders Budgeted indirect costs Budgeted activity direct costs	Actual money spent ($) Actual labor cost Actual material cost Actual dollars billed Actual cost of change orders Actual indirect costs Actual activity direct costs	Total money spent ($) Total labor cost Total material cost Total dollars billed Total cost of change orders Total indirect costs Total activity direct costs

Table 3.2: Variables for S- curves (Clough and Sears 1998; Russell et. al, 1997)

developed based on planned schedules and budgets. The actual S-curves are plotted as the project progresses during the construction phase. These are based on the updated schedules and budgets and are compared against the planned S-curves. Finally, during close out phase, the S-curves at the completion are developed, which are usually of more importance, in planning for the next project of a similar type. All of the three types of S-curves are stored in the company historical records. This will help the management in the decision-making process for managing the similar project in future (Russell et. al, 1997). The different S-curves are used to generate real time control charts. These are described in the next section.

3.5.3.2 Real time control charts

Based on the data in the database and S-curve plots, different variables can be identified as predictors of project outcome during the planning, construction and close out phase of the project (Russell et. al, 1997). If only those portions of S-curves are plotted on a separate graph for each variable where a statistically significant difference exists between the successful and less than successful projects, then the resulting graphs are real time control charts (Russell et. al, 1997). The real time control chart eliminates the unnecessary portion of S-curves (the portion with non significant variation from the planned values) and makes it easier for the project managers to concentrate on a particular project variable. Thus, real time control charts are an enhanced form of S-curves that help the project managers in decision-making and taking corrective action pertaining to the specific project variable. The logic of using real time control charts is shown in Figure 3.8. As shown in the figure, the S-curves for the planning and

construction phase of the project are used to generate the real time control charts during the construction phase. Similarly, the real time control charts are generated before the project close out phase (Russell et. al, 1997). In first case, the charts will predict the progress of the project for the remaining 70% of the project, as planning occupies 30% of the total project Where as, in second case, the charts will

predict the progress of the project during final 20% of the project, as the close out phase spans the final 30% of the project (Clough and Sears, 1998). The data from the both types of charts is stored in the historical records, to be used as guideline for future projects of similar nature.

This section explained the design of project control system. The project control system makes use of the decision support system for the decision-making process (Zapalac et. al, 1994). The components of the decision support system are discussed next.

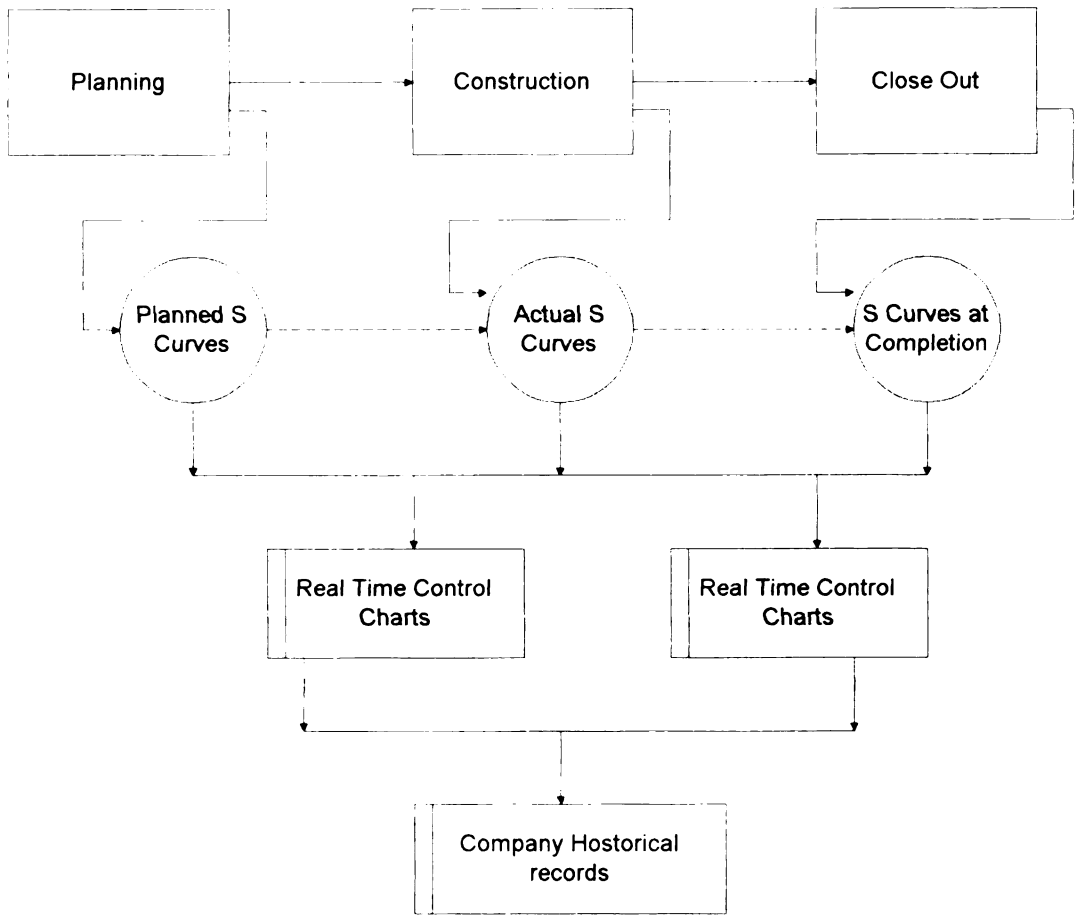


Figure 3. 8: Logic of using Real time Control Charts

3.6 Decision support system

Any decision support system (like a project control system in itself) has three main requirements. The first one is to understand the decision making process. The next is to explicitly define the control functions of project participants and the level of function, and the third requirement is to consider the structure of the decisions (Warszawski, 1985). All these are discussed in the following sections.

3.6.1 Decision making process

The decision making process as defined by Simon (1960) involves three steps. The first is the intelligence phase, where the decision maker recognizes the problem and gathers the data. The next phase is the design phase, which focuses on developing the alternative solutions. Finally, the choice phase is where the user selects the alternative. In each phase, specific information has to be provided by various tools to the decision makers (controller or control group) at each control level (Sanvido and Paulson 1992; Warszawski 1985; Zapalac et. al, 1994). Current project control techniques help the management to recognize the problems, while the information for developing solution is obtained formally and informally. The decision process is aided by information storage, which consists of current information and knowledge base (Sanvido and Paulson 1992; Warszawski 1985). Current information is mainly used for project controls while the knowledge base is used for future planning. The decision and information flow diagram is a good representation of the decision-making process as shown in Figure 3.9.

The various control functions involved in the decision-making process are discussed in the next section.

3.6.2 Control functions and its levels

Usually three levels of planning and control can be defined for a typical large size project (Sanvido and Paulson, 1992). These are as follows:

1) Strategic control: This is a process of deciding on the objectives of the organization, on changes in these objectives, on the resources used to attain these objectives and on the policies and procedures that govern acquisition, use and disposal of these resources (Sanvido and Paulson 1992). The strategic planning involves the company senior management from president to the project manager. The project plan, schedules, and budgets are the components of strategic planning (Clough and Sears 1998; Sanvido and Paulson 1992).

2) Management control: This is a process by which managers assure that resources are obtained and used effectively and efficiently in the accomplishment of organization's objectives (Sanvido and Paulson 1992). The management control involves the site manager or construction superintendent. Typical project control activities, like resource, labor management, time acceleration and cost reduction form the part of management control (Clough and Sears 1998; Russell et. al, 1997; Sanvido and Paulson 1992).

3) Operational control: This is a process of assuring that the specific tasks are carried out effectively and efficiently (Sanvido and Paulson 1992). The operational control involves the general foreman or site supervisor. The

experience and the field observation of these people provide the operational control (Clough and Sears 1998).

The third component of the decision support system, which is structure of decisions, is discussed in the next section.

3.6.3 Structure of decisions

The decisions made during the life cycle of the project may or may not be repetitive. The decisions can be recognized as programmed, un-programmed and semi programmed decisions (Sanvido and Paulson, 1992). Programmed decisions are routine and repetitive and can be modeled. They are dictated by the organizational procedures, policies and strategic planning. The programmed decisions are structured and have a definite input-process and output cycle associated with them. Un-programmed decisions are novel, unstructured and consequential. They are not dictated by any policies or procedures but are usually made by an individual based on his or her experience and informal information and knowledge (Sanvido and Paulson 1992). The semi-programmed decisions lie within the above two types. Usually these decisions are made based on available formal information but also by making use of informal information, experience and judgement. They can be seen as a response to the expected need (Sanvido and Paulson 1992; Zapalac et. al, 1994).

The objective of an information system is to provide both formal as well as informal information for programmed, un-programmed and semi-programmed decisions (Sanvido and Paulson 1992; Whitten and Bentley 1998). The formal information involves facts and figures such as resource rates, material prices, etc. This can be used for programmed and

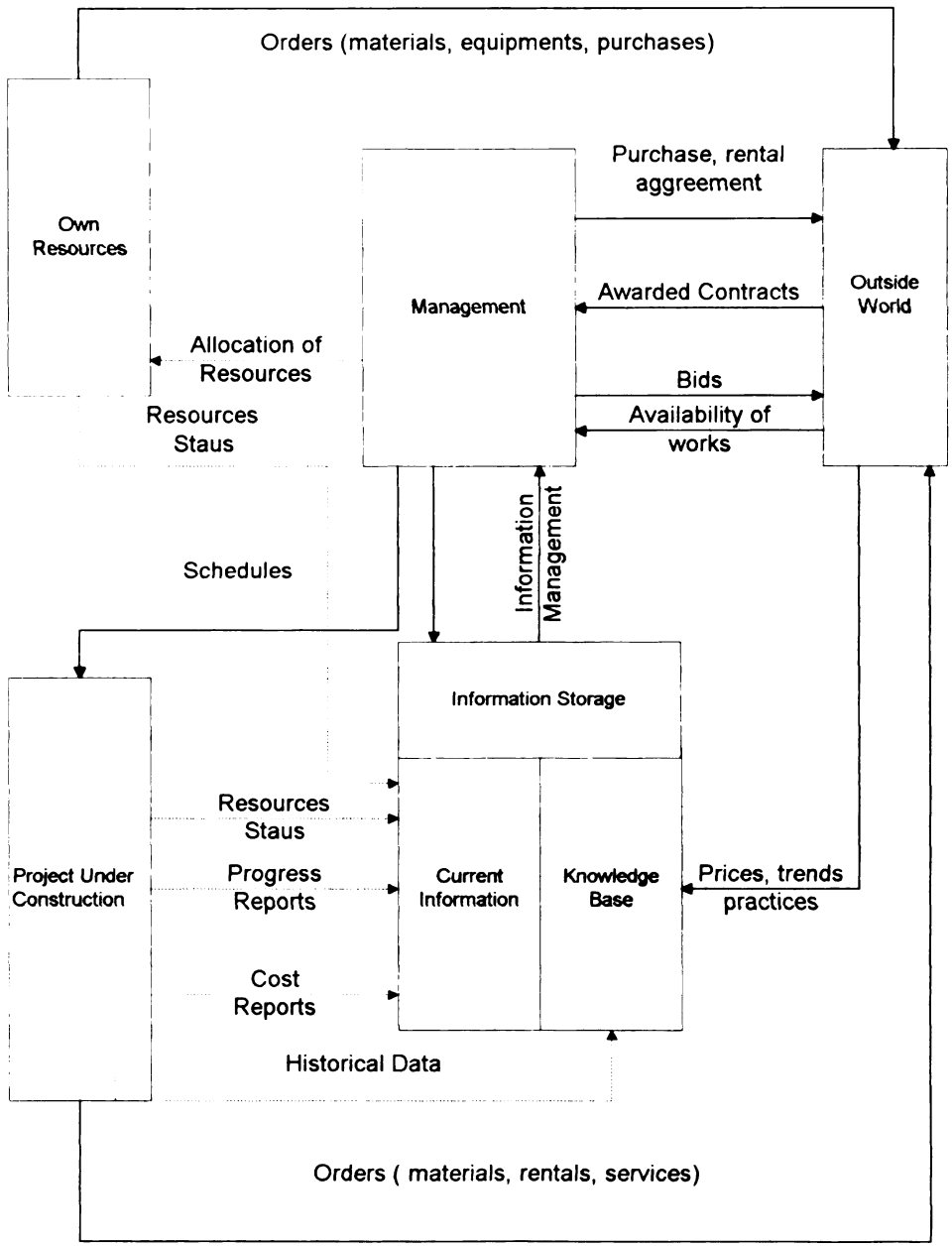


Figure 3.9: Decision and Information flow

semi programmed decisions. The informal information involves the experience and judgment of the personnel and is usually used for un-programmed decisions (Kang and Paulson 1998).

This section described the decision support system. The next building block of this research work is the project control-information system. This is described in the following section.

3.7 Project control-information system

The goal of the project control information system is to provide formal and informal information to be used at various levels of decision-making in the project control cycle. The information system set up involves the following steps (Sanvido and Paulson, 1992):

1. Establishment of decision matrix
2. Development of a project control system
3. Providing a method for developing a solution in the decision making process
4. Monitoring use and effectiveness of the information system and adjusting as required.

These steps are discussed in the following sub sections.

3.7.1 Establish a decision matrix

The decision matrix defines the major decisions to be made at the strategic, management and operational levels on the project, their degree of structure and the responsible party. The first step on any project is to organize the project and allocate the decision-making authority according to rules and policies (Sanvido and Paulson 1992; Clough and Sears

1998; Zapalc et. al, 1994). The matrix developed in Table 3.3, describes the key decisions made by each participant. It represents three levels of control as defined in the previous section. Again, the decisions are divided into programmed, semi-programmed and un-programmed type. The decision makers represent various project participants at each control function level.

3.7.2 Develop a project control system

The primary function of the project control system is to provide "intelligent" information, which is used for project progress monitoring (Russell et. al, 1997; Sanvido and Paulson 1992). The control system is comprised of formal and informal information. The control system sets up a reference standards or monitor board that highlights the deviations from the acceptable performance levels (Clough and Sears 1998; Russell et. al, 1997). The performance variations beyond acceptable limits trigger warning and initiate corrective action at a relevant decision level. The decision maker may consist of one or a group of decision makers (Zapalac et. al, 1994). The project control tools used during the intelligence phase of decision-making, provides data on the three basic elements in the construction system, i.e. input, process and product or output (Sanvido and Paulson 1992; Zapalac et. al, 1994). The data is provided to all three control functional levels as shown in Table 3.4.

3.7.3 Provide a method for developing solution in the decision making process

The design phase of decision-making involves inventing, developing and analyzing the possible courses of action. The major steps involved in the design phase are selecting a

	Senior management to Project Manager	Site Manager / Site in charge /	Site Supervisor / General Foreman
	Strategic decision level	Managerial decision level	Operational decision level
Decision type			
Programmed	Submit payment request Updates schedules and budgets on monthly basis	Hire labor Develop weekly schedules and budgets Develop timesheets	Order materials Inventory materials Accelerate production
Semi-programmed	Develop project plans Estimate project costs Develop schedules	Develop RFIs Prepare change orders Forecast material and labor needs Develop cash flow projections	Estimate work in place quantity Estimate labor and material spent and required Plan and forecast weekly progress
Un-programmed	Replace personnel / contractor Hire new people Develop new policies	Replace sub contractors Manage and maintain inventory, equipments, etc.	Manage accident recovery Manage weather delays Resolve labor strikes

Table 3.3: Decision matrix for project controls (Sanvido and Paulson 1992)

Decision authority	Senior management to Project Manager	Site Manager / Site in charge /	Site Supervisor / General Foreman
Control type	Strategic level	Managerial level	Operational level
Input	Feedback on project budget Milestone performance evaluation	Feedback on construction budget and schedule	Schedule delays Production and delivery times Labor hours spent
Process	Project execution Corrective actions Schedule and budget updating	Means and methods analysis Time acceleration	Method studies Questionnaires Interviews, etc.
Output	Quality assurance Monthly cost and schedule updates	Quality assurance Weekly cost and schedule updates	Timesheets Daily schedule and budget updates

Table 3.4: Data for different control levels (Sanvido and Paulson 1992)

decision making mechanism, collecting information and implementing the decision (Sanvido and Paulson, 1992). These steps are discussed in the following sections.

3.7.3.1 Select a decision making mechanism

Selecting the decision- making mechanism involves allocating the responsibility for a decision to an individual or a group of individuals. Most project decisions are programmed. They are usually allocated to a single decision maker in the hierarchy. However, when the decision made by an individual affects multiple parties, then the decision- making mechanism will be a group (Sanvido and Paulson 1992; Zapalc et; al, 1994, Rezgui et. al, 1998). A control group should make decisions where affected by more than one parties. To be successful, the decision-making mechanism must have the ability, skill, knowledge, and set of values to make the required decisions; and it must be supported by the information relevant to the decision being made (Zapalc et. al, 1994).

3.7.3.2 Collect information

The decision maker needs to assemble the information to identify and determine the nature of the problem. Figure 3.10, is the flow chart showing how to collect and analyze information in different phases (Sanvido and Paulson 1992). In the first phase, the project control system will highlight the problem and its cause and the decision maker can then proceed to solution development and implementation. If the project control system does not identify the cause of problem, the decision maker proceeds to phase two, comprising of problem orientation, data collection and data analysis. If the problem is identified, the development of a solution is next step. If the problem is still not identified, then the user

moves to phase three where further data is collected and analyzed prior to solution development (Sanvido and Paulson 1992).

Once the problem is identified then the decision making mechanism develops solutions. This mechanism may utilize techniques like brainstorming, Pareto analysis, process charts, flow charts etc. (Sanvido and Paulson 1992; Russell et. al, 1997). The decision maker should also identify creative and articulate users who might contribute to the selection or design of new methods or procedures that will solve the problem.

3.7.3.3 Implement a solution

This is the choice phase of decision making that involves evaluating each of the proposed solutions and choosing one of them on the basis of given set of criteria. This is done by an individual or group of people depending up on the decision -making mechanism. Examples of groups are quality circles, steering committees, employee groups, problem solving teams etc (Sanvido and Paulson 1992; Rezgui et. al, 1998, Zapalac et. al, 1994).

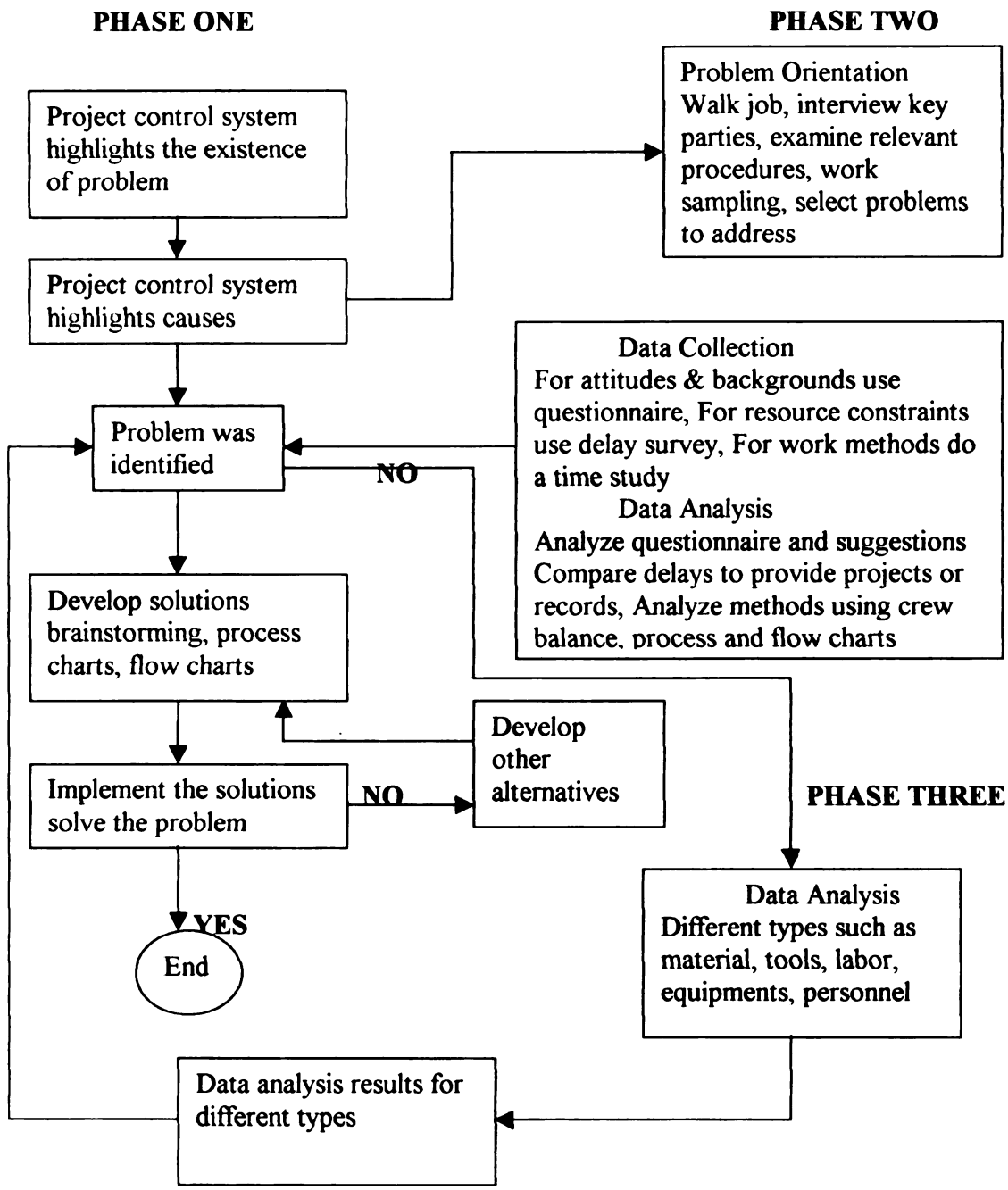


Figure 3.10: Flow chart for information collection and analysis

(source: Sanvido and Paulson, 1992)

3.7.4 Monitor use and effectiveness of the information system

The project organization continually grows and shrinks, thus leading to a change in the decision levels of the people. Also, as the employee's progress from lower to higher level, they use different information, skills and knowledge to make new decisions (Sanvido and Paulson 1992; Whitten and Bentley 1998). Thus the management needs to continually monitor the decision-making levels and the appropriate information system set up to choose the needs of the project.

This section explained the components of the project control information system. The next section will describe the data-warehousing concept that will be also used for this research work.

3.8 Information access or Data warehousing

Information access is defined as the application of data acquisition, data management and data delivery technologies to give the end user direct access to key-business information for reporting and analysis purposes (McCarthy et. al, 1998, Whitten and Bentley 1998). The information access aids in daily decision-making, allows users to monitor and quickly respond to the business needs and facilitates forecasting and planning efforts (Wirth 1999, Whitten and Bentley 1998). There are many reasons as to why the information access technology is booming. Some of them are identified here (Wirth 1999; Orr 1995):

- Emergence of key enabling technologies with excellent user interface.
- The huge volume of corporate data that needs to be stored by the systems, usually at a central location.

- Increasing technical abilities of the end users, managers and executives.
- The need for competitive advantage.
- Proliferation of packaged business applications in the 1990's.

The main component of any information access system is data warehouse. The data warehouse is made up of attributes, architecture, and implementation methodology (Wirth 1999; Rob, Peter and Coronell 1999). These components are described in the following sections.

3.8.1 Data warehouse attributes

The data warehouse is a collection of data, which supports corporate reporting and decision-making. The data is subject-oriented, integrated, non-volatile and is time variant (Wirth 1999).

3.8.2 Data warehouse architecture

A typical data warehouse architecture schema is shown in Figure 3.11. The architecture has the following components:

- Operational data store: This contains an updateable set of integrated data that can be sued for organization wide tactical decision-making (Wirth 1999).
- Data warehouse: This contains snapshots of data extracted from the operational sources that are integrated, cleansed and loaded in readily accessible format for strategic decision support. This also includes any design schema, fact and dimension tables, data aggregation to meet end user's requirements, and historical

repository designed to provide short and long term business planning and decision making (Wirth 1999).

- Data delivery (query and reporting) tools: There are multiple interfaces available for the end users who need access to corporate information for decision-making purposes. The common interfaces are standard reporting, Ad hoc query, DSS tools, data mining tools and report distribution tools (Wirth 1999).

3.8.3 Data warehouse implementation methodology

The implementation methodology cycle is shown in Figure 3.12. It is clear that the implementation is an iterative process that starts with the need identification phase and finishes at the user training. The end user tool configuration and testing is the core of the implementation (Wirth 1999; Whitten and Bentley 1998). The phases are discussed in brief in the following sections.

Needs identification and requirements gathering (Wirth 1999; Whitten and Bentley 1998): The top priority is to gather the requirements that support the business goals of the enterprise. This involves data acquisition, data definitions and data structure design. The main considerations are subject areas, different reports, and uniform data definitions.

Data modeling and prototyping (Wirth 1999; Whitten and Bentley 1998): Modeling the underlying business processes and identifying the data repositories is a necessary step before developing a data warehouse. Also, prototyping helps building the consensus. It helps in staying focused on meeting the business goals and identifying areas that may need to be investigated and restructured prior to going into the production.

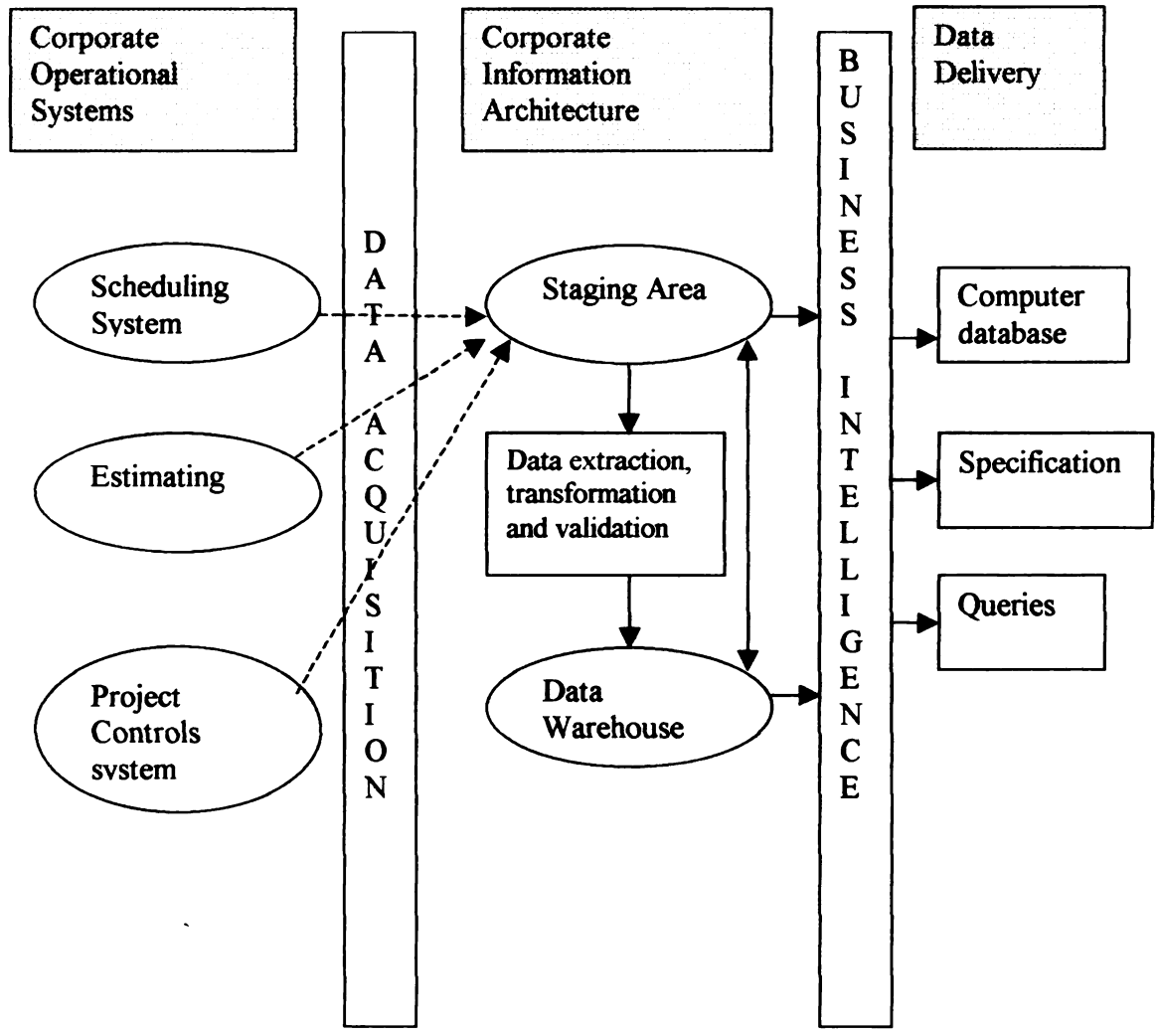


Figure 3.11: Data Warehouse Architecture (Wirth 1999)

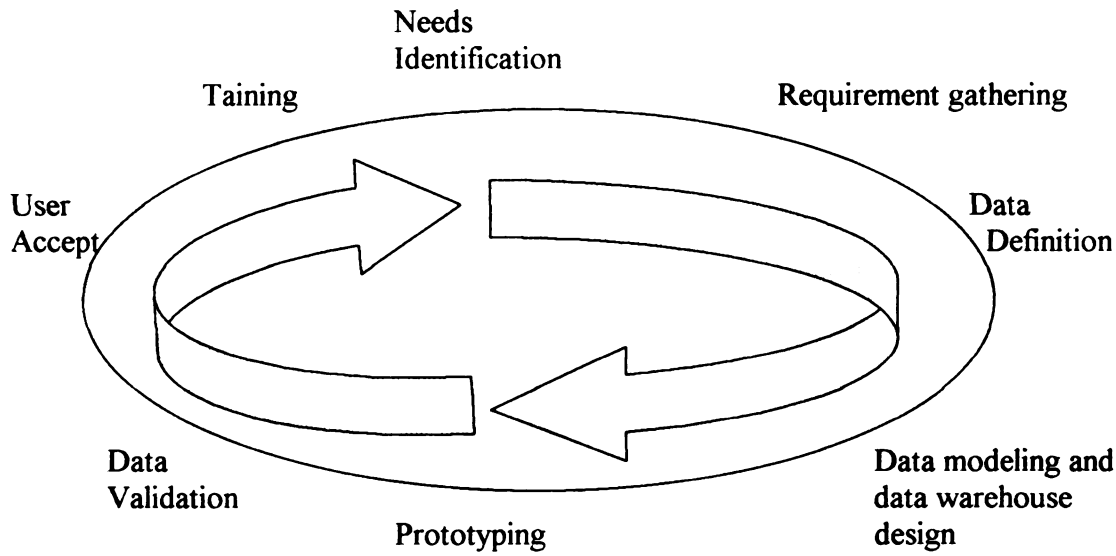


Figure 3.12: Implementation Methodology Cycle (source: Wirth 1999)

User acceptance (Wirth 1999; Whitten and Bentley 1998): The data warehouse is not complete with the user acceptance because as the style of business changes, the business goals change and thus user requirements change necessitating the modification of the data warehouse.

Benefits of a data warehouse: There are many value-added benefits of a data warehouse (Wirth 1999; Whitten and Bentley 1998) such as:

- Protecting operational system performance
- Integrating operational data from multiple sources.
- Forcing a common and consistent definition of business data elements
- Empowering end users, thus reducing dependencies on IS department.
- Turning corporate data into information, knowledge and competitive advantage.

3.9 Summary

This chapter developed the concepts that will be used for developing the research methodology. The concepts developed were based on the literature review and the knowledge and the experience of the researcher in the construction industry. The following concepts will be developed and used in detail for developing the integrated system model between scheduling and project controls: 1) REA modeling concepts as applied to construction management environment, 2) scheduling and project controls processes, 3) a decision support system, 4) a project control system, and 5) a data warehouse.

The above concepts will be developed in detail to achieve the two main goals of this research work. The first is to develop an integrated REA model for scheduling and

project controls, and to develop the framework for computer implementation of the REA model. The second goal is to develop the information system that will make use of the data from the REA model for project control purposes. These are developed in the next chapter.

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INTEGRATED SYSTEM FOR PROJECT PLANNING AND PROJECT CONTROLS USING REA MODELING TECHNIQUE

VOLUME II

By

Yogesh Prabhakar Joshi

A THESIS

Submitted to
Michigan State University
In partial fulfillment of the requirements
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MASTER OF SCIENCE

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Chapter 4: Integrated REA model for project planning and project controls

The concepts presented in chapter 3 are used in this chapter to develop the main research output. The research work consists of two main goals; the first goal is to develop an integrated Resource-Event-Agent (REA) model for scheduling and project controls, and to develop a framework for computer implementation of the REA model. The second goal is to develop an information system that will make use of the data in the REA models. The proposed information system can be used by the CM Company to manage the construction projects. The integrated system architecture proposed in this research work includes the integrated REA model for scheduling and project controls and the information system, which makes use of this integrated model. The REA models are based on the various project processes that occur during the planning, construction and controls phase of the project. The output of these models is the identification of data elements for scheduling and project controls processes. These data elements are stored in the database system, which is designed based on the REA models. The database system supports the information system. The goal of the information system is to provide the real time data for decision-making during the project controls phase. This chapter explains the proposed integrated system architecture and its design components.

4.1 Integrated System Architecture and its Design

The integrated system is essentially a dynamic information system that integrates all the products, processes, entities, information and data at a single or central location (Miyatake and Kangari 1993; Rezgui et. al, 1998). The core of the integrated system is the intelligent database, which has mainly two types of knowledge bases, past or historical and the present or the actual knowledge. The proposed integrated system can be divided into two major integration architectures. The first one is the organizational integration, and the second is the technical integration (Fischer and Kunz 1995). The organizational integration involves discussion between the CM Firm and the owner, engineer, and the architect, during the planning stage. The technical integration links the software applications that support the various project participants (Fischer and Kunz 1995; Miyatake and Kangari 1993; Rao et. al, 1997).

The proposed integrated system architecture is shown in Figure 4.1. The integrated system architecture includes the REA models for project planning, and controls phase. For this research work, the project execution phase is divided into the construction and controls phase. The construction involves implementing the plans in the field, while the controls involve monitoring and managing the construction activities so as to achieve the goals set during the planning phase (Clough and Sears 1998). The REA models are developed for the scheduling process during the project-planning phase, and for the project controls process. The data from these models is stored into the database system, which is the core of the data warehouse.

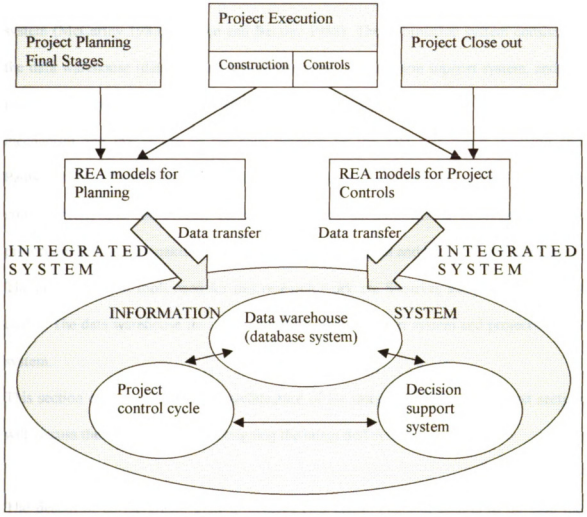


Figure 4.1: Integrated system architecture

The data transfer mechanism will transfer this data from the database into the information system (McCarthy 1982; Whitten and Bentley 1988). The information system consists of the data warehouse (database and knowledge base), the decision support system, and the project control system. The decision support system involves a decision-making mechanism and makes use of the data supplied by the data warehouse (Sanvido and Paulson 1992; Zapalac et. al, 1994). The project controls system consists of project control cycle, and the project control tools. The decision-making process under the project control system makes use of decision support system and the project control tools. The project control tools used for this research work are S-curves and real time control charts. The data warehouse thus supports the decision support system and project control system.

This section explained the overall architecture of the integrated system. The next section will discuss the steps involved in designing the integrated system.

The design of an integrated system involves two goals. The first goal is to develop the REA model and the implementation framework for the REA model. The second goal is to develop an information system.

This first goal is accomplished through following steps (David 1998; McCarthy 1982):

1. Describe the organizational setup and mode of operation of a CM firm (section 4.2.1).
2. Develop a value chain for the organization based on its set up and mode of operation (section 4.2.2).

3. Develop an enterprise-wide model of the data called global view or conceptual schema (section 4.2.3).
4. Develop REA data models and the generalized REA framework for the implementation (section 4.2.4).
5. Design the implementation tool, such as a database system, based on the framework developed in the previous step. The implementation design involves logical design and physical design (section 4.3.5).

The second goal is accomplished through the following steps:

1. Develop a data warehouse (section 4.3.1)
2. Develop a decision support system that makes use of the data warehouse (section 4.3.2)
3. Develop a project controls system that makes use of the decision support system and also the data warehouse (section 4.3.3)

4.2 First goal: REA model and its implementation framework

The output of the first goal is REA models for planning and project controls, the generalized REA framework for implementation of REA models, and the database system, designed to implement the REA models. The design of the database system is based on the generalized framework.

4.2.1 Organizational setup and mode of operation of a CM firm

The organization chart for the example CM Company is shown in Figure 4.2. The various participants and their levels define the organization hierarchy structure. Each level has the responsibility and functions associated with it, as discussed in chapter 3.

Let us assume that the owner decides to build a facility and hires an architect and an engineering firm to design the facility. The owner also hires the CM firm to manage the project, for a fixed price agreed on in the contract and for a certain duration of time. The construction contract is awarded to a general contractor (GC) to construct the project. The GC then hires subcontractors to perform a certain portion of the work in the project, for some fixed price and agreed period of time (Clough and Sears 1998). The architect and the engineer supply all the necessary drawings and specifications. The specifications provided by the architect describe the material, installation, and execution requirements to build the structure. These specifications are usually categorized under 16 different CSI divisions. During the planning process, the CM, owner, architect and engineer coordinate to devise a definite schedule, budget, and plan of action for completing the project (Fischer and Yin 1992; Froese 1992). The GC develops his/her own schedules and budgets to construct the project. The CM develops it's own schedules and budgets, to manage the project. The scheduler, in the CM Company gets schedules from the GC and the sub-contractors. He also communicates with the owner, architect, and engineer to develop a final working schedule of the project. Usually, different types of schedules are developed that are used by various project participants (Clough and Sears 1998; Fischer and Aalami 1996; Rezgui et. al, 1998). The schedule participant matrix is shown in Table 4.1. The details involved in each type of schedule are shown in this table.

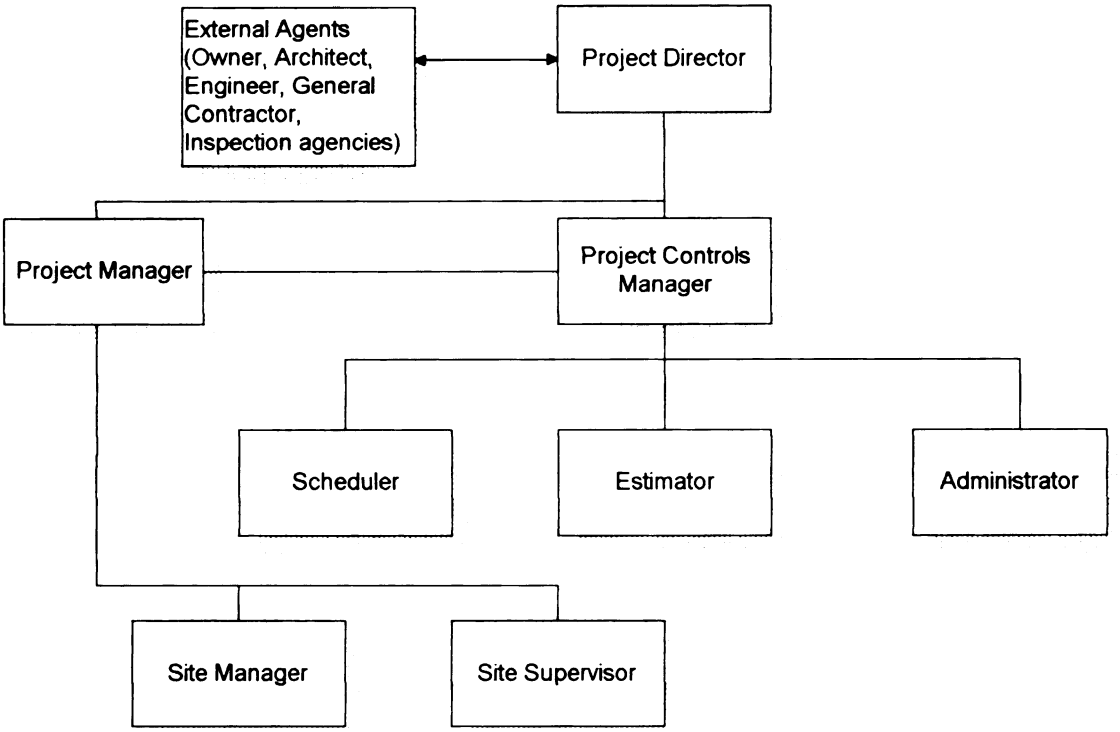


Figure 4.2: Organization Chart for a Construction Management (CM) firm (Clough and Sears 1998)

On the other hand the estimator, in the CM Company, with the help of the accounting manager, develops the project budgets, which include cost budget and fund budget. The budgets developed by the GC are also used in this process. The cost budget shows how money will be spent for completing different work items in the project (direct cost for the project); the money required to run the project (indirect cost) and the total money spent (total cost) (Zapalac et. al, 1994). On the other hand, the funding budgets show how money will be acquired and profit will be made during the construction. The components of cost and fund budgets are included in Table 4.2. Finally, the project manager (PM) and the project director (PD), review the schedules and budgets and make any changes or modifications to generate the final budgets and schedules (Clough and Sears 1998; Fischer and Aalami 1996). Depending on these schedules and budgets; all activities are planned, such as material acquisition, labor allocation, equipment use, submittals, inspections, etc. Also, control formats are developed to track the usage of all resources.

During the actual construction process, the labor, equipment, and materials are utilized as already planned and scheduled. Each activity/work item performed is tracked by labor hours spent, quantity of material used, and equipment hours used. The labor hours are tracked using time sheets; the material quantities are tracked using material cards; and equipment use is tracked using time cards or equipment sheets (Clough and Sears 1998; Russell et. al, 1997). The amount of work performed is also measured by the CM'S site supervisor, and entered periodically in the control formats that are developed during the final stages of planning. The percent work complete is used to generate pay requests on a periodic basis by the GC, subcontractors, and approved by the CM.

	Project Participant		
	Senior management to Project Manager	Site Manager / Site in charge /	Site Supervisor / General Foreman
Schedule control type	Strategic Schedule	Managerial Schedule	Operational Schedule
Schedule type			
Overall schedule	Overall project duration, critical path, milestone dates, key dates, major completion dates, dollars spent, method to be used, procurement and delivery dates etc.		
Key date schedule	Key dates like "start" and "finish" for critical activities, planned manhours, qty. of work in place, payment dates, ispection, testing and submittal dates, etc.	Key dates like "start" and "finish" for critical activities, planned manhours, qty. of work in place, payment dates, ispection, testing and submittal dates, etc	
Milestone schedule		Completion dates for major activities, budgeted qty of work, man hours, constraints for milestones, payment dates, calender dates for admin. activities, etc.	
Major phase schedule		Start and finish dates for major phases such as foundation, external walls, steel structure, framework, enclosures, finishes, roofing, UG Utilities, HVAC, etc.	Start and finish dates for major phases such as foundation, external walls, steel structure, framework, enclosures, finishes, roofing, UG Utilities, HVAC, etc.
Critical activity schedule		Start and finish dates, budgeted qty. of work in-place, budgeted man hours, dollars billed and spent, etc.	Start and finish dates, budgeted qty. of work in-place, budgeted man hours, dollars billed and spent, etc.
Detailed activity schedule			Day to day activity start and finish times, floats, man hours, lags, fabrication time, etc.

