Project Control Techniques
Reconstruction of Occupied Buildings

By

Mohamed M. Attalla, P.Eng.

A thesis
presented to the University of Waterloo
in fulfilment of the
thesis requirement for the degree of
Master of Applied Science
in
Civil Engineering

Waterloo, Ontario, Canada, 1996

0-612-21531-8

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ABSTRACT

The construction industry is one of the largest industries worldwide. Reconstruction of occupied buildings constitutes a significantly large portion of construction spending. Therefore, any research done in the area of reconstruction of occupied buildings is of high practical value.

Projects dealing with reconstruction of occupied buildings have a unique character which differs from that of new construction projects. Reconstruction projects are becoming increasingly more important as building owners as well as metropolitan cities face economic, environmental and space constraints for new construction projects.

The primary objective of this study is to investigate the use of conventional control techniques in reconstruction projects in occupied buildings and conduct a comparison between the project performance of reconstruction projects and the project performance of new construction projects.

To gather observational data, three different approaches were utilized in this research: A comprehensive literature review, interviews with several construction practitioners, and a participant-observer approach was utilized

This study researched and rediscovered the most commonly used project control techniques. Three quantifiable performance factors were utilized to conduct a comparison between reconstruction and new construction projects. The outcome was that, new construction projects outperform reconstruction projects. This study identified some of the problems and factors affecting the control of reconstruction projects.

It is recommended that further research be undertaken to examine and investigate success factors

and other control techniques which may contribute to enhancing the performance of reconstruction projects.

It is also recommended that these factors and techniques be used to develop a model for a non-traditional project control system to control reconstruction projects in occupied buildings.

To my wife, Rafaa, whose love, selfless help and encouragement gave me the strength to complete this work.

ACKNOWLEDGMENTS

I would like to express my gratitude and appreciation to all the individuals who have helped to make this thesis possible. I am particulary grateful to my supervisor, Professor Robert McKim for his guidance, understanding and valuable input in this work. Professor Mckim has generously given his knowledge and time. His technical insight and support have been greatly appreciated. I am also thankful to Professor R.W. Cockfield and Professor M. Pandy for their help and valuable input into this research..

I would also like to express my sincere appreciation for the support of my colleagues and superiors at the North York Board of Education. I owe special thanks to Mrs. Sheila Penny, Manager of Design and Construction Services and Mr. Frank Coppinger, Superintendent of Facilities and Transportation services.

My greatest debt of gratitude goes to my wife Rafaa, my daughter Rana and my son Ahmed. They have made many sacrifices throughout the compilation of this thesis and have always shown love, patience and understanding.

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CHAPTER 1

INTRODUCTION

Management of a construction project is one of the most challenging management assignments in an enterprise. The objective is, of course, to finish the project within budget and on schedule while maintaining the quality requirements of the specifications. Meeting this challenge is not acheived without an adequate planning and control system.

1.1 WHAT IS PROJECT CONTROL AND WHY IT EXISTS ?

The definition of control is " to check or verify, and hence to regulate" [Shorter Oxford English Dictionary]. It is also defined as " making situations behave according to certain desired performance criteria" [Beer, 1996]. Construction project control is more than just procedures. It is a process that generates a building or a facility at the lowest reasonable cost within a reasonable time frame.

Economic pressures and the lack of clear leadership within any construction organization make project control essential to construction projects. Inflation has turned potentially successful projects into near disasters. Overruns of time and budget have destroyed many projects and damaged the reputation of the design professionals who prepared the plans. Modern clients expect construction professionals to employ a variety of control methods to combat rising construction costs and minimize project time.

1.2 PROJECT CONTROL SYSTEMS AS THE APPLICATION OF CONTROL TECHNIQUES

Project control is not a specific set of services that can be applied in the same manner to each and every project. A project control system is not the development of something entirely new. It is more the bringing together of many proven project control techniques. Furthermore, because the exact combination of control techniques varies significantly to meet the unique needs of each project, no single detailed control system is appropriate for every construction environment. Therefore, every owner, contractor and engineer should become aware of all project control techniques in order to be able to employ the most appropriate technique to his or her project.