Table 4.1: Schedule Participant Matrix (Clough and Sears 1998; Sanvido and Paulson 1992)

	Direct costs related to activities	Time / Processes
Cost budgets	Labor costs Material costs Equipment costs Administrative costs	Labor hours spent Quantity of material used Equipment hours used Administrative work done
Fund budgets	Pay requests Payment approvals Payment received Percentage retainage Funds acquired	Labor, material and equipment use hours Measurement of work in place Approval of work in place Job costing Work completion

Table 4.2: Cost and fund budget components (Clough and Sears 1998; Russell et. al, 1997)

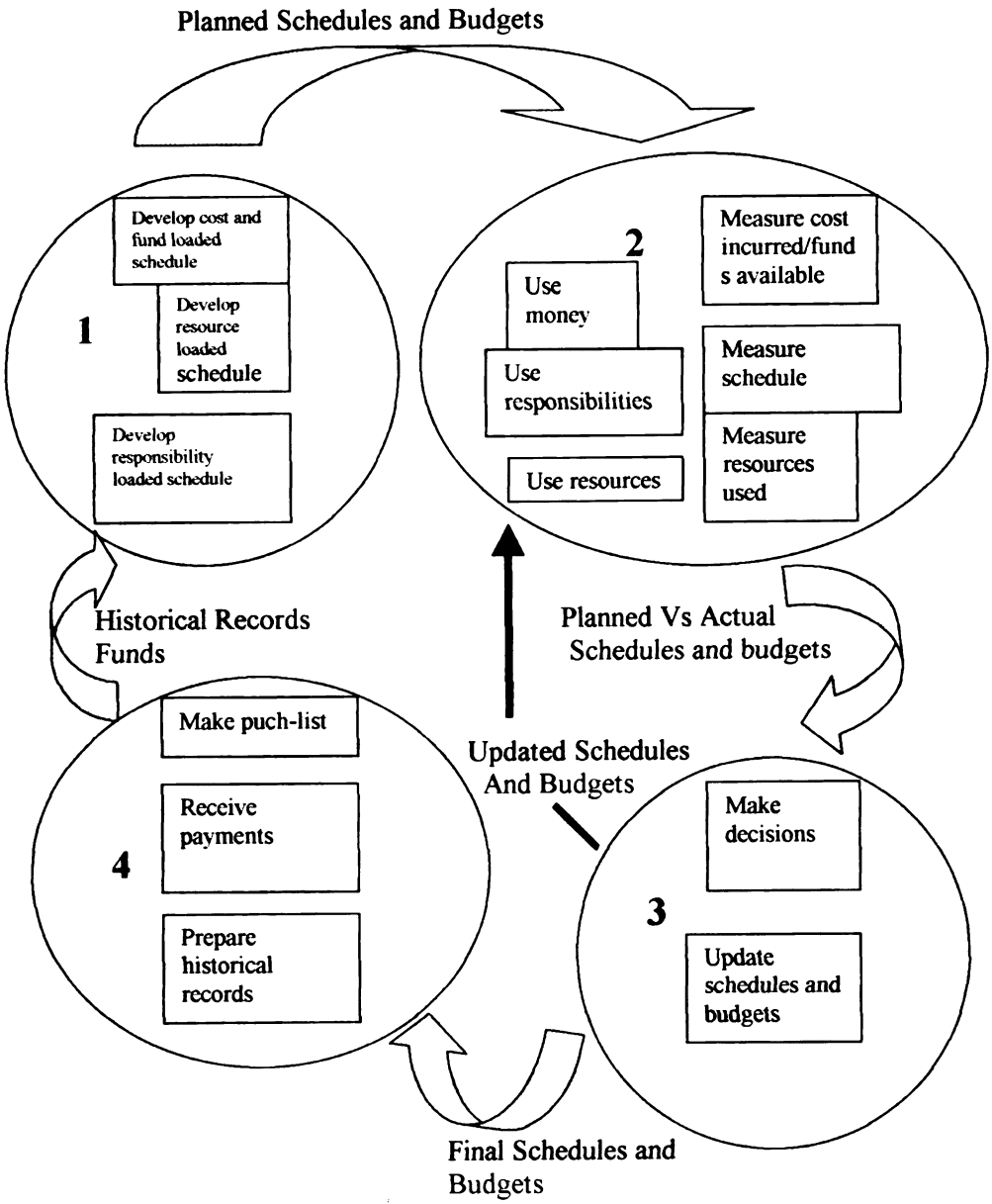
The owner will usually pay most of the pay request and retain certain money as percentage retainage, as agreed in the contract (Clough and Sears 1998). The start and end of any activity is monitored and compared to the planned start and completion in the schedules. If the activity is behind schedule because of the low labor output, then the GC might be asked to either increase the crew or use overtime with the same crew as the first measure. Usually, the method of work or construction technique is not changed unless found necessary (Clough and Sears 1998; Russell et. al, 1997). Depending on the measured progress and the records obtained from the supervisor, the various reports, such as S- curves, are generated for project control purposes. If the actual S-curve values lie within the acceptable limits, then no management action is required. If the values are below the acceptable limits, then it needs management action (Clough and Sears 1998; Russell et. al, 1997). Several S-curves are used by project managers for decision-making (Russell et. al, 1997; Zapalac et. al, 1994). The S-curves are discussed in more detailed in sections 4.4.3.3.1. The decision-making process involves discussion between the project manager, general contractor, owner, and the architect. The schedules and budgets are then updated depending upon the new plan of action and the updated schedules and budgets now serve as the boundary limits for the project. The change orders issued by the owner / architect / engineer are managed by the CM (Russell et. al, 1997; Anderson 1997). The changes are made in the schedules and budget to reflect the change orders. The project is considered to be complete, only after the owner is ready to move in or the facility is ready for use. The final payment to the CM and the GC is made by the owner, according to the conditions already set and agreed upon in the contract.

This section completes the first step in developing the REA models and it's implementation framework. The second step, which involves developing the value chain for the organization, will be discussed in the following section.

4.2.2 Value chain for the organization

The value chain for the CM organization is developed in this section. According to Callon (1996), "The value chain for any organization is a systematic method for examining all the activities a firm provides and how they interact." In actual practice, this definition can be viewed as a series of input-output processes with a resource flow between them, the ultimate objectives of the processes being "customer value." In the case of a CM firm as described above, the ultimate objective is to complete the project successfully within the agreed time and budget, thus providing the customer value on one hand, while generating value for the organization, on the other hand (David 1998; Fischer and Aalami 1996; Greets and McCarthy 1998).

As shown in Figure 4.3, the value chain, for the example CM has four main project phases at the top level. These are planning, execution, and close out. The project execution phase is further divided into construction and controls phase for this research work. The researcher believes that the construction and controls are interdependent processes as construction involves implementing the plans in the field, while control involves monitoring and managing the construction activities to make sure that the progress is as per planned (Clough and Sears 1998). In Figure 4.3, the top-level processes under each phase are shown in the rectangular boxes. The processes under construction and controls phases are different from a managerial perspective.



Legend:

1: Project Planning phase **2: Construction phase**
3: Project Controls phase **4: Project Closeout phase**

Figure 4.3: Value chain for the CM Company

The construction processes add value to the organization as they occur. This is because they consume money, resources, and employee services and help to complete the project whereas, the project control processes are more of a managerial type, which ensure that the commitments made during the planning phase are fulfilled through the construction phase (Russell et. al, 1997; Kang and Paulson 1998). These processes do not add value at the instance when they occur, but they will eventually add value to the business after the commitment is fulfilled. The construction processes consume resources, while the control processes monitor and manage the consumed resources and set new limits to consume the resources as the project progresses (Clough and Sears 1998; Russell et. al, 1997). The project controls processes are the focus of this research work and therefore it is convenient to divide the entire project execution phase into construction and controls.

In Figure 4.3, the value added to the business from one project phase to another is represented by using block arrows. Thus planned schedules and budgets, actual and planned schedules and budgets, updated schedules and budgets, and final schedules and budgets are the value added inputs and outputs from one phase to the next phase. The actual attributes of these inputs and outputs are shown in Figure 4.5

Once the top level processes in the value chain are identified, they are further subdivided to form what is called "process tree diagrams" (Geerts and McCarthy 1998). In the process tree diagram, as shown in Figure 4.4 (P1), the process "develop schedule" is decomposed into two "leaf" nodes on either side of a middle process, which is at the root level. The two leaves are "develop activity" and "develop logic." These leaves can be again subdivided further. However, the researcher here recognizes the very important recommendation by Hollander et al. (1995), which states "conceptual models are

decomposed from the enterprise level value chain down until they reach the point at which decision-makers need information to plan, evaluate, and control the economic events." The leaf level processes shown in Figure 4.4 (P1) are the ones that can be planned, evaluated, and controlled. All these processes are "business events" as typically identified in REA modeling language. The "economic events" are the root level, or top leaf level processes. The economic and business events are discussed in section 4.2.3.1.2. The "leaves" from tree diagram 4.4 (P1) are merged together to produce different combinations of integrated processes as shown in Figure 4.4 (P2) to 4.4 (P4). Finally all the integrated processes developed in Figures 4.4 (P2) to 4.4 (P4), are integrated in a single integrated view as shown in Figure 4.4 (P5). Notice that the tree in Figure 4.4 (P5) has all leaves from different trees in Figures 4.4 (P2) to 4.4 (P4).

The same concept is applied to develop process tree diagrams and an integrated process view for project construction and controls phase. This research work excludes all the processes under project close out, as the main focus of this research work is project controls. Also in practice, the controls phase will end at the beginning of the close out phase (Russell et. al, 1997). The various process tree diagrams and integrated process views are shown in Figure 4.4 (P6) to 4.4 (P10). All of these diagrams are developed on the same concept as explained above, and the integrated process view consists of leaves from different process trees.

The ultimate output of each project phase in the value chain is the identification of data elements and the resource flow associated with each process (David 1998). This is shown in Figure 4.5. Note that all the data elements shown in this figure will become attributes of events and entities in the REA model (David 1998; McCarthy 1982), which is

developed in the subsequent sections. These entities become tables in the proposed database system used to implement the REA model, and are transferred during the data transfer process, as shown by the arrow in the integrated system architecture (Figure 4.1). The term "global view," shown in this figure, is explained in section 4.2.3.3.

This section completes the second step in achieving the first goal. The next section will describe the third step, which is developing an enterprise-wide model, called global view.

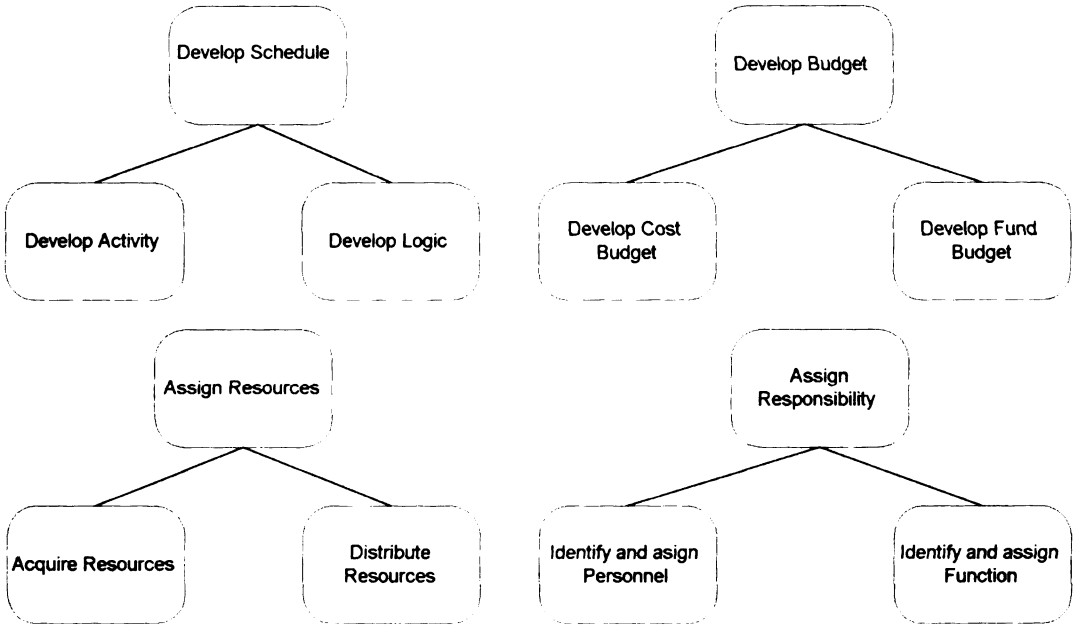


Figure 4.4 (P1): Process Tree Diagram for major project planning activities

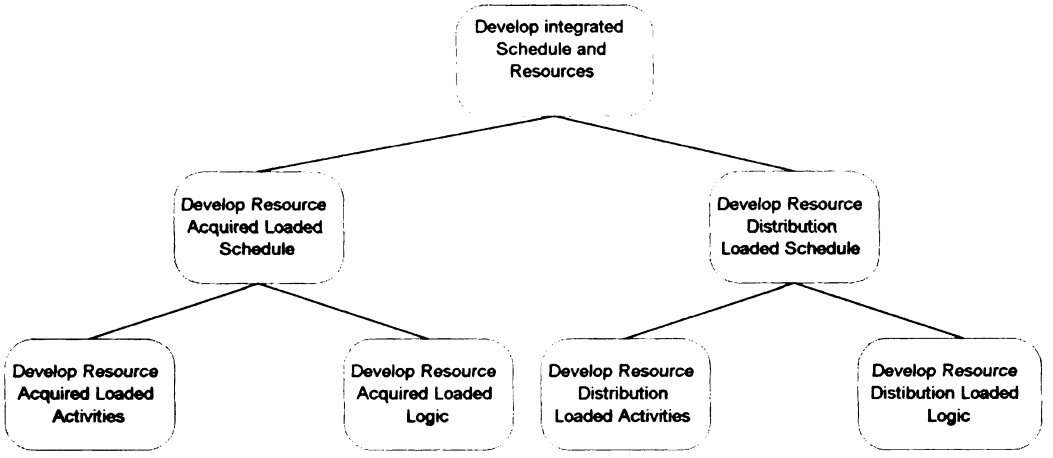


Figure 4.4 (P2): Integrated process view for developing integrated schedule and resources

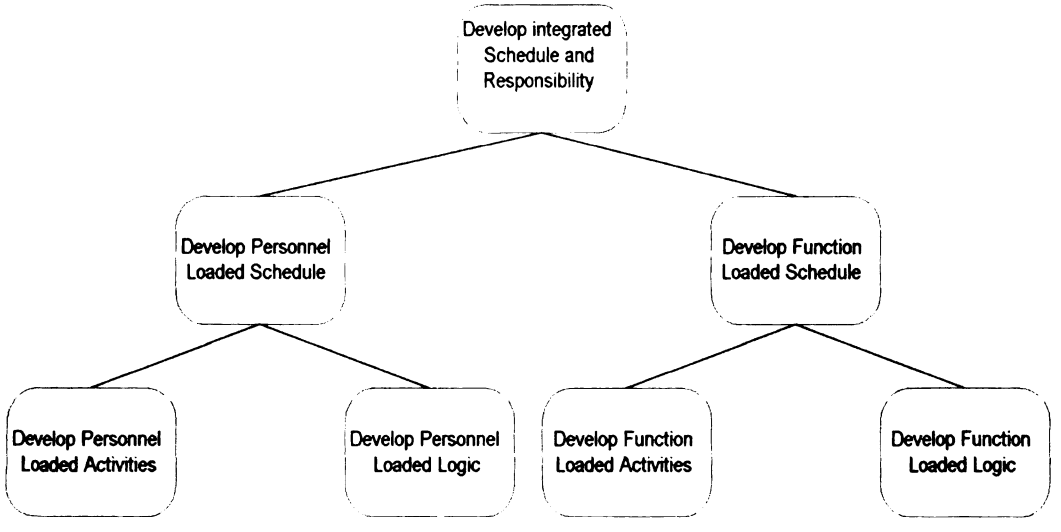


Figure 4.4 (P3): Integrated process view for developing integrated schedule and responsibility

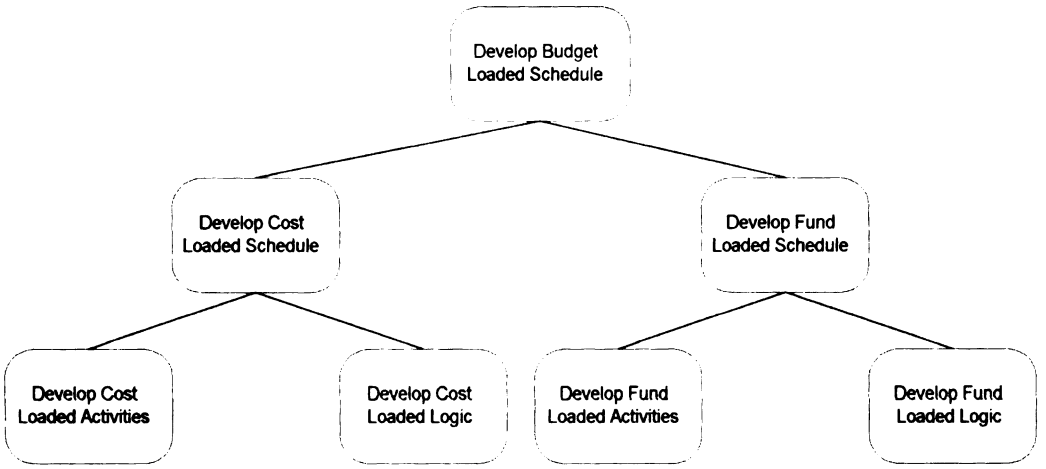


Figure 4.4 (P4): Integrated process view for developing budget loaded schedule

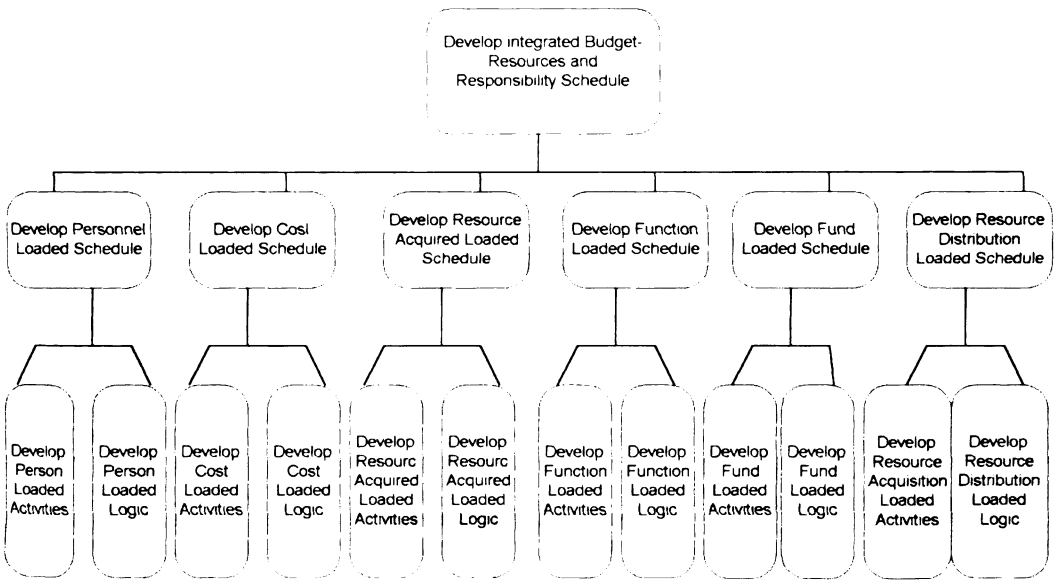


Figure 4.4 (P5): Integrated process view for developing integrated budget, resource and responsibility schedule

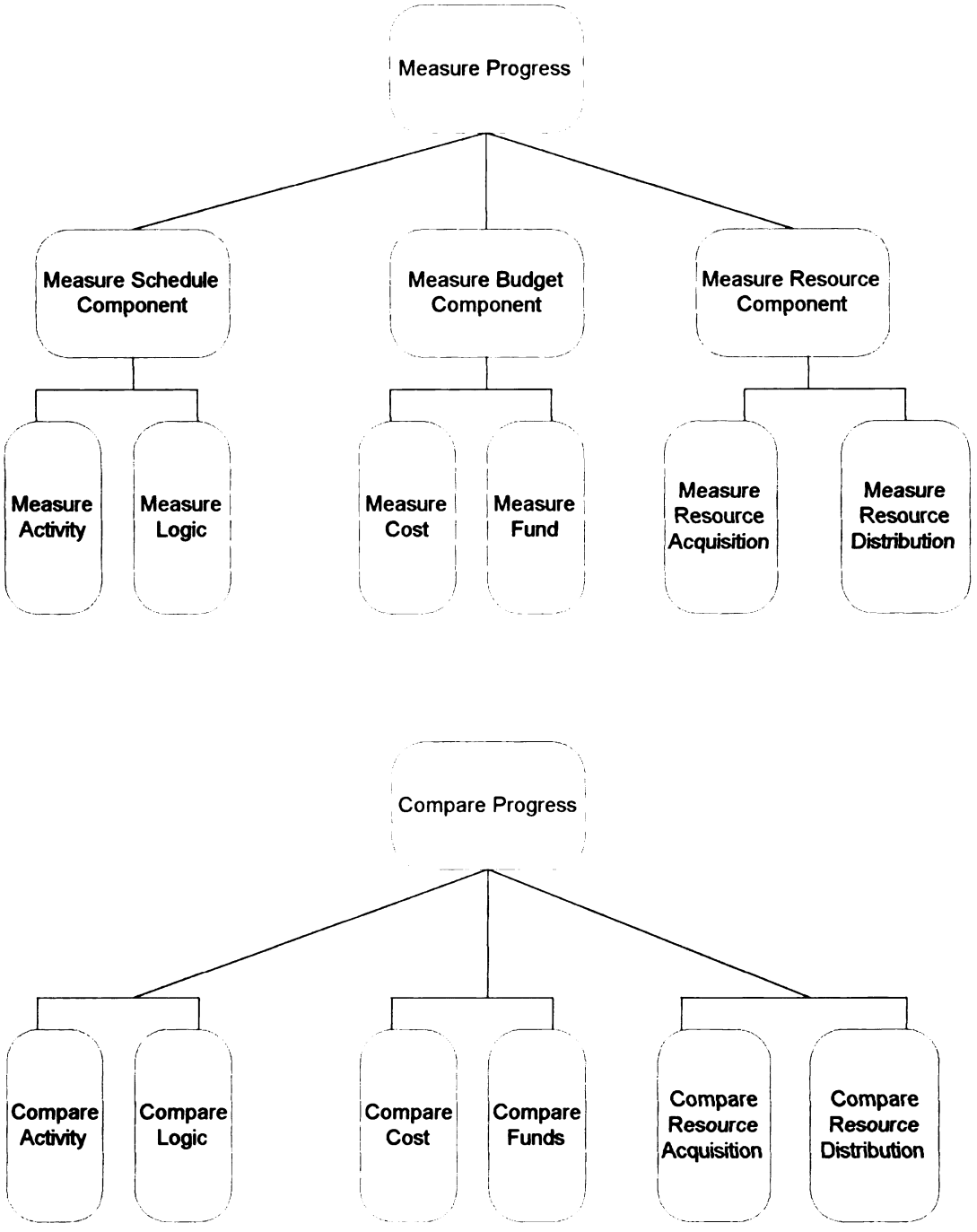


Figure 4.4 (P6): Process Tree diagram for measure project construction processes

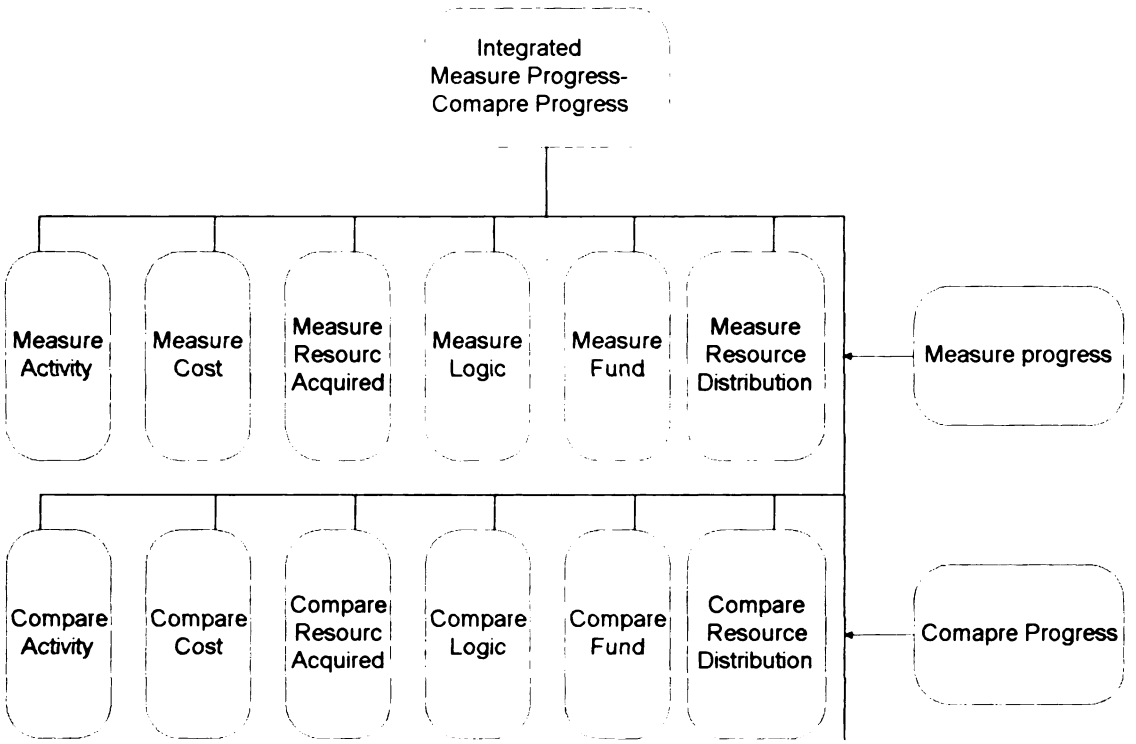


Figure 4.4 (P7): Integrated process view for measure progress and compare progress

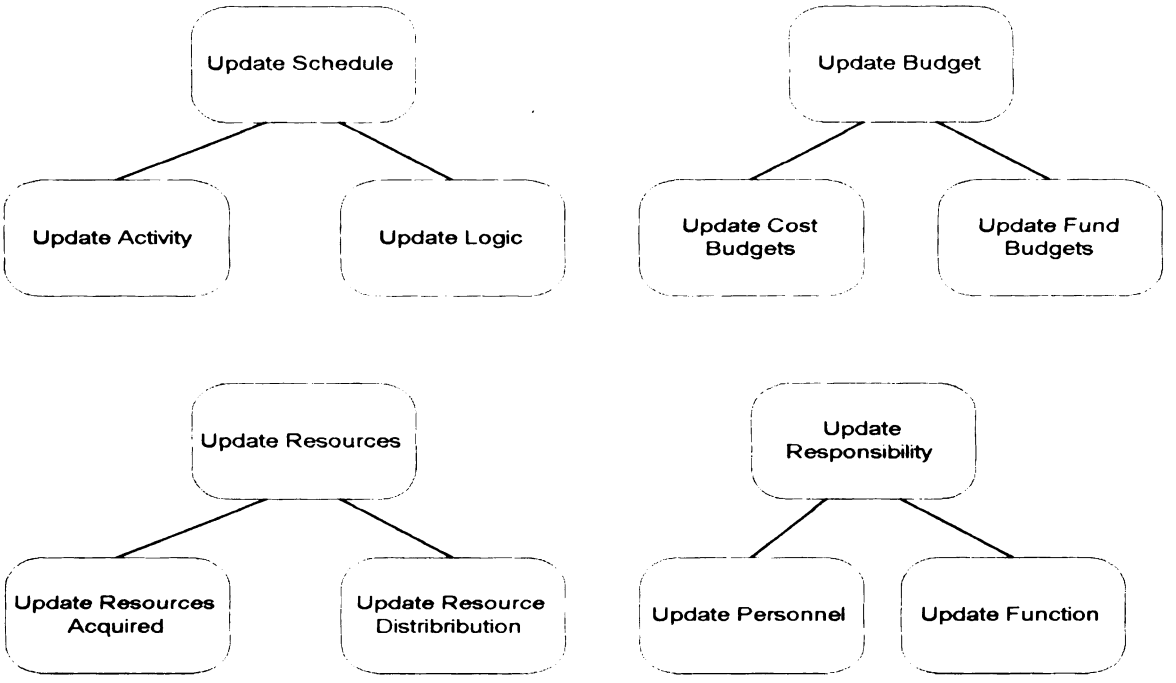


Figure 4.4 (P8): Process Tree Diagram for major project control processes

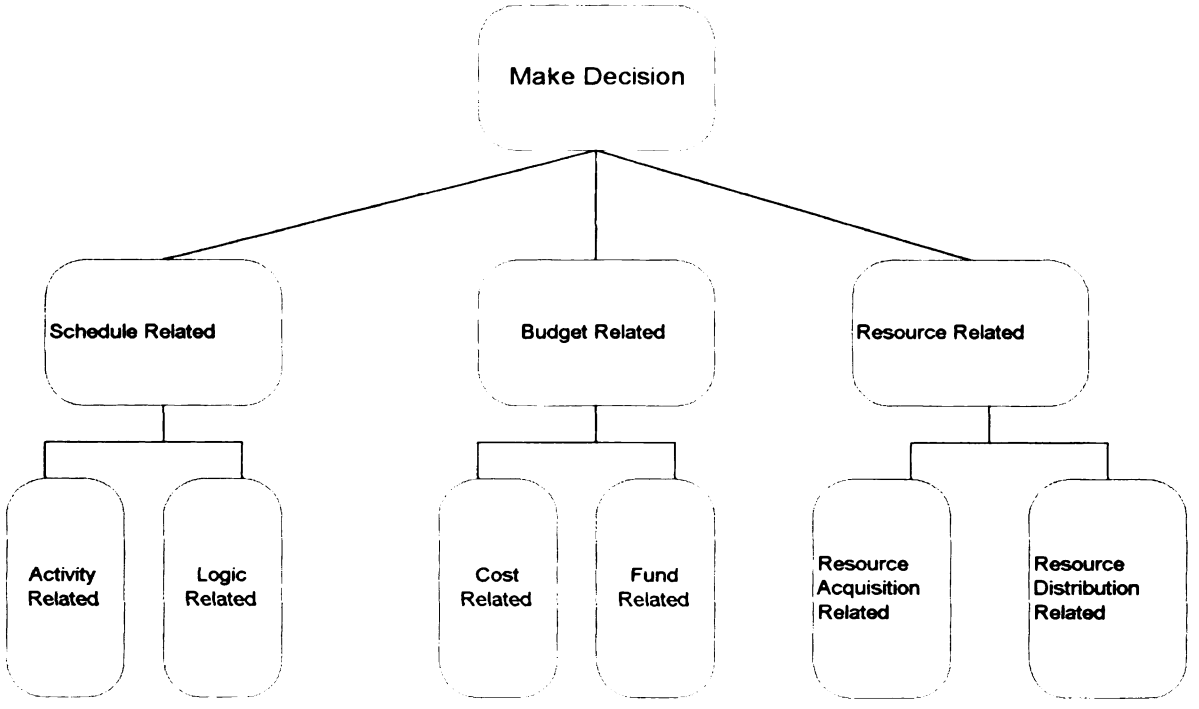


Figure 4.4 (P9): Process tree diagram for major project control processes

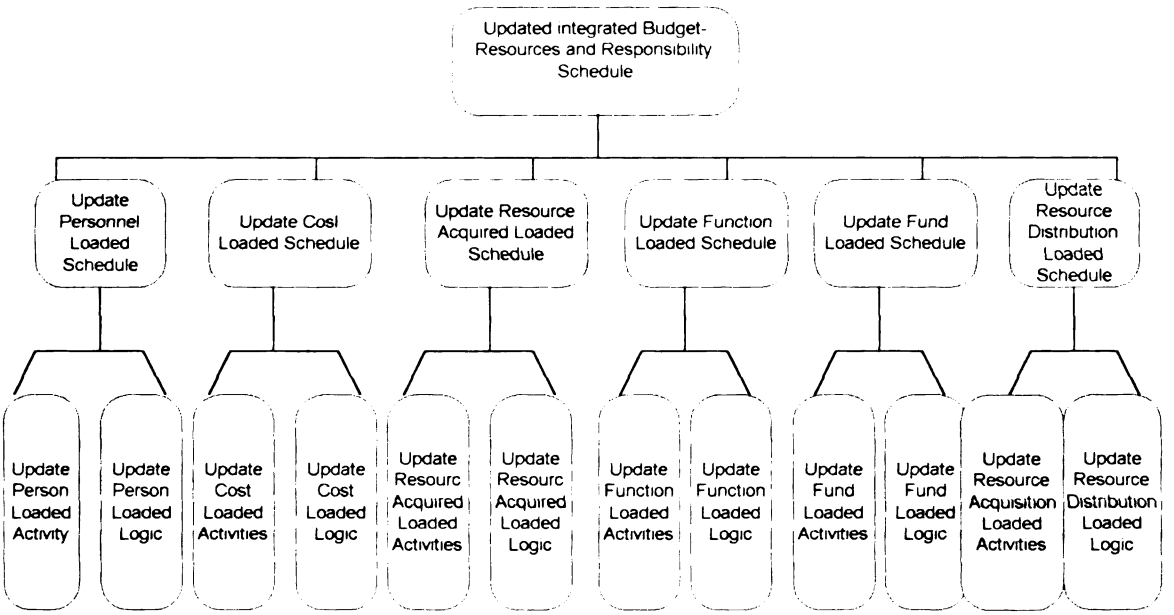


Figure 4.4 (P10): Integrated process view for updating integrated budget, resource and responsibility schedule

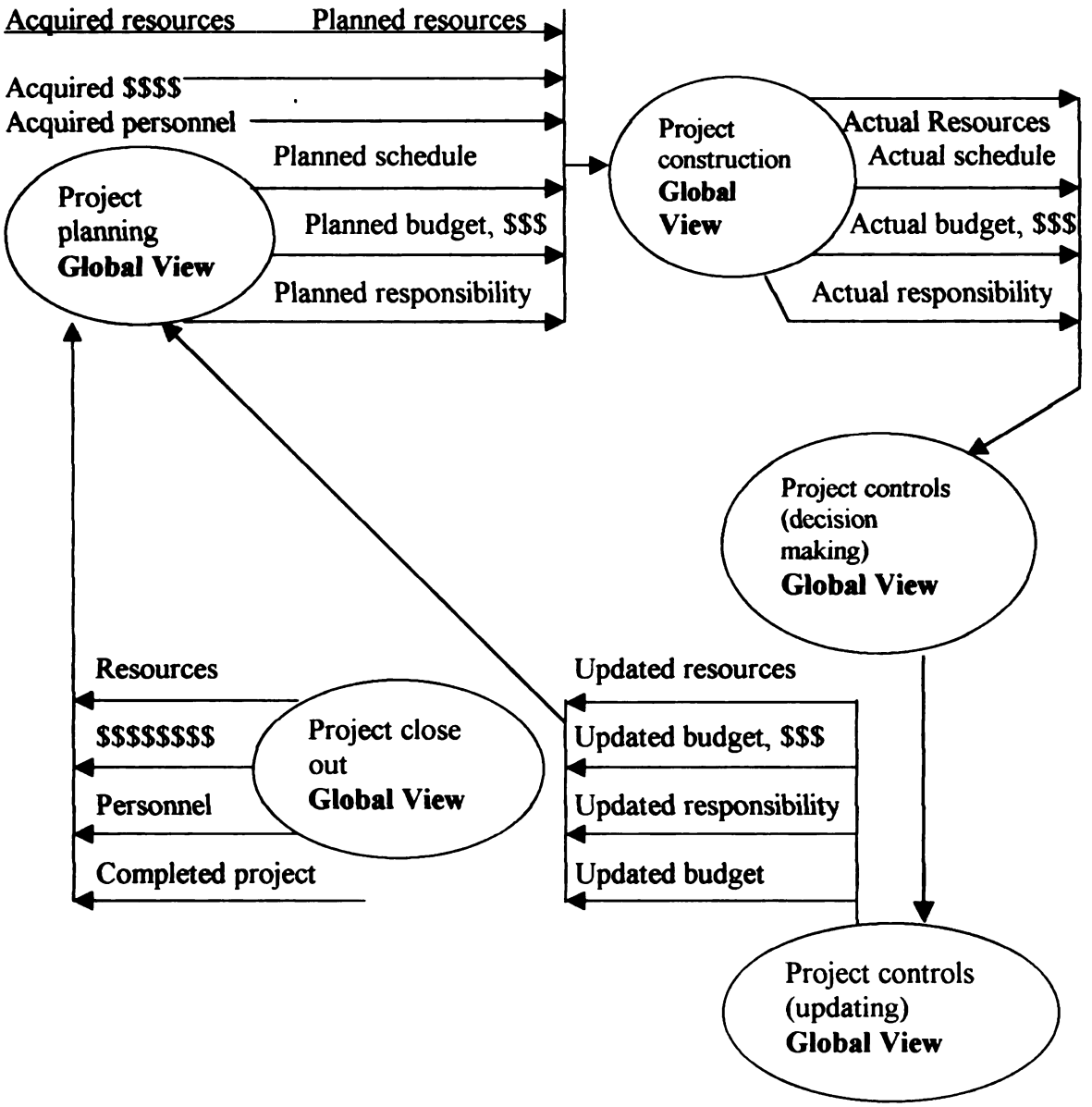


Figure 4.5: Data flow across different project phases

4.2.3 Enterprise–wide model or global view

The enterprise-wide model, called global view, is developed from the individual REA models using view modeling and view integration techniques (McCarthy 1982), which are discussed in sub-sections, 4.2.3.2 to 4.2.3.3. First, REA models for various top-level processes in the value chain are developed using view modeling. These individual REA models are called "local views." These models are then integrated using the view integration technique and the integrated REA model is called "global view" (McCarthy 1982).

4.2.3.1 REA model template

A typical REA model template for business process is shown in Figure 4.6 (David 1998; McCarthy 1982). The model has two halves - "give and take." If the top half represents a "give" or "decrement" event, then the bottom half represents "take" or "increment" event. The two events are called duality events. Both the halves are represented in exactly the same fashion, and only differentiated by their functionality aspect. For example, in the case of the sale of an inventory, the "give" event is SALE, which gives away the resource, i.e. inventory. Whereas, the "take" event is CASH RECEIPT, which increases the resource such as cash. Starting from the left side, the resources are shown in the rectangle. The events are shown using the rectangle in the center. The agents are of two types, internal and external agent, shown using rectangular boxes on the right side. The relationship between resource and event, and event and agent is shown using diamond shapes (David 1998; McCarthy 1982).

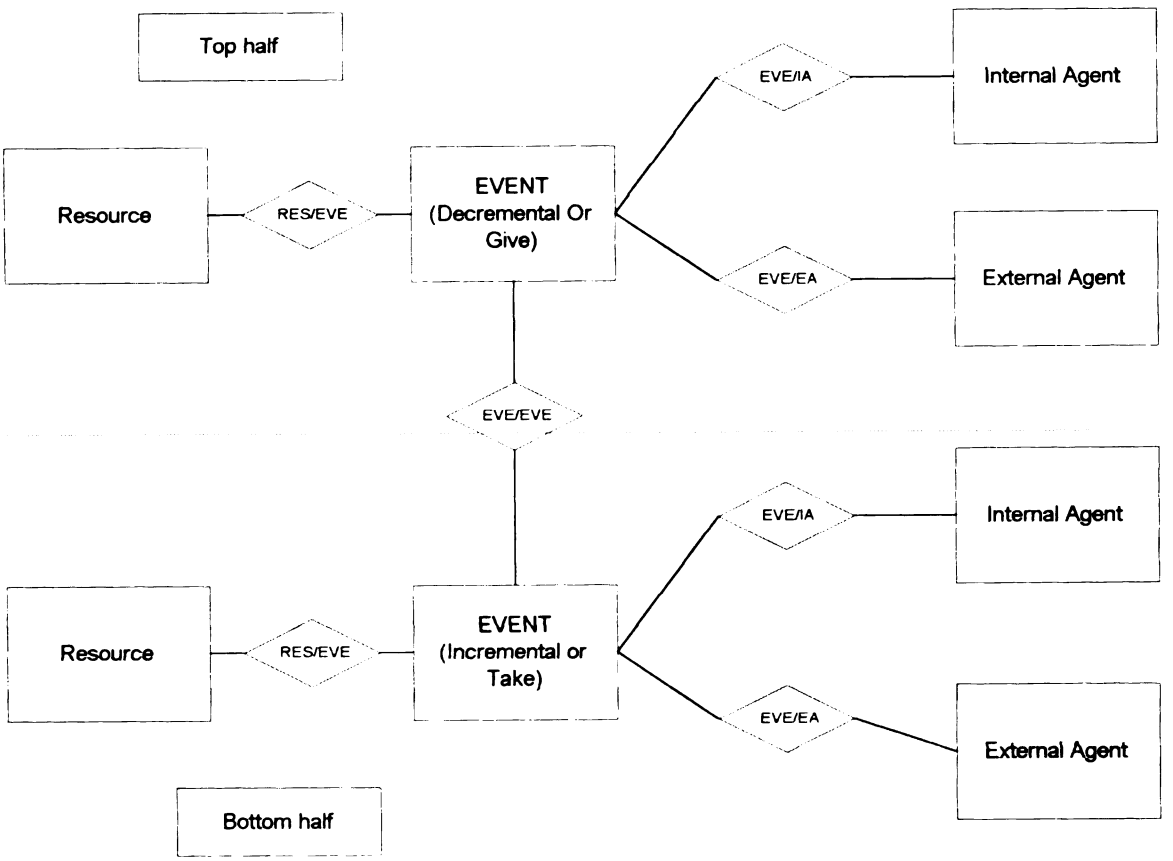


Figure 4.6: A typical REA model for business process (McCarthy 1982)

Developing REA models for top-level processes in planning and controls, involve three steps (McCarthy 1982). The first step is to define and identify "resource", "events", and "agents", as explained in sections 4.2.3.1.1 to 4.2.3.1.2. The next step is the view modeling, used to develop REA models for scheduling and project controls, as explained in section 4.2.3.2. The third step is the integration of REA models using the view integration technique, as explained in section 4.2.3.3.

4.2.3.1.1 "Resource," "Event," and "Agent" in REA model

The events are all the processes that consume resources, or increase resources. The resources are classified into labor, material and equipment. Also money ($) is recognized as one of the resources. The agents are of two types, internal agent and external agent. Internal agents are the employees of the company like project manager (PM), accounts manager (AM), project director (PD), scheduler (S), estimator (E), site superintendent (SS), general foreman (GF). The external agents are architect (A), engineer (E), owner (O), General Contractor (GC), inspection agency (I), and supplier (S) (David 1998; Fischer and Aalami 1992). These notations will be used throughout the remaining sections of this chapter, to denote the internal and external agents. Three major types of events are identified for each project phase. These are economic events, business events, and information events (David 1998). These events are discussed in the following sub-sections.

4.2.3.1.2 Economic events

Economic events are those, which change the quantity of resource (David 1998; McCarthy 1982). Following events are identified as economic events: **1) planning phase:** develop schedule, develop budget, assign resources, and assign responsibilities, **2a) construction phase:** use resources, use funds, use responsibility, measure budget, schedule, and resource component, **2b) controls phase:** make decisions, update schedule, update budget, update resources, and update responsibilities, and **3) close out phase:** make punch-list, prepare as built drawings, receive payment, inspection and testing. It should be noted that events under planning and controls are commitment events and do not necessarily consume resources and add value at the instance when they occur, or when they are modeled in this research work. However, they will eventually add value to the business when the commitment is fulfilled. Therefore they are treated as economic events at the top level.

4.2.3.1.3 Business events

Business events are defined as any business activity that management wants to plan, monitor and evaluate. These events result in changes to the physical world and provide new information to the firm's management (David 1998). For example, develop activity or develop logic is not an economic event, as no resources are increased or decreased at the time this events occur. However, this is a business event because once the activity is generated and logic is built, there is new information available, which can help the management plan, monitor and control operations (Clough and Sears 1998). For example, fund allocation and resource distribution for the activities may be finalized when activity

logic and sequencing is finalized. Staffing decisions may be based on activity logic. Management will have more information about the relationship between activity sequencing and resource requirements and cost aspects.

4.2.3.1.4 Information events

As defined by David (1998), "Information event is a procedure or set of procedures that are performed in organizations to manipulate and communicate information. No new data is created and no change occurs in the real world, that the system is describing. It communicates information that has already occurred." For example, select construction method or installation procedure is an information event that merely confirms the methods agreed up on in the contract documents. As suggested by David (1998), "the REA diagram should not be used to document information processes. Their strength lies in modeling the activities, which occur in the real world, and helping management evaluate these events. Information events on other hand, while perhaps necessary in organization, are merely the processes that use the information captured about the resources, events and agents. They are an implementation issue, rather than a design issue."

The above sub-sections identified three types of events and various resources and agents.

4.2.3.1.5 Events used in REA models

After defining the three types of events in the previous sections, the economic and business events to be used in the REA models are defined in this section. Each of the economic events in project planning and controls phase has sub events that are required

to complete the economic event. As discussed in chapter 3, these are the business events (David 1998). Therefore, the events like develop activity, develop logic are business events. For each phase of the project, the various business events are merged to form the single top-level event or economic events. Thus, develop schedule is an economic event having "develop activity," and "develop logic" as the related business events. This is because to develop a schedule, first it is required to develop an activity and then to define the sequence among the activities, called activity logic. In this manner the economic events and the related business events, for every phase of the project are developed. These are shown in the process tree diagrams, described in the previous section. The economic events and business events for the planning phase are shown in Figure 4.4 (P1). Merging the business events to form an integrated economic event is shown in Figures 4.4 (P2) to 4.4 (P4). Figure 4.4 (P5) is the single view-integrated event for all business events involved in planning. Similarly, the economic and business events during construction and controls are shown in Figures 4.4 (P6, P7 and P9). Where as, Figures 4.4 (P8 and P10) represent a single integrated view or event for all business events involved in construction and controls phase.

4.2.3.2 REA modeling for project planning and controls

The business events for the planning and controls phase of the project, as identified in the process tree diagrams are modeled using the REA modeling template. This includes identifying resources, events and, agents associated with each business event. The following economic events along with the related business events under planning and controls, are modeled in this research work:

1) Project planning phase

- Economic event: Develop Schedules
- Business events: develop cost loaded schedule, develop fund loaded schedule, develop resource loaded schedule

2) Project controls phase

- Economic event: Make Decision
- Business events: make fund decisions, make cost decisions, make resource decisions
- Economic event: Update Schedules
- Business events: update cost loaded schedule, update fund loaded schedule, update resource loaded schedule

It is assumed that the budgets are already developed during the planning phase, and the event "develop budget" is not modeled in this research work. However, once the budgets are assumed to be developed, then the schedules will be loaded with the cost and fund aspect of the budgets to generate the business events such as, "develop fund loaded schedule," and "develop cost loaded schedule." Also only top level business events as identified above will be used to develop the integrated model. For example, the event "develop cost loaded schedule" has two underlying processes or events such as, "develop cost loaded activity," and "develop cost loaded logic" as identified in the process tree diagrams. These underlying events are not shown in the integrated REA model developed in section 4.2.3.3, and shown in Figure 4.7. These events are, however, modeled as individual REA models, as developed in the next section, and shown in Figures 4.6 (R1a-c) to Figure 4.6 (R8 a-c).

4.2.3.2.1 REA template without duality event

The REA models are developed for various business events under a particular project phase. However, these models do not show the duality events associated with the business events. For example, the REA model for "develop fund loaded schedule" is shown in Figure 4.6 (R1a). Notice that, the events "develop fund loaded activities" and "develop fund loaded logic" are the related business events required to complete the event, "develop fund loaded schedule." These events are not the duality events associated with the main event. The duality event is "make fund decisions," which will be a business event under the project controls phase. The two duality events will be connected in the complete REA model framework using view integration as described in section 4.2.3.3.

For the REA model shown in Figure 4.6 (R1a), the resources identified are labor, material, equipment, (unless otherwise specified) and money ($) as required. The "+" sign above the $ sign means money is being acquired and this increases the cash balance. The "-" sign above the $ sign means that the money is spent or cost incurred and decreases the cash balance. The internal agents can be estimator (E), scheduler (S), accounts manager (AM), project manager (PM), project director (PD), and the external agent will vary depending on who is the customer or client for that particular event. For example, in this case, the external agent can be architect (A), owner (O), engineer (E) or general contractor (GC). The important aspect of this REA model is that the event, "develop fund loaded schedule" has two types of internal agents. The first type is a "developer" such as PM, S, and AM who develop the schedule. The second type is an "end user" such as PM or PD who uses the schedule to manage the project (Clough and Sears 1998). As shown in Table 4.1, depending on the schedule participant matrix, this

second type of agent (i.e. end user) can be PD, PM, SS, etc. Thus the internal agent will change depending on the type of schedule to be used. The matrix showing the internal and external agents for the particular phase and global view of project processes is shown in Table 4.3. Therefore in the model, these agents are only shown as "internal" and "external " agents and the reader has to refer to Table 4.3 to identify the internal agent associated with a particular event. The REA model shown in Figure 4.6 (R1a) is a typical REA model for business events under project planning and controls. The REA model template as shown in Figure 4.6 (R1a) will repeat for all other business processes identified in the process tree diagrams. These REA models are shown in Figure 4.6 (R2 a-c) to Figure 4.6 (R8 a-c). The reader should note that all these REA models for various events under a particular project phase, show only half of the typical REA model template. In other words, no duality relations are shown and there is no incremental and decremental association between the events that are modeled. Therefore, the events "develop cost loaded activity," and "develop cost loaded logic" are not the duality events for "develop cost loaded schedule" event. They are merely the events required to complete the process of developing the cost loaded schedule. The duality relationship in the integrated REA model is discussed in detail in section 4.2.3.3.1. The researcher proposes to use the concept of duality relationship in the sense that the two events under consideration are merely complimentary events of each other.

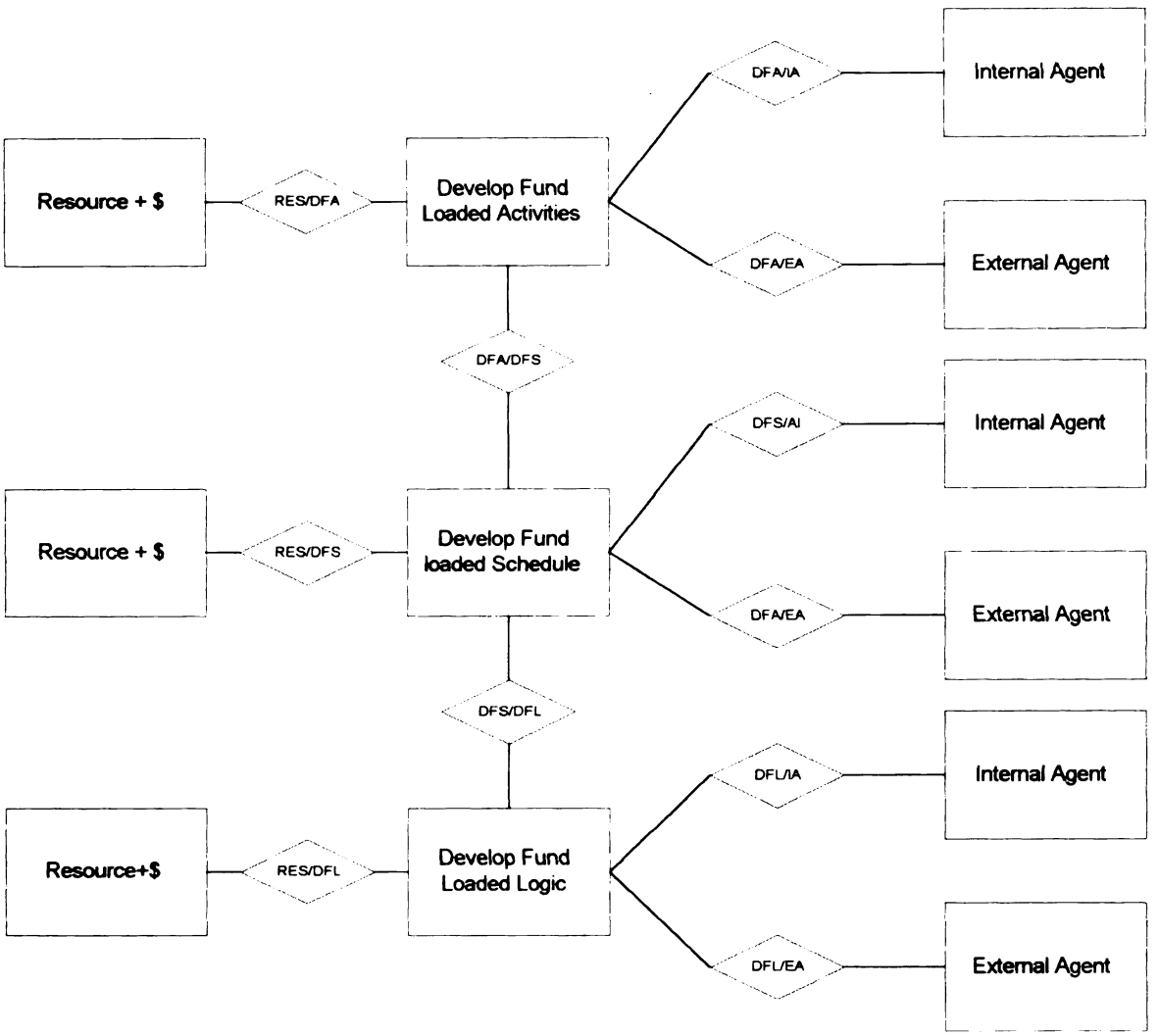


Figure 4.6 (R1 a): REA model for developing fund loaded schedule

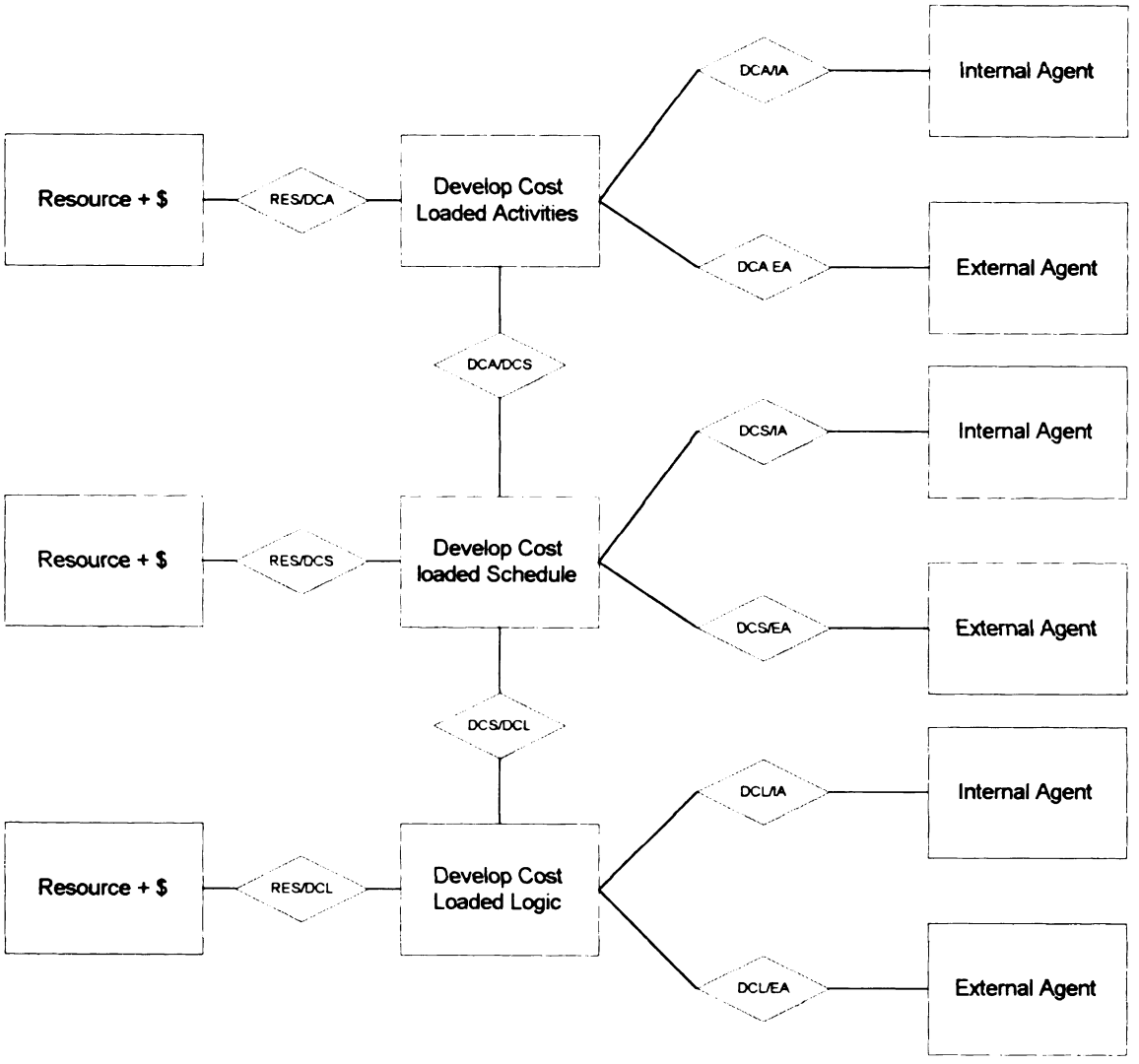


Figure 4.6 (R1 b): REA model for developing cost loaded schedule

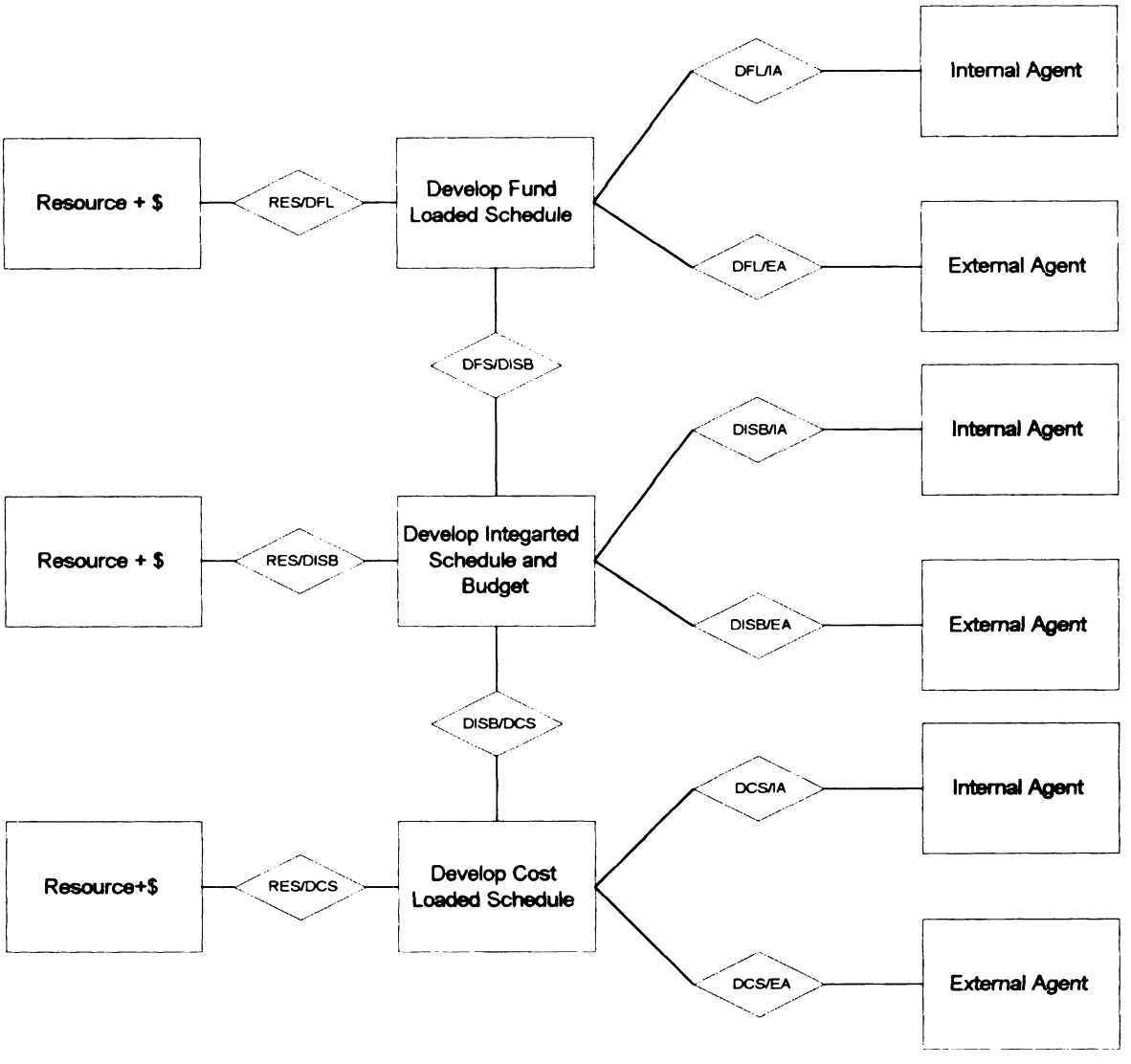


Figure 4.6 (R1 c): REA model for developing integrated schedule and budget

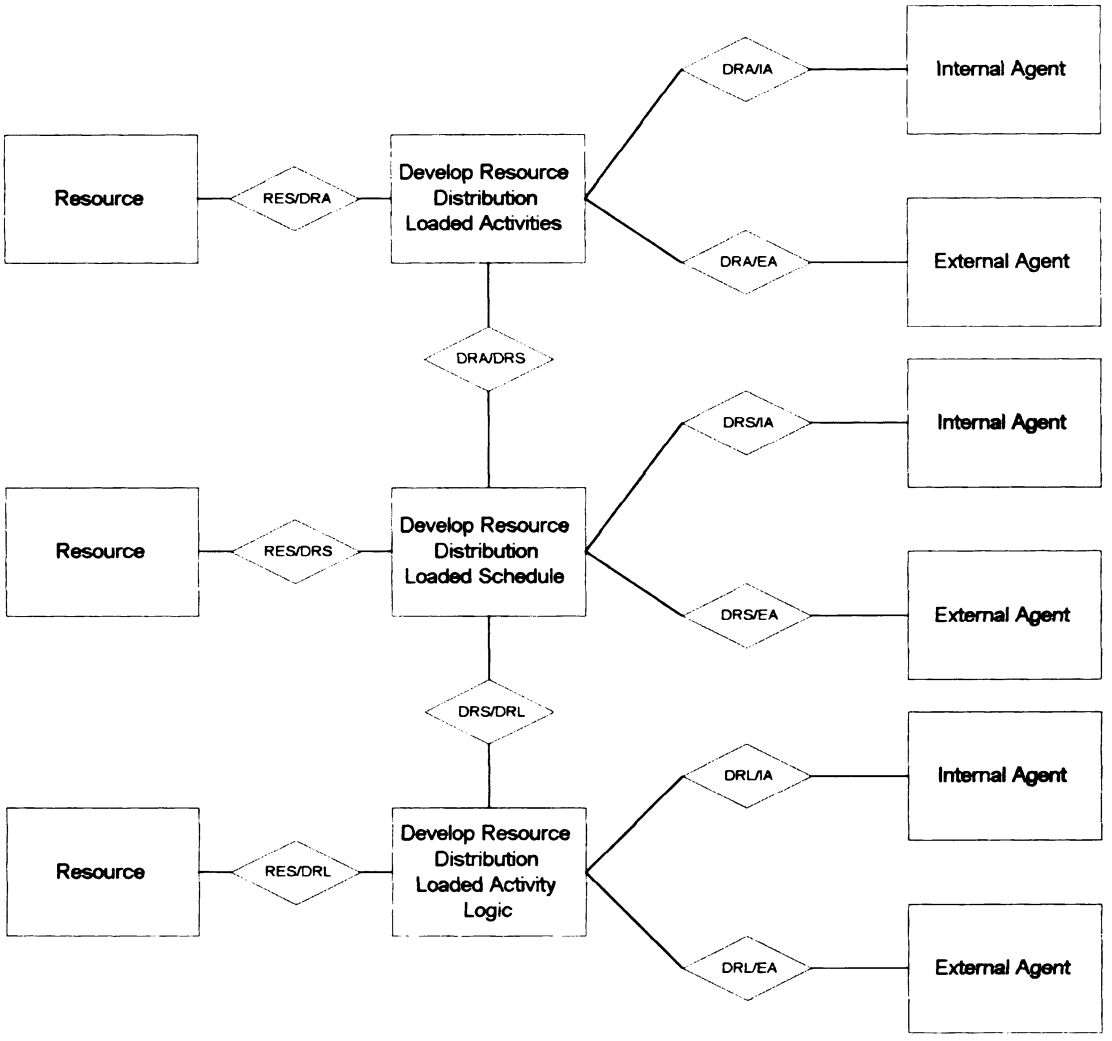


Figure 4.6 (R2 a): REA model for developing resource distribution loaded schedule

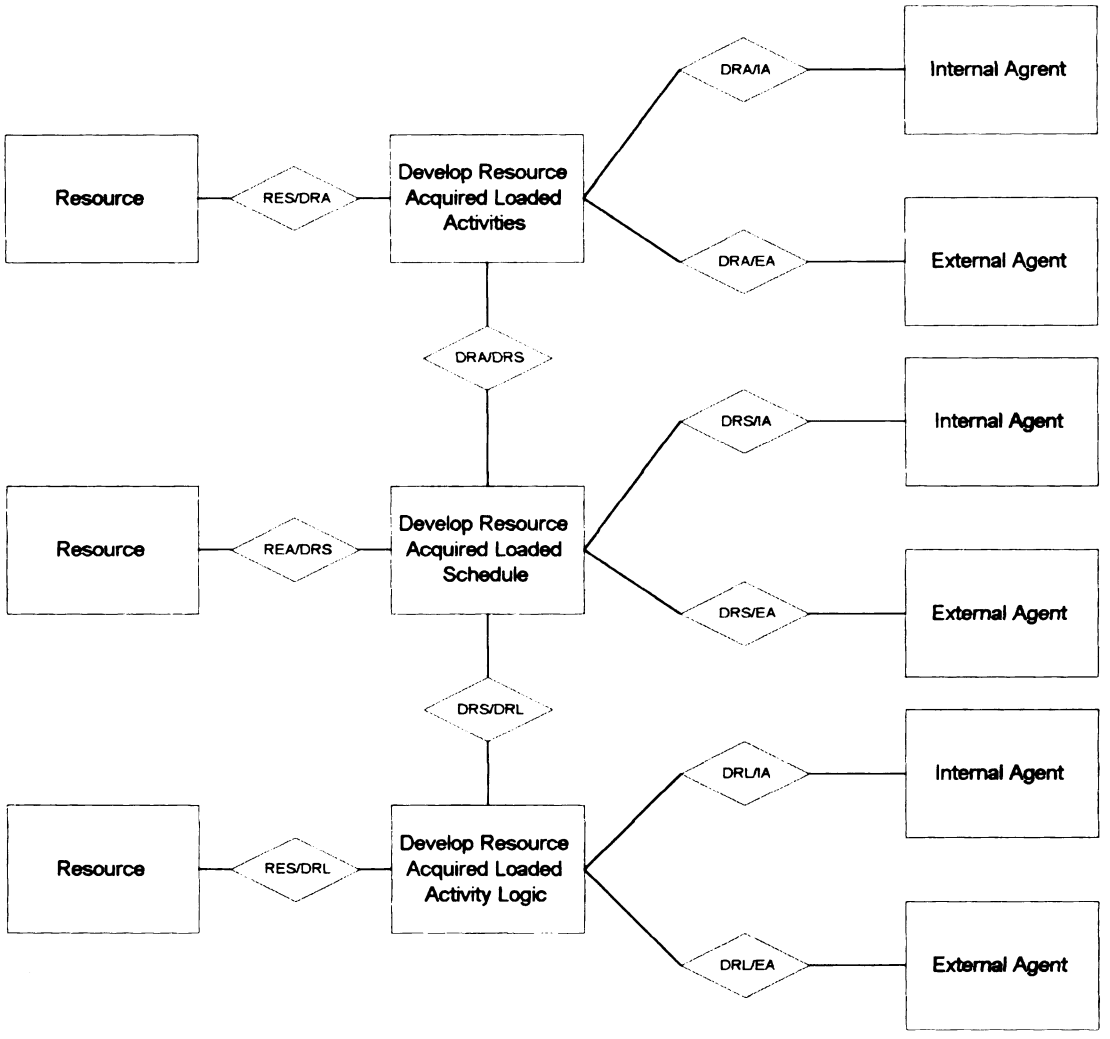


Figure 4.6 (R2 b): REA model for developing resource acquired loaded schedule

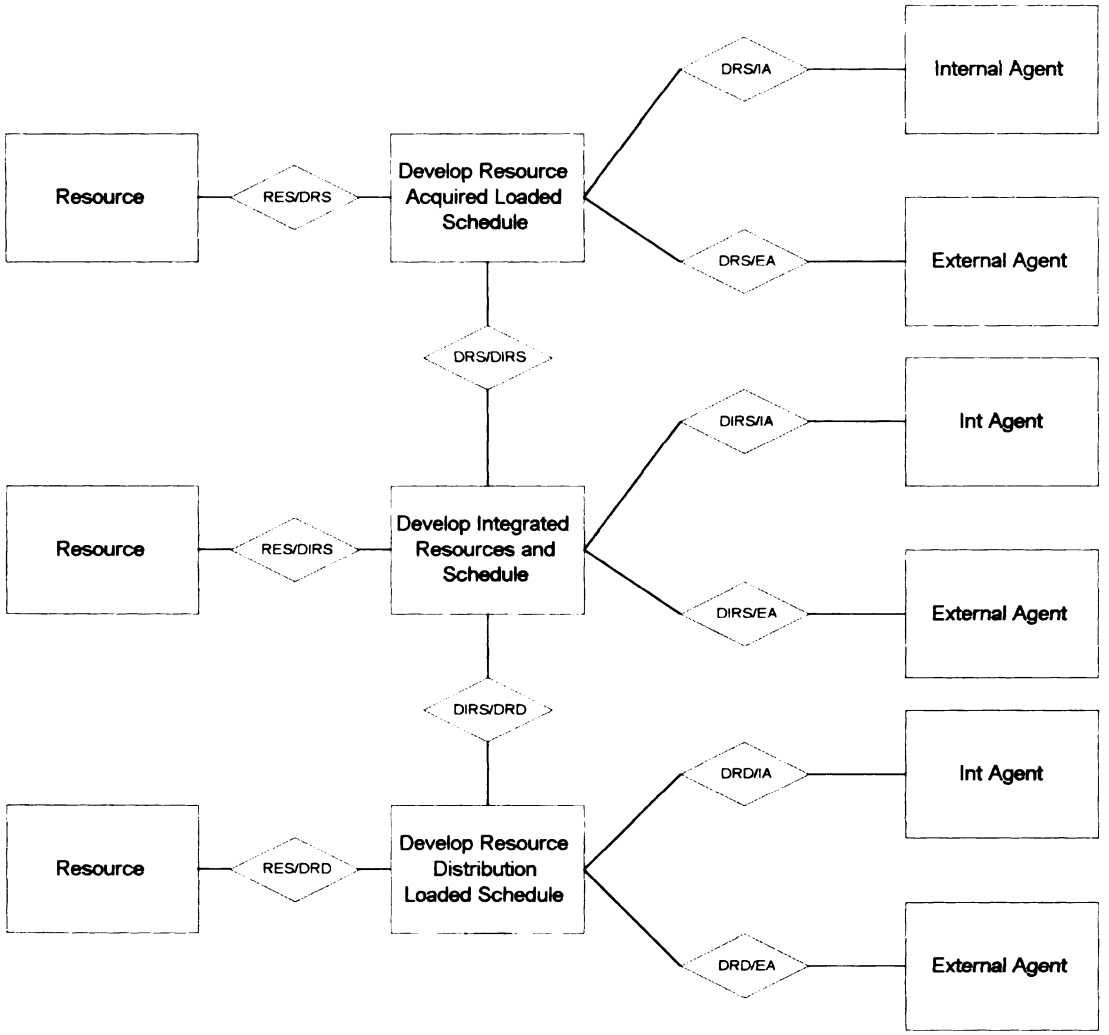


Figure 4.6 (R2 c): REA model for developing integrated resource and schedule

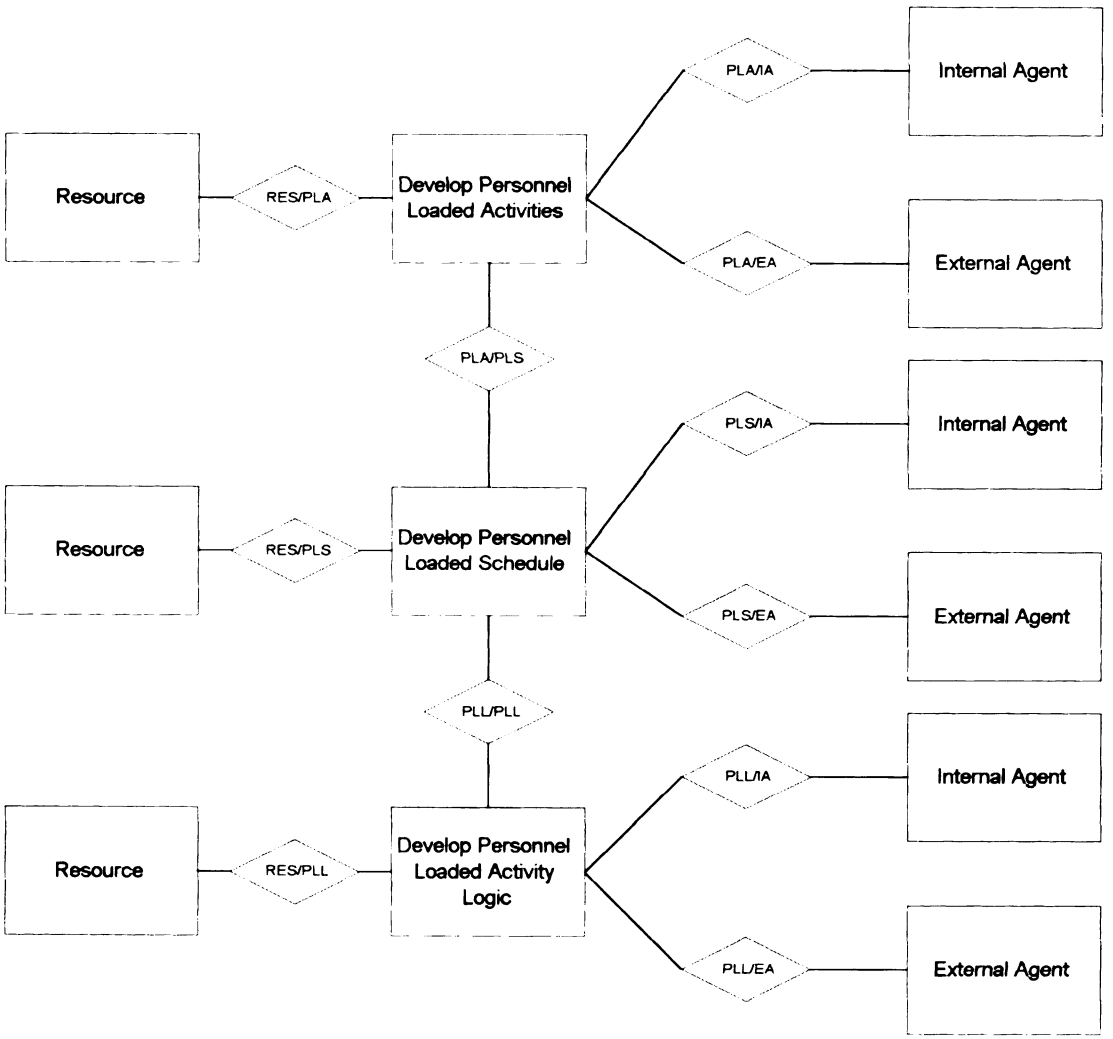


Figure 4.6 (R3 a): REA model for developing personnel loaded schedule

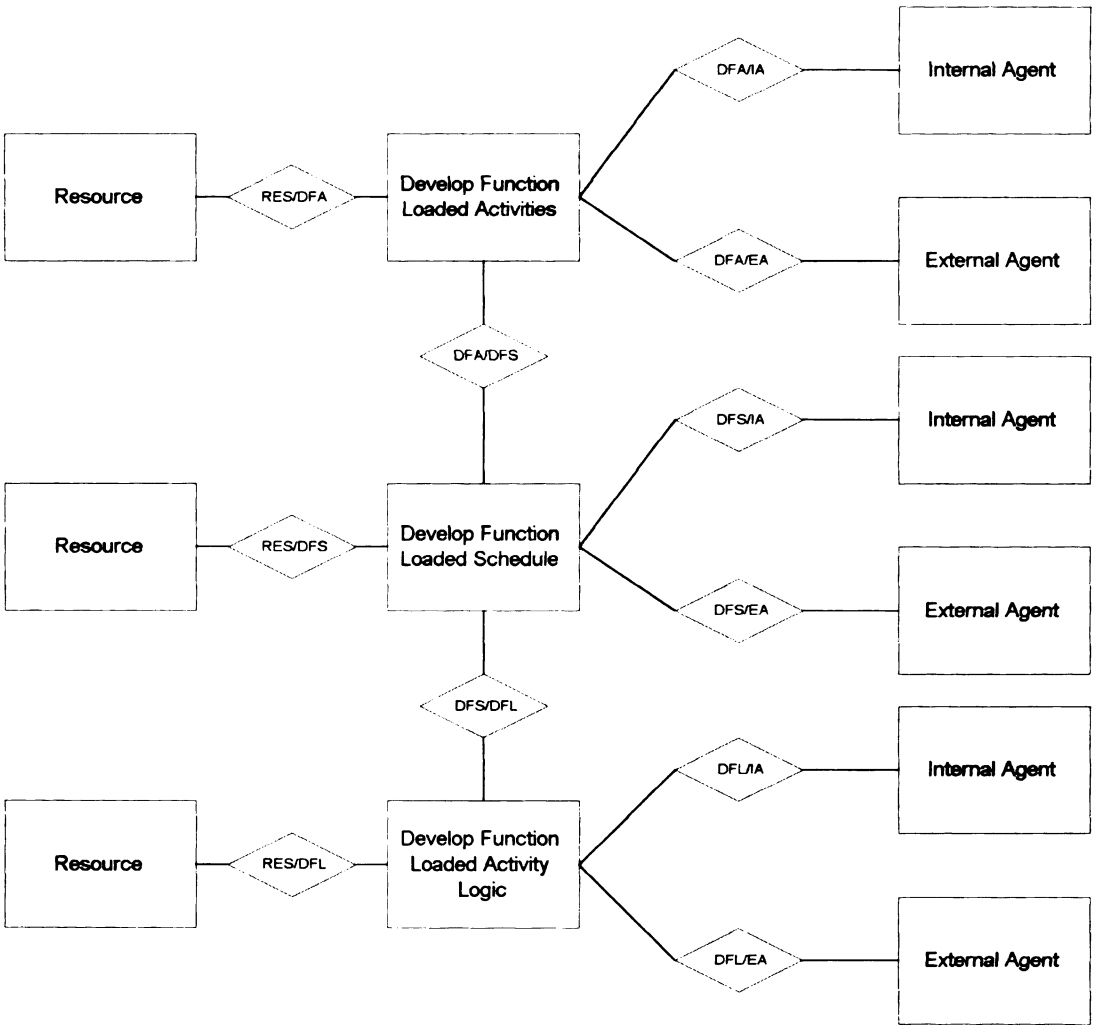


Figure 4.6 (R3 b): REA model for developing function loaded schedule

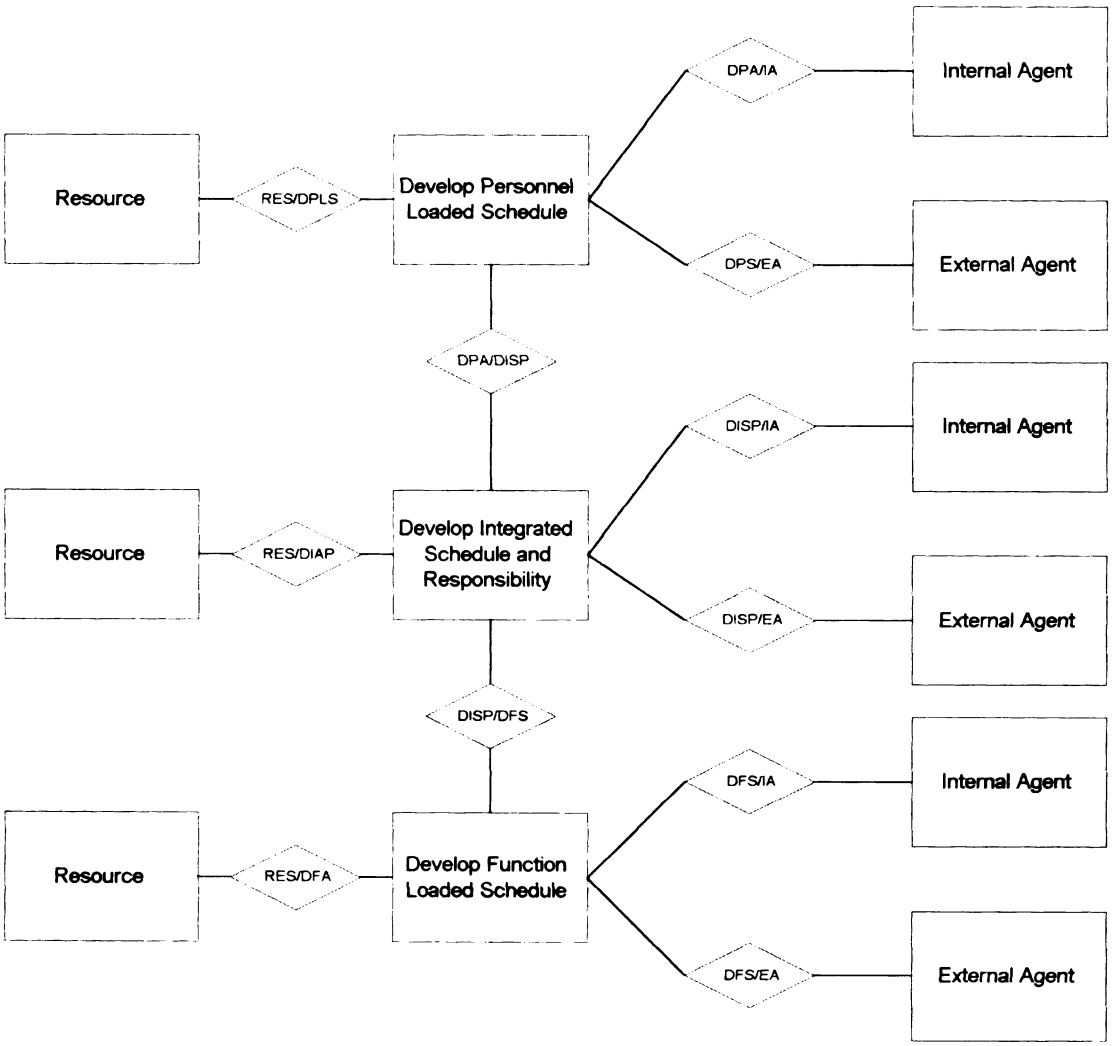


Figure 4.6 (R3 c): REA model for developing integrated schedule and responsibility