1.3 PROJECT CONTROL OPERATIONS WITHIN A FIRM

Project control operations should be placed organizationally close to the construction management functions. By no means should it be an element under accounting. However, accounting information should be made available to project control staff. Project control staff utilize accounting information to perform their cost control functions. The presence of a computer system would be considered a great asset that supports project control. This system should be operationally independent of other systems such as accounting and payroll because it needs to be available at all times.

In construction projects, where several activities or disciplines are to be integrated and there is a need to coordinate the cooperation of various functional departments within the project organization, an appropriate project control system should act as the information centre to all parties .This system monitors and reports on every function performed by every party within the project organization. Being the project information centre, different persons associated with the project may have access to the control system to obtain data related to their duties within the project organization.

1.4 PROJECT CONTROL AND RECONSTRCUTION OF OCCUPIED BUILDINGS

The construction industry is characterized by its size, diversity and complexity. It is also characterized by its different work environments and disciplines. Unlike other industries which tend to have a single focus, the construction industry is made up of a number of separate work environments. Each of these environments tends to have its own characteristics while at the same time forming an integral part of the construction industry.

An effective control system must take into consideration the unique characteristics and disciplines of each environment in order to ensure effective interaction and communication within the project environment. It is useful to review the primary environment of the project and to examine how data and information transfer between the different parties. Effective control of data and information is essential in order to examine performance trends, influence outcome and modify adverse trends in performance.

This thesis focuses on the basic environment of reconstruction projects in occupied buildings. The main objective is to determine if conventional control techniques are adequate for reconstruction projects of occupied buildings. A comparison is conducted between the project performance of reconstruction projects and that of new construction under the utilization of conventional control techniques.

This work utilizes three different control functions to measure and compare the outcome of both types of projects. These control functions are cost, schedule and quality. These functions were selected as the basis for the investigation and comparison because they were reported as the most significant by the three main parties involved in any construction project: the owner, engineer and contractor.

1.4.1 Why Reconstruction of Occupied Buildings ?

The construction industry is one of the largest industries worldwide. Reconstruction of occupied buildings constitutes a significantly large portion of construction spending. Therefore, research done in the area of reconstruction of occupied buildings is of high practical value.

In spite of the increasing importance of reconstruction projects, surprisingly little is found in the literature concerning these types of projects. Thereby creating the need to study the social and economic impacts of these projects and also measure and control their outcome and performance.

Projects dealing with reconstruction of occupied buildings have a unique character which differs from that of new construction projects. Reconstruction projects are becoming increasingly more important as building owners as well as metropolitan cities such as Toronto, New York and Los Angeles face economic constraints. Environmental and demographical constraints are two more factors which make the need for reconstruction of occupied buildings more appealing.

Fig. 1.1 shows the spending on new construction vs. reconstruction since 1970 in one of the most congested municipalities in North America.

1.4.1.1 Demographical Factors

The change in population in metropolitan areas is a crucial factor which impacts the need for reconstruction in occupied buildings. The population in metropolitan areas increased dramatically in the last few decades due to a variety of reasons. One reason is outside immigration. Metropolitan Toronto is a good example of outside immigration, whereas Metropolitan New York is a good example of inside immigration. Since these metropolitan areas suffer from lack of space to build new buildings, they tend to upgrade existing buildings in order to accommodate the increased service