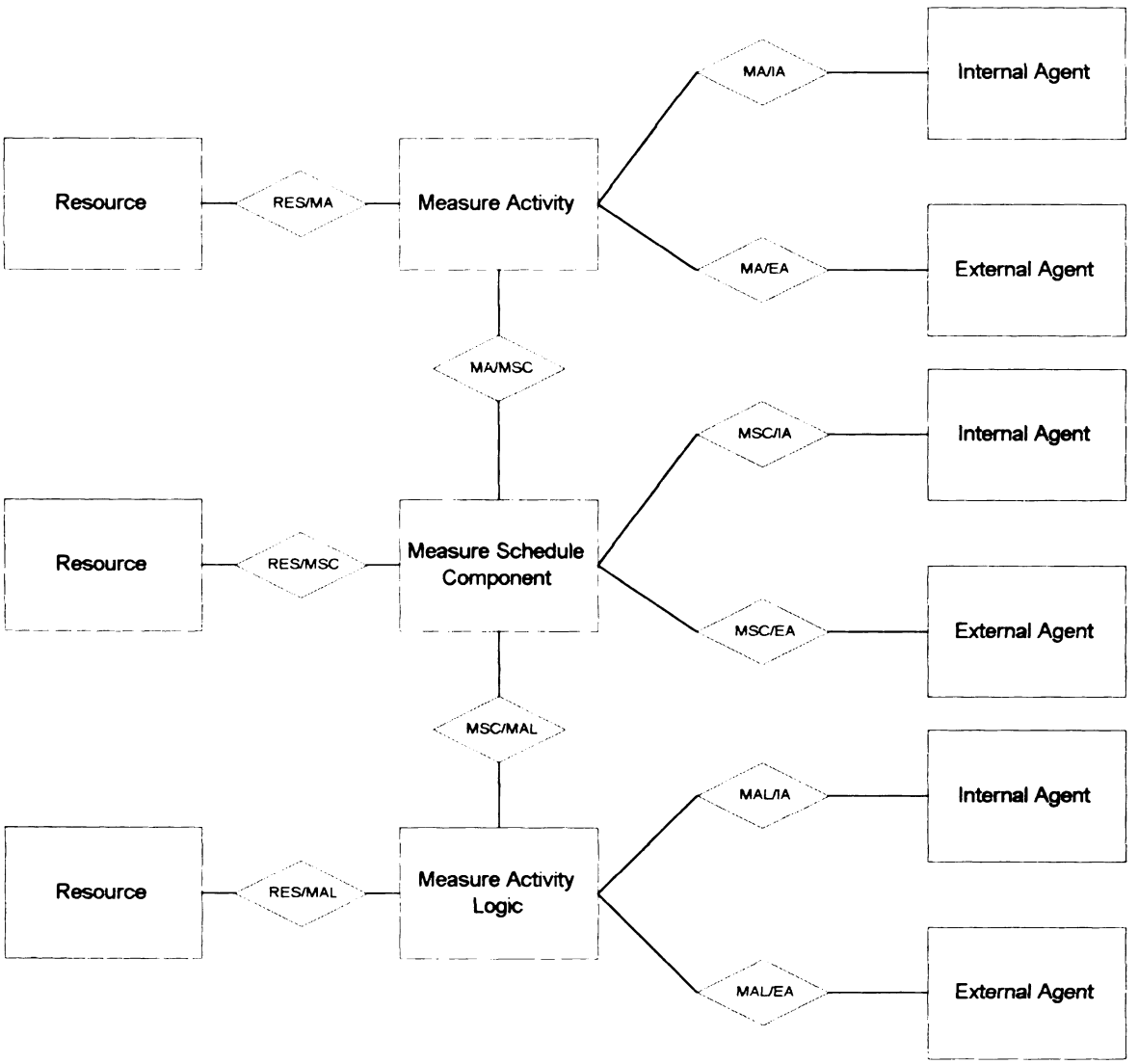


Figure 4.6 (R4 a): REA model for measuring schedule component

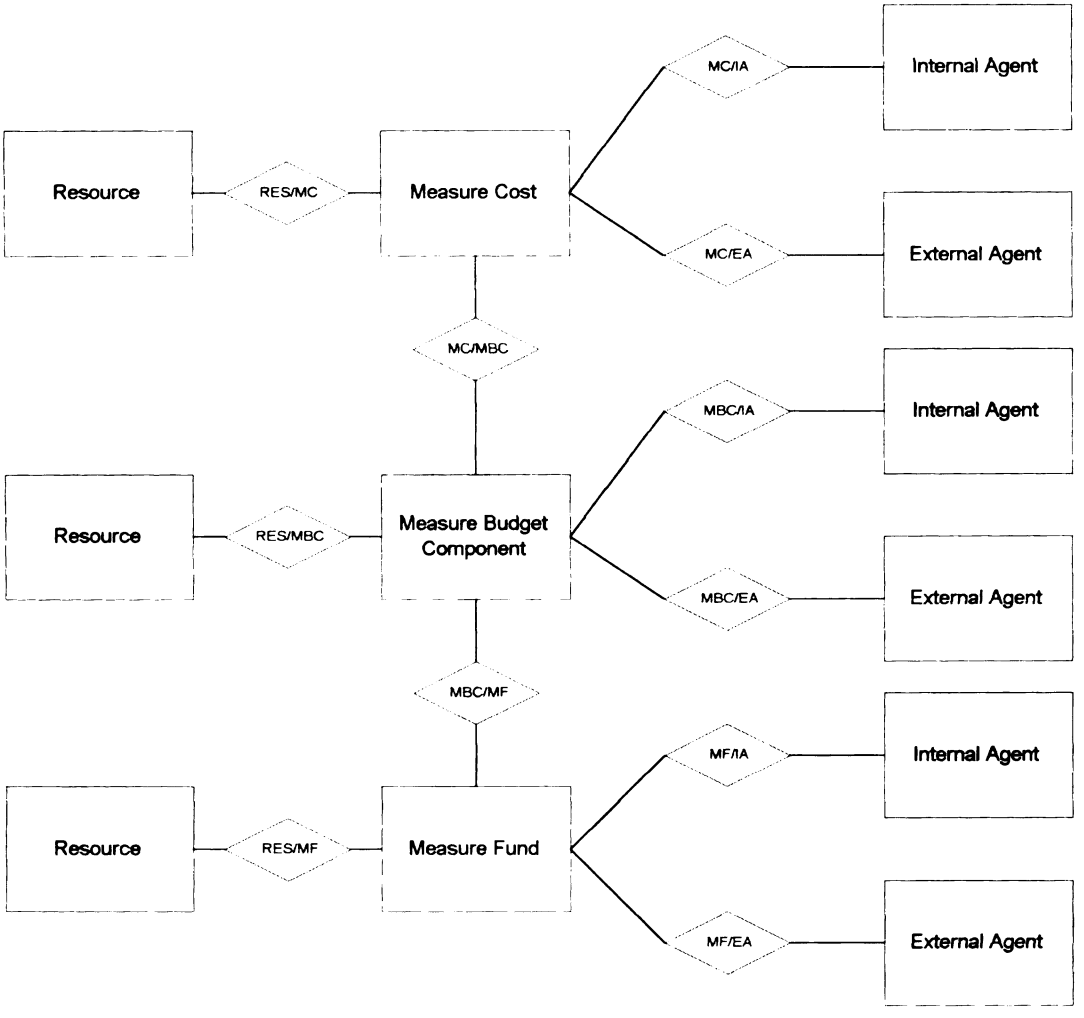


Figure 4.6 (R4 b): REA model for measuring budget component

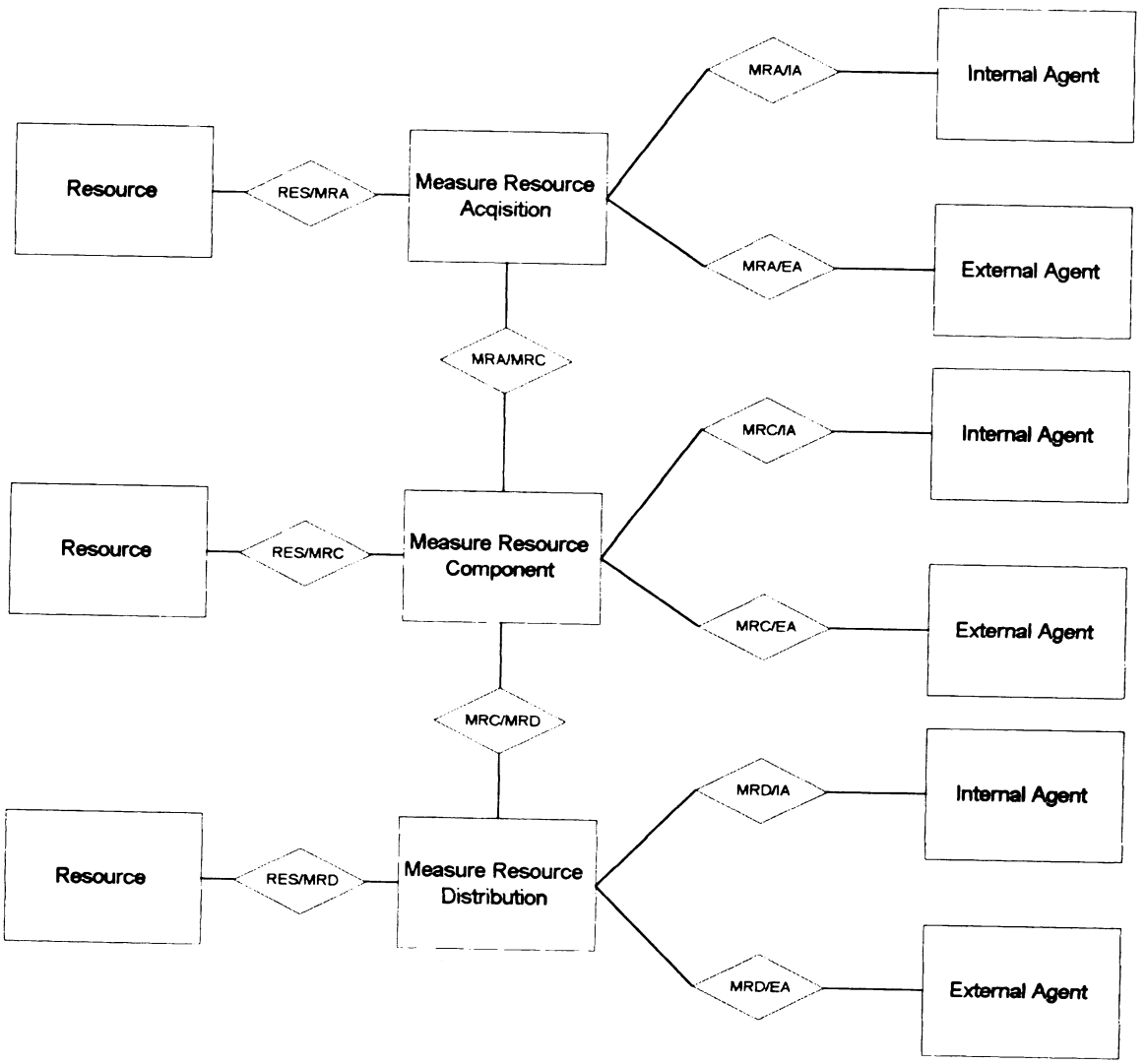


Figure 4.6 (R4 c): REA model for measuring resource component

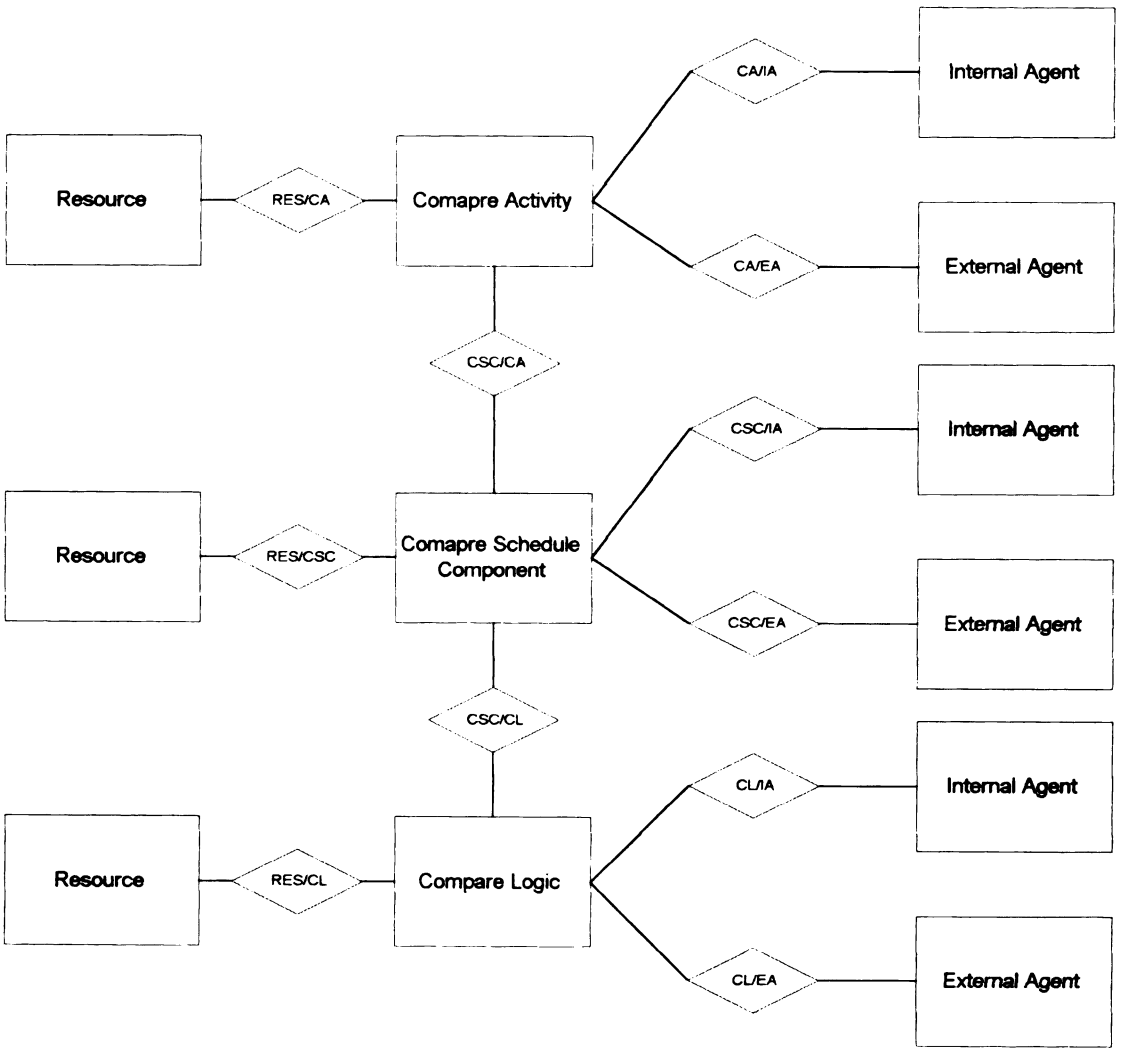


Figure 4.6 (R5 a): REA model for comparing scheduling component

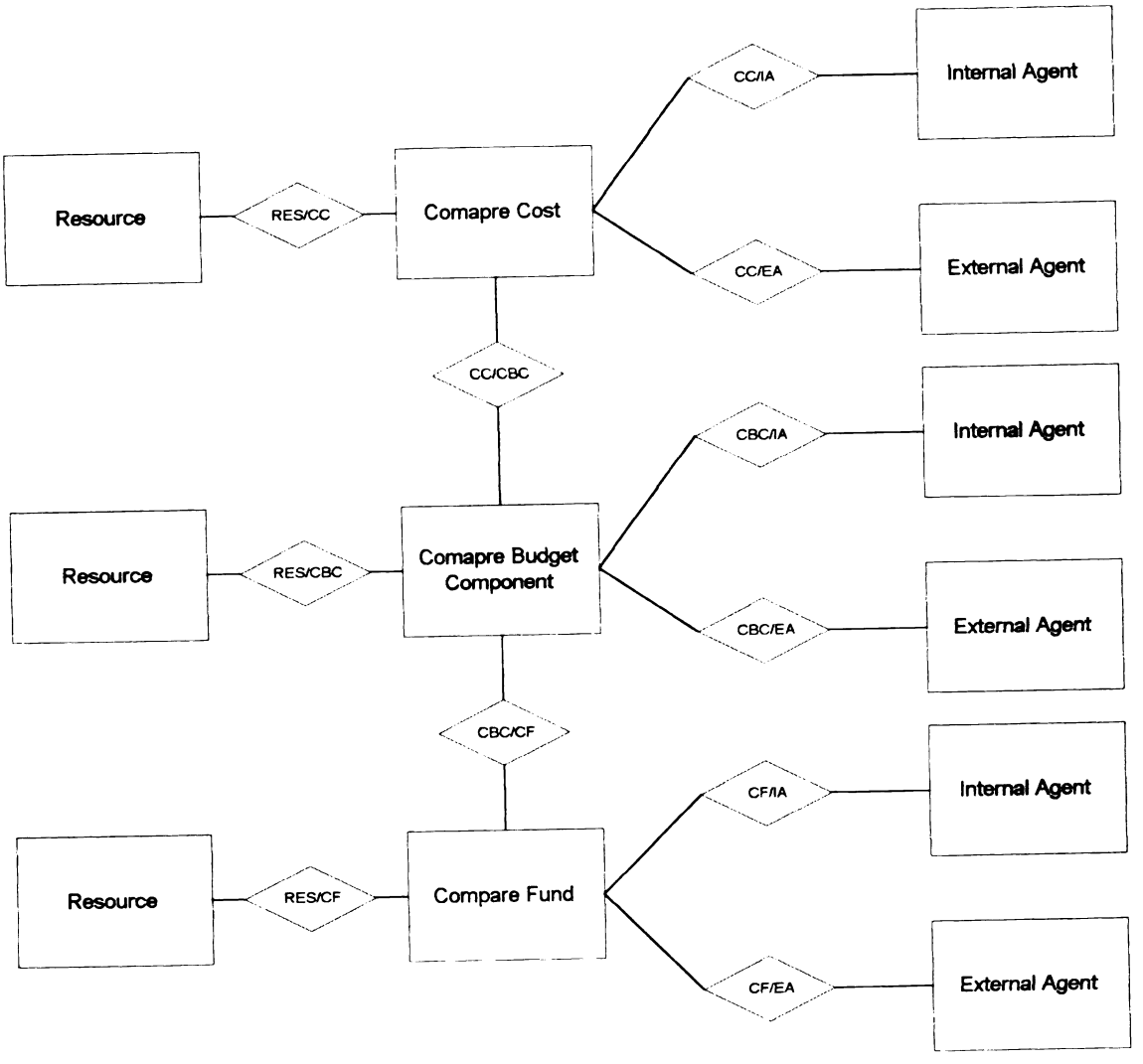


Figure 4.6 (R5 b): REA model for comparing budget component

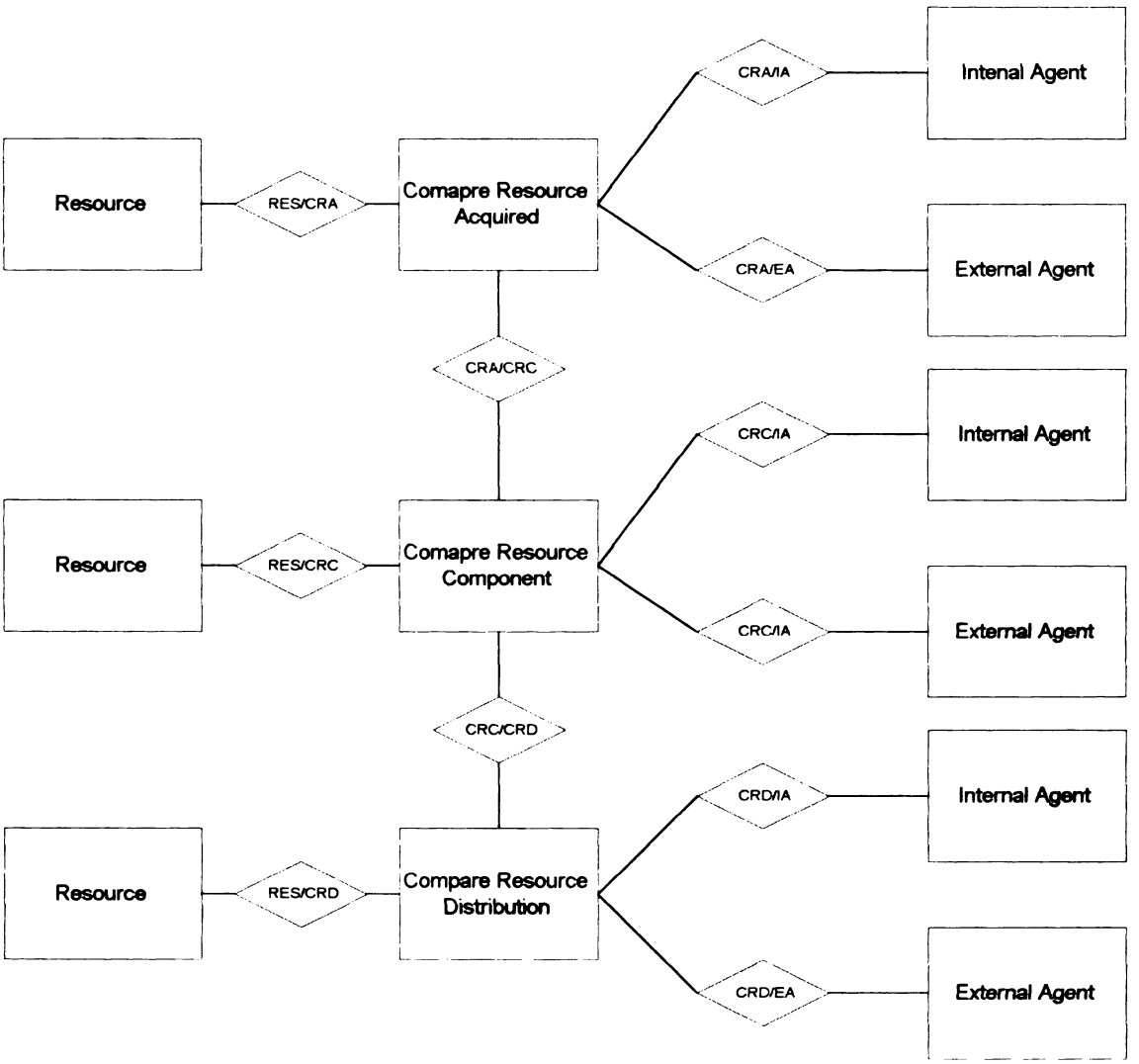


Figure 4.6 (R5 c): REA model for comparing resource component

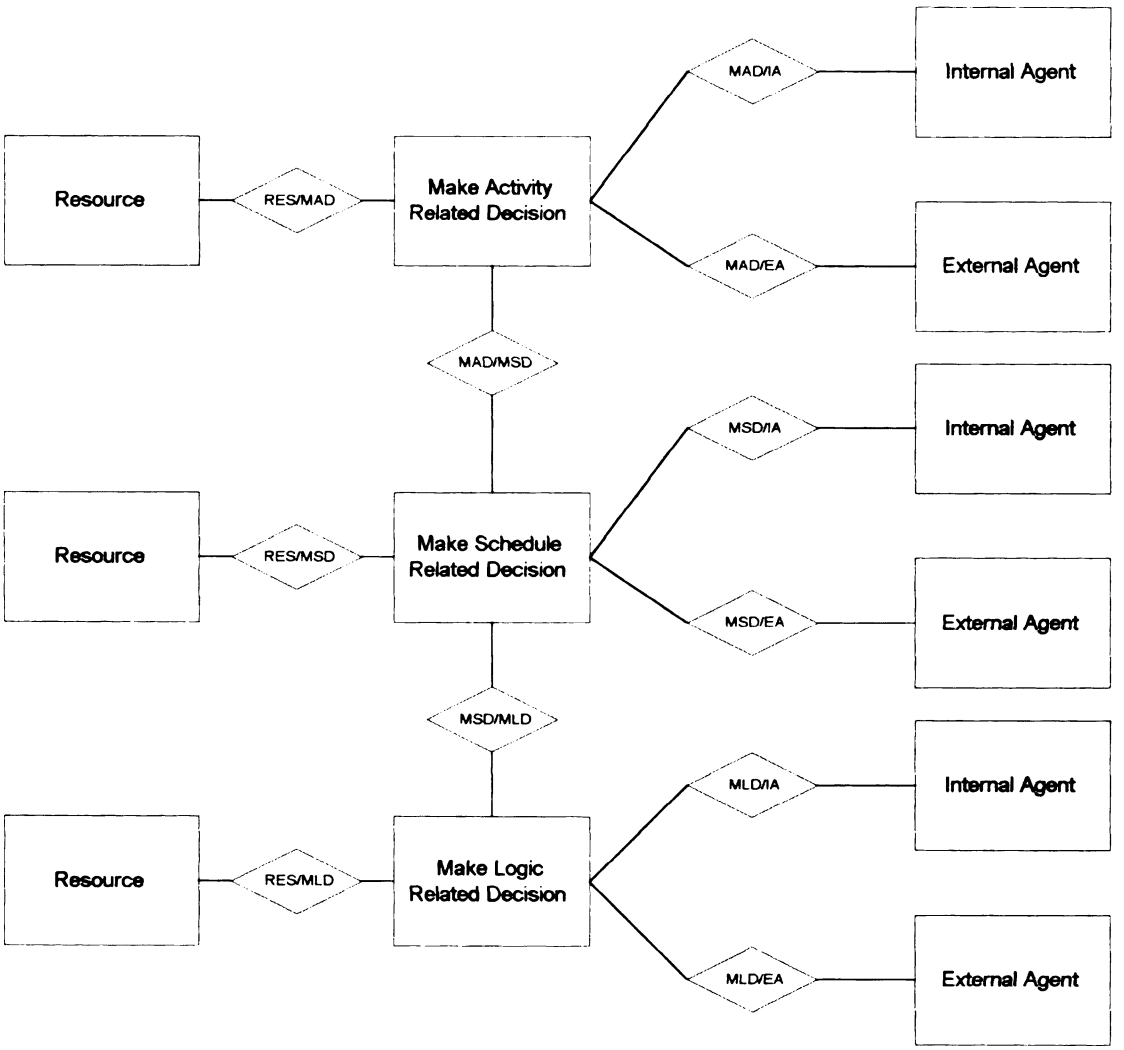


Figure 4.6 (R6 a): REA model for making schedule related decision

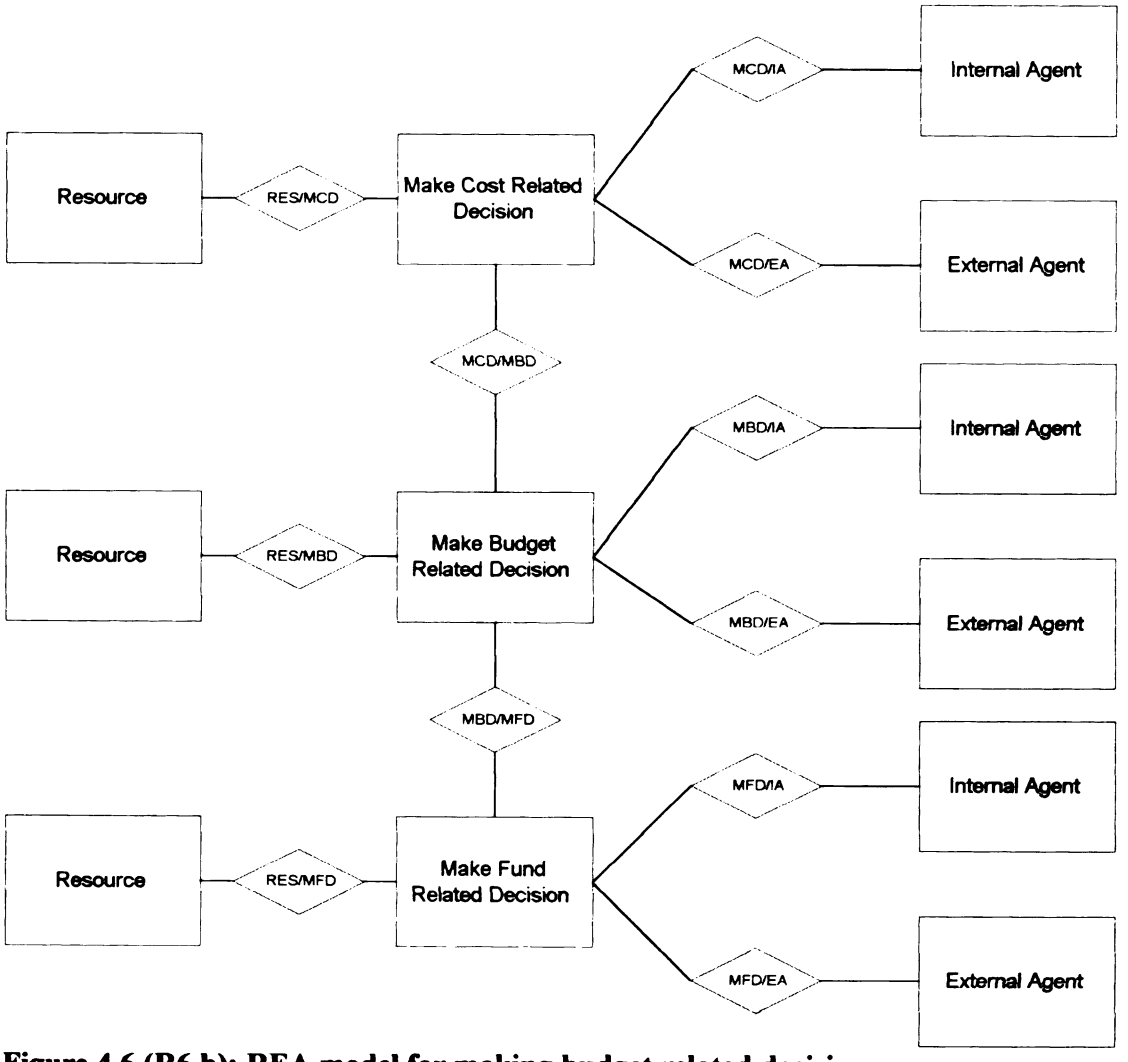


Figure 4.6 (R6 b): REA model for making budget related decision

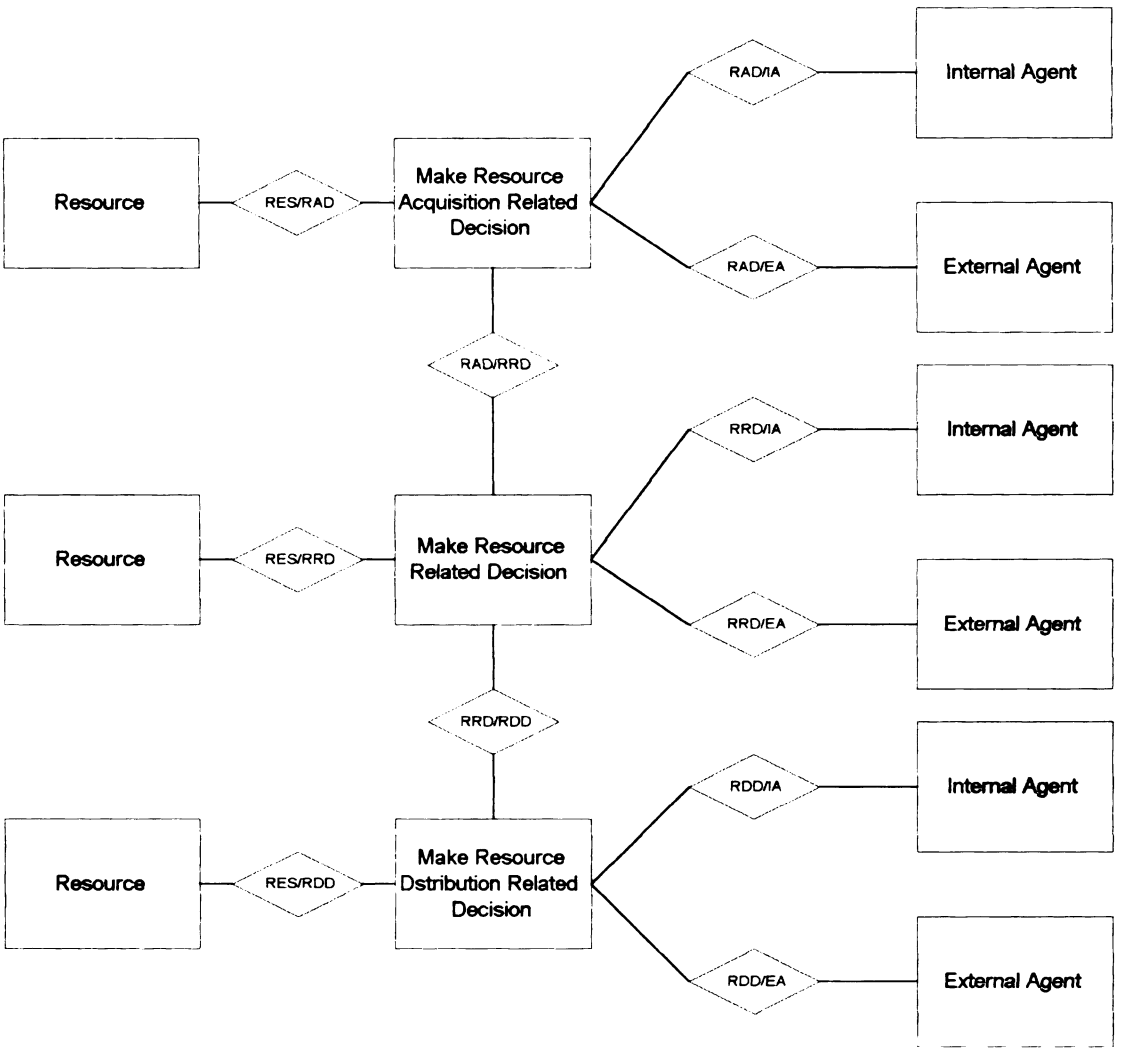


Figure 4.6 (R6 c): REA model for making resource related decision

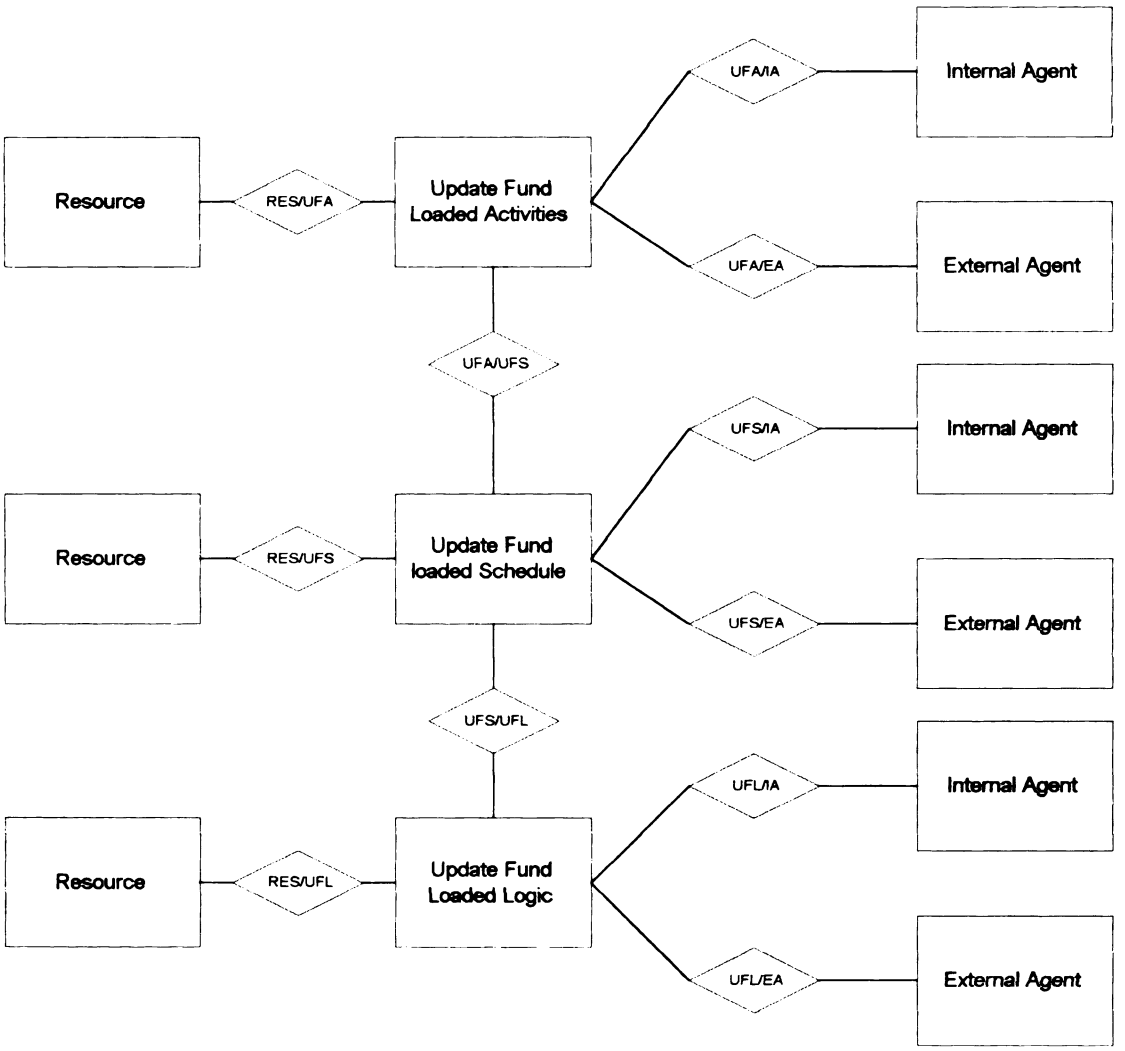


Figure 4.6 (R7 a): REA model for updating fund loaded schedule

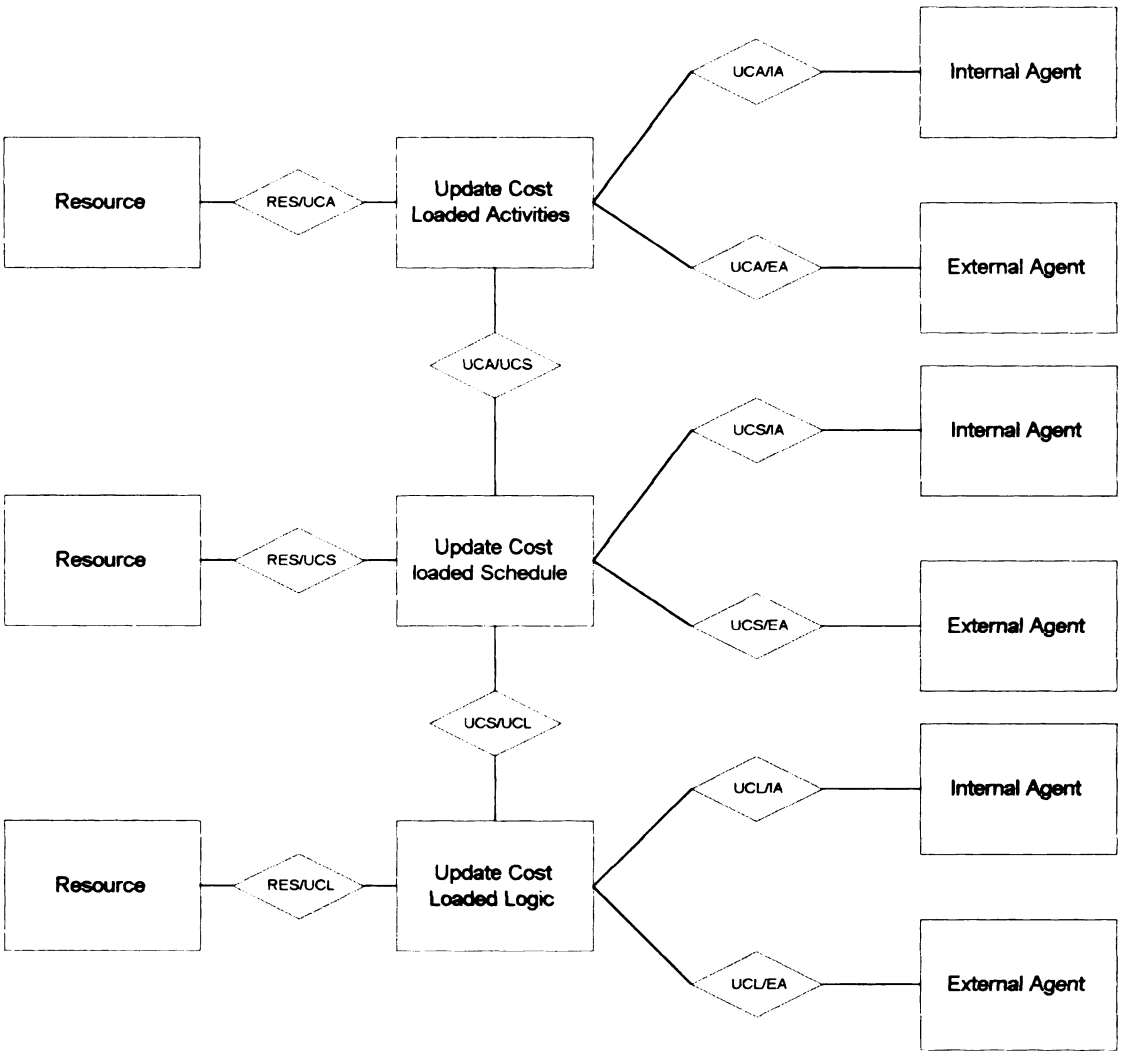


Figure 4.6 (R7 b): REA model for updating cost loaded schedule

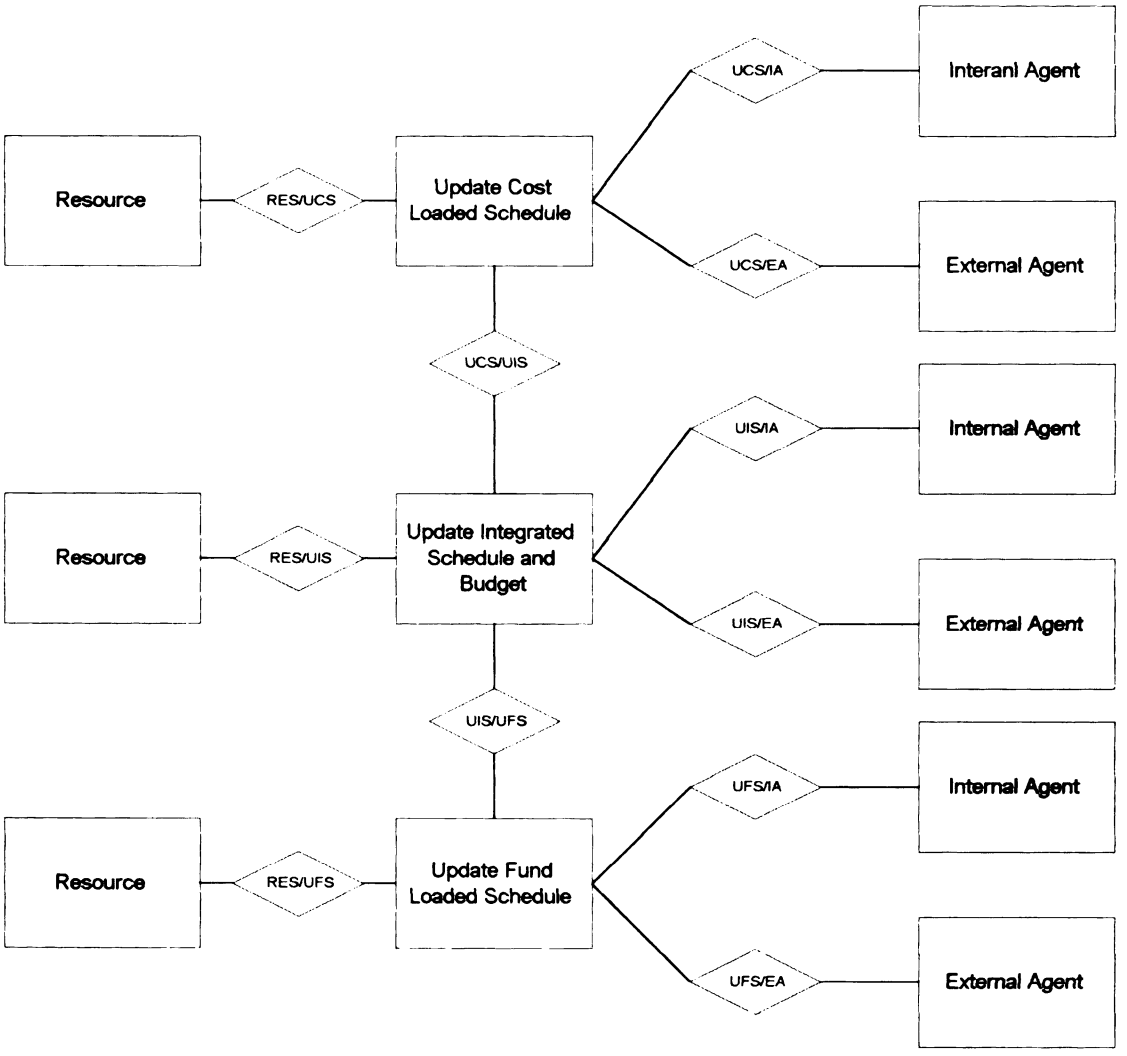


Figure 4.6 (R7 c): REA model for updating integrated schedule and budget

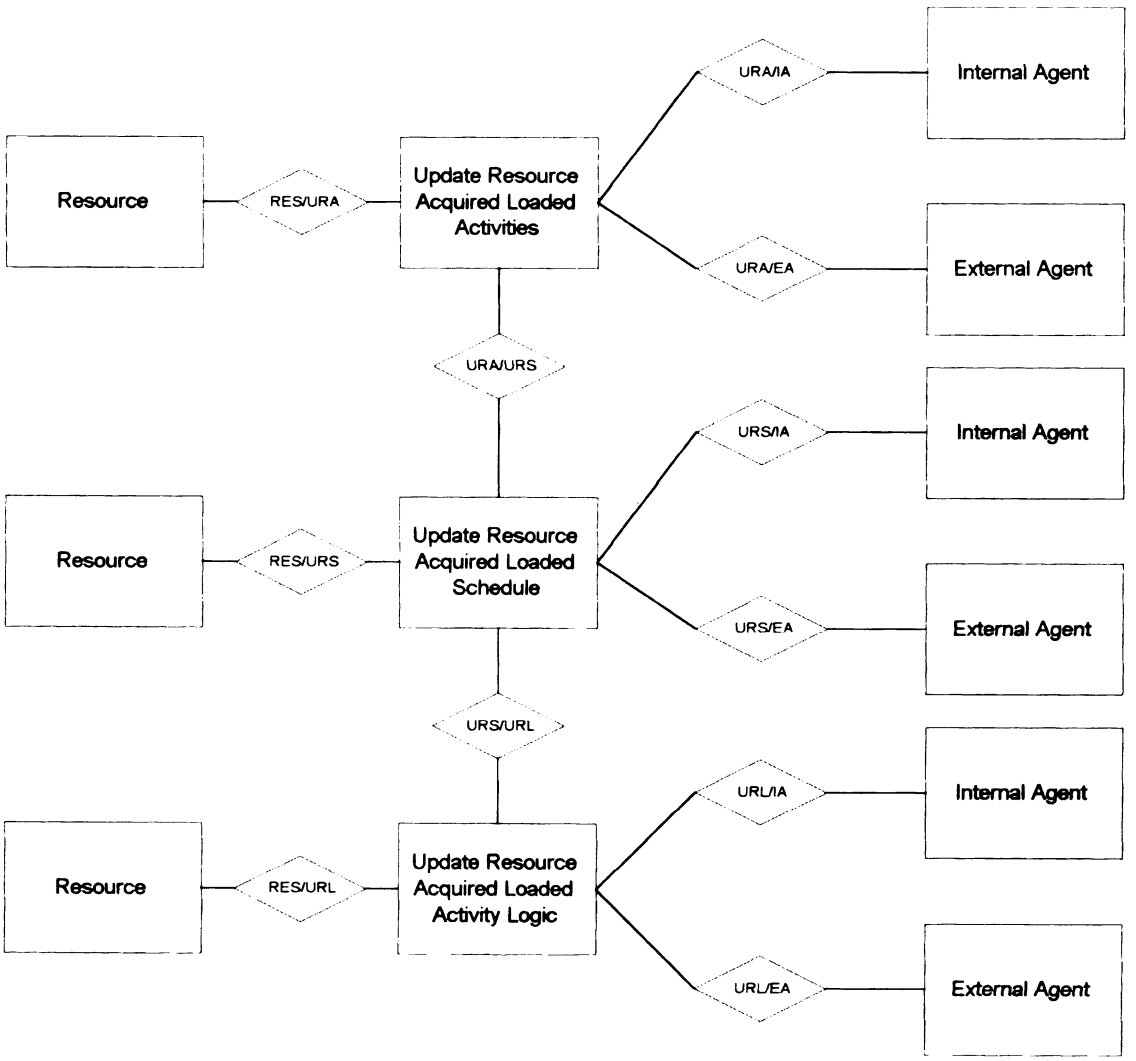


Figure 4.6 (R8 a): REA model for updating resource acquired loaded schedule

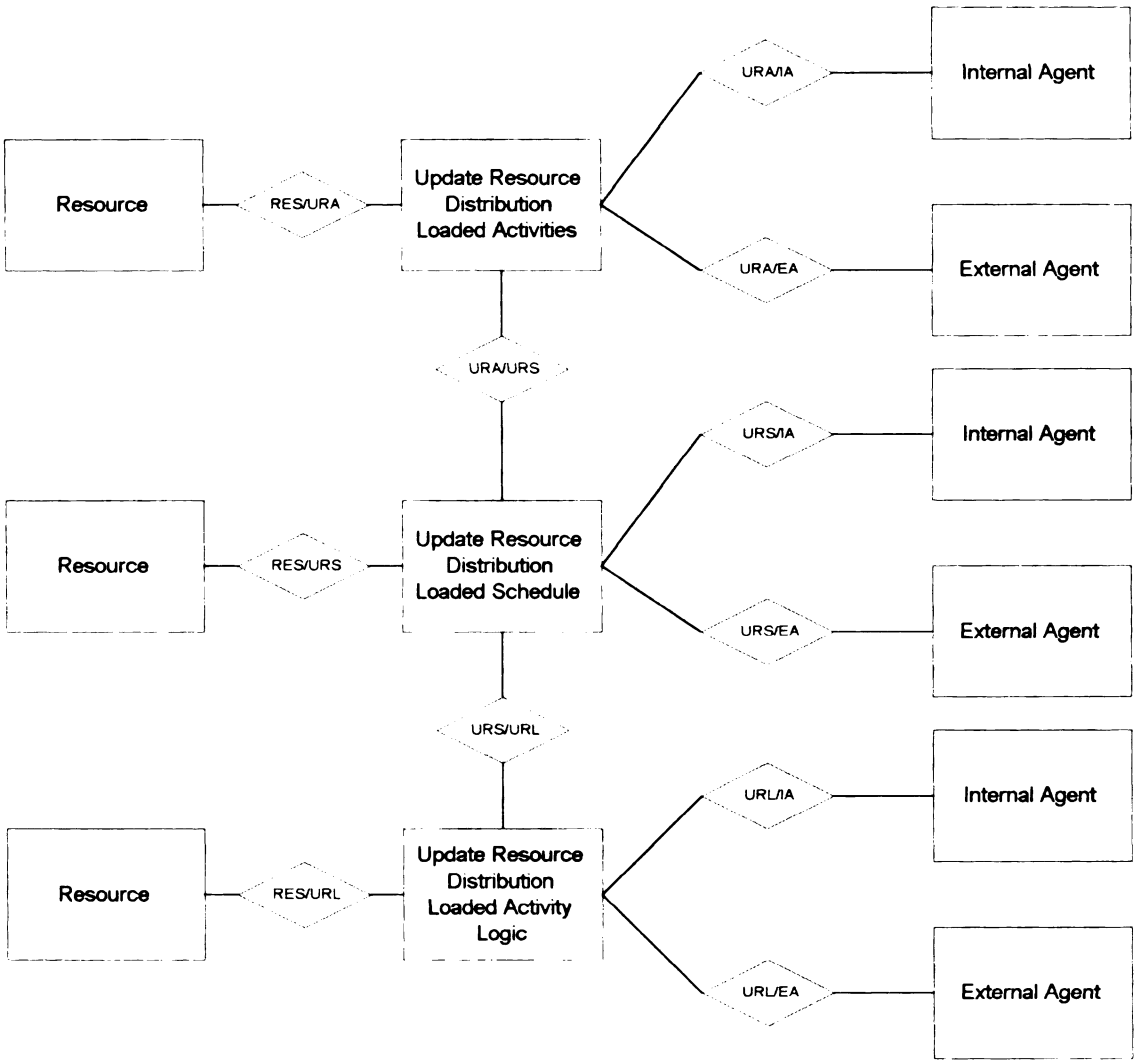


Figure 4.6 (R8 b): REA model for updating resource distribution loaded schedule

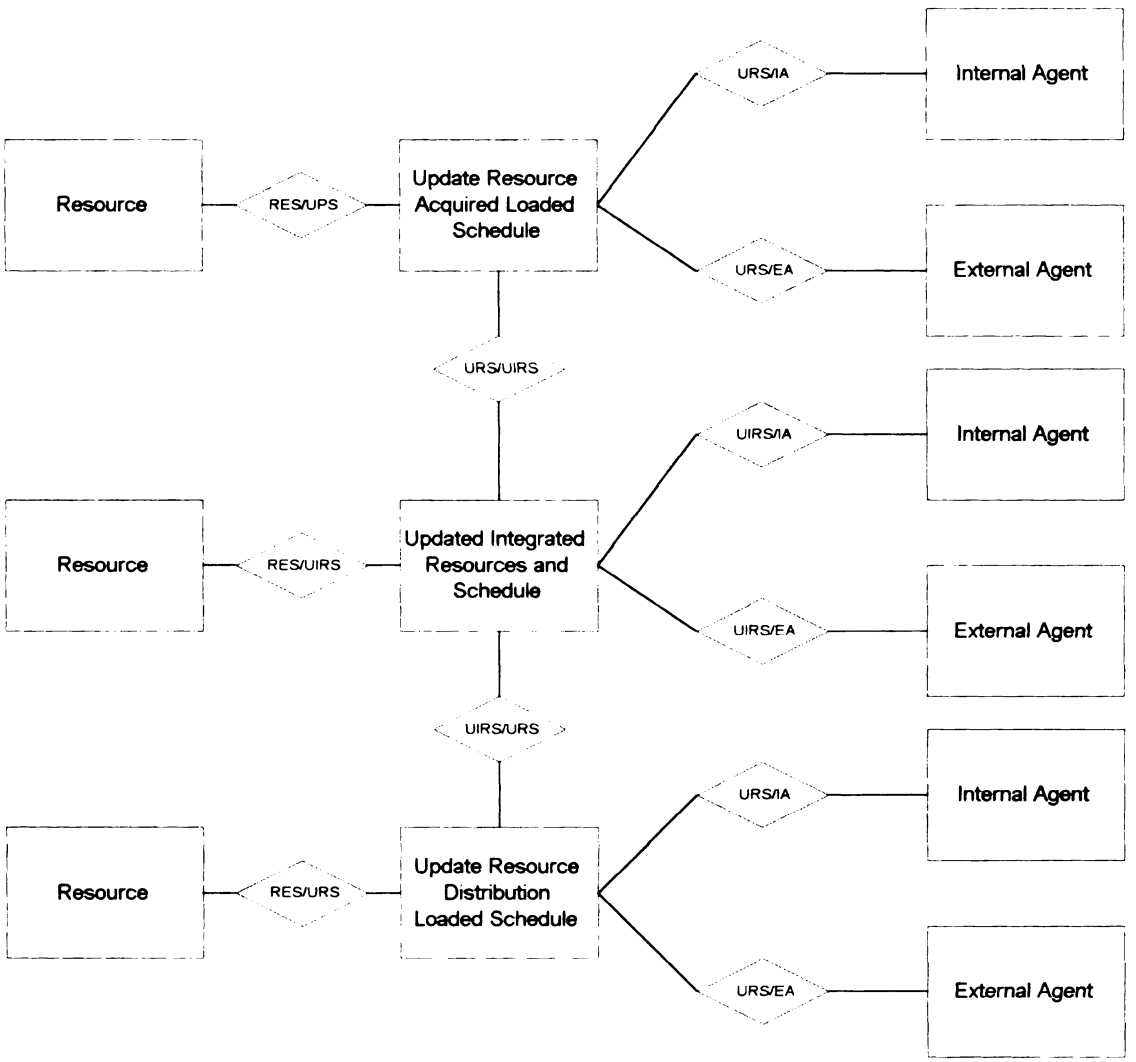


Figure 4.6 (R8 c): REA model for updating integrated resources and schedule

Project phase	Internal Agent		External Agent
View	Global view	Local view	Global view
Planning	PD, PM, AM, SM	E, S	A, O, EG
Construction	SS, SM, PM	GC, SUB, GF	A, O, EG, T
Controls	PD, PM, AM	SS, SM E, S	A, O
Close out	PD, PM, AM	SS, GC, SUB, GF	A, O, EG, T

Notes: Symbols and their description:

PD: Project Director
PM: Project Manager
AM: Accounts Manager
SM: Site Manager
E: Estimator
S: Scheduler
SS: Site Superintendent
GF: General Foreman
GC: General Contractor
SUB: Sub Contractor
A: Architect
O: Owner
EG: Engineering
T: inspection / Testing Agency

Table 4.3: Phase and View Participant Matrix (Greets and McCarthy 1998)

After developing REA models for business events under the planning and controls phase, the next step in developing the integrated REA model is to integrate all these models the using view integration technique. This is explained in the next section.

4.2.3.3 View integration

Once the various REA models are developed for business processes (business events), under the project planning and controls phase, a complete "view integration" (David 1998; McCarthy 1982) of all the above REA models is done, as shown in Figure 4.7. The integrated REA model represents the complete REA chain for the organization, for the project planning and controls phase. View integration involves connecting various REA models through the common resources and internal and external agents that are components of individual REA models (David 1998; McCarthy 1982). The resources and duality relationships or duality events are connected along the vertical frame of the model, while agents and duality events are connected along the horizontal frame of the models. For example, the resource money ($+), is common between the events "develop fund loaded schedule," "make fund related decision," and "update fund loaded schedule." These three events are also the duality events associated with each other as explained in the next section 4.2.3.3.1. The resource is connected in the vertical frame. Usually the internal agent for business events at the top level under particular project phase will be the same. For example, the PM may be an internal agent for the top level event, "develop cost loaded schedule," "develop fund loaded schedule," and "develop responsibility loaded schedule" all under the planning phase. Therefore, the business events across same project phase can be connected by using an internal agent. Similarly,

it can be argued that the external agent is same for the various business events across different project phases. For example, for a given project, the external agents can be A, E, O and will remain as the external agents throughout the project life cycle. Therefore, all the business events across the planning and controls phase can be connected using the common external agent. Thus in the integrated REA model, the internal and external agents are connected in the vertical frame. It should be noted that the set of internal and external agents will vary for underlying business processes. This set will essentially be a sub-set of the main set that includes all the internal and external agents. These classifications and hierarchies are discussed more in detail under section 4.2.4.

In this way, connecting the different REA models across project planning and controls leads to the integrated REA model for the organization. Similar view integration can be performed for REA models in the construction and controls phase. As explained earlier, the REA modeling for the construction phase is out of the scope of this research work.

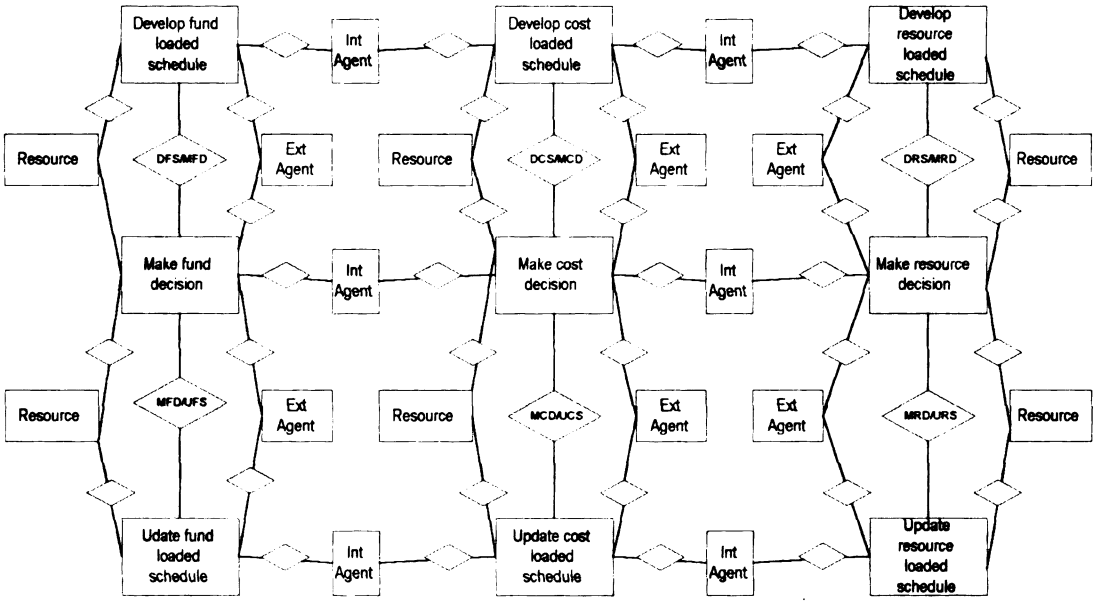


Figure 4.7: View Integration for REA models for project planning and controls phase

4.2.3.3.1 Duality relationships in the integrated REA model

The integrated REA diagram, as shown in Figure 4.7, shows duality relationship across various economic events under different project phases. For example, "develop cost loaded schedule" and "make cost decisions" are the events with duality relationship. The cost loaded schedule helps the management to measure the cost incurred for activities, compare it to the planned cost and make cost related decisions depending on cost overruns or under runs (Fischer and Aalami 1992; Russell et. al, 1997). Similarly, "make cost decisions," and "update cost loaded schedule" are the duality events. The duality relationship does not necessarily imply that two events occur simultaneously. Also these duality relations are not the conventional "give," and "take" type relations that are used in the REA modeling technique. The duality relation adopted in Figure 4.7 merely represents the impact of one event on another and also an organization's willingness to participate in the complete business cycle. These relationships can be viewed as sequential relations that define the order in which the business events will occur from top to bottom in the integrated REA model. For example, the event "develop fund loaded schedule" will lead to event "make fund decision," which in turn leads to the event "update fund loaded schedule." Each event is thus modeled individually and then view integration is performed to consolidate the individual REA diagrams into a company wide diagram (McCarthy 1982).

4.2.3.3.2 Other relationships in the integrated REA model

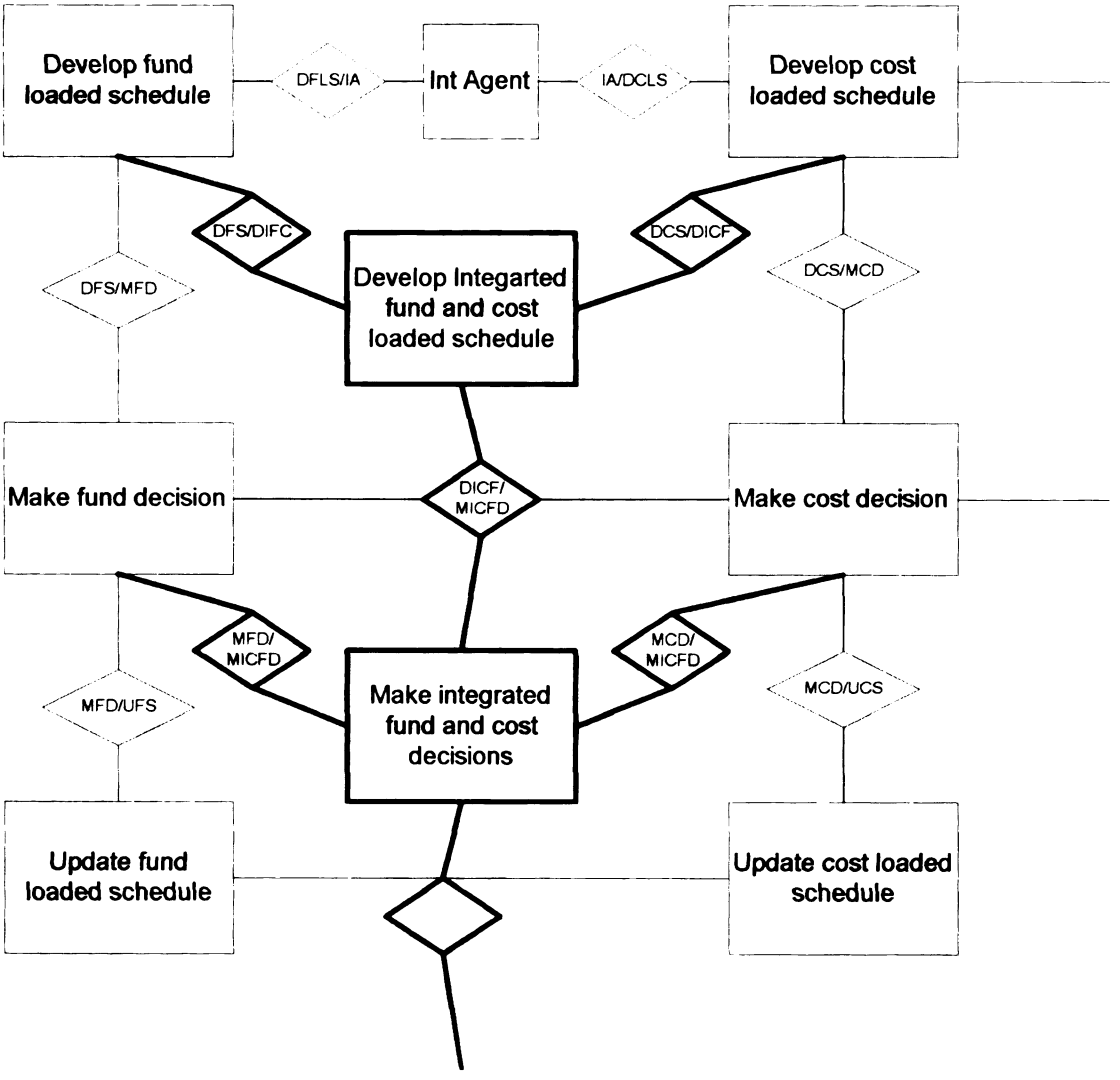
There can be other relationships shown across various economic events in the integrated REA model also. The events "develop cost loaded schedule," and "develop responsibility

loaded schedule" can be connected with a direct relationship link, even though the same can be derived based on the connections shown in the existing model, using mathematical or logical procedures. Similarly the events "develop fund loaded schedule," and "develop cost loaded schedule" can be connected together to the single event "develop integrated cost and fund loaded schedule." The associated duality event with the "develop integrated cost and fund loaded schedule" can be "make integrated costs and fund decisions." These relations are shown in Figure 4.7.1. For drawing convenience, only these other relations are shown in the diagram and all other links and connections will remain the same as shown in Figure 4.7.

4.2.3.3.3 Underlying REA models and relationships for an integrated REA model

The integrated REA model does not include economic events from the project construction phase. These economic events form the base for various economic events in the project controls phase. Therefore, corresponding to each event under the project controls phase there will be an underlying REA model for processes under the project construction phase. This can be explained using Figure 4.7.2.

There can be various events such as "execute the work activity," "measure work performed," "receive change order," etc. which may require updating the cost records within the company. This can be identified as event "update cost loaded schedule." Each of these events underlying the event "update cost loaded schedule" will have an REA pattern. Consider event "pour concrete" during the construction phase. The related duality event can be "cash disbursement" for the contractor who poured the concrete.



Legend:

——— Relationship link as in existing integrated REA model shown in Figure 4.7.

——— Other possible direct, or derived link not shown in Figure 4.7.

Figure 4.7.1: Other relationships in integrated REA model for project planning and controls

Once this event occurs, it will bring change in activity records such as duration, percent-complete, cost incurred and will need to update the schedules. The REA model for this event is shown in Figure 4.7.2. The entire model will form a "duality" event for the event "update cost loaded schedule," as it shows the reasons to update the schedule. Developing the REA models for all such events in the construction phase is out of the scope of this research work. It is assumed that the underlying models are already in place. Also the CM firm is more interested in planning and controls aspect of the project than the construction aspect (Fischer and Aalami 1992; Russell et. al, 1997).

If the view integration of REA models for the planning phase to close out phase of project is done, then it will provide the overall REA integrated model for the entire project. The REA diagrams thus demonstrate how the current system supports the organization.

This section completes the third step of view integration by developing the global view. The integrated REA model as developed above also completes the third step in achieving the first goal. The next section will describe the fourth step in detail. The fourth step includes development of the REA data model and the generalized framework for its implementation.

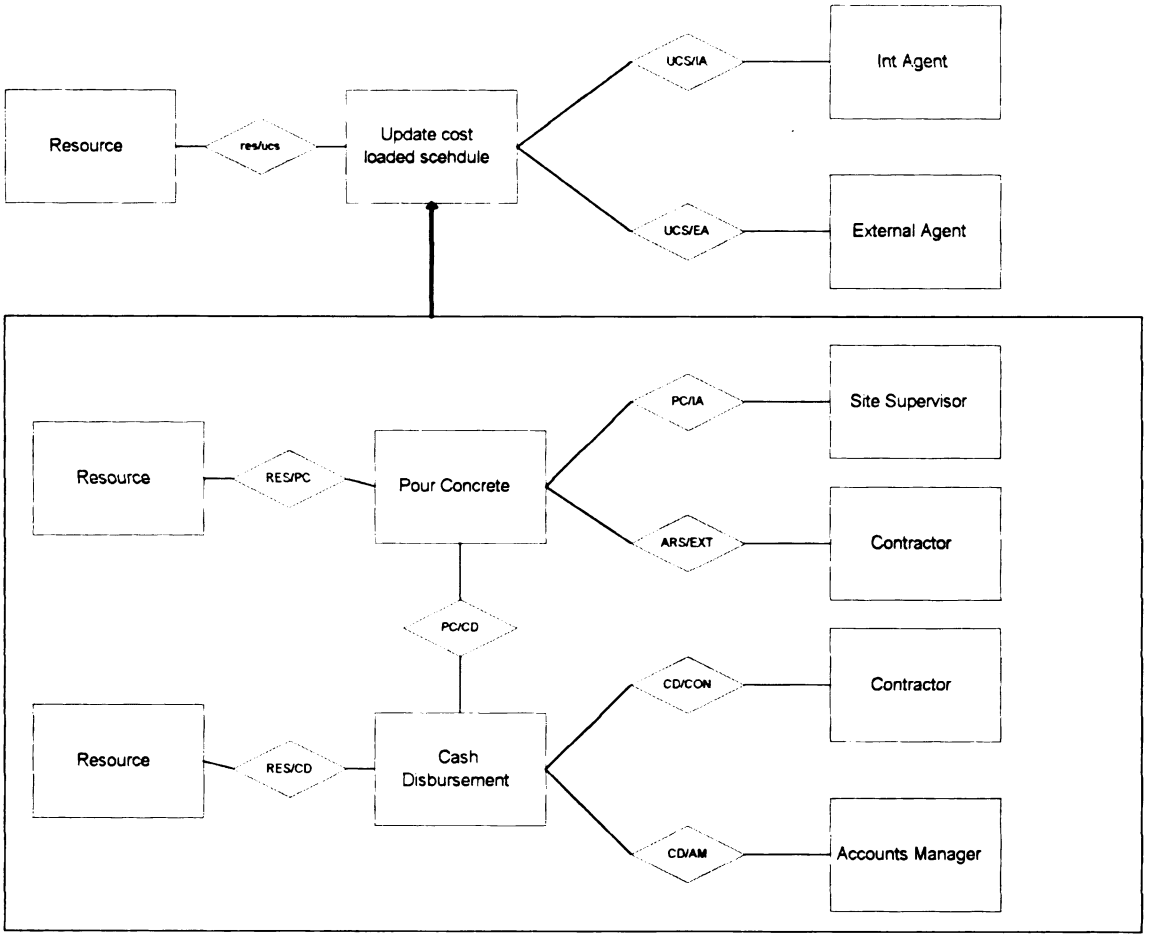


Figure 4.7.2: underlying REA models for top level project control events in the integrated REA model

4.2.4 REA data model and the REA generalized framework

The REA data model design process produces conceptual schema and external schema. Conceptual schema is the view integration of business events, expressed in terms of REA diagrams (McCarthy 1982), while external schema represents view modeling of business events, expressed in terms of REA diagrams (McCarthy 1982). Once conceptual schema and external schema are developed, then the generalized REA framework can be developed to implement the conceptual and external schema in the database system. This is explained in the section 4.2.4.2.

4.2.4.1 REA model design process

The REA data model design process is completed through following steps (McCarthy 1982):

1) Requirements analysis: The local views of data are identified such as, generate activity, develop activity logic, acquire resources and distribute resources.

2) View modeling: The local views of data are restated in terms of the REA model such as, "develop fund loaded schedule," or "develop resource loaded schedule."

3) View integration: The local views, expressed in terms of REA models, are combined into a global view such as "develop schedules," "make decisions," and "update schedules," etc.

4) External schema: This step involves determining procedures for materializing the local views from the global view, such as, updating schedules by the scheduler and updating cost-budgets by the project manager.

The output of the data model design process consists of two items: 1) an enterprise-wide model of data (global view), and 2) a set of local views accompanied by procedural specifications for their derivation from the global view. The common terms used for global and local view are conceptual schema and external schema (McCarthy 1982). The third type of specification, the internal schema, concerns physical storage considerations that are more hard-core, hardware issues and are out of the scope of this work.

The REA models constitute the following types of relationships (Stumf et. al, 1996; McCarthy 1982):

- Associations: It relates the information objects or entities of different types to form new objects. For example, the relationship "is used for" is formed by connecting the entities "resource" and "resource loaded schedule." (Stumf et. al, 1996). In Figures 4.6 (R1 a to R8 c), the associations are named after entity sets as shown in diamonds. For example, Figure 4.6 (R1 a) shows relation between "resources" and "develop cost loaded activities" event as "RES/DCA." This convention is adopted only for the sake of simplicity in drawing the figure; the logic implied in the relationship is almost self-explanatory. For example, in the Figure, 4.6 (R6a), the relationship between "make schedule related decision," and "internal agent" is of the type "is made by", where schedule related decision is made by the internal agent such as PM or PD.
- Classification: It relates the same group of entities to different class types. For example, the entities "internal agent" and "external agent" are classified into the types "developers," and "end users." The reason being that some of the internal agents act as developers while some act as end-users (Stumf et. al, 1996).

For example, the estimators and schedulers develop schedules and budgets. Whereas, project directors and project managers use these schedules and budgets. In certain cases, the same agent may be developer at one instance and end-user at another instance. For example, a project manager is involved in developing final schedules and budgets and he/she also uses the schedules and budgets developed for project controls. The classification structure is shown in Figure 4.8.