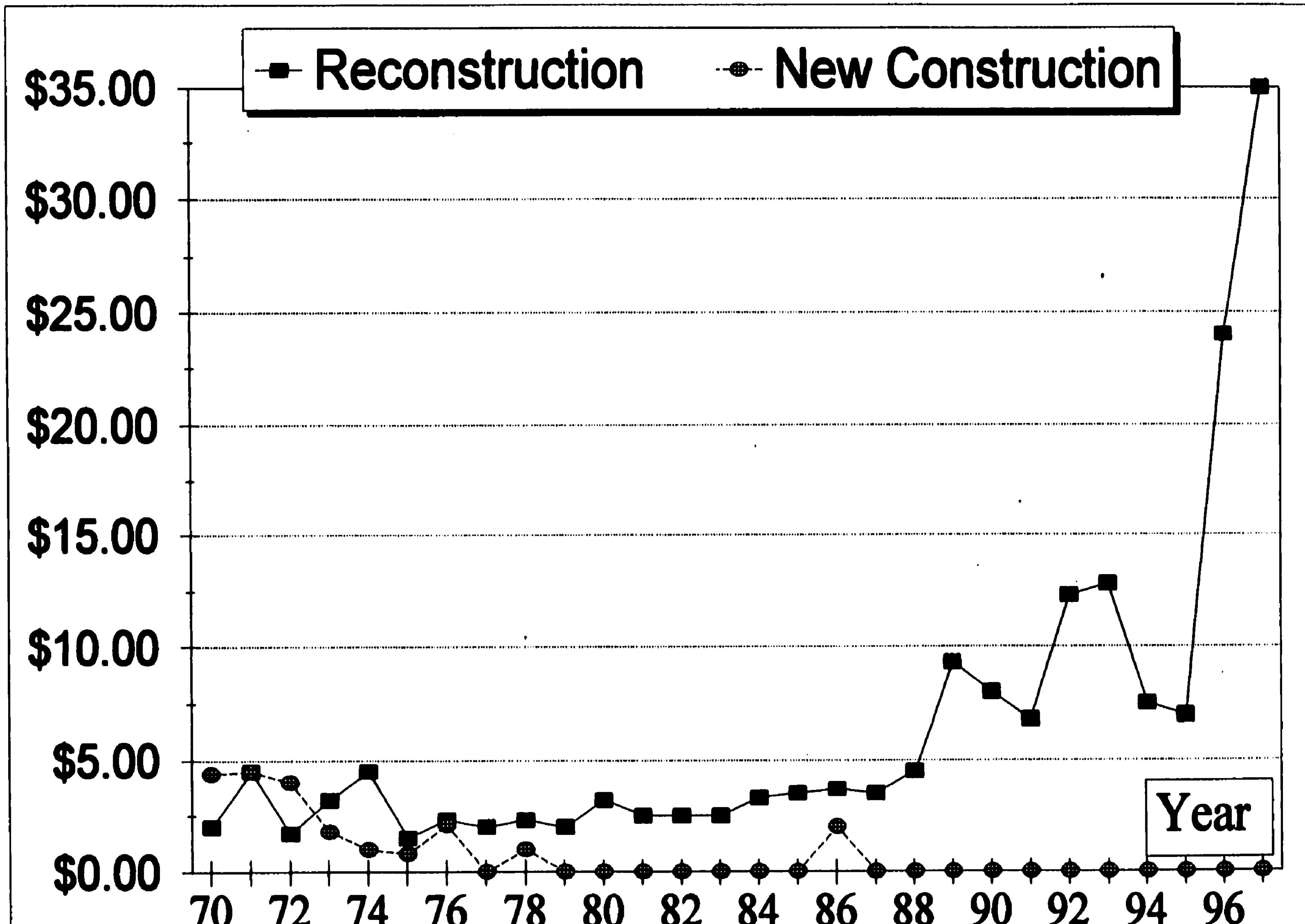


Fig. 1.1 Spending on new construction Vs. reconstruction (M)

requirements of the increased population. Increased enrollment in schools and universities is an example of this demographical factor. This factor imposes a need to increase the capacities of the schools or universities through expanding or replacing the existing buildings. Hospitals and government offices that are rendering services to the public face the same challenge.

1.4.1.2 Environmental Factors

The increased public awareness of environmental hazards and the proposed regulations to overcome such hazards impose another constraint on building owners and local and central governments to comply with these regulations . This increases the need for more reconstruction projects.

Asbestos removal is a good example in these types of projects. Since asbestos is designated as a hazardous material, building owners and public organizations are sponsoring programs to remove materials containing asbestos from their facilities. Unfortunately, asbestos is present in floor tiles, ceiling tiles and pipe insulations which makes its removal and the subsequent replacement of the building components a complex and awkward task. This is due mainly because appropriate safety regulations have to be undertaken and the existing facility has to be kept operational during this type of reconstruction.