- Generalization: It relates the different subtypes or subsets of entities to a generalized type or superset. For example, the entities "labor," "material," and "equipment" generalize to the entity "resource" (Stumf et. al, 1996). The generalization used for this research work is shown in Figure 4.8. The different types of resources such as, labor, material, and equipment are all generalized to single entity called "resource." Similarly, different types of responsibilities such as managerial, strategic etc, can be generalized to single entity called "responsibility".

The overall example of database design for REA models developed for the process "develop cost loaded schedule" is shown in Figure 4.9. The focal point of the database is a conceptual schema which characterizes the object systems in terms of entities (boxes) and relationships (diamonds) (McCarthy 1982). Shown on the right side of the figure are two local views of data needed to satisfy these example users:

1) A project manager responsible for making decisions related to the cost budgets.
2) The scheduler responsible for producing various scheduling reports.

The actual database will involve many more entities and many such external schema (as suggested by dotted lines). The development of a database system using Microsoft Access is explained in section 4.2.5.1.3.

This section explained the REA data model design process and various relationships involved. Also, conceptual schema and external schema are identified. The next section will develop the generalized REA framework for implementing the conceptual and external schema in the database.

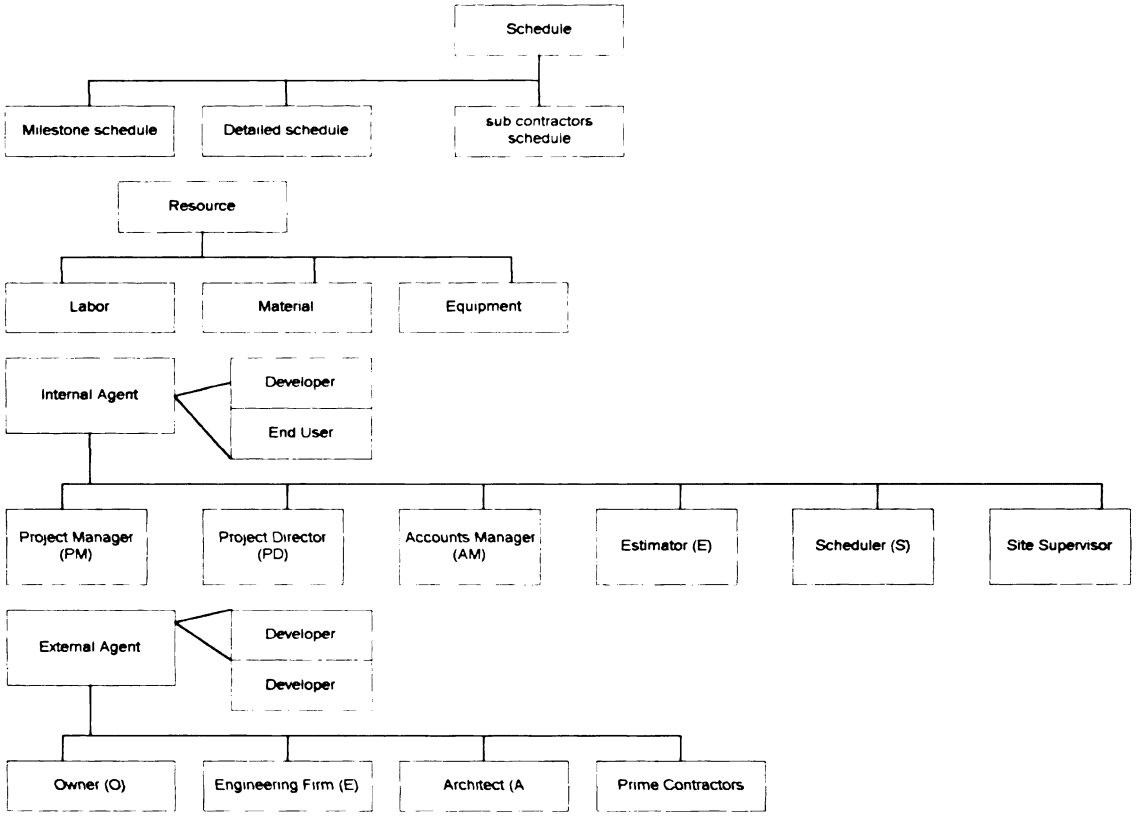


Figure 4.8: Generalization and classification hierarchy for REA model

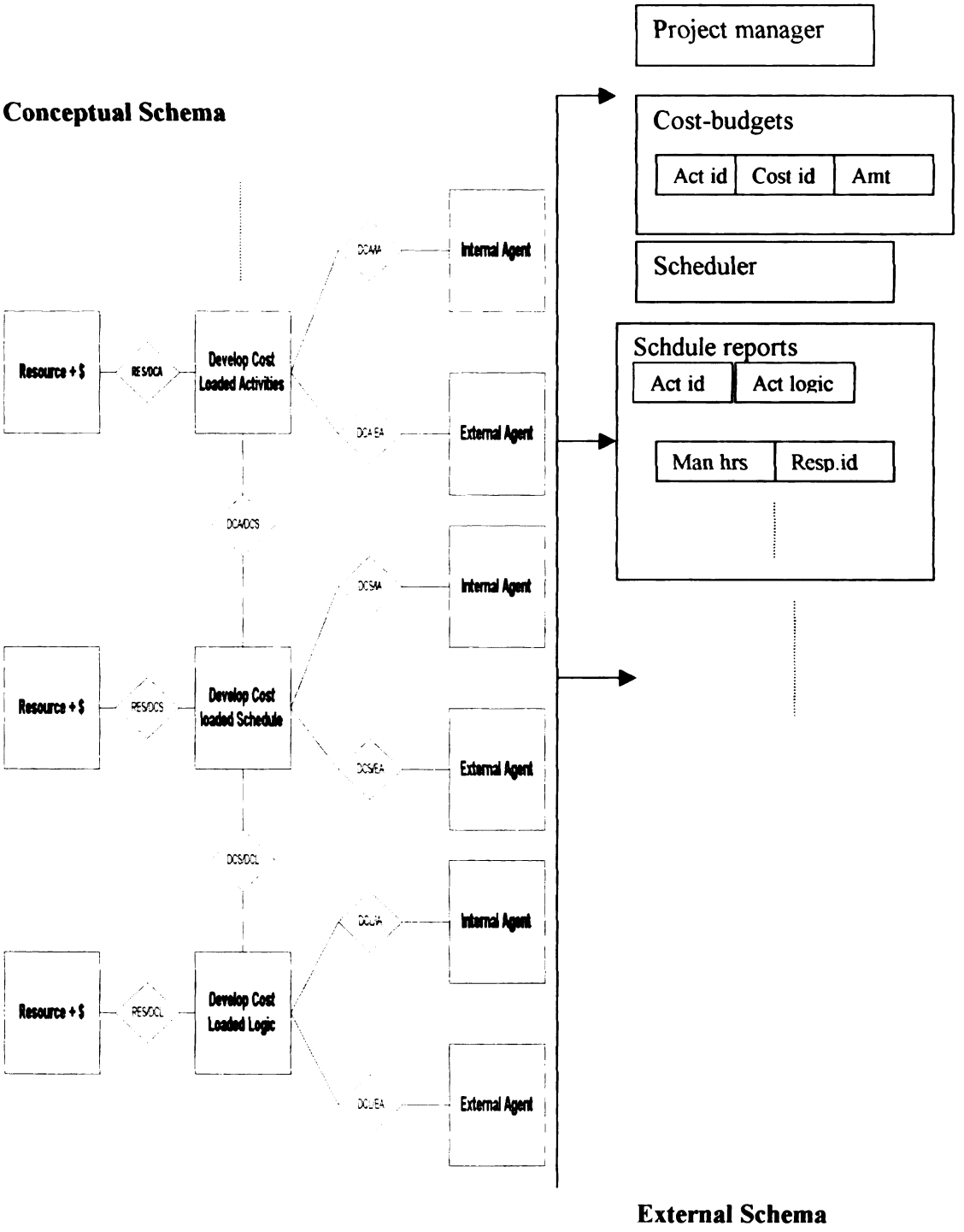


Figure 4.9: Schema specification for database

4.2.4.2 Generalized REA model framework

When all generalized elements of the REA model are combined, the R-E-A framework shown in Figure 4.10 results (McCarthy 1982). The role declarations for each of the generalized associations are illustrated in Figure 4.11. Based on this REA model as a framework, the semantic representation of local views is developed in the following sequence (McCarthy 1982):

1) The economic event involved (develop resource acquired loaded schedule) is identified, and the data elements describing that event are specified as event attributes, such as resource ID, description, budgeted quantity, as shown in Table 4.4 (Clough and Sears; Russell et. al, 1997).
2) The economic resource affected by the event (Resource) is identified along with its attributes such as Equip ID, description, cost as shown in Table 4.4, and
3) The internal and external agents in the event, say the project manager and owner, are identified along with their attributes and responsibilities. This is also shown in Table 4.4

The diagram illustrating the REA view modeling of " develop resource loaded schedule" is shown in Figure 4.6 (R2 a). The view integration of these models is done based on the following sequence as suggested by McCarthy 1982 and modified by the researcher:

1) First, the two events across planning and controls, are associated with a duality relationship with one event supporting the other event either in terms of sequence of occurrence or merely as a complimentary even.
2) Second, the external agent sets are combined for events across planning and controls. The internal agent sets are combined for events under the same phase.

3) Third, the generalization decisions are made. For example, labor, material and equipment are generalized into resource.

4) Finally, the events across different project phases are tied with the common resources.

The example of view integration is already shown in Figure 4.7. The generalized framework will include events such as, "develop schedule," "make decision," and "update schedules," which are the top level economic events.

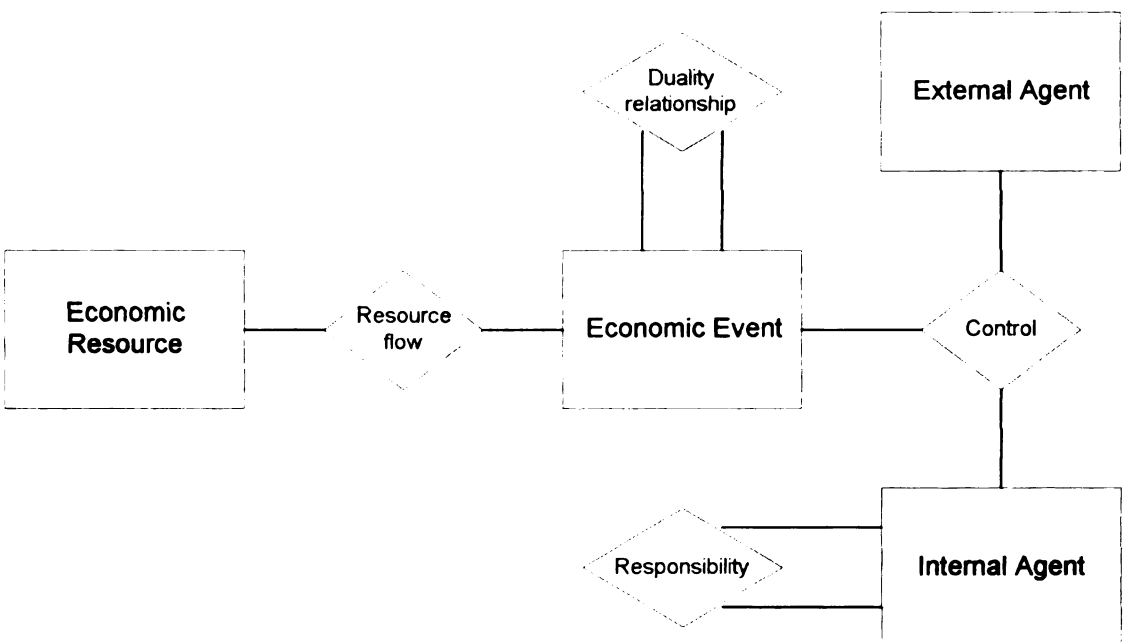


Figure 4.10: Generalized REA framework (McCarthy 1982)

Resource Flow

Participating Entity sets	Economic Resource	Economic Event
Roles	Resource	Flow

Duality

Entity sets	Economic Event	Economic Event
Roles	Increment	Decrement

Responsibility

Entity sets	Internal Agent	Internal Agent
Roles	Developer	End user

Control

Entity sets	Economic Event	Internal Agent	External Agent
Roles	Exchange Transaction	Developer / End User	End User

Figure 4.11: Role declaration

The REA framework provides a basis for declarative features of conceptual schema. These features model facts about object systems in terms of entities, association of entities and generalization of entities (McCarthy 1982). For developing a working data model, the declarative features are supplemented by procedures that specify as to how the system will use the data, or facts it has available (McCarthty, 1982). The declarative features consist of base objects. Base objects are those elements that represent economic events, resources and agents, as well as relationships between them. The procedural features consist of methods for materializing conclusions about those base objects (McCarthy 1982; Stumf et. al, 1996).

The following procedures, as recommended by McCarthy (1982), are adopted for this purpose:

1) Triggered procedures: are invoked when economic events are recognized and cause immediate updates to the base objects. An example is an update to the resource loaded schedules triggered by use of resources.
2) Adjustment procedures: affect base objects but only at specified intervals. An example is a daily or weekly adjustment to cost and funds done by the estimator or project manager by adding funds and subtracting costs.
3) View procedures: produce dynamic windows on the database through which different classes of users may separately view information. The data elements materialized as a result of view procedures are "virtual" in the sense that they exists only when the procedure is invoked. An example is a view that allows the project managers to look at imbalance between budgeted and actual values of duration and cost as "S-curves" or "real time control charts".

4) Derivation procedures: produce information derived from, but not directly affecting base objects, at periodic interval. Examples are total dollars spent for a particular month or for particular construction-phase of the project.

The capability to support all four of these procedure types varies among different database management systems. However, the commonly used scheduling software application such as Primavera, and the documentation management software application such as Prolog Manager and Expedition, are found to support these procedures as per the researcher's experience with the use of these software. These capabilities can be also verified in the software manuals for these software application packages (Expedition 1998; Primavera Project Planner 1998; Prolog Manager 1998). For this research work, the author proposes Microsoft Access as the database management system, to implement REA models. The design of this database system is explained in section 4.2.5.1.3.

This section explained the generalized REA framework for implementing conceptual and external schema. This also completes the fourth step in achieving the first goal for this research work. The next step involves the REA implementation design. This is discussed in the next section.

4.2.5 REA implementation design

The implementation design is based on the generalized framework developed in the above section. The design has two aspects, namely, logical design and physical design as suggested by McCarthy (1982).

Logical design: This involves the translation of the global REA model and various views into the schema definition language and the subschema definition language of a particular database management system proposed for the use in the company. The output of this phase also includes volume and usage information, program design guidance and other physical guidelines for the database administration staff (Fischer and Kunz 1995; McCarthy 1982).

Physical design: It is the process of selecting the data storage and data access characteristics of the database. It affects not only the location of the data in the storage device, but also the performance. The various issues that need to be addressed under physical design are, performance, security, access rights, data encryption, backup and recovery, data integrity, company standards and control levels (Fischer and Kunz 1995; McCarthy 1982).

The physical design is out of the scope of this research work. The logical design is done using Microsoft Access database system. This is explained in the following sections.

4.2.5.1 Logical design

The logical design is accomplished through the following three steps (McCarthy 1982):

a) Identifying and storing the key business events as entities in the database
b) Identifying the data elements, which become the attribute of the entities
c) Designing the database system by selecting particular database system such as, Microsoft Access

4.2.5.1.1 Identification and storage of key business events

Once the business event-level analysis has been completed as presented in the previous section, the key business events are identified. These key events along with their attributes are stored in the database system as entities (David 1998; McCarthy 1982). By definition, each of the events included on the business level diagram (4.6 (R1a) to 4.6 (R10c)) are important to the management, and once they occur the world has changed and new information is available that could be used to make decisions. Therefore, it is necessary to develop a detailed list of attributes that are necessary to store the event. Once the attributes have been identified, then a database can be created. In general, each entity will become a table in the database, with a key attribute to uniquely identify each entity, and various other attributes that describe the entity (David 1998; McCarthy 1982). In addition the relationship between the entities will be implemented so that the data across tables can be integrated to respond to the management requests. In this manner, integrating REA models will lead to merging the Unique IDs for various entities in the database tables (McCarthy 1982).

4.2.5.1.2 Identification of data elements

After identifying the entities, the database tables are developed for various entities with their attributes. The following concepts are also incorporated in the REA models developed in the earlier sections, in addition to the generalization and classification (McCarthy 1982; Stumf et. al, 1996):

- Aggregation: This is a relationship between component and sub component, for example, the events "build activity," and "build activity logic" are part of building schedule.
- Grouping: This is a relation between a member object and a set object; for example, an inspection agent is a member of an inspection team or agency.

These concepts are used during the actual database implementation of REA models.

The attributes are the required data elements that originate from the planning phase and are required to flow through the project construction and controls phase. For this research work only time and cost related data elements are used such as "activity cost," "activity duration," "resource cost," "labor hours," etc. These are shown in Table 4.4. The attributes and elements such as "personnel," "responsibility function," etc., need not be modeled but can be simply used as additional attributes for the other entities in the database.

4.2.5.1.3 Design of a database system using Microsoft Access

The proposed REA model is implemented using Microsoft Access as the database system (Access 1997). According to researcher's experience with this software, it is easy to design, operate and manage the database system using Access as compared to many other database management systems (Access 1997). The Access database system has the following main components: Tables, Queries, Forms and Reports. All of them are discussed in brief here and the reader is advised to refer to the manual for Microsoft Access 97, for further knowledge.

ENTITY	ATTRIBUTES					
	Unique id	Other attributes				
Labor	Emp#	Address	Name	Category	Crew	Budgeted Qty
Material	Mat#	Desciption	Suppl #	Supp Name	Unit	Budgeted Qty
Equipment	Equp#	Desciption	Suppl #	Supp Name	Type	Budgeted Qty
Activity	Act ID	Description	Division	Start Date	Finish Date	
Logic	logic ID	Description				
Cost	Cost ID	Description	Division	Direct Cost	Indirect Cost	Total cost
Fund	Fund ID	Description	Division	Total Amount		
Responsibility	Resp ID	Description				
Cost loaded activity	**Act ID**	**Cost ID**			**Resp ID**	
Cost loaded logic	**Logic ID**	**Cost ID**			**Resp ID**	
Fund loaded activity	**Fund ID**	**Act ID**			**Resp ID**	
Fund loaded logic	**Fund ID**	**Logic ID**			**Resp ID**	
Resource loaded activity	**Emp#**	**Mat#**	**Equp#**	**Act ID**	**Resp ID**	
Resource loaded logic	**Emp#**	**Mat#**	**Equp#**	**logicID**	**Resp ID**	
Project Manager	Emp#	Name	Address	Pay	Resp ID	
Project Director	Emp#	Name	Address	Pay	Resp ID	
Accounts Manager	Emp#	Name	Address	Pay	Resp ID	
Schedular	Emp#	Name	Address	Pay	Resp ID	
Estimator	Emp#	Name	Address	Pay	Resp ID	
Site Supervisor	Emp#	Name	Address	Pay	Resp ID	
General Foreman	Emp#	Name	Address	Pay	Resp ID	
Site Manager	Emp#	Name	Address	Pay	Resp ID	
Owner	Name	Name	Address	Pay	Resp ID	
Architect	Name	Name	Address	Pay	Resp ID	
Engineer	Name	Name	Address	Pay	Resp ID	
Agency	Name	Name	Address	Pay	Resp ID	
General Contractor	Name	Name	Address	Pay	Resp ID	

Table 4.4: Entity and Attributes table (David 1998)

i) Tables:

The two steps as described in section 4.2.5.1.1 and 4.2.5.1.2 above are implemented in the Access database system and the resulting database table structures with various entities and their attributes as shown in Figure 4.12. Each row of this table corresponds to each table in the complete database.

The unique IDs for various entities can be joined or merged together to produce the entity that makes use of both the unique IDs as its identification key (Access 1997). In Figure 4.12, the "Bold Type" IDs indicate that they are merged and other attributes attached to the Unique IDs can be made available whenever required. For example, the entity "cost loaded activity" uses "Act ID," and "Cost ID" attributes and all other attributes attached with these two can be made available for this entity. Note that "Resp ID" is simply used as another attribute for cost and fund loaded schedules and represents the person responsible for that particular schedule. Similarly, the person responsible for management of a particular activity, is indicated by "Resp ID," attribute for the entity "Activity" The relationship between these entities as described in the REA models (section 4.2.4.1), is used to create relationships between different database tables.

ii) Queries:

The queries are set of criteria that retrieve data elements from the underlying tables based on the criteria. Queries can be designed, based on single or multiple tables. They essentially make use of various relations implemented across different database tables (Access 1997).

An example of a simple summary query is shown in Figure 4.13. This query calculates the total cost for various activities and total duration for all these activities. The total cost

and total duration is obtained by summarizing ("criteria") the cost and duration for individual activities. The results are stored under the field total cost and total duration in the database table.

iii) Forms:

The forms are customized menus or screens that allow the end user to add new record, or update the existing records from the underlying tables. The forms are based on tables and or queries (Access 1997)

An example of form used for adding new activity is shown in Figure 4.14. The scheduler can enter information in the various fields for the entity "activity".

iv) Reports:

The reports are customized screens or printouts of the selected records from the database tables. The reports can be based on the tables, forms and queries (Access 1997).

An example of reports such as S-curves and real time control charts, used in this research work, is explained below:

Example 1: Generating S-curves

The management needs to generate an S-curve for total cost spent for activities, over the duration of the project. The attributes required are total cost and total duration, which are obtained by the summary query as explained above. This data in the query is used to generate the graphs of cost vs. time, i.e., S-curves. Also, this data can be imported into the spreadsheet such as Microsoft Excel, to generate the customized charts and graphs (Excel 1997).

TABLE 1	TABLE 2	TABLE 3	TABLE4	TABLE 5
Labor	Material	Equipment	Activity	Logic
Emp #	**Mat#**	**Equp#**	**Act ID**	**Logic ID**
Add	Description	Description	Description	Description
Name	Supplier #	Supplier #	Division	
Category	Supplier Name	Supplier Name	Start Date	
Crew	unit	Type	Finish date	
Qty	Qty	Qty		
Rate	Rate	Rate		
Cost	Cost	Cost		

TABLE 6	TABLE 7	TABLE 8	TABLE 9
Cost	Fund	Responsibility	Cost loaded activity
Cost ID	**Fund ID**	**Resp ID**	**Act ID**
Description	Description	Description	**Cost ID**
Division	Division		**Resp ID**
Direct cost	Total Amount		
Indirect cost			
Total cost			

Figure 4.12: Database tables (Access 1997)

TABLE4		**TABLE 6**
Activity		Cost
Act ID		**Cost ID**
Description		Description
Division		Diviosion
Start Date		Direct cost
Finish date		Indirect cost
QUERY TABLE		
Total Cost	**Total Duration**	
$$$$	no.of days	**Activity**
$$$$	no.of days	**Activity**
$$$$	no.of days	**Activity**
$$$$	no.of days	**Activity**
..	.....	**Activity**
...	..	..

Figure 4.13: Summary query example (Access 1997)

Data input form for "Activity"

Activity ID

Activity Description

Start Date

Finish Date

Logic ID

Click on this button after you are done click

Figure 4.14: Example of Form (Access 1997)

For Project Manager, the other information that will be useful in the S-curve is the person responsible, the resources attached to the activity, the funding attached to the project milestones etc. (Clough and Sears 1998; Russell et. al, 1997). Using the relationships that are implemented across different database tables, this information can be easily pulled up in the same S-curve reports. For this example, the data from "Responsibility," "Resources," and "Fund" tables is retrieved in the S-curve report. This is also based on a query, which can be designed using structured query language (SQL) or by programming in Visual Basic language (VB). In this manner, S-curves for various project variables can be generated, along with the other necessary information required by the project manager. The S-curves are shown in Figure 4.15.

Example 2: Generating real time control charts

The real time control charts are those portions of S curve only, which affect the project progress during a particular project phase (Russell et. al, 1997). From the database point of view, this requires writing a parameter query. The parameter query will allow the project manager to select such variables from the database tables or directly from S curve reports, and then generate the real time control chart (Access 1997). Again, these charts can be generated in the Access or in the spreadsheet such as Excel. The real time control chart is shown in Figure 4.15.

The interesting feature of this database system is that the end user, like a project manager, need not worry about the query design part. The user-friendly screens, such as forms, allow him to enter his data or choose from the available data and generate reports

in one click of button (Access 1997). Once the reports are generated, the management can now make decisions based on the nature of the report and take necessary actions.

The next section will describe the data storage system, as used in the CM environment, and how the proposed database system in this work can be used to integrate the data from the different data stores.

4.2.5.2 Data storage system in CM firm

According to the researcher's knowledge and experience, the CM firms usually store the scheduling data in Primavera, whereas the project documentation and management data is stored in Expedition or Prolog Manager. The cost and budget data is usually stored in database systems like Access or spreadsheets like Excel. Using the open database connectivity feature (ODBC), these software applications can exchange data with the Access database system (Expedition 1998; Primavera Project Planer 1998; Prolog Manager 1998), which is designed based on the REA models. For example, Cost ID from spreadsheet, Act ID from Primavera, and Resp ID from Expedition can be merged in single table in the proposed database. Therefore, the proposed database system will have all the information from different data storage systems. Thus, the REA modeling technique helps in integrating the data from different data storage systems into a single database management system (McCarthy 1982). The design of a complete relational database system is out of the scope of this work but the sample example of tables, queries, forms and reports was explained in the previous sections.

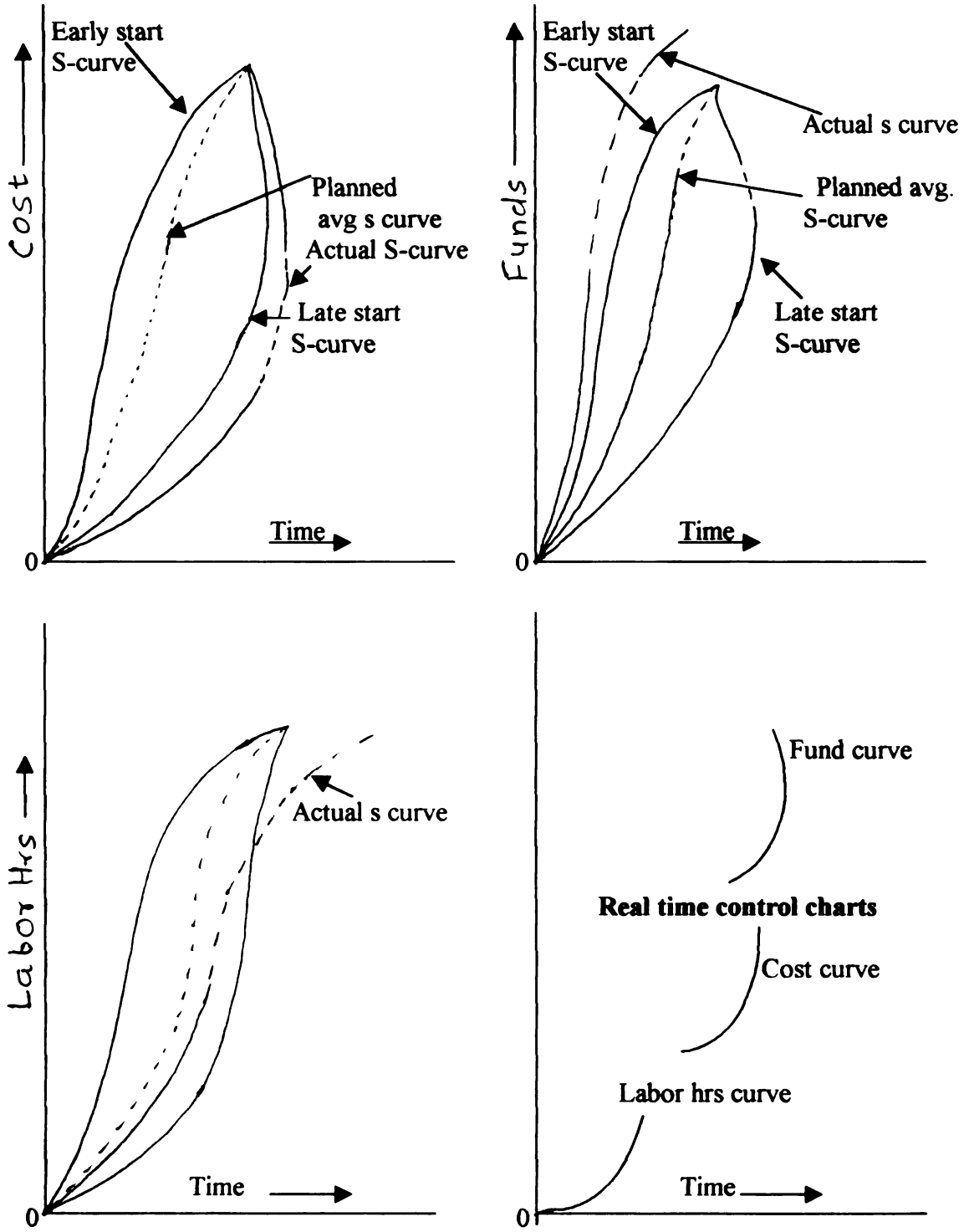


Figure 4.15: S curves and real time control charts (Clough and Sears 1998; Russell et. al, 1997)

This section described the final step in achieving the first goal. With the design of a database system to implement the REA models, the first goal of designing the REA model and its implementation framework is also complete. The next goal is to develop the information system.

4.3 Second goal: Development of an information system

The second goal is the development of an information system that will make use of the proposed REA model. This includes designing the components of an information system such as, data warehouse, decision support system, and project controls system. These components are discussed in the following sections.

4.3.1 Data warehouse

A data warehouse is a collection of data which supports corporate reporting and decision-making. The data is subject-oriented, integrated, non-volatile and is time variant (Wirth 1999; Whitten and Bentley 1998). The data warehouse design includes data warehouse architecture and implementation methodology. These are discussed in the subsequent sections.

4.3.1.1 Data warehouse architecture

The data warehouse architecture stores the corporate data in a structured manner. The corporate data includes the data about various project processes such as scheduling, budgeting, and documentation control. Typical data warehouse architecture is shown in Figure 4.16. The architecture has the following components:

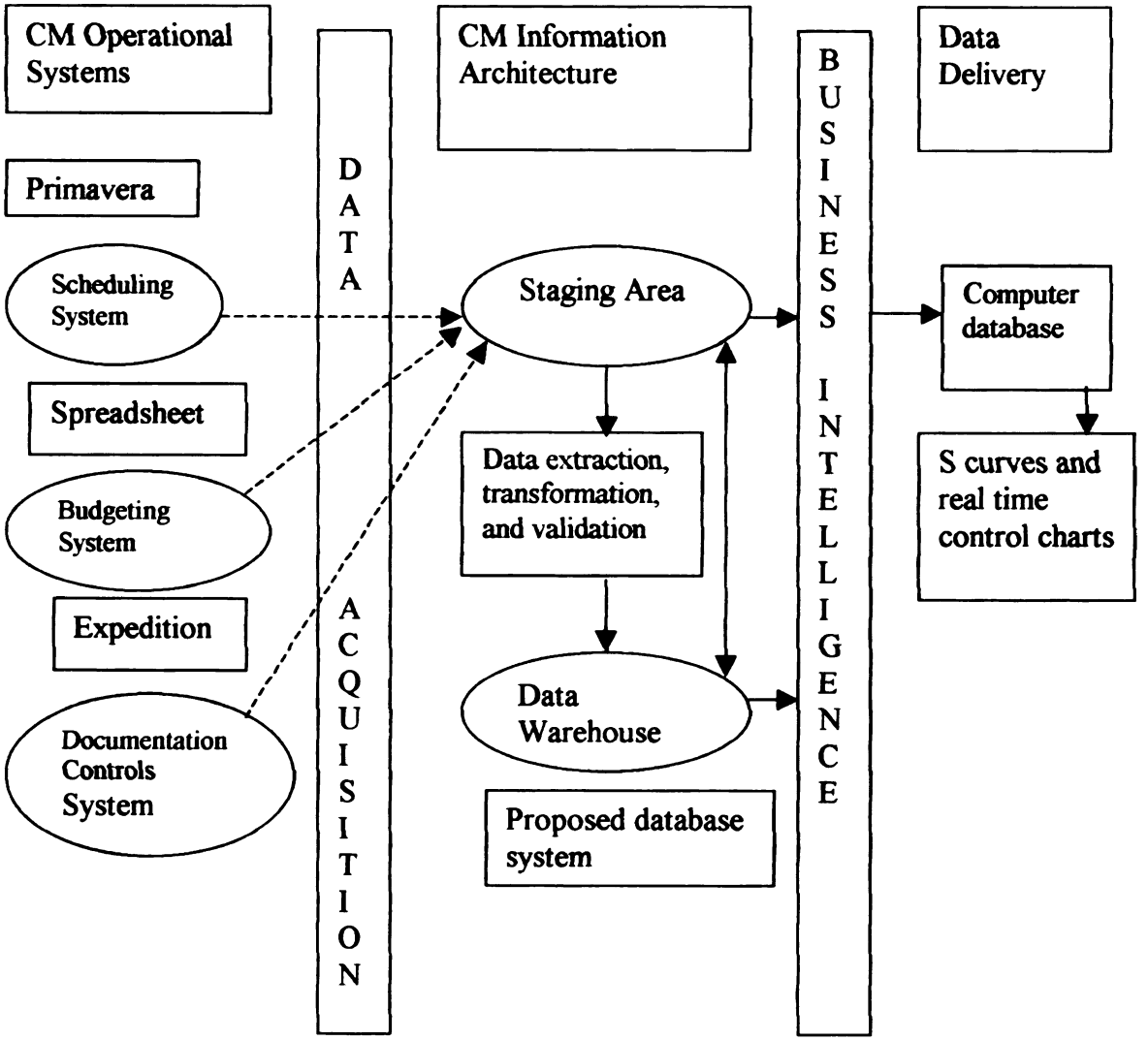


Figure 4.16: Data Warehouse Architecture (Wirth 1999)

- Operational data store (Wirth 1999): This contains the data elements (attributes from Table 4.4) related to scheduling, budgeting and documentation control. The scheduling data is stored in Primavera, the budgeting data is stored in database or spreadsheets, and Expedition or Prolog Manager is used for the purpose of documentation control purpose. The data in each of the storage system can be used for organization wide tactical decision-making.
- Data warehouse (Wirth 1999): This contains snapshots of data extracted from the operational sources as explained above. The data from scheduling, budgeting and documentation control storage system is integrated, cleansed and loaded in the central database system, such as Access, for strategic decision support. This includes any designed schema, fact and dimension tables, data aggregation to meet end user's requirements, and also the historical repository (knowledge-base), which is designed to provide short and long term business planning and decision making.
- Data delivery (query and reporting) tools (Wirth 1999): There are multiple interfaces available for the end users such as project managers or project directors who need access to corporate information for decision-making purposes. The common interfaces are standard reporting, Ad hoc query, and report distribution tools. This research work makes use of standard reporting tools such as S-curves and real time control charts that are generated from the available data in the database tables. The use of S-curves and real time control charts is explained in detail in section 4.3.3.3.1.

The database system developed in this research work is the core of the data warehouse architecture. This database system has all the data elements from the individual database systems. Also there is a direct two way link between the proposed database system and the individual database systems under the CM operational systems. This link will allow the data transfer in both directions. Further, the end user can have a control over the individual database system as well as the integrated database system. This linking is the "technical integration" aspect of the proposed integrated system as described in section 4.1. The design of such a link is out of the scope of this research work and will be addressed under areas of future research in chapter 6.

This section described the architecture of a data warehouse. The next section will describe the implementation methodology used to implement the architecture.

4.3.1.2 Data warehouse implementation methodology

The implementation methodology cycle is shown in Figure 4.17. It is clear that the implementation is an iterative process that starts with a needs identification phase and finishes at the user training. The end user tool configuration and testing is the core of the implementation (Wirth 1999, Whitten and Bentley 1998). The phases are discussed in brief in the following paragraphs.

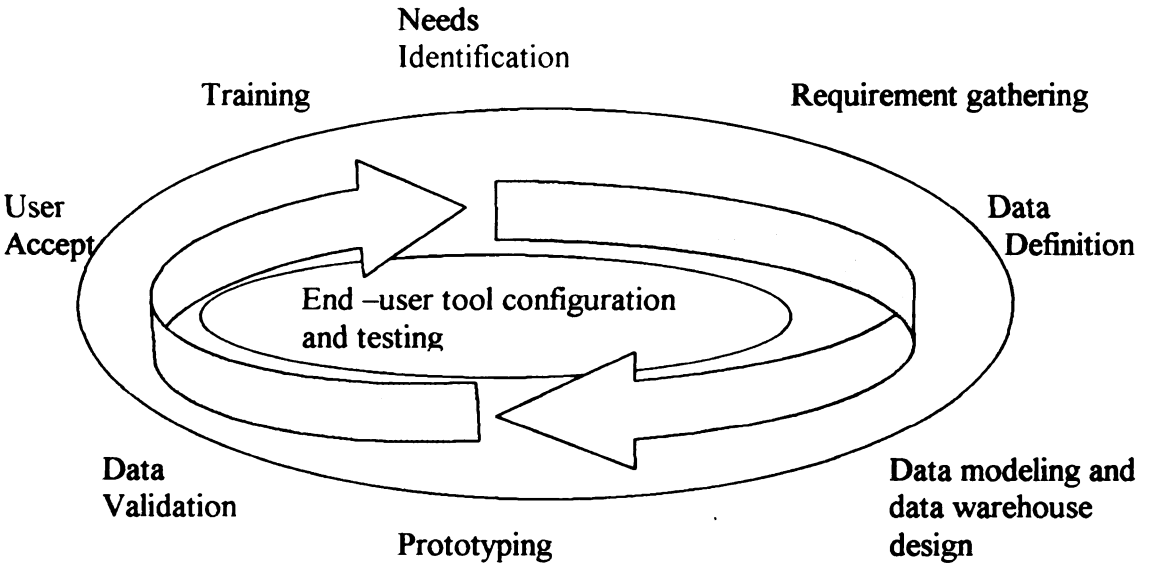


Figure 4.17: Implementation Methodology Cycle (Source: Wirth 1999)

1) Needs identification and requirements gathering: The top priority is to gather the requirements that support the business goals of the enterprise. This involves data acquisition, data definitions and data structure design (Wirth 1999, McCarthy et. al, 1998, Whitten and Bentley 1998). The main considerations are subject areas, different reports and uniform data definitions. The IT staff analyzes various data storage systems available to support various functioning aspects such as budgeting, scheduling and documentation control and makes recommendations regarding any customization or improvements required in the same. The IT staff may also recommend the design of new system such as central database system to integrate the data in various data storage systems.

2) Data modeling and prototyping: Modeling the underlying business processes and identifying the data repositories should be done before developing the data warehouse. This is achieved by developing the value chain and subsequent REA models for planning and project controls, as explained in the previous section 4.2.1. The prototyping helps building the consensus. It helps in staying focused on meeting the business goals and identifying areas that may need to be investigated and restructured prior to going into the design of new systems (Wirth 1999, McCarthy et. al, 1998, Whitten and Bentley 1998). Thus a prototype model should be developed to suit the nature of business. This prototype model is an integrated REA model, called global view, as developed in the section, 4.2.3.3.

3) User acceptance: The data warehouse is not complete with the user acceptance because as the style of business changes, the business goals change and thus user requirements change necessitating the modification of the data warehouse (Wirth 1999, McCarthy et. al, 1998, Whitten and Bentley 1998).

The data warehouse provides the real time data required for the decision-making purpose. This completes the design of data warehouse, the first step in developing an information system. The next step of designing the decision support system is discussed in the next section.

4.3.2 Decision support system

The decision support system involves the decision- making mechanism and project controls tools. The goal of the decision support system is to assist in the decision-making process, during the project controls phase (Sanvido and Paulson 1992; Russell et. al, 1997, Zapalac et. al, 1994). The REA modeling helps in developing the database system, which integrates the data related to time and cost, across the project planning and controls phase, providing the real time data whenever required. The decision-making process is discussed in the next section, whereas the project control tools are discussed under the project control system, in section 4.3.3.3.

4.3.2.1 Decision making mechanism

The decision-making mechanism involves three phases such as, intelligence phase, design phase, and the choice phase (Sanvido and Paulson 1992). These are discussed in detail in the following sub sections.

4.3.2.1.1 Intelligence Phase

Depending on whether the actual S-curve lies within the limits of early start and late start curves or not, the decision-maker (PM or PD) recognizes the problem and gathers the data (Clough and Sears 1998; Russell et. al, 1997). For example, using the S-curve for

total cost vs. total duration, as explained in section 4.2.5.1.3 (iv), the PM will gather data about the activity durations, allocated costs, resources, person responsible, etc. The data can be gathered from the data storage system or may need communication between the PM and other project participants such as scheduler, estimator, and site superintendent (Sanvido and Paulson 1992). The decision-maker needs to assemble the information to identify and determine the nature of the problem. Figure 4.18, is the flow chart showing how to collect and analyze information in different phases (Sanvido and Paulson 1992). In the first phase, the project control system will highlight the problem and its cause and the decision-maker can then proceed to solution development and implementation. If the project control system does not identify the cause of problem, the decision-maker proceeds to phase two, comprising of problem orientation, data collection and data analysis. If the problem is identified, the development of solution is next step. If the problem is still not identified, then the user moves to phase three, where further data is collected and analyzed prior to solution development. Once the problem is identified then the decision-making mechanism develops the solutions.

4.3.2.1.2 Design phase

This phase focuses on developing alternative solutions. Depending on the nature of S curves for different variables such as, "total cost spent," "total labor hours spent," "total equipment hours spent," "total funds spent," etc., the project manager can make decisions about the resources, money, activity schedules and budgets (Clough and Sears 1998; Russell et. al, 1994).

4.3.2.1.3 Choice phase

In this phase the project manager will select the best alternative looking at the real time control charts generated from S-curves, as explained in section 4.2.5.1.3 (iv), example 2, for different variables. The choice phase involves evaluating each of the proposed project variables, and choosing one of them on the basis a of given set of criteria. The criteria could be completion date forced by the owner, availability of more resources to accelerate the projects, etc. (Clough and Sears 1998; Russell et. al, 1997). This is done by an individual PM or groups, depending up on the decision-making structure as defined by the decision-hierarchy matrix, shown in Figure 3.3.3, chapter 3. Examples of groups are quality circles, steering committees, employee groups, problem solving teams etc. (Sanvido and Paulson 1992).

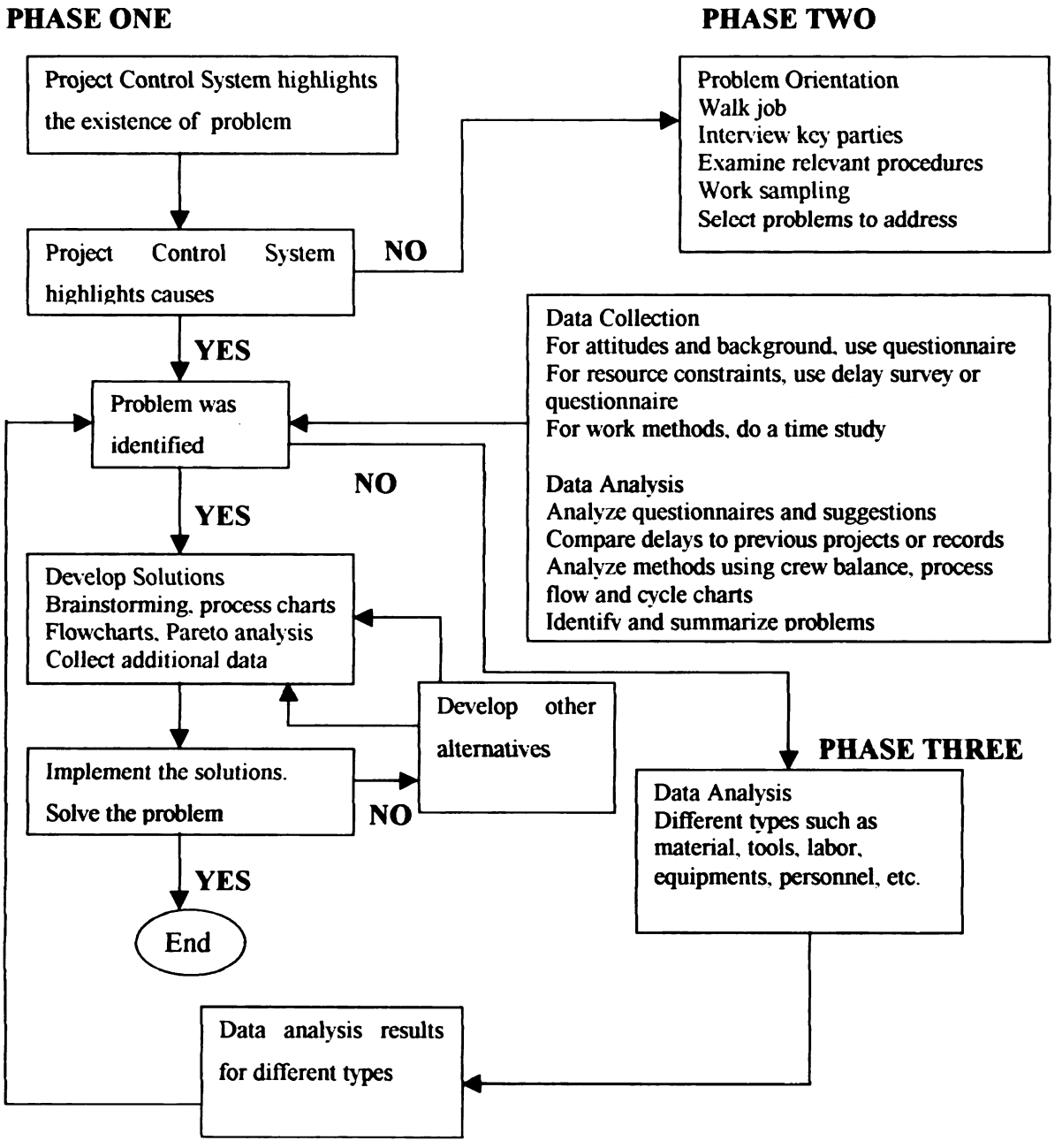


Figure 4.18: Flow chart for information collection and analysis (Source: Sanvido and Paulson 1992)

In each of the above phases, the specific information will be provided by the integrated database system to the decision-makers (individual or group) at each control level, as explained in section 4.3.3.2. The decision process is aided by information storage, which consists of current information and knowledge base. Current information is mainly used for project controls while the knowledge base is used for future planning (Sanvido and Paulson 1992; Warszawski 1985).

The database system proposed in this research work, focuses only on the current information, which is stored in the database tables, and developing a knowledge base is out of the scope of this research and is discussed in chapter 6, future areas of research.

This completes the design of the decision support system, which is the second step in developing an information system. The next step is to design the project control system. This is discussed in the next section.

4.3.3 Project control system

The project control system consists of a project control cycle, the control functions and levels of project participants, and the project control tools such as S-curves and real time control charts (Clough and Sears 1998; Sanvido and Paulson 1992; Russell et. al, 1997). The project participants make use of the project control tools for the decision- making process, during the project control cycle. These system components are described in the following sections.

4.3.3.1 Project control cycle

The project control cycle for the CM firm is shown in Figure 4.19 (Clough and Sears 1998). The core component of such a project control cycle is the project controls processes and the flow of the data elements during these processes.

The value chain identified for the CM Company (Figure 4.3) shows the processes involved in project controls phase. These are, make schedule decisions, make budget decisions, and make resource decisions. However, these are the first level economic events and are further decomposed into sub events such as, measure and compare schedule, budget and resource component. All these sub events, identified as business events in the REA model, have the data elements such as planned values and actual values as their attributes. These elements were shown as the output of project planning and construction phase in Figure 4.5. These events were identified in the beginning under process tree diagrams in section 4.2. The values of these attributes are used to generate "S curves" for schedule, budget and resource components. The S-curves in turn generate "real time control charts", which are used by the project management team to make decisions (Russell et. al, 1997). Depending up on nature of S-curves and real time control charts, the decisions are made regarding schedule, budget, and resources, which initiates the final three processes in project controls phase, i.e. update schedules, update budgets and update resources. The schedule, budget and resource values used to generate S-curves are already shown in Table 4.4. The entire project control system along with various processes is shown in Figure 4.20.

The decision making process involves various control functions and its levels, as described in the next section.

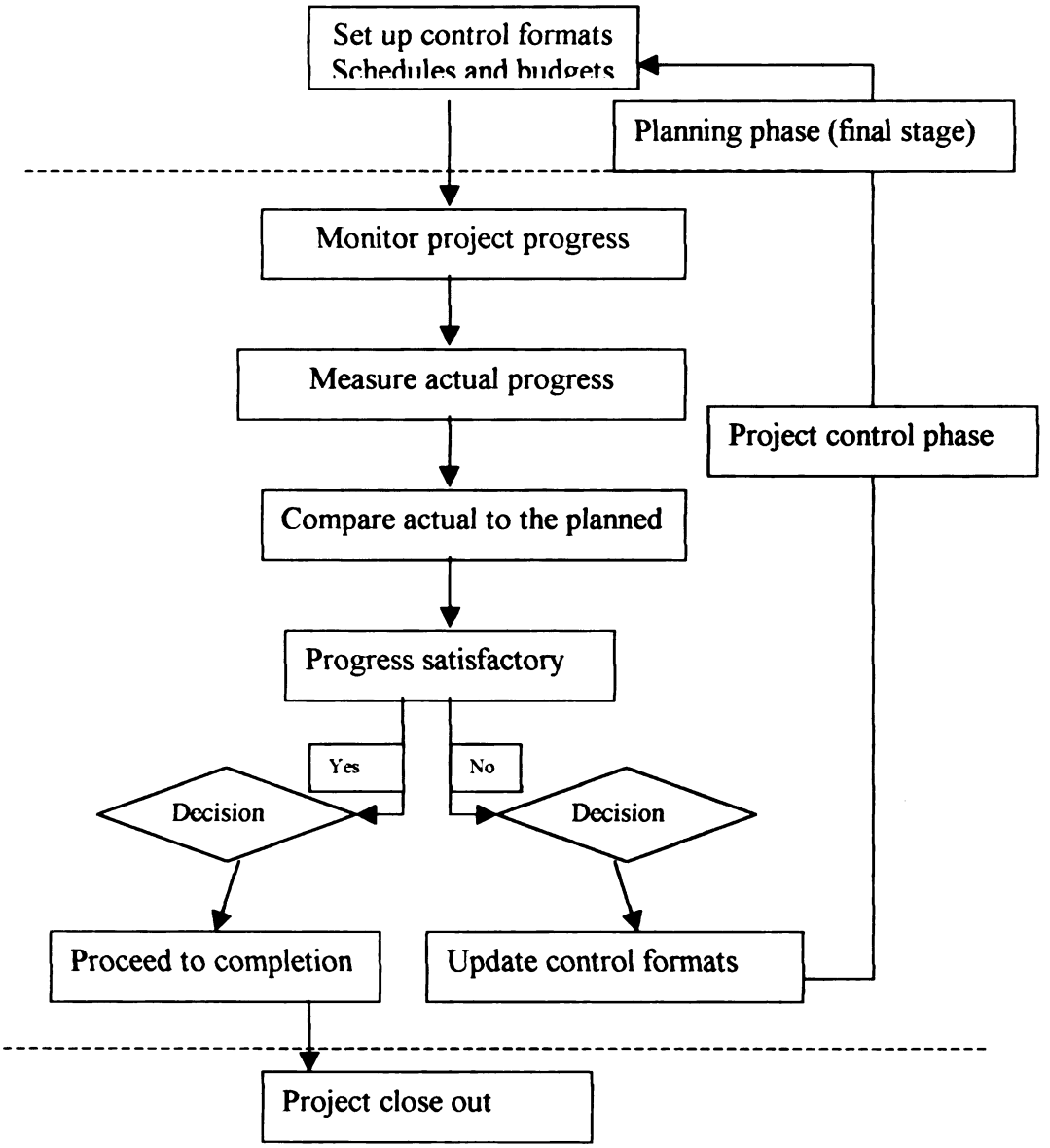


Figure 4.19: Project control cycle (Clough and Sears 1998)

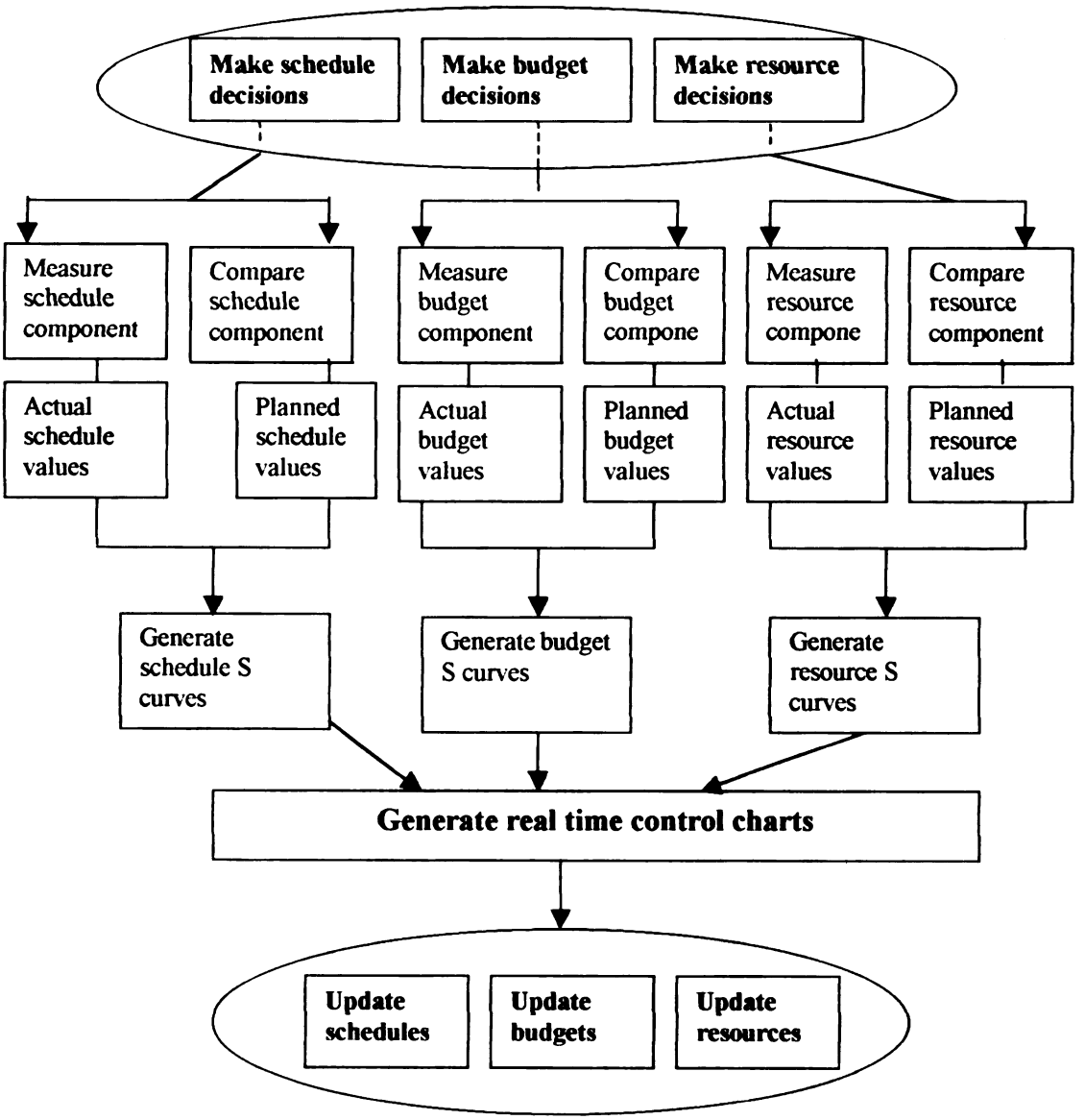


Figure 4.20: Project Control System

4.3.3.2 Control functions and its level

Usually three levels can be defined for a typical large size project (Sanvido and Paulson 1992). These are as follows:

- Strategic control: This is a process of deciding on the objectives of the organization, on changes in these objectives, on the resources used to attain these objectives and on the policies and procedures that govern acquisition, use and disposal of these resources. The strategic control is at the top level in the organizational hierarchy that includes the project participant such as project director, owner, etc. (Clough and Sears 1998; Zapalc et. al, 1994) as shown in Figure 4.21).
- Management control: This is a process by which managers assure that resources are obtained and used effectively and efficiently in the accomplishment of the organization's objectives. Management control is the next level in the hierarchy and includes PM, AM, S, E (Clough and Sears 1998; Zapalc et. al, 1994), as shown in Figure 4.21.
- Operational control: This is a process of assuring that the specific tasks are carried out effectively and efficiently (Sanvido and Paulson 1992). The operational control is at the last level in the hierarchy and includes GC, and GF etc., as shown in Figure 4.21.

As discussed in the earlier sections of REA modeling (section 4.2.3), the various control levels are merely attached as an additional attribute, "Resp ID," to the particular activity in the database.

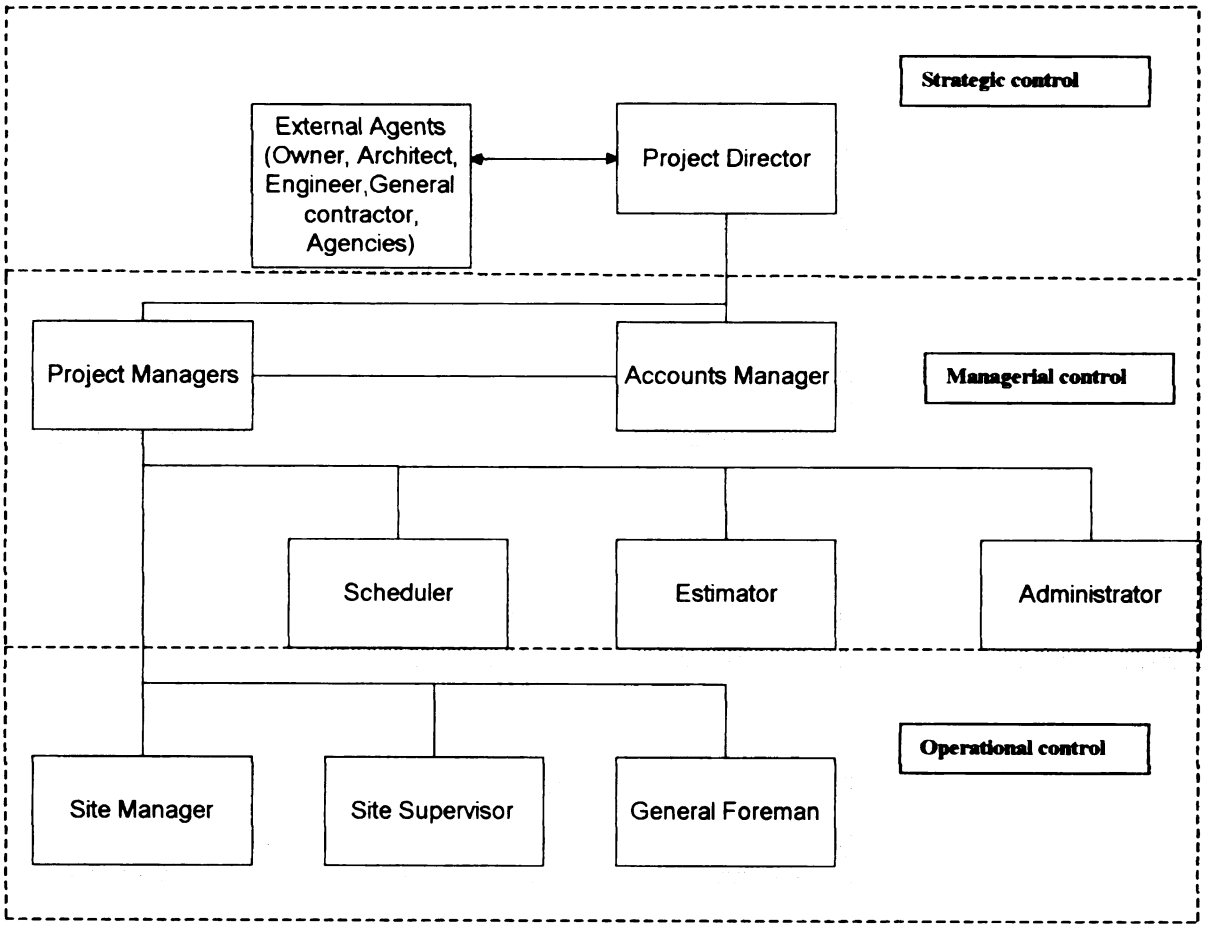


Figure 4.21: Control levels in organization hierarchy

Thus, for a particular activity, what type of decision could be made and who will make it is all defined by the responsibility code (Table 4.4). The various control levels, as discussed above, make use of project control tools such as S-curves and real time control charts. The next section will explain the use of these tools.

4.3.3.3 Project control tools

The project control tools used for this research work are S-curves and real time control charts. Once the database system is developed, the data elements for S-curves and real time control charts are identified and used in developing reports that are used by the management. The S-curves and real time control charts used are different for different control functions (Russell et. al, 1997). For example, the Project Director will use S-curves generated from overall or milestone project schedules. The Project Manager may use S-curves generated from milestone, key-date and critical activity schedules (Clough and Sears 1998; Russell et. al, 1997). These S-curves are generated from the details involved in each schedule, as shown in schedule participant matrix (Table 4.1). The S-curve reports trigger the process of project controls, which involves decision-making and taking corrective actions. The S-curves and real time control charts are already discussed in chapter 3, section 3.5.3. Their use in project controls these will be discussed in the following sections.

4.3.3.3.1 S-curves

The S-curves are the plots of cost vs. time (Clough and Sears1998). The two major categories of S-curves are identified such as "time related" and "cost related". The variables that will be used under each category are listed in Table 4.5. Clearly, the time related variables are obtained from schedules and cost related variables are obtained from budgets (Clough and Sears 1998; Russell et. al, 1997). Again, the variables are obtained from the attributes in Table 4.4. For each phase of the project, time and cost S-curves can be plotted. The S-curves for early start and late start of activity are developed for each variable during the project planning. Thus two boundary limits are defined for the project controls. The upper limit is defined by early start S-curve, and the lower limit is defined by the late start S-curve. The actual variable values, as obtained during the project construction phase, are entered into the database system to generate the "actual S- curve" plots. If this curve lies within the boundary limits then project progress is considered satisfactory. The actual S-curve, above early start curve (upper limit), will indicate that a project is far ahead of the planned schedule and is running under budget, which is a very good result from the management's perspective (Clough and Sears 1998; Russell et. al, 1997). The actual S-curve, below the late start curve (lower limit), will indicate that the project is running far behind the schedule and over budget, which is a poor result from the management's perspective (Clough and Sears 1998; Russell et. al, 1997). This will draw the immediate attention of the management team and will trigger the decision-making process that decides upon the corrective action to be taken. The sample S-curves are shown in Figure 4.15. The nature of the actual S-curves predicts the future of the project.