1.4.1.3 Social Factors

Social factors also contribute to the increasing need for reconstruction of occupied buildings. One example is Barrier Free Programs where building owners and public organizations adopt plans to upgrade their buildings to secure access to persons with disabilities. This may include removing stairs, constructing ramps, building elevator shafts and modifying existing washrooms. Such construction projects involve a large amount of uncertainty and complexity.

1.4.1.4 Technological and Economical Factors

Given the high pace of change in science and technology, it is crucial to remain competitive in today's market place in order to meet the public expectations of the level of services provided by public organizations. These organizations have to design programs to continuously improve and upgrade their facilities. This may include interior renovations of a computer facility or a blood testing lab to accommodate more advanced equipments. Another example could be retrofitting the mechanical and electrical systems for energy conservation purposes.

1.4.2 Definitions

Reconstruction projects can be defined as the modification, conversion or phased complete replacement of an existing facility. Modification may involve expansions, additions, interior renovation or upgrading the functional performance of the facility. Conversion includes changing the type of the facility to perform a different function or provide a different service. Phased replacement is a complete replacement. However, because the building is occupied and the owners can not shut down the building during construction, both demolition of the existing facility and the construction of the new facility have to proceed in phases.

In the last few years, building owners have invested large amounts of money in reconstructing existing buildings while keeping them operational. These reconstruction projects fluctuate from a few thousand to several million dollars. On July 12th, 1996, Princess Margaret declared the new Princess Margaret Hospital open. The new hospital included conversion, expansion and upgrading an existing building at a cost of 95 million dollars. North York Board of Education will completely replace Earl Haig S.S. in a phased replacement procedure at a cost of 34 million dollars. Metro Toronto School Board launched an HVAC and lighting retrofit project in 350 buildings as a part of its massive energy conservation program at a cost of about 95 million dollars. Other organizations have programs for barrier free access and interior renovations programs that add up to millions of dollars. These millions of dollars worth of investments require further research to study the performance of these reconstruction projects and assess their outcome. The assessment of the outcome will assist in improving the performance of future projects.

Table 1.1 shows the percentage of average spending on various reconstruction activities in recent years within one of the interviewed organizations in one of the most congested cities in North America. Considering the reliability and accuracy of the data, it can be used as an indicator of the spending patterns in other organizations.

NO.	ACTIVITY	%
1	Expansions and phased replacements	38.58
2	Upgrading the functional performance of the facility	29.24
3	Retrofit	24.46
4	Interior Renovation	7.72

Table 1.1

Table 1.1 shows that expansions and replacements are the most funded reconstruction activities which absorb 38.58 % of the available funds for reconstruction. Upgrading the functional performance of existing facilities absorbs 29.24 % of the available funds. This may include upgrading the building fabric such as the construction and performance of exterior walls or exterior windows. It may also include reroofing the entire facility to prevent leakage or heat losses. Making the facility accessible to people with disability and upgrading the drainage and storm systems are two important items.

Almost one quarter of reconstruction funding goes to retrofitting activities. When owners can not afford the high cost of replacing the facility, they retrofit the deteriorating mechanical and electrical systems. This may include boilers and chillers replacements or retrofitting for energy conservation purposes.

7.72 % goes to interior renovation to accommodate new programs or to change the use of the space.

1.5 RESEARCH PROCESS

This research studied the most common principles of project control techniques and the conventional methodologies of project management. Three approaches were utilized to conduct this exploratory study: a comprehensive literature review, informal interviews with several construction practitioners; and field observation.

As mentioned earlier in this work, very little useable information was found during the literature search concerning reconstruction projects. Most organizations that are involved in reconstruction projects of occupied buildings have developed their own management tools which they have modified through their experience. Therefore, a statistical survey approach was adopted to gather and obtain information about these types of projects. As a step in the direction of obtaining information that leads to the understanding of these projects, this survey is concerned with the evaluation of the performance of reconstruction projects in occupied buildings and measuring their outcome. In order to have more useful and meaningful results, new construction projects were also surveyed in order that a comparison be conducted between project performance in reconstruction and project performance in new construction environments.

The survey was also aimed at exploring and examining the use of conventional control techniques in both construction environments. The survey was conducted in the form of a questionnaire and structured interviews with a number of construction professionals to discuss the questionnaire.