	Planning Phase	Construction Phase	Closeout Phase
	Variables	Variables	Variables
Time Related	Budgeted man hours Budgeted construction complete Planned fabrication hours Planned installation hours Planned equipment hours	Actual man hours Actual construction complete Actual fabrication hours Actual installation hours Actual equipment hours	Total man hours Total construction complete Total fabrication hours Total installation hours Total equipment hours
Cost Related	Budgeted money ($) Budgeted labor cost Budgeted material cost Dollars to be billed Budgeted cost of change orders Budgeted indirect costs Budgeted activity direct costs	Actual money spent ($) Actual labor cost Actual material cost Actual dollars billed Actual cost of change orders Actual indirect costs Actual activity direct costs	Total money spent ($) Total labor cost Total material cost Total dollars billed Total cost of change orders Total indirect costs Total activity direct costs

Table 4.5: Variables for S- curves (Clough and Sears 1998; Russell et. al, 1997)

can be identified as the project control variable (Russell et. al, 1997). Based on nature of S- curves, the project can be identified as "successful" (meeting or exceeding schedule and budget requirements), or "less than successful" (not meeting the schedule and budget requirements). For a successful project, the actual S-curve will typically lie within the two limits, or may occasionally lie above the upper limit. For an unsuccessful project, the actual S-curve will lie below the lower limit (Clough and Sears 1998; Russell et. al, 1997). The project managers can make use of S-curves to keep track of project progress and make sure that it is progressing according to plan or they can even compare the actual S- curves to the S-curves for a successful project of similar nature in the historical records. Usually, a single project S-curve is not sufficient to decide the progress of project or the project control variable, and therefore to make the necessary decisions (Russell et. al, 1997). To account for this, the use of real time control charts is proposed in this research work. Also, the use of additional information along with the S-curve is another method, as explained in the section 4.2.5.1.3 (iv), example 2. The real time control charts are described in the next section.

4.3.3.3.2 Real time control charts

Based on the data elements in the database tables and the nature of the S-curves, different variables can be identified as predictors of project outcome during planning, construction and controls phase of the project. If only those portions of S-curves are plotted on a separate graph for each variable where a statistically significant difference exists between the successful and less than successful projects, then the resulting graphs are real time control charts (Russell et. al, 1997). The real time control chart eliminates unnecessary

portions of S-curves (the portion with non-significant variation from the planned values), and makes it easier for the project managers to concentrate on a particular project variable. Thus real time control charts are an enhanced form of S-curves that help the project managers in decision making and taking corrective action pertaining to the specific project variable. Those portions of actual S-curves that lie either above or below the lower limits are considered for developing these charts. If all the portions of the S-curves above the upper limit are plotted Vs time, then the resulting chart is the one for the successful project. Therefore, if the management concentrates on these portions, i.e. the variables used in the corresponding S-curve, then controlling these variables will ensure the successful completion of project (Clough and Sears 1998; Russell et. al, 1997). On the other hand, if all the portions of S-curves above the lower limit are plotted Vs Time, then the resulting real time control chart is the one for the unsuccessful project. Therefore, keeping close track of the variables in the different portions of control chart will help in avoiding the project schedule, and budget- over runs.

The logic of using S-curves and real time control charts has been explained in chapter 3, section, 3.5.3.1-2.

This section explained the use of S-curves and real time control charts, and how these are generated from the proposed database system. This completes the design of project control system. This also completes the three steps involved in developing an information system in the integrated system architecture.

4.4 Summary

This chapter provided the details of the integrated system architecture and accomplished the two goals for developing the integrated system. The first goal included developing the global view of the REA model and it's implementation framework. The second goal included developing the various components of the information system such as, the data warehouse, the decision support system, and the project control system. The output of the REA model design and its implementation framework is the proposed database system in Microsoft Access. The complete database design is out of the scope of this research work. However, the components of the database system such as, tables, queries, forms and reports were discussed with relevant examples. The detailed design of the data warehouse is not included but only the overall architecture, and the steps involved in the architecture design were discussed. For the decision support system, the steps involved in decision-making process were discussed and how the data warehouse supports the decision support system was also described. For the project controls system, the main components such as project control cycle, the project control functions and its levels, and the project control tools were identified. Under the project controls cycle, the project controls processes and the data flows were discussed. Under the control functions different levels were identified and the reports, such as S-curves and real time control charts, were discussed under project control tools. The proposed integrated system architecture has two components. The one is the database system, which integrates scheduling and project controls data. This database system is stored in the data warehouse. The other component is the information system that will make use of the integrated database system, for

managing the project. Therefore, developing the proof of concept involves two major steps:

1. To show that the REA modeling technique can be used to develop an integrated database system between scheduling and project controls.
2. To show that the proposed information system set-up along with its components can be used by the CM Companies to better manage the construction projects. This information system will make use of an integrated database system, in the data warehouse.

Chapter 5: Developing proof of concept

5.1 Introduction

The proposed integrated system was developed in the previous chapter. It consists of the database system and the information system. The database system was developed by first developing the integrated REA model for the scheduling and project controls, and then using the REA implementation framework to design the database system. This research work made use of Microsoft Access database system to generate data tables. The S-curves and real time control charts were produced making use of this data table structures. Further, the different components of the information system were designed. This information system can be used by the CM Company to manage the projects. In this chapter, case studies will be discussed to evaluate the application of the proposed integrated system architecture to the two actual case study- construction management (CM) companies. The case studies evaluate the application of REA modeling for developing an integrated system between scheduling and project controls, and the potential use of the proposed integrated system for project management and controls in the real life construction project environment.

5.2 Methodology

The present set-up and mode of operation adopted by the two case-study companies is studied in detail. The third case study analyzes the application of the REA modeling technique from a software developer's perspective.

The main focus of this study is scheduling and project control systems adopted in each company. The knowledge about these systems is gained by interviewing their project manager and is also supplemented by the researcher's internship experience in one of these companies. The data is gathered about the following aspects of each company:

- Company set up and mode of operation
- Value chain
- Scheduling and budgeting processes
- Identification of resource, events, and agents under the project planning and controls phase
- Decision-making mechanism
- Project control cycle
- Project control tools
- Data warehouse architecture

The data gathered about the above aspects is compared to the components of the proposed integrated system architecture developed in this research work. Based on the comparison, the recommendation and changes are suggested by the researcher for improving some of the business processes in the case-study companies. The project managers were then requested to review the application of the REA model and the implementation framework for its potential use in real project environment. They were also asked to evaluate the potential application of the components of the proposed integrated system.

Each case study is organized into four sub-sections. The first sub-section describes the various components as listed above. The second one gives the comparison between these

components and the components of the proposed integrated system architecture. The third sub-section describes the recommendations and changes suggested by the researcher. The final and the fourth section includes the review, and feedback of the case-study participants, i.e. project manager.

The first case study is an industrial project, managed by a CM Company. The other case study includes the analysis of a CM Company. The third case study involves a software development firm, which uses the REA modeling technique for designing various enterprise resource planning (ERP) packages for the automotive industry. This company is also researching the use of REA modeling technique for designing various database systems for the construction industry. Therefore, the application of the REA modeling technique is analyzed from three different perspectives of specific CM-project needs, overall CM-Company needs, and the software professional needs. The case studies are described in the following sections.

5.3 Case study 1

This case study involves a CM firm, which is hired by the owner to manage the construction of an automotive facility. The data collected about various aspects of the company and the project is organized into the following sub-sections. This data is compared with the components of the proposed integrated system architecture.

5.3.1 Company set up and mode of operation

This case-study company is a large size international company that works as a designer (D), contractor (C), and also as a construction management (CM) firm. The typical

duration of their projects is about 48 months and the projects typically exceed $40 million, in value. The organization chart for this project is shown in Figure 5.1

5.3.2 Project details

The case-study project is of an industrial type, which involves construction of an automotive facility for the owner. The construction work is awarded to a series of contractors, for certain amount, and over an agreed duration. The case-study company is hired by the owner to manage the entire project for a fixed management fee. Therefore, this is a "CM with fee" type of contract. The company is not responsible for the changes in the project budget but simply manages the project within the budget approved by the owner. However, the company is required to work with the owner's representative to manage the different construction contractors and the overall project within the assigned budget and the scheduled duration. The project value is approximately $200 millions and is expected to be completed in the span of, at the most, two years. The company set-up for this project is similar to one shown in Figure 4.1, except the external agents involve a series of contractors, rather than a single general contractor (GC).

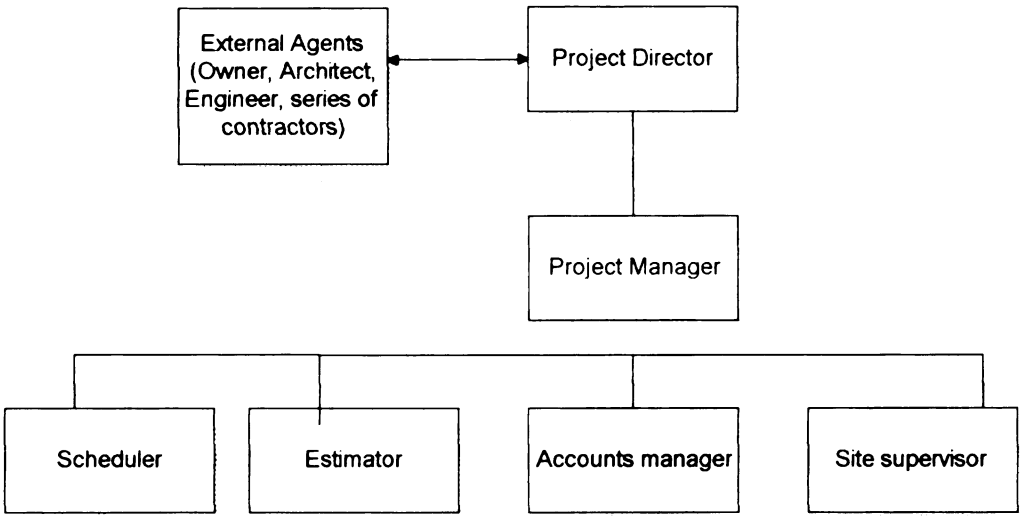


Figure 5.1: CM Organization set-up for the project (case study 1)

5.3.3 Value chain

Based on the discussion with the project manager, it was determined that the value chain of this company involves planning, construction, and the controls phase, as the main value adding phases. The company develops schedules and budgets during the planning phase. The project construction and controls phase involves processes such as measuring project progress, updating schedules and budgets, and decision-making. The value chain processes are shown in Figure 5.2, which is similar to Figure 4.3.

5.3.4 Scheduling and budgeting processes

The owner's budget for this project includes details about the cost commitments associated with the milestones such as, "excavation complete," "foundation complete," etc., as well as with key activities such as, "pour caissons," "excavate foundation," etc. The budget is developed by the owner's team and is distributed to the CM firm for review and any recommendations. The CM firm assists the owner in developing and managing his budgets. On the other hand, the CM firm has also developed its internal budget for this project. The budget was developed by the estimators in the company and involved discussion between estimator, project manager and, the project director. The project manager, however, finalized all the budgets. The schedules for this job were jointly developed by the CM Company, and the owner. The owner's schedule for this project looked like a process flow chart, which is a common scheduling method used in building of such an "automotive facility" type project. This schedule was then modified by the CM Company, to fit into the CPM-schedule mode. The schedules obtained from the owner were in the form of simple bar charts with start and finish dates and an overall

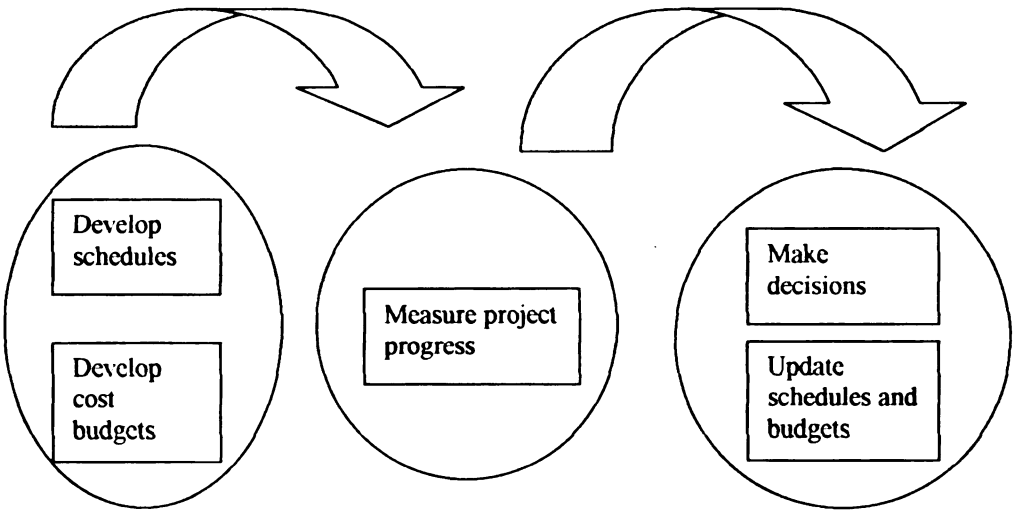


Figure 5.2: Value chain processes for scheduling and project controls for the project (case study 1)

sequencing of different bars. The owner's schedule was developed during the design stage itself, whereas CM's schedule was developed during the final stages of planning before the beginning of the construction phase.

5.3.5 Resource, events, and agents under scheduling and project controls

Resources used for the project are the same, i.e., labor, material, and equipment. The prime contractors provide these resources and the information related to each resource is simply tracked by the CM Company. The agents are internal and external. The internal agents include the project director, project manager, scheduler, and estimator within the CM firm. The external agents include the owner, architect, engineer, and several prime contractors. The generalization and classification relationships used to develop the integrated REA model for scheduling and project controls is shown in Figure 5.3, which is similar to Figure 4.8. The integrated REA model for scheduling and project controls is shown in Figure 5.4, which is similar to the integrated REA model shown in Figure 4.7.

5.3.6 Decision-making mechanism

There is no definite decision-making structure and most of the decisions are made by the PM, PD or by a team-approach. The organizational hierarchy defines the decision authority and the various decision types that can be made by the decision-authority, for this project. The project manager reviews the operational decisions made by the general

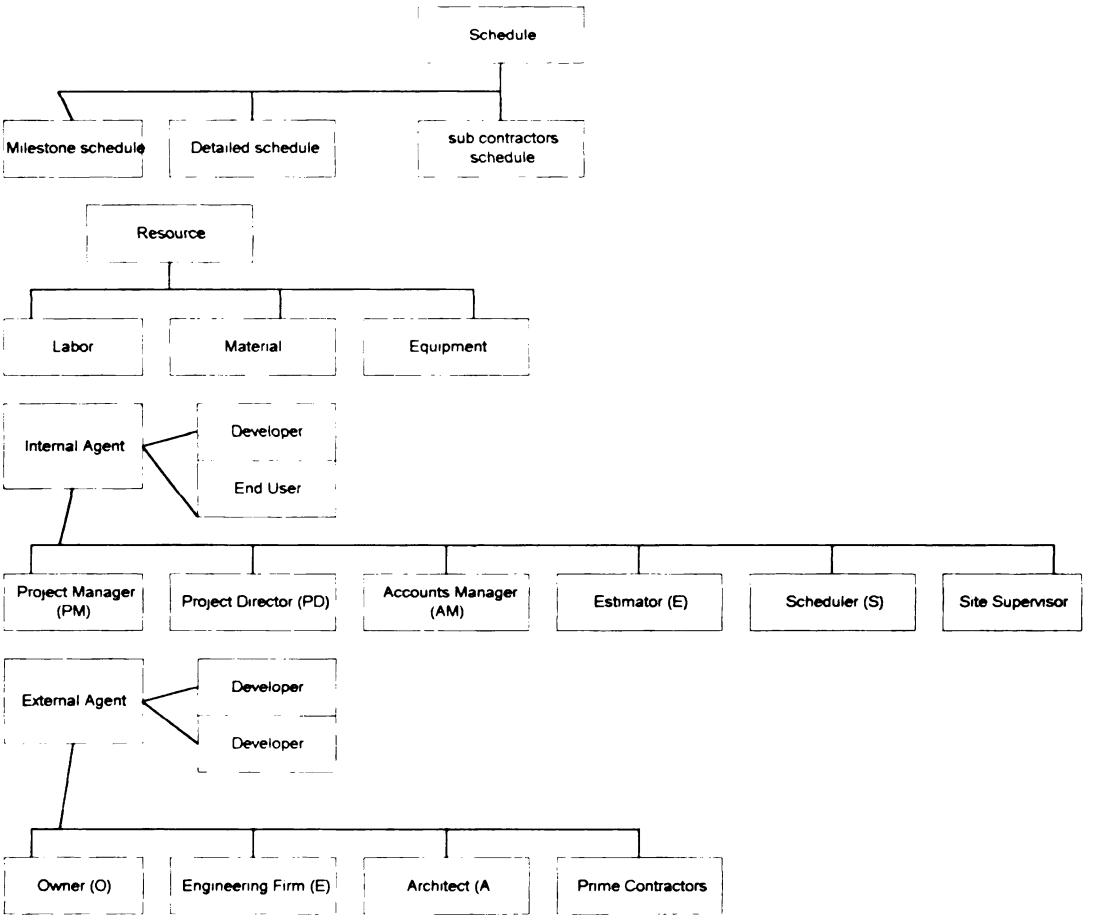


Figure 5.3: Generalization and classification hierarchy for REA model (case study 1)

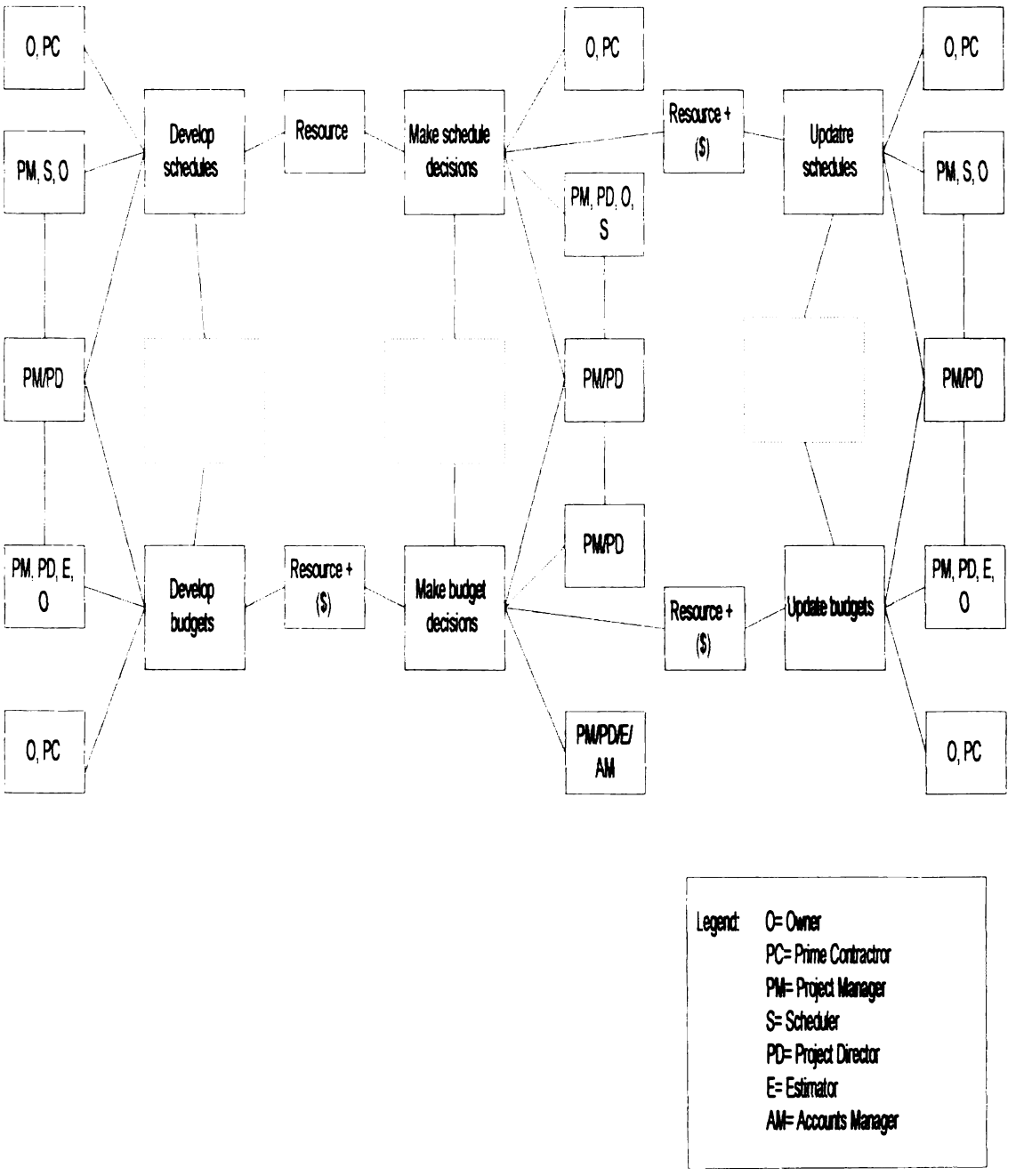


Figure 5.4: Integrated REA model for project planning and controls (case study 1)

contractor and any changes are made, if necessary. During the decision-making process, the project manager coordinates with contractors, the internal agents, and also the external agents. Most of the decisions are directed by the owner and involve discussion between the project director, project manager, owner, architect, and the engineer.

5.3.7 Project control cycle

The information about project progress is gathered by the project director, either from the contractor through the inspection reports or from the project manager through the weekly progress reports. Each week, the project control system generates the customized "dot-matrix" reports (explained in the next section), which triggers the decision-making process. These reports are analyzed by the project manager, the owner, and also the engineer. Depending on nature of the report, decisions are made about either expediting the activity using more resources or putting in more money.

5.3.8 Project control tools

Early start, early finish, and late start, and late finish S-curve reports are used as the tools for determining the status of the project and the project progress. The S-curve parameters more commonly used are resource hours (budgeted and actual), and total costs (budgeted and actual). Based on these S-curves, the customized charts or histograms are developed to assist the PM in decision-making. These are not necessarily the real time control charts, but serve the same purpose. The company has a specially designed dot-matrix system used for project control purposes. This system is designed to integrate the data from scheduling with the database system, which is used for project controls purposes.

The database system produces the S-curve report that highlights those activities that are out of the acceptable boundary limits. The system is called dot-matrix system because, the points on S-curve (the parameters) are matched with the three types of dots i.e., green, red, and yellow. Thus the matrix of, dots and S-curve point, is formed. If the parameter value lies in the green dot limits, it means that the project progress is good, or as planned. If the parameter value lies between the yellow dot limits, it means the progress is slower than what is expected, and needs some management action. If the parameter value lies anywhere in red dot limits, it means the project progress is totally unacceptable and needs serious attention and corrective measures. Depending on this report, decisions are made and new dates or resource data is entered into the database system, which is automatically reflected in the P3 schedule, because of the integrated design. The project control cycle for this project is shown in Figure 5.5, which is similar to the project control cycle shown in Figure 4.19.

5.3.9 Data warehouse architecture

The preferred systems in this company are P3 for scheduling, and the customized database system for budgeting and documentation control. The owner's schedules originally in Microsoft Project, are updated to P3 by the CM firm. The company is also planning on using Prolog Manager for documentation control and issue tracking purposes. The data warehouse architecture used for this project is shown in Figure 5.6, which is similar to Figure 4.16.

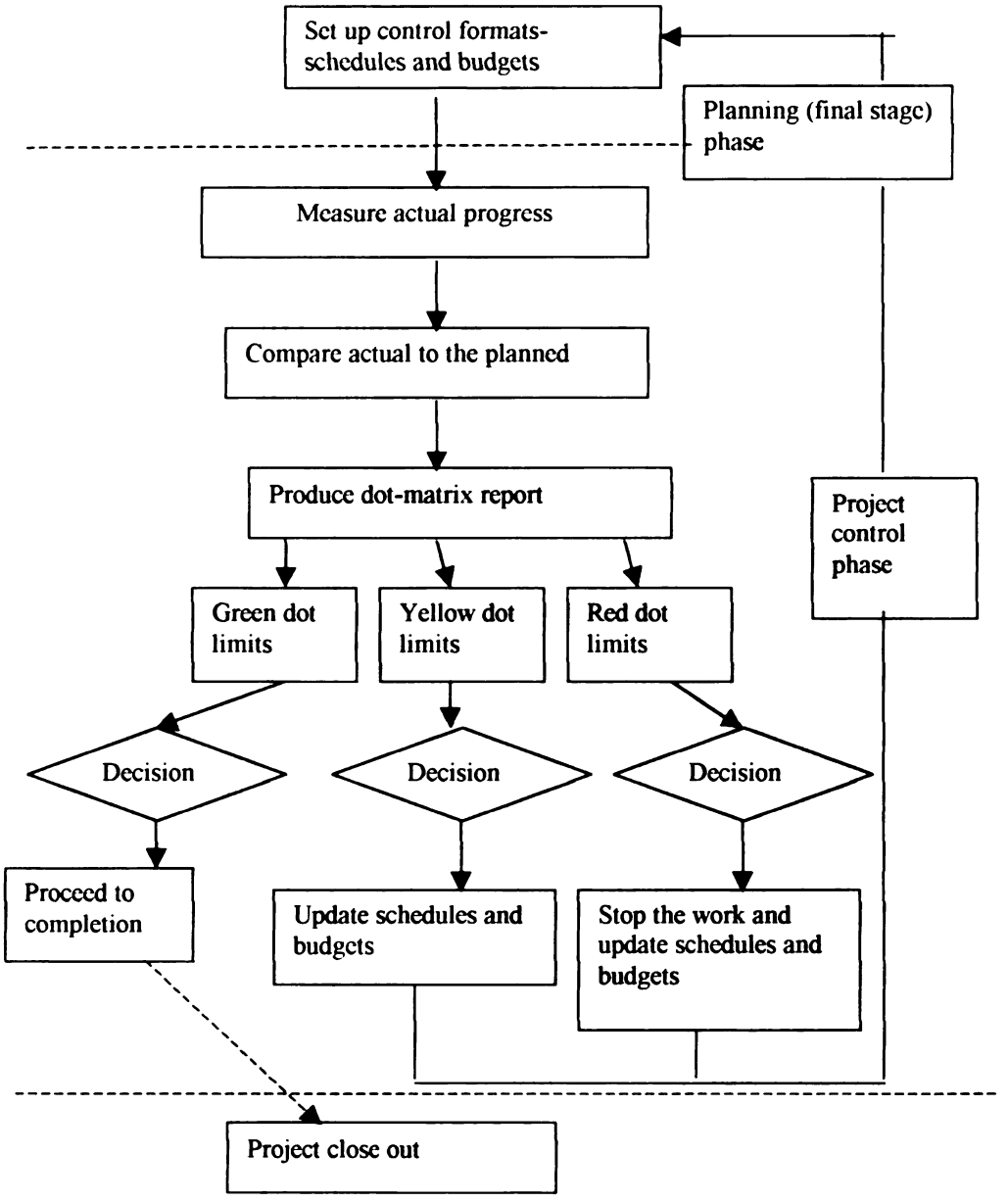


Figure 5.5: Project control cycle for the project (case study 1)

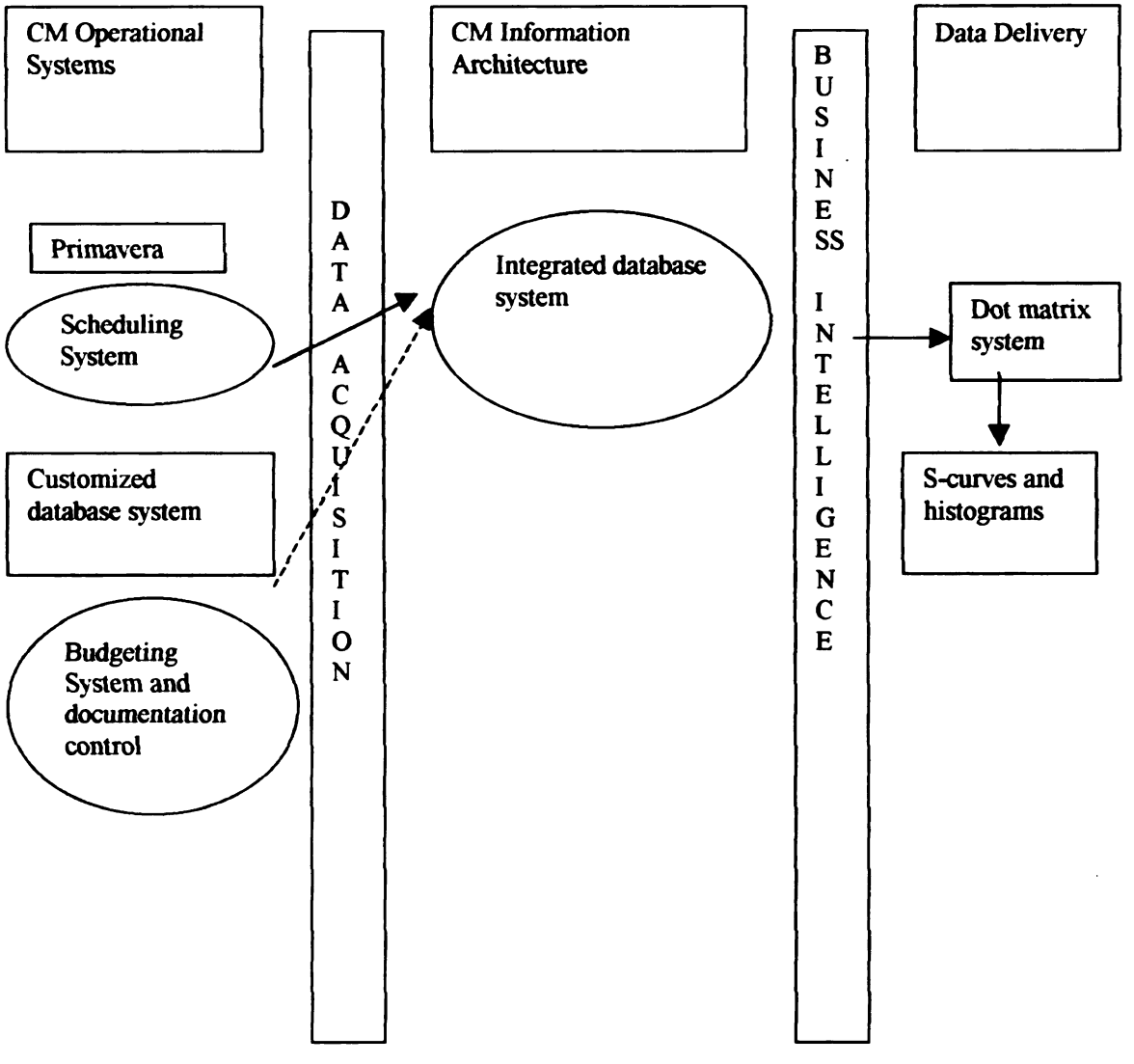


Figure 5.6: Data Warehouse Architecture for the project (case study 1)

5.3.10 Comparisons

The data gathered about the various aspects of the case-study company is compared with the components of the proposed integrated system architecture, Figure 4.1. The points of comparison are as follows:

1. The processes or events identified under the value chain are similar to those identified in this research work. These events also support the researcher's attempt of add the management and control events as economic events and to prove that they add value to the business.
2. The schedule and budget development process as adopted in this company is similar to the one assumed for the example company in this research work. However, a variation exists in the sense that the basic-preliminary schedules, and budgets are developed by the owner, while, the final schedules, and budgets are jointly developed by the CM Company, and the owner. Therefore the schedule, and budget developing process, is actually directed by the owner.
3. The resources, events and agents identified for this case-study company are used in developing integrated REA models for scheduling and project controls. However, in the case of external agents, there is no single GC, but a series of "prime contractors".
4. The decision-making mechanism used by this company is more project specific and is directed by the owner. This will affect the decision control levels adopted in this research work and will need to identify the specific attributes of the entity "Responsibility" in the database table.

5. The project control cycle as described in the previous section is similar to the project control cycle used in this research work. The project control tools used by the company are mainly S-curves and histogram reports, which are similar to the tools proposed in this research work. The histograms are another form of the real time control chart, as they are plotted only for those variables that affect the project progress.
6. The data warehouse architecture used in the company is similar to that used in this research work. The data related to schedules being stored in P3, estimating data stored in Timberline, and other data related to project management and documentation is stored in Prolog Manager. Also, the two-way data transfer between the scheduling system and the project control (dot-matrix) system supports the integration between the two systems. These software applications strongly support the Access database system suggested in this research work, as an implementation tool to integrate data across different applications.

5.3.11 Recommendations and changes

Based on the above comparison, the researcher proposes the following changes or recommendations that have potential benefits for improving the current business practice for this specific project:

1) Developing a structured decision-making mechanism

At present, the decision-making mainly involves communication and discussion between the project director, project manager, and the owner's senior management. The decisions are more often directed by the owner and are implemented by the company. It will be

beneficial to develop a detailed decision-making structure with the control functions defined for each decision-making level such as strategic, managerial, and operational.

Benefits:

- The company will have more control over managerial and operational decisions. The strategic decisions made by the owner are driven more often by the budget and schedule constraints. The managerial and operational decisions are often based on the company set-up, mode of operation, the technology, and user skill available in the company. Therefore it will be beneficial for the CM Company to make such decisions. For example, the company can decide about the use of a particular software application such as Prolog Manager for issue tracking and controls purposes, depending upon the available technology and the employee skill set. This is more of an operational control, which can be adopted as a company-wide strategy in the future, for similar projects.

2) Extending the integration capabilities of a dot-matrix system to the cost control system.

At present, the dot-matrix system integrates the data across the P3 and Access database system. It will be beneficial to extend this integration capability to the cost database system used by the company to track the project costs and budgets.

Benefits:

- The integration of the dot-matrix system and the cost database will ensure that the decisions made regarding individual activities or milestones are reflected in the costs and budgets associated with the activity.

- The data transfer can be achieved by the single click of button, which runs the underlying query, designed to update records in cost database.

3) Identifying the processes at the task level, which are the candidates for business process reengineering, and storing these tasks as entities in the dot-matrix system.

At present, the owner issues different flow charts for various processes that are typically used in the operations like building, assembling, and installing in the automotive manufacturing industry. All this information is stored in the company database system, or as paper archives. The start and end dates of these processes are critical and often drive the project control process and decision-making. If only those tasks are identified, that can be redesigned and reorganized, to reflect the change in the main process at higher level. Then the company can concentrate on those tasks and make any changes without affecting the major processes at higher level. These tasks are similar to the business events at the lowest level of the process tree diagrams, developed in this research work for scheduling and project controls. It will be very useful to store these tasks as individual entities in the dot-matrix system. These entities will have unique IDs and other attributes like other entities, and will be also reflected as "key activities" in the primavera schedule.

Benefits:

- The decision-making process can concentrate on these "key activities", and it will be easy for the management to redesign these activities.
- It will be easy to plot the "individual tasks" in the dot-matrix system rather than plotting the whole process itself as a milestone event. The information obtained in the dot-matrix view will be more specific and provide a more detailed picture.

4) Use of an issue tracking system such as Prolog Manager

The company is already planning on implementing Prolog Manager as the database system for issue tracking and documentation controls purposes. It will be helpful to design the various modules in this system to match the table structures in the dot-matrix system. The modules can be developed based on the Entity Relationship (E-R) diagrams, which can be designed based on the integrated REA model developed in this research work. Prolog Manager is easy to use as compared to Expedition, and allows more flexibility in the design of various modules. It is an economical system as it consumes less money in purchase, maintenance and user training as compared to other such systems. Moreover, the capability of Prolog Manager to exchange data with Microsoft Access will be of great use since the present dot-matrix structure used for project controls is designed using the Microsoft Access database system.

Benefits:

- This will achieve a smooth flow of data across the Prolog and the dot-matrix system. It will eliminate the double entry and ensure the data integrity.
- For project controls and issue tracking purposes, the project manager can have additional information related to various activities, in the same dot-matrix view. This will help in assigning the responsibilities and directing the decisions to the appropriate level.

5.3.12 Feedback from the company

The above noted recommendations were reviewed by the project manager and found useful with certain modifications. The company agreed upon the need of setting up a

decision-making mechanism or structure to benefit its business operations. The second recommendation was not found necessary, as the company is already assigned the gross profit margin value by the owner, and it was more important to track the schedules to meet with the various milestones than to track the budgets. The third recommendation was found highly useful by the project manager, as it was easier to manage the "task" level than the major process level. Finally the recommendation about use of Prolog Manager as one of the components of data warehouse was found suitable for the information system needs of the company. The project manager suggested following modifications in the research work:

- To develop a strategic plan or methodology to implement the recommendations made in this research work, first on a project and then on an organization-wide level.
- To accommodate a series of prime contractors in the proposed REA model, rather than a single GC.

5.4 Case study 2

This case-study company is also a CM firm, which manages the construction projects for the owner for some fee. The information about this company was gathered by interviewing a senior executive and also supplemented by the researcher's experience as a summer intern in the company. The data collected about various aspects of the company and the project is organized in the following sub-sections.

5.4.1 Company set up and mode of operation

This case-study company is a CM firm that has a matrix-organizational structure. It is set up to support projects under a geographical line management. The line management group then supports the project teams. The typical duration of the their projects is about 36 months and the projects typically exceed $20 million in value. The average project value that the company works on is of value $75 million. Of the 1,700 employees, about 150 are administration, the rest are assigned to the project. The organization chart for this company is shown in Figure 5.7.

5.4.2 Value chain

The main value adding phases identified under the value chain for this company are, design, planning, and controls phase. The processes identified under planning include developing the schedule, budgets and assigning responsibilities. The project controls phase involves the processes such as schedule and budget updating, and decision-making. The various processes under the value chain are shown in Figure 5.8, which is similar to Figure 4.3, developed in chapter 4.

5.4.3 Scheduling and budgeting processes

The company is given a fixed gross profit margin (GMP) and a fixed project value by the owner. Relative to this project value, the company prepares the project cost profiles with the help of the CM support team. The CM support team includes the estimator, scheduler, and the accounts manager. The cost profiles are finalized by the project manager in

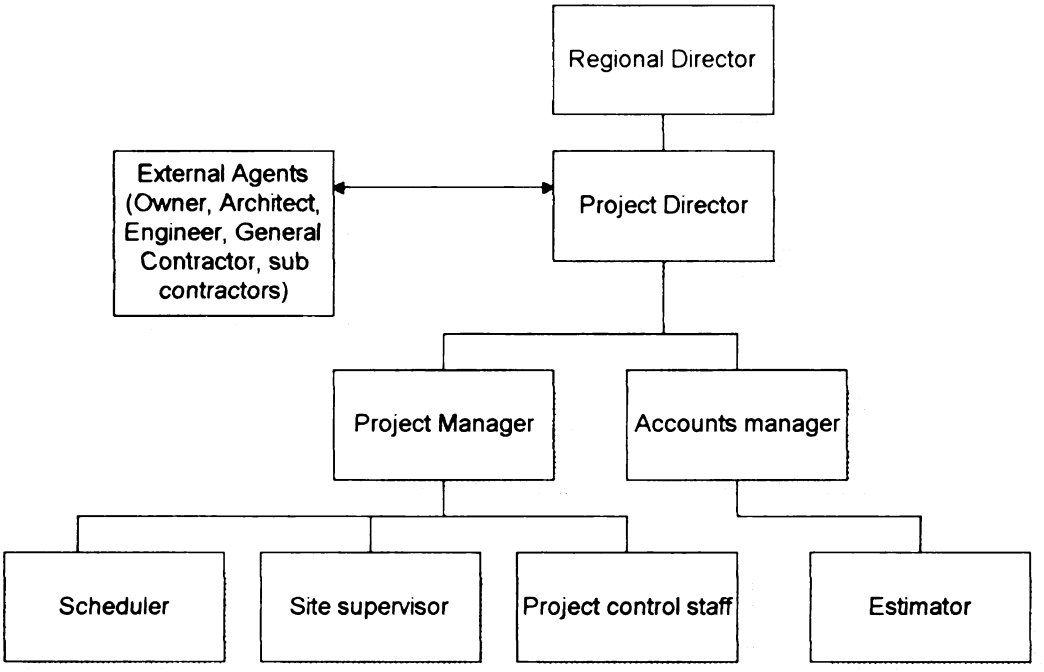


Figure 5.7: CM Organization Chart (case study 2)

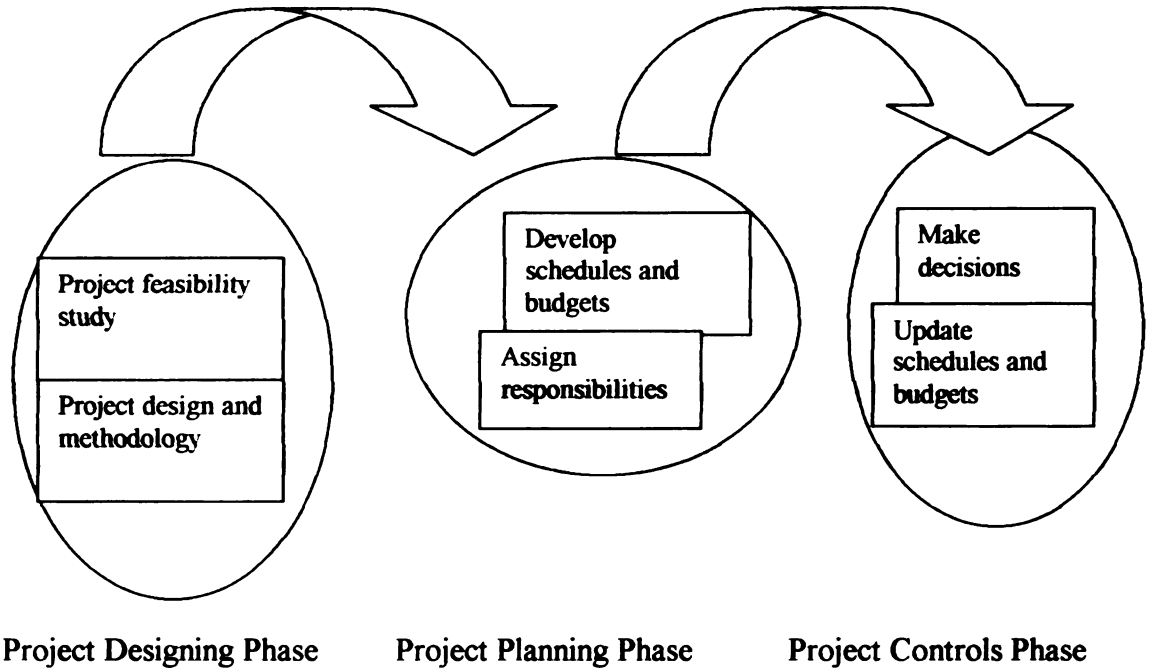


Figure 5.8: Value chain processes for the company (case study 2)

discussion with the regional project director. During the initial stages of planning, schedules are prepared mostly as a probable sequential order to complete the project. Only during the final stages of planning i.e., before the beginning of actual construction, a detailed schedule is prepared, which incorporates all the details such as resources, cost, responsibilities, etc. The detailed schedule also includes the GC's schedule. Usually the project director and the project control team in the office use the overall or the milestone schedules. Whereas the site supervisor and the project control staff on the site use the detailed schedules.

5.4.4 Resource, events, and agents under scheduling and project controls

The company does not track the resources independently, but the schedules are loaded with various resources. Resources are, however, the same: labor, material, and equipment. They are owned and supplied by the GC. The agents are internal and external agents. The internal agents include, project director, project manager and upper management. The external agents include the owner, architect, engineer, and a general contractor.

The generalization and classification hierarchy for developing REA models is shown in Figure 5.9, which is similar to Figure 4.8. The integrated REA model for scheduling and project controls is shown in Figure 5.10, which is similar to the integrated REA model as shown in Figure 4.7.