1.5.1 Questionnaire Development

A comprehensive research of the principles of project controls was conducted in order to develop the questionnaire, whose focus was to investigate the use of conventional control techniques and measure the performance of both reconstruction and grassroots projects.

Test interviews were conducted to examine the validity of the questions and also to observe the flow of questions. Input from the test interviews was used to revise the questionnaire. The revised questionnaire resulted in a set of practical, useful and objective questions. The questionnaire utilized three control functions as the basis for measuring project performance. These three functions were cost, schedule and quality. The questions were structured in such a way as to avoid any subjective answers as much as possible. The questions were further structured to obtain quantifiable data that could be used to measure the cost, schedule and quality performances. These quantified measures were then used to compare the performance of several projects.

1.5.2 Questionnaire Layout

Appendix one includes a copy of the questionnaire. All questions were of the forced-response variety, Yes or No, in order to reduce the interview time and encourage more people to participate. Space was also provided, so that any additional data could be obtained in a free format. The questionnaire focused on the performance of three main control functions: cost, schedule and quality. These functions are considered by most construction professionals the main indicators of the overall project performance.

Part 1: Organization and Project Information

The seven sections in this part were aimed at soliciting general information about the surveyed project and identifying its nature. Information such as type of organization, location, position of the interviewee within the organization, and the building type were required. The type of project and the project format were also required.

Part 2: Cost Control

In this part, four sections were included to gather measurable data to enable the researcher to quantify the cost performance of the project and also identify the cost control techniques that are used for the project. The purpose of sections one, two and three was to obtain information related to the original contract value, cost control planning tools and other tools used to measure, control and analyze cost progress. Section four, on the other hand, included questions designed to measure and analyze the outcome of the project such as contract value at completion, number of change orders and analysis of reasons for changes.

Part 3: Schedule control

The same layout which was used in part two was also used in part three. Part three included four sections designed to measure and analyze the schedule performance of the project. The first three sections have solicited data regarding the planned duration of the project, schedule planning techniques and other techniques used to measure, control and analyze the schedule progress. Section four was more concerned with the outcome of the schedule performance.

Part 4: Quality Control

The definition of the term quality varies among construction professionals. Also, different organizations have different perspectives as to what quality is. Therefore, in order to place bounds around this research, quality control for the purpose of this questionnaire was defined as inspecting and testing materials and workmanship for compliance with the contract specifications and the applicable codes. Several round table discussions took place with different construction practitioners to arrive at a set of quantifiable measures for quality. Section four includes seven questions designed to exhaust the personal feelings of the interviewees and provide an objective evaluation of the quality performance of the project.

Part 5: Control Functions Weighting Factor

Currently, there is no agreement within the construction industry as to the significance of cost, schedule or quality to the overall project performance. Also, different parties within a particular project have the same disagreements. This part is an attempt to explore and investigate the views of the construction practitioners in order to enable future researchers to assign weighting factors to those control functions

Part 6: Other Control Functions

This section was included to give the interviewee the opportunity to express in a free format his / her views regarding other control functions that they believe could contribute to the performance of any construction project, and particulary those which are sensitive to reconstruction of occupied buildings.

1.5.3 The Survey Data Collection Process

Initially, the plan was to collect the data using the telephone and facsimile as the communications tools.

The advantage of using this procedure was to encourage the project participants to complete the questionnaire at their own convenience. The data received through this method, however, was insufficient and there were some obvious misunderstanding of some questions. Therefore, interviews were conducted on a one to one basis with the project manager or the project administrator of the organization. In these interviews, the questions were utilized as a vehicle to direct the interviewees towards different aspects of construction. In some interviews, more than one project was discussed and examined. However, a separate questionnaire was completed for each individual project

The need for confidentiality of certain data provided for this research was recognized. The participant companies and individuals were assured this confidentiality by means of a letter directed to them (copy of the letter is included in Appendix 2). This procedure assisted the researcher in obtaining reliable project data without compromising the confidentiality of proprietary data. The firms also became comfortable entrusting this data to the researcher.

CHAPTER 2

PROJECT CONTROL FUNCTIONS AND THE PROJECT ORGANIZATION

Before investigating and exploring the available principles of the project control techniques used in the construction industry, it is important to develop an understanding and appreciation of other factors that interact with the various control functions in forming an overall project control system. Fig. 2.1 shows the three main control functions: cost, time and quality in addition to other related factors within the project organization.

Fig. 2.1 shows how the project format, project parties, and project life cycle are all factors that affect the project control functions and determine to some extent which project control technique should be used to control certain functions. These factors are explained below.

2.1 CONTROL FUNCTIONS

The three main control functions as viewed in this thesis are cost, schedule and quality. The main objective of most construction professionals under reasonably normal circumstances is to finish the project on time, within budget and to the expected quality parameters.

These three control functions are highly related. The failure of one control function will eventually lead to the failure of other control functions. Also, an attempt by the construction team to achieve excellent performance in one function may lead to the failure of other functions. For example, an owner who attempts to minimize the cost of a facility may compromise on the quality of the final

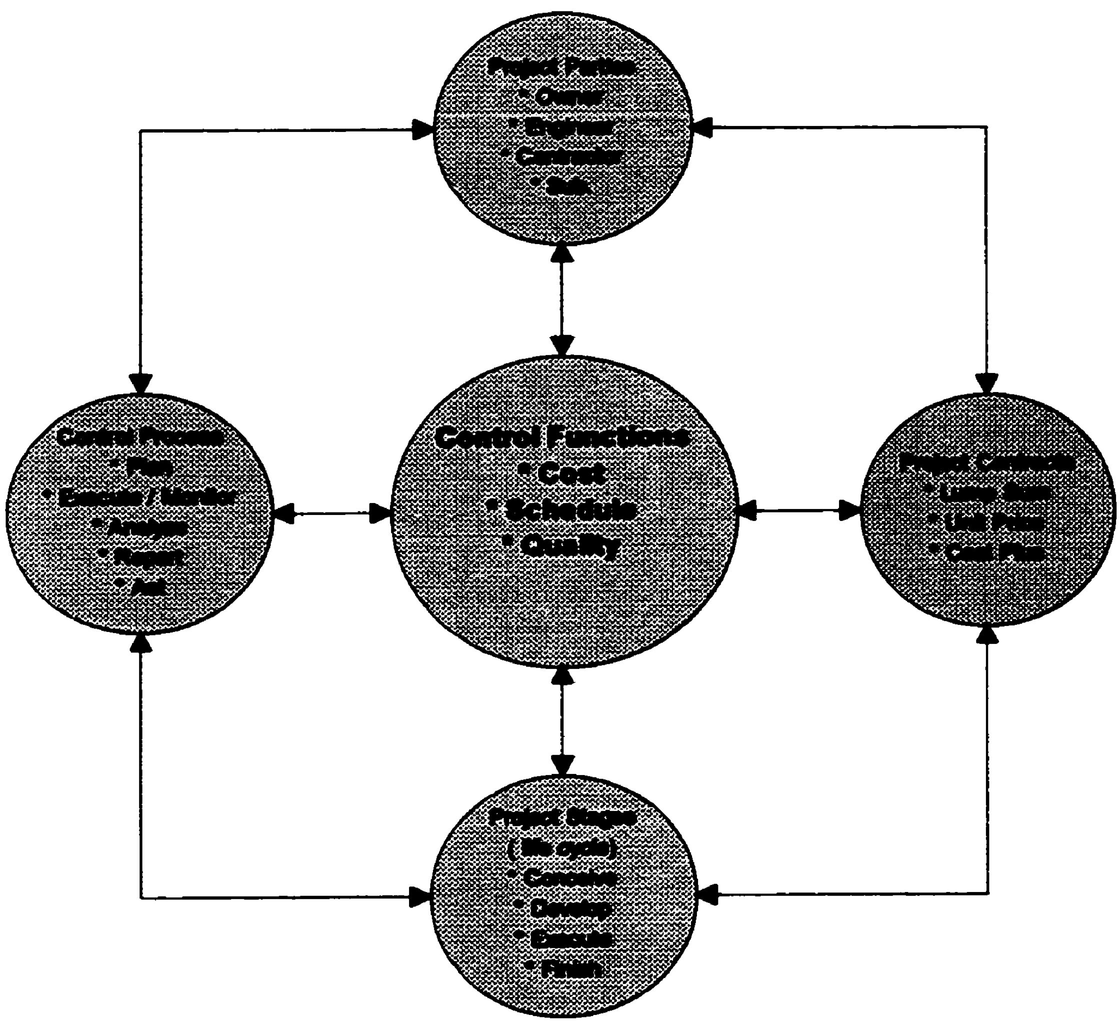


Fig. 2.1 Project Control Functions and the Project Organization

product which may lead to rework which may consequently lead to extra cost.