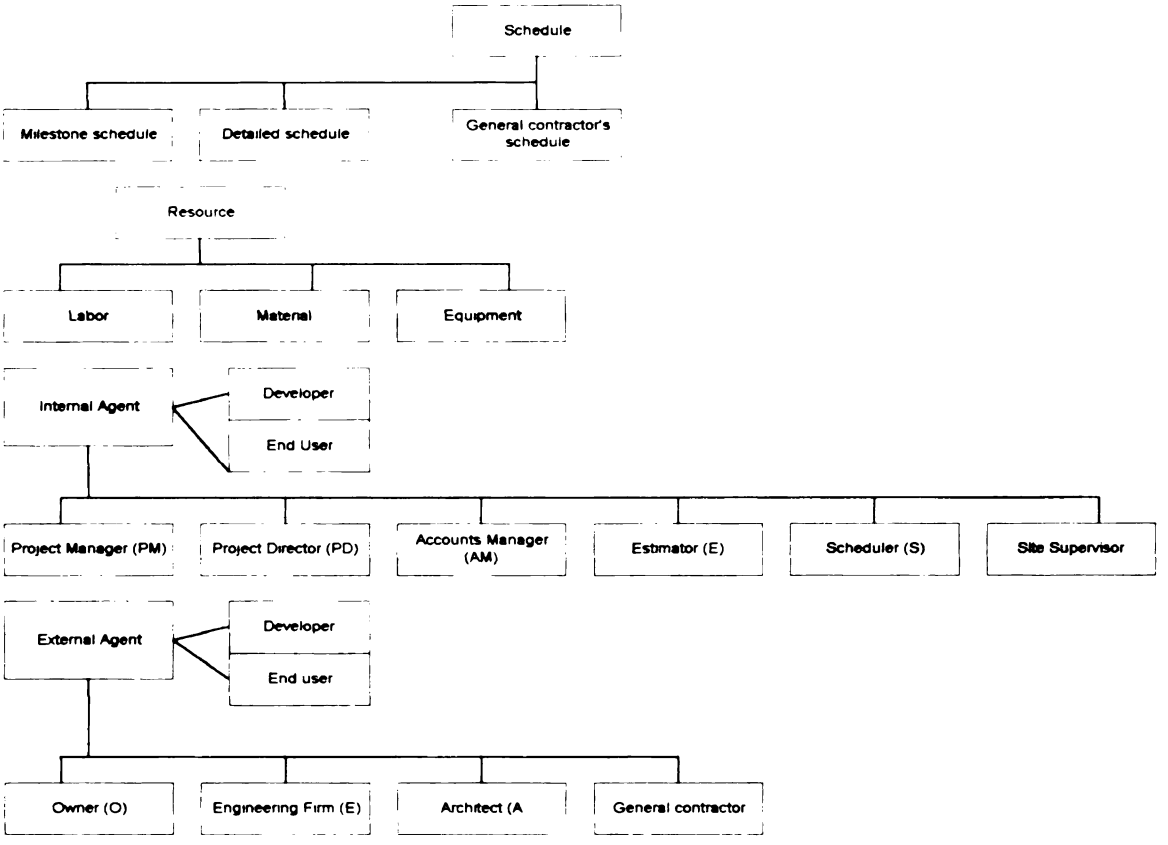


Figure 5.9: Generalization and classification hierarchy for REA model (case study 2)

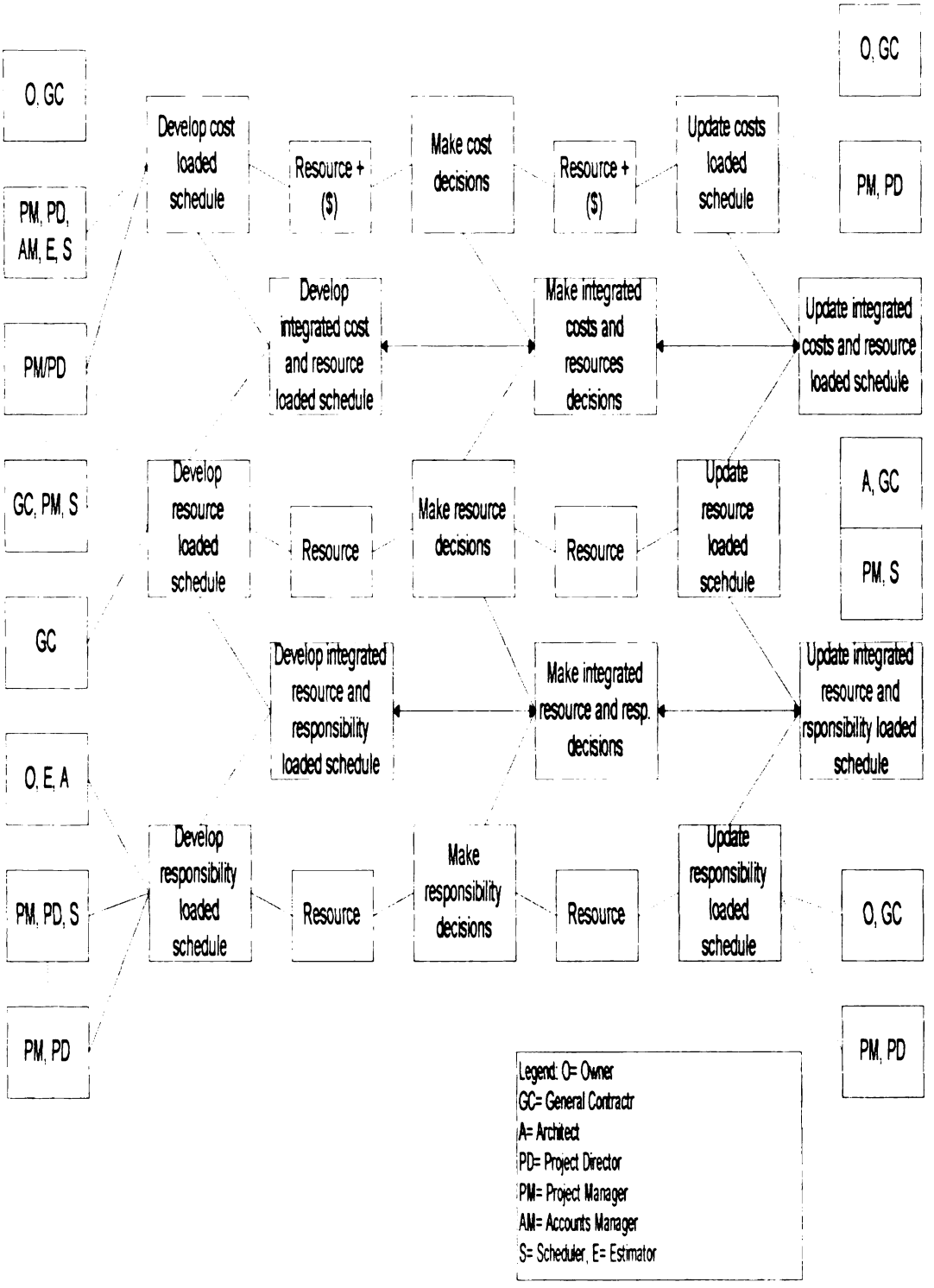


Figure 5.10: Integrated REA model for project planning and controls phase (case study 2)

5.4.5 Decision-making mechanism

The company has three levels of decision-making i.e., strategic, managerial, and operational. The strategic decision-making involves the market leader, and the senior management of the company. Market leaders are responsible for achieving all cost and schedule targets on a project, case-by-case level. The managerial decision-making involves the project directors and project managers. They are empowered to make all decisions regarding the project. Finally, the operational decision-making is done by the operational team, which includes the regional operations manager, the regional cost engineer, the chief estimator, the scheduler, and the project controls director.

During the decision making process, project managers coordinate with the CM support team to reach key decisions. It also involves communication on regular basis with the other team leaders, the project director, and the market leader.

5.4.6 Project control cycle

The information about project progress is gathered either from the project manager or through daily inspection reports. Sometimes the contractor will update progress against listed items in the detail project schedule. This is usually followed by an inspection to validate the report. Each month, the project schedule is both paper and electronically archived. The approved schedule is usually a modified version of the baseline or the final schedule prepared during the planning stage. The project progress is input into various S-curves, followed by the discrepancy report. This report is discussed and utilized as a tool for determining a recommended path forward for accomplishing the scheduled goals. Crashing a schedule (throwing money at problems) is a last resort to reconciliation and

achieving milestones. The project control cycle is shown in Figure 5.11, which is similar to the project control cycle shown in Figure 4.19.

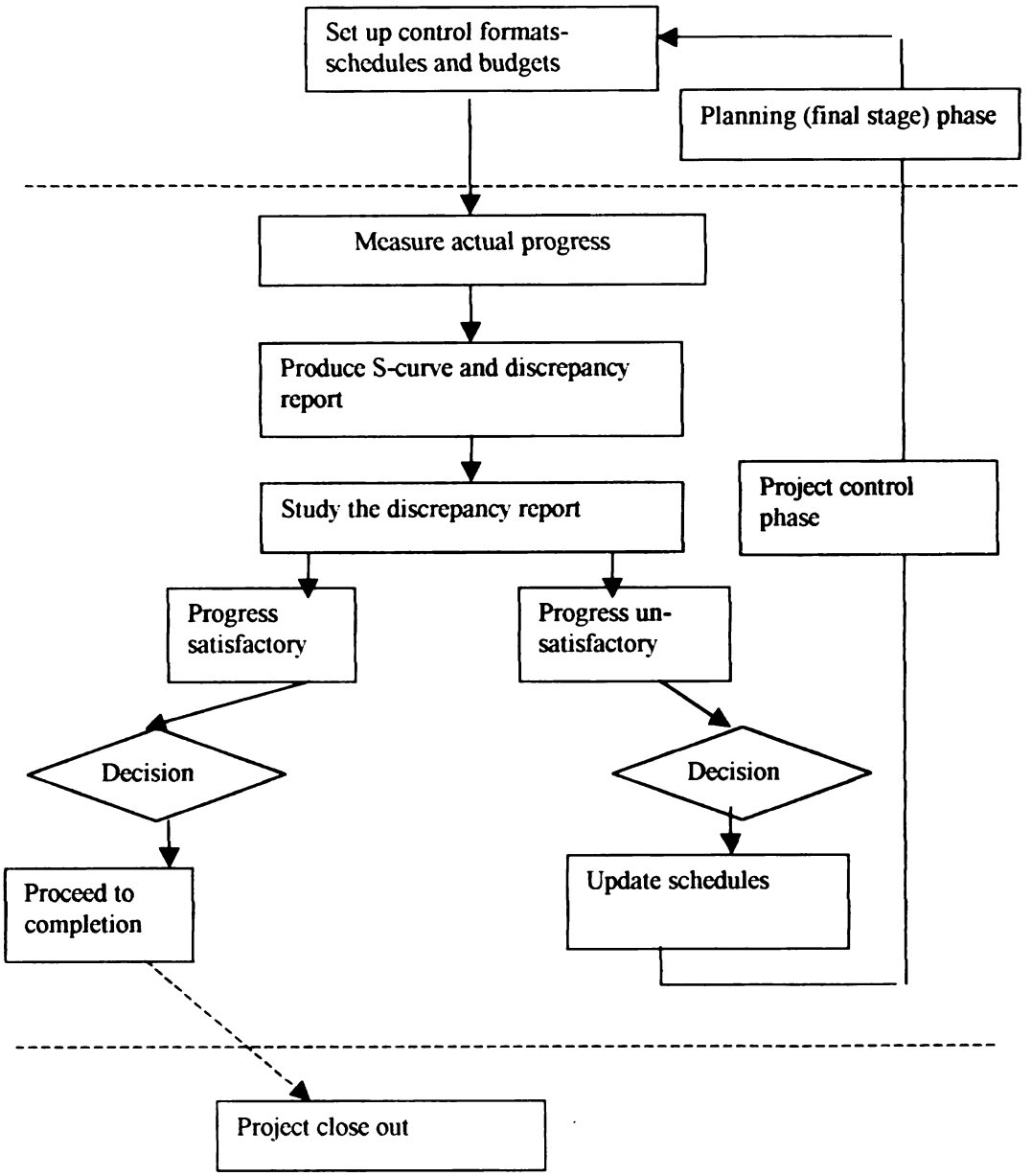


Figure 5.11: Project control cycle (case study 2)

5.4.7 Project control tools

Early finish and late finish S-curves are the most useful tools for determining the status of the project and whether the scheduled goal can be reached. The planned and actual S-curves are plotted. The narrow gap between the two indicates that the activity logic is very detailed and has a less float available and demand close attention. A wide gap between the two curves indicates that the activities have ample float and do not demand serious attention. The parameters more commonly used to plot the S-curves are resource hours (budgeted and actual), total costs (budgeted and actual), and cost allocated to the milestones (budgeted and actual). Based on these S-curves, progress histograms are plotted for the various S-curve parameters.

5.4.8 Data warehouse architecture

The preferred systems in this company are Timberline Plus Estimating (CSI/Uniformat) for estimating and P3, or Sure Track for scheduling. The printouts from software systems produce the paper archive of the cost and schedule progress for the project. The information and the documentation for the projects are usually managed by utilizing a document management system within an issues tracking method. Sometimes this is a paper process and takes quite a bit of management time, and at times, more staff. The current method of choice, however, is utilizing an information electronic system such as Expedition or Prolog Manager. This requires considerable user training which, for a larger project, proves beneficial and pays off, as the requirements for information are committed to the owner. The data warehouse architecture adopted in the company is shown in Figure 5.12, which is similar to Figure 4.16.

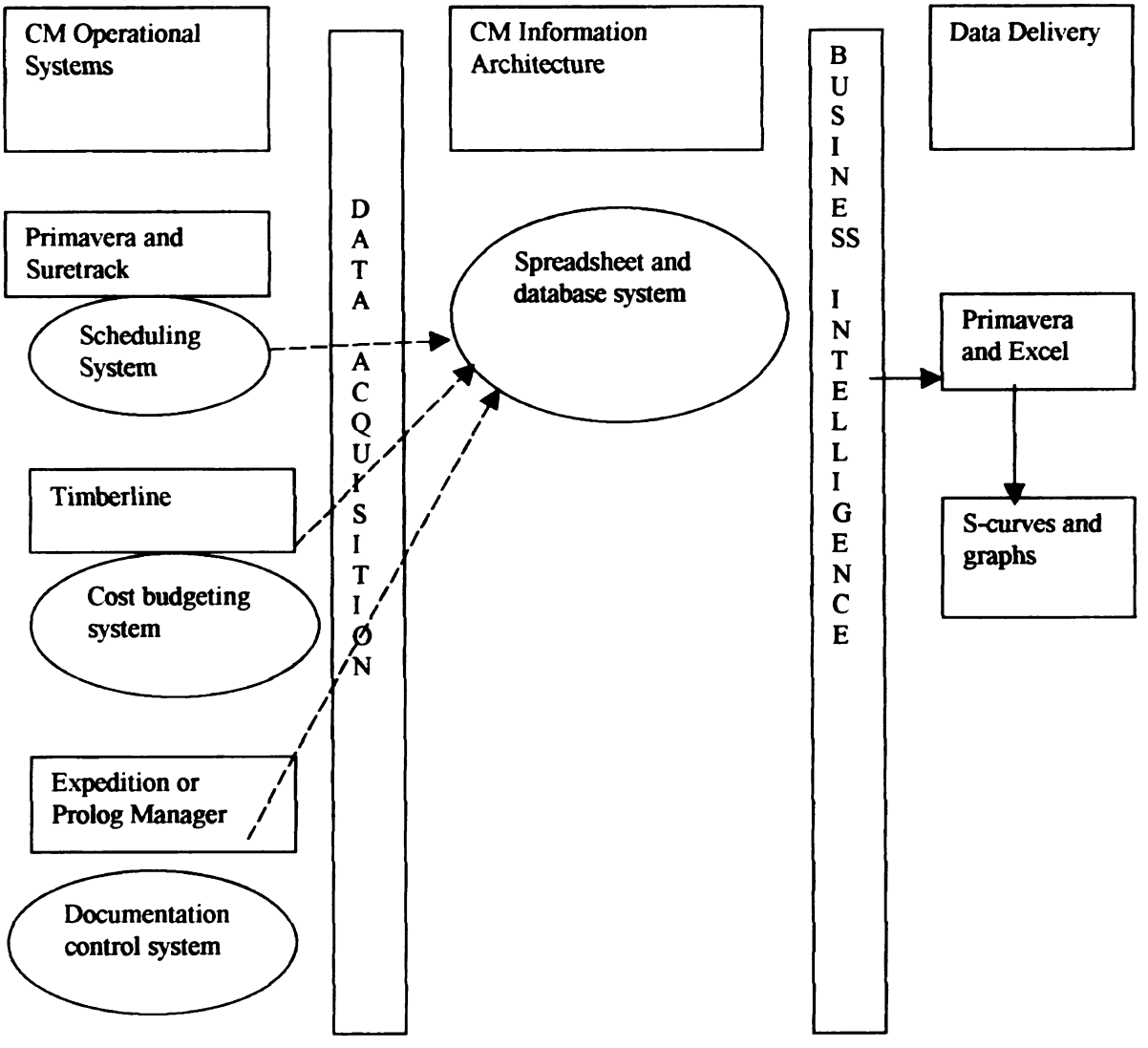


Figure 5.12: Data Warehouse Architecture in the company (case study 2)

5.4.9 Comparisons

The data gathered about the various aspects of the case-study company is compared with the components of the proposed integrated system architecture. The points of comparison are as follows:

1. The events identified under the value chain for this company are similar to those identified in this research work. These events also support the researcher's attempt to add the management and control events as economic events, and to prove that they add value to the business.
2. The schedule and budget development process, as adopted in this company, is similar to the one assumed for the example company in this research work. The schedules include details such as responsibility, activity details, etc.
3. The activities in the schedule are loaded with resources. The information about resources is not tracked separately, but as an attribute of the activities. The agents identified are project director, project manager, accounts manager, estimator, and scheduler ad internal agents. Whereas, the external agents identified are owner, architect, engineer, and GC. These are used to develop the integrated REA model for scheduling and project controls.
4. The three levels of decision-making adopted in this company match with the decision-making mechanism developed in this research work.
5. The project control cycle described in the previous sections is similar to the one used in this research work. The project control tools used are S-curves and progress histograms. The histograms are not the real time control charts. This is

because they are plotted not only for the project progress variables, but also for all the S-curve variables.

6. The data warehouse architecture in the company is similar to the proposed data warehouse architecture in this research work. The data related to schedules is being stored in P3, estimating data is stored in Timberline and other project related data is stored in Expedition. These software applications also support the Access database system suggested in this research work, as an implementation tool to integrate data across different applications.

5.4.10 Recommendations and changes

Based on the above comparison, the researcher feels the following changes or recommendations will benefit the current business practice for this organization.

1) Design and use of an integrated system

At present, the estimating data is stored in Timberline, the scheduling data is stored in P3, and the management and controls data is stored in Expedition and or Prolog Manager. Each of them serves the needs of an individual specialist. The central database system that will integrate data from all these repositories will be helpful in this case. This database system can be developed based on the integrated REA model developed in this research work and using Microsoft Access as an implementation tool.

This database system does not need to include the data from all sources at one place, but will simply provide slots (table spaces) to store the data. For example, the scheduling data can be stored in "Activity table" with "Activity ID" as the unique identifying key. This

"Activity ID" can be the same, as used in P3, and will therefore pull up all the information associated with the particular Activity ID from P3. Similarly, all the cost data associated with the activity can be pulled up from Timberline. The "Responsibility ID" code or "Resource ID" can be linked with the respective IDs in Expedition or Prolog manager.

Benefits:

- Decision-making: The cost, schedule and managerial data will be available at one place for the project managers. This will help to a great extent in the decision-making process.
- Report generation: The S-curve and real time control charts can be generated in the single click of button. Further, they can be imported in spreadsheets for customized editing or can be edited in the same database.
- Information gathering: In the same S-curve view, the management can have the information about the resources, personnel- responsibility, external agent-details, etc. This additional information will always help in making right decisions and taking corrective actions.
- Knowledge base and future planning: The data stored in this database system can serve as a very good knowledge base for projects of similar nature in the future. The whole database system can be used for future planning by the senior management, rather than collecting information from various discipline specialists regarding schedules, budgets and documentation controls.
- Software benefits: Microsoft Access is easy to use and handle as compared to the systems like P3, Timberline and Expedition. The project managers often need to

know about generating reports, and customizing modules in this software, which is time consuming. The cost spent in maintaining, updating and reports generating in these software is very high and in fact sometimes out of proportion, considering the least types of reports (such as S curves) generated. The user training for these software products consumes considerable corporate money and employee's time. The use of a database system such as Access will cut down these costs. Again, the project manager need not hire a specialist who has the expertise in all the related software applications. Moreover, it is easy to customize this database system in any way.

Considering that the present technology is likely to migrate to the SQL, it will be of immense advantage to use Microsoft Access that will have the smoothest flow and transformation into SQL.

2) Incorporating funding budgets in the budgeting system

The present budget system only includes developing detailed cost budgets for the projects. It will be helpful to add the funding component as suggested in this research work. The funding component can be again attached as "Fund ID", in the proposed database system. This "Fund ID" will be same as in Timberline or any other budget storing system.

Benefits:

- Project management: For large projects or Project Programs, funding plays a major role in managing the projects. The fund budgets will show how the money is acquired, generated and utilized. It will describe when and how the funds are acquired, and where they need to be used in the project.

- Decision-making: The researcher feels that, matching the costs and fund S-curves will probably provide the best picture of the project progress. This will help in identifying the key points for strategic decision-making.

5.4.11 Feedback from the company

The above recommendations were reviewed by the senior executive and found useful with some modifications. The company agreed upon the need of an integrated system to better manage the large projects. It was also agreed that the proposed integrated system architecture will serve two purposes: the first, to develop the central database system, and the second, to set up the project information system. The benefits of report generation and information gathering were found useful, especially for large project programs. The large project programs involve a series of projects to be constructed for the same owner, under a single contract. The recommendations related to the software application such as Microsoft Access for the design of the central database system were also found acceptable. In fact the company has already implemented various custom designs in Microsoft Access for various purposes such as generating time sheets, pay requests, cost account updating.

The company executive suggested the following modifications in the research work:

- To extend the integrated system concept to the various construction phases such as design, pre-planning, procurement, and close-out to complete the circle of construction management.

- To address the issues such as short-term and long-term business goals, organizational and behavioral changes, and risk-management during the implementation of integrated system.
- To address the changes required in the proposed REA model, to suit the "At-risk" nature of the construction management business, which is an emerging trend.

5.5 Case study 3

This case study company is a software-development firm, which develops customized enterprise resource planning (ERP) packages for supply chain management functions. The company has developed such customized application packages in the past for the accounting and automotive firms. Recently, the chief technology officer of this company has been also approached by various construction firms to develop the customized software applications for their business needs. This company is involved in researching over the use of the REA modeling technique for developing integrated package applications for the construction industry. The chief technology officer of the company was interviewed by the researcher and his feedback is included in the following sub-sections. The first sub-section includes his review and opinion about various aspects of this research work and the second sub-section includes the changes and modifications as suggested by him.

5.5.1 Review and opinion

The standard models for construction project scheduling and job costing are compatible with the REA model, and could easily fit into such a framework. The proposed integrated

system can be successfully implemented in the CM environment, where the CM firm manages a lot of projects. The effort to design and use such an integrated system will pay off for the CM firm that manages a large number of complex projects. The aggregated events, such as integrated process views developed in this research work, can be used for modeling duality relationships for project control purposes in REA models. It is fairly simple to develop the database system using Microsoft Access as the tool, as suggested in this research work. Also it is fairly simple to transfer the data from this system into more robust database systems.

5.5.2 Recommendations and modifications

The following recommendations were made, and changes suggested by the human subject:

- To incorporate the duality relationship events that are structured around cash flows, which are extremely important especially to the sub-contractors, and material vendors. The example of such events can be, "work completion," and "pay request" for the sub-contractor. Whereas for vendors the possible example can be, "material delivery," and "cash disbursement" as duality relationship events.
- To extend the REA model template to accommodate the informal information also.
- To design the REA model with flexible slots for internal and external agents, which change according to the project type.
- To use Oracle, Java, and Sun Solaris as the technology tools to implement the REA models into the computer systems.

- To address the issue of runtime performance for the REA models using the techniques of Nakamura and Johnson as described at the following web site: http://jeffsutherland.org/oopsla98/nakamura.html

5.6 Summary

This chapter was dedicated to applying the proposed integrated system concept to the real life project environment. The two case study CM Companies were used to collect the data and analyze the same for the possible application of REA modeling and the proposed integrated system. The data collection involved interviewing key personnel. The recommendations and changes suggested by the researcher were found useful in both the companies. The recommendations also identified the benefits associated with each change. Finally the third case study company was interviewed to review the application of the REA modeling technique in the construction management environment. The REA modeling technique was accepted as the possible technique to design the integrated system applications for the business needs of the CM firm. Finally the modifications and changes suggested by the human subjects were included at the end of the related sections. These modifications will be incorporated into the future area of research for this research work. The next chapter will discuss the future areas of research.

Chapter 6: Summary and future area of research

6.1 Introduction

This research work was aimed at developing an integrated REA model for scheduling and project controls, the framework for its computer implementation, and the information system set up, which can make use of the database system. These goals were accomplished through the research objectives. This chapter will discuss in detail about the conclusions that can be drawn based on the research work and the future area of research. The conclusions are derived from the research objectives described in chapter 1. The future area of research describes how this research work can be used to further develop various components of the integrated system that are designed in this research work. The chapter ends with summarizing the research work.

6.2 Conclusions

The integrated REA model developed between scheduling and project controls can be used to develop a database system. This database system integrates the data between scheduling and project controls and helps the management in the decision-making process during project controls. The proposed information system setup can be adopted by the CM companies to derive the potential benefits of the integrated system. The following conclusions, related to the objectives of this research work, can be derived.

6.2.1 Conclusions about developing REA model for scheduling and project controls for a CM environment

- In the construction management business, the scheduling system generally assumes more importance than the estimating system. This is because the owner already finalizes the project cost, and all project estimates and budgets are prepared pertaining to this cost. It is more important for the CM Companies to prepare a detailed schedule of the project to meet the scheduled duration. The change in duration causes a change in the project budget, and hence the project value. The project controls system makes use of the various schedules for managing the time and cost aspect of the project.
- The value chain concept and the REA modeling technique can be used to analyze the business processes in a CM Company. The processes related to scheduling and project controls can be easily broken down to task level activities. Therefore, developing the value chain leads to the identification of processes from the top level to the bottom-task level (Figure 4.3). These task level processes can be represented in the database system as entities. Furthermore, merging of the tasks, i.e. entities, leads to an integrated database system, which incorporates all the processes from top to bottom level during scheduling and project controls.
- The REA model developed for scheduling and project controls breaks down the two processes into simple events or tasks. The REA pattern can be used to model the various business processes under scheduling and project controls over the entire project life cycle. The output of the REA models is identification of data and attributes, used to generate the reports such as S-curves and real time control

charts (Figure 4.5). The data elements generally used by the CM Companies are budgeted, and actual-labor hours, total cost, resource hours etc. The data elements used in this research work are included in Table 4.5.

- Based on the individual REA models for scheduling and project control processes, an integrated REA model is developed (Figure 4.7). This model integrates the resources and agents that are common across the two processes. The output of the integrated model is the database tables that store various resources, events, and agents as entities in the database tables. The entities in tables have a unique identifying attribute, called "identification key" or "ID." Different ID's across different tables can be merged or grouped to produce a customized report such as S-curves or real time control charts. Thus, the integrated model can be used to integrate the data between the scheduling and project controls system, and stores it in a database system.
- It can be concluded that, generating S-curves and real time control charts requires developing a common coding system between time and cost related data elements, for any project. This is similar to developing a common work break down structure (WBS) model between the estimating and scheduling system.

6.2.2 Conclusions about developing a generalized framework for computer implementation of the REA model

- The various components of the individual and integrated REA model can be generalized into higher levels using data aggregation, classification, and generalization hierarchies (Figure 4.8). For example, the labor, material, and equipment can be generalized to "Resource." The generalization provides a single view of the various components of the REA model.
- The generalization process is very helpful in designing the database system as an implementation tool for the REA model. The generalized framework can be used to develop "entity-relationship" diagrams. These diagrams are used by the computer programmers to develop the database management system.
- The generalized framework provides a complete view of the various processes that occur in the scheduling and project controls systems. It provides the semantic representation of local views, which are the task level processes pertaining to the specific end user, i.e. the internal or external agent (Figures 4.9, 4.10, and 4.11).
- The generalized framework can be used to design the logical and physical aspects of the database system. It helps in identifying the technology to be used in designing such a database system.

6.2.3 Conclusions related to developing an information system that will make use of the REA model and the generalized framework.

Based on the components of the information system, the conclusions are further classified into three sections. The first section is related to the data warehouse, the second section is related to the project control system, and the third section is related to the decision support system. All of them are discussed in the following sections.

6.2.3.1 Conclusions related to the data warehouse

- The proposed data warehouse architecture (Figure 4.16, Chapter 4) can be used to house the various database systems that are used in the CM Company. The data related to estimating, scheduling, and project controls is usually stored in the respective database systems, i.e. data repositories. The proposed integrated database system can be used as a single repository to store the data related to estimating, scheduling, and project controls. This database system can be developed based on the generalized REA framework.
- The data warehouse architecture will help in managing the data at a single location, which can be made available to the project managers for decision-making. Further, it allows the end user to control the data in the individual database system. Any changes made in the individual database systems can be easily and instantaneously reflected in the integrated database system and vise-versa. This ensures data integrity, and eliminates duplicate entries.
- The data warehouse essentially stores data that is of interest to the project management team. Any outdated or unwanted data within the individual database

systems used for scheduling and project controls can be cleansed and re-loaded into the integrated database system. This will help in generating customized reports and charts, such as S-curves to be used for project controls purposes.

- The suggested data warehouse implementation strategy (Figure 4.17, Chapter 4) can be successfully used in the CM Company in designing and implementing the integrated system between scheduling and project controls. The various phases described in the methodology are step-by-step guidelines to complete any integrated system development project.

6.2.3.2 Conclusions related to project control system

- The project control system set up (Figure 4.20, Chapter 4), and the project control cycle suggested in this research work (Figure 4.19, Chapter 4) can be successfully used for project controls purposes by the CM Companies. The focus of this cycle is the identification of the scheduling and the project control processes. Once these processes are identified, then the logic is developed to manage the time, and cost related aspects of the project. This logic is a project control cycle.
- The three levels of project controls proposed in this research work, i.e. strategic, management, and operational control, can be adopted for any medium to large size construction project. These levels help in identifying the personnel responsible for decision-making process in the project control cycle (Figure 4.21).
- The project control tool suggested in this research work are S-curves and real time control charts (Figure 4.15). These tools are found very useful by the project managers for the project controls purposes. The S-curves provide a quick view of

the project progress pertaining to specific project variables such as total cost or labor hours spent. This helps the management in decision-making and deciding about plan of action. The real time control charts, on the other hand, help the management in concentrating on the specific project variables, which are found to affect the progress of the project. Therefore, the real time control charts eliminate the unwanted portion of S-curves and provide a complete picture of the project progress.

6.2.3.3 Conclusions related to the decision support system

- The decision-making mechanism developed in this research work can be successfully used for project controls purposes. The intelligence phase of this mechanism will help in recognizing the problems related to project progress and will highlight the causes. This is aided by analyzing the nature of S-curves. The design phase will help the management in developing the various solutions to the problems that are identified. The choice phase will allow the project managers to choose the best possible solution depending on nature of the project S-curves or real time control charts.
- The flow chart developed in this research work for information collection and analysis (Figure 4.18, chapter 4) can be used to streamline the decision-making mechanism.

6.3 Future area of research

This research project focused on developing an REA model and the framework for its computer implementation for scheduling and project control processes. The REA model developed is based on the original REA model template used for accounting systems. The construction domain is the professional CM environment and the domain company selected for the research work is a medium to large size CM firm, handling the project of a minimum value $100 million, and of a minimum duration of two years. The integrated REA model is used to develop the database tables whereas the REA implementation framework is used to develop a database system that generates the S- curves and real time control charts as tools for the project controls. The REA model and the framework developed in this research work were used for developing the proof of concept, using two case studies of CM companies, and one case-study of a software-developer firm. Based on the work done in this research project, the feedback from the case-study companies, and the researcher's knowledge of the construction industry, the different areas of future research are identified. They are broadly classified in modeling of construction domain, data warehouse design, knowledge base systems (KBS), automated intelligent systems, different project environments, project controls and decision support system, and educational needs. All of them are discussed in the following sections.

6.3.1 Modeling in the construction domain

The following possible research areas are identified under REA modeling for the entire construction domain and not only for the construction management domain.

1. The REA model developed in this research work is only for certain events in certain phases of the project. The events were mainly related to scheduling and project control processes, during the planning and construction phase of the project. The same REA template can be applied to the design stage of the project, and also the close out stage of the project. This will lead to the REA template for the complete life cycle of the project. This template will be a very useful base object, upon which a complete ERP package can be built for the entire project. The REA model will always serve as the framework to build the ER model a very important step in building any information system database.
2. Similarly, the same concept of REA modeling can be applied to different processes such as estimating, documentation control, and project management processes during the various project phases.
3. For this research work only time and cost related parameters were selected for scheduling and project controls. Other parameters such as resource management, and quality can be also studied using the REA modeling technique.

This is the overall future area of research for REA modeling. However, the following specific areas can be also pursued under REA modeling aspects:

1. Duality relationship: Not all the duality relationships used in this research work are of give and take nature. For example, "develop resource loaded schedule" and "develop resource distribution loaded schedule", do not share give and take

relation but merely depict how one helps in developing the other. It will be a very interesting and challenging task to explore hard-core give and take relations and model the same as it is done in the original REA modeling used in accounting.

2. The duality relationship concept can be extended to the cash flow events for the subcontractors such as "generate pay request", or "cash disbursement" event for the vendors (as suggested by the human subject in case study three).

6.3.2 Data warehouse design

The scope of this research work was limited to identifying and forming the entities in the database tables and developing the example of various database features such as tables, queries, forms, and reports. The actual design of complete relational database system was not covered in this research project. It will require more of a technical research work to design such a database system. The designing will include identifying and designing the database language, the structure to be used, identifying the software application that will best support the design requirements, and addressing the physical design requirements. The physical design requirements need to address issues such as the operating system, performance standards, user access, security, and hardware issues. According to the researcher's experience with use of commercial software applications, primavera, expedition and prolog can be used as the software implementation tool.

However, the cost of design, maintenance, and operation for each application is different and will affect the final selection of the implementation tool.

6.3.3 Knowledge based systems (KBS)

The database developed in this research work is a simple relational database and does not include a knowledge base. The REA model developed does not identify various data repositories, but simply assigns the attributes to the various entities. It will require a considerable research work to identify such data repositories and incorporate the knowledge base wherever required. The knowledge base will be mostly used during the decision-making process and for future planning. The designing of such KBS can make use of various relation types such as aggregation, association, generalization, classification, grouping, which were incorporated into the REA model. These relation types can be used in design of rule-based KBS.

6.3.4 Automated-intelligent systems

The REA model developed in this research work, assumes that the end user will typically perform the functions like measurement, comparison, data updating and generating reports for managerial purposes. All these tasks could be automated to produce the required reports on the desktops of project managers. This will require developing a uniform coding structure across schedules and budgets. Thus once the entities are identified from the REA template, the next task could be to develop a coding structure to be used for storing these entities. The coding structure can be a WBS or a bar coding application. Thus all the data associated with particular code will be transformed whenever any operation is done on particular element in the database. These codes can be incorporated into various formulas that generate S-curves, thus auto generating such S-curves whenever required. The uniform coding structure will help integrate all the

different fragments of the same data, developed by different developers. For example, the estimators and schedulers usually develop the budgets and schedules independently and then merge them together in different software applications, such as a spreadsheet. The merging process can be automated once the coding structure is developed. This same feature is used in the present commercial windows integrator between scheduling and estimating, designed by Timberline Software Inc.

6.3.5 Different project environments

The construction domain for this research work is the professional construction management environment. The REA modeling technique can be applied to different construction domains such as at risk Construction Management, Design –build, Turnkey, and General Contracting. Each of these environments has a unique set of project phases, processes, and participants. For example, in design build environment, all the project activities occur under a single roof. The project participants are all the internal agents and the external agents are the owner and suppliers. There is more communication and participation of various individuals during the project planning phase than in the PCM or ARCM environment. Thus depending upon such activity sets, the REA template for each project system may be different. It is the researcher's belief that, integrated systems can be best used for, "At risk construction management," and "Design build nature of business," as it offers the following benefits over the other project environments (as also suggested by the human subject in case study two):

- The data generation, processing and updating is all done in-house, thus eliminating need of different modules in the integrated system to account for data acquisition, processing and updating.
- The global view of the REA model will incorporate almost all the project phases and various processes.
- The owner of such an integrated system (the construction company) will have more and better control over the design and operation of the system, therefore considerably reducing design and operation costs in the initial stages.
- The best potential use of the integrated system can be made as the nature of business requires supporting the project starting from its design phase (developing the project from scratch) up-to the completion phase.

6.3.6 Project controls and decision support system

This research work focused on the traditional project control cycle and the project control tools such as s curves and real time control charts, used for decision-making process. A research could be made to explore other ways of doing project controls and find out the different project control tools. The logistics of updating schedules and budgets is very important for multi project programs. The batch processing recommended in this research work can be used for this purpose. However, the logistics will change depending up on particular project environment. For example, for general contracting work, only that portion of schedule and budgets will be updated for which the GC is responsible and it may be only a particular component of the whole project. Hence, devising the logistic for different business needs is another area of research.

The decision support system developed in this research work is mainly based on three generalized types of decision and control functions such as strategic, managerial and operational. There are also other and more specific types of control functions like pure administrative, pure technical and pure design control. For example, arranging a project coordination meeting is a pure administrative function. How to coordinate (using wireless communication, video conferencing, online chat etc.) such meetings, is pure technical control. Finally "what should be discussed" and in "what time sequence", is pure design control related to project coordination meeting. All these different function and controls have specific information needs and they go through a specific decision-making process. Therefore identification of a specific decision and control functions and designing a decision support system for supporting these could be another area of research.

6.3.7 Educational needs

It is the researcher's belief that the use of REA modeling technique should not be restricted to only traditional accounting systems and transaction processing information system but should be extended to other fields also such as construction and project management. The concepts developed in this research work can be used for designing a course in "application of REA modeling for construction," in an academic curriculum. There is an increasing influence of information system and information technology applications over the construction industry and incorporating such a curriculum course will only add to the better understanding and use of these applications by the construction professionals.

6.4 Summary

The integrated system is a dynamic integrated information system that provides the real time data for the end user. The design of any integrated system between two or many different systems, involves modeling the systems and building the framework for the implementation of the model. The design of model involves a detailed analysis of the value chain for the organization and various business processes. The implementation framework involves more operational, technical and physical aspects of the system. It is during the implementation framework design process that the factors like organizational and behavioral changes, short-term, and long-term business goals need to be considered. Finally any integrated system is less beneficial without automation. It is very important for a system analyst or system designer to automate the various processes that are at the core of such integrated system. Therefore, it will be more beneficial to have the construction professionals involved in designing of an integrated system, as part of the system developers, and not only as the end users.

This research work is an attempt to design an integrated system between scheduling and project controls using the REA modeling technique. The research work also developed an information system that will make use of the data generated from the integrated REA models, for project control purposes. In the researcher's opinion, the REA modeling technique is a very good tool to design an integrated system framework and also the computer implementation model of the framework. The integrated system architecture developed in this research work will help in integrating the scheduling and project control process, and setting up the information system to achieve the best potential use of this integration for the construction management business.

Appendix Section 1

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Appendix Section 2

Review and comments by the Project Manager (Case study company 1)

We feel that the concepts developed in this research work, especially those related to project controls and decision support system, will benefit the current business practice, in our company. Also the recommendations made in the research work can be implemented to get the related benefits. From the manager's perspective, the following two recommendations, as made by the researcher, have strong potential benefits for the present project:

Developing a structured decision-making mechanism- it is true that for this project, most of the decisions are directed by the owner. The proposed decision-making mechanism will make it easy for the project participants to understand their control function levels and the associated responsibilities.

Identifying the processes at the task level, which are the candidates of business process reengineering and storing the same as entities in the dot matrix system- for this project type, the activities are typically broken down to different tasks, that are shown on the process flowcharts. It will be easy to control the processes at the "task-level" and concentrate on the individual tasks. Also these tasks can be stored in the dot-matrix system to generate the progress reports.

The use of issue tracking system such as Prolog Manager- the management of information and documentation, for this project is of great importance to the company, as our business is committed to the owner, for the successful project management and delivery. The Prolog Manager software application will very well suit our present and future information system needs.

Overall we agree with the recommendations made in this research work, and the proposed benefits. It is beyond our knowledge to comment about the appropriate use of REA modeling technique, as proposed in this research work. However, following issues need to be addressed in this research work:

To develop a strategic plan or methodology for implementing the recommendations on a project and also on organization-wide level.

To accommodate a series of prime contractors, rather than single General Contractor (GC), in the proposed REA model.

Review and comments by the Quality Manager (Case study company 2)

Let this letter serve as confirmation from me that you have accurately described our organization, interviewed me and have captured the essence of our concerns about the objectives of your research. Your outlining our controls, processes and value chain is valid.

After reading your thesis submittal, I took some time to consider the ramifications of your theoretical model. First, as you know, much of what you are doing is already commercially available and possible. Some exceptions to that however. The finishing touch is the "complete" implementation or the "robust" solution as you noted.

I only question whether the model is achievable beyond a rudimentary implementation. Does it take a "genius" to have a complete virtual managed solution? I hope it does not, but clearly someone or some firm will take this management model and attempt a full utilization. Whoever has the patience to evolve this capability at a broadbase level in an organization will, in my opinion, succeed at advancing while simplifying the project delivery. Any good research requires faithful compliance to the stated steps and solid analytical conclusions.

I would encourage you to seek a place where your work can be continued. Obviously to mine the depth of possibility you need an actual project to engage these activities. The caveat is you might have to duplicate your work while your "Extended Beta" research is done in parallel. It is only then that baseline comparison to achieved benefits can demonstrate the ultimate goals. Reduced cost, rapid response, comprehensive coverage of risk issues to name a few.

Review and comments by the Chief Technology Officer (Case study company 3)

Q. Do you think REA models will serve the purpose of developing integrated system applications?

A. Yes. The standard models for construction project scheduling and job costing are compatible with the REA model, and could easily fit into such a framework.

Q. Which construction environment is the best suitable for use of such big packaged systems, environments such as CM, GC, Design Build, Turn Key, etc.?

A. I'm really only familiar with CM and GC environments and their level of systems investment varies with the size of the firm. The system requirements for the GC that does not work itself are different and simpler than a CM that manages lot of projects. So between those two, CM would be most suitable. That being said, I think that the day of big packaged ERP is passing, and the day of the Internet business service is coming.

Q. Do you think, we can find better "hard core give and take" duality relationships for project controls processes?

A. I think project controls processes should measure actual Vs estimated inputs and outputs from construction processes. In that sense, the duality is between the inputs (resource consumption) and outputs (resource production). The project control comparison, however, is between the actual and estimated costs and completion times, and it is not a duality relationship. However, aggregates of the hard-core events and duality relationships could be used for project controls.

Q. What other types of duality relationships can be used for this work?

A. There area whole set of duality relations around cash flows that are extremely important, especially to contractors. For example, when they do their work, claims arise

for progress payments likewise for material vendors. I understand that these are outside the scope of your current work, but they could be incorporated in the future, especially if presented as the Internet connection hub.

Q. What could be possible drawbacks of REA modeling from construction industry's perspective?

The following drawbacks as came to my mind: inability to model the informal information such as market trends, historical records, site related data etc. Construction industry heavily relies on informal information tool.

The other major drawback can be, the "agents" in the model will change pertaining to particular construction environment.

A. Professor McCarthy often mentions runtime performance, but that is easily manageable using the techniques of Nakamura and Johnson as discussed at the following web site: **http://jeffsutherland.org/oopsla98/nakamura.html**

I suppose if you restricted a system to REA event templates and did not consider any other information, that would be a drawback.

If you design the system with flexible agent slots, for example a collection of agent roles per event, with only one internal agent really required, then internal activities either should not need external agents, or the external agent would belong to maybe a different department in the same company.

Q. What technology / implementation tool could be used for data warehouse development? What factors would govern that?

A. The technologies that I would suggest for developing a large system today would be Oracle, Java and Sun Solaris, presented as an Internet business service. That's the technical architecture of most of the construction hubs.

Q. The database system used in this research work Microsoft Access. Do you feel it's good to use it considering the ease and user friendliness of the software?

A. Access databases do not handle many concurrent users, so the answer to the question depends on the number of users. However, it is fairly simple to take a solution developed in Access and port it into a more robust database.

Q. What is the possible future of such integrated system for construction as compared to one for supply chain market?

A. Internet construction systems which have many of the features that you propose are developing very quickly; the next year they will become popular, because many construction project bids will be let on these systems.

Q. What could be the "emerging trends"?

A. The Internet construction hub as cited in the previous answer.

Q. What is your opinion about this thesis work in terms of it's originality, innovativeness, concept development, and it's application in real life?

A. The thesis is original and innovative in its use of REA modeling technique to management processes. I am not really qualified to say if these are valid uses of REA models. In real life, I think that near-real-time comparisons of actual Vs estimated costs and times would be very valuable to a construction project. However, for small projects,

these comparisons can usually be guesstimated adequately by project managers, and large expenditures of time and money on computer systems to do the same thing would not be acceptable. For large construction companies who oversee many complex projects, the effort to construct such a computer system would probably pay off. (You indicated that company size was a criterion for applicability of your ideas, so I am agreeing here.)

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