<u>Cost Control:</u> The control of cost is essential to all parties involved in a construction project. Owners, contractors and architects have a mutual interest in controlling cost. However, a contractor organization would normally carry out the cost control function in a more detailed level than an owner or an architect organization. The contracting relationship between the owner and the contractor also impacts the level and type of cost control. Different contract strategies are explored later in this chapter. However, for the purpose of this thesis, the focus is on a lump sum contract. Also, the depth and intensity of cost control varies significantly at the various stages of the project life cycle. The concept of project life cycle is discussed later in this chapter.

Controlling the cost should be done in a reasonable way since it may affect other control functions.The concept of cost control and several cost control techniques are investigated in chapter three of this study.

<u>Schedule Control :</u> The time required to complete a construction project is usually of major significance to all parties involved. Similar to cost control techniques, schedule control techniques are impacted by the various stages of the project life cycle and the contract format. It should be noted that squeezing the project schedule more than its reasonable limits in order to meet unrealistic deadlines may have a negative impact on quality and cost. Also, stretching the schedule beyond a reasonable time frame may have the same negative impact on cost and quality. Schedule control is studied in greater details in chapter four.

<u>Quality Control:</u> In this work, quality control is considered to be the process of testing and inspecting material and workmanship for compliance with the specifications and the applicable codes. This process is also impacted by the type of organization, contract format and the project life cycle. In this thesis, quality control is studied in a lump sum contract environment and within the execution and finish stages of the project life cycle. Also, quality control is highly related to both cost and schedule functions. Furthermore, quality may be considered as a product of cost and schedule control.

Quality control is discussed in more detail in chapter five.

2.2 PROJECT CONTRACTS

Any construction project can be implemented under many contracting forms. Every contract form creates different contractual relationships, obligations and reporting responsibilities which affect the project control functions and, consequently, affect the control techniques that are used to control these functions.

It is possible to broadly categorize the contracting formats into three generic formats. The three formats which are most widely used in the North American construction industry are (1) the lump sum (stipulated price) contract, (2) the unit price contract and (3) the reimbursable cost (cost plus) contract [McKim, 1990].

These contracting formats can be implemented in many forms such as a single contract form, multiple contract form or turnkey form. The following is a brief discussion of these main contracting formats. For the remainder of this thesis, however, the investigation focuses on the lump sum type contract between the owner and a single contractor.

2.2.1 Lump Sum Contract

Single Contractor : Under this form, the owner and one general contractor enter into a contract with a stipulated fixed price. The contractor has full responsibility of all construction work. The general contractor normally has the right to use any combination of his own forces and subcontracting, although the owner may reserve the right to approve all subcontractors and major vendors. Under this type of contract, both the owner and the contractor establish and operate a project control system that corresponds to their needs. Different control techniques are investigated and presented in the following chapters.

Multiple Contracts: This format is normally used in larger projects. The project is divided into major components and separate contracts are awarded for each component such as site work, concrete, ...etc. Usually, the owner establishes the overall project control system and requires the contractors to provide certain information in specified formats that enable the owner to combine these pieces of information and produce general reports.

Turnkey: In this format, the owner gives the overall project functions, including engineering procurement and construction to one firm. The selected firm may handle all functions using its own staff or may subcontract portions to other specialized firms. Usually, the turnkey firm establishes and maintains a project control system that integrates all activities. It is not the intent of this work, however, to investigate in details the control techniques that can be used for this contracting form.

2.2.2 Unit price Contract

Under this type of contract each unit of work has a specific price and the total price is arrived at by multiplying the number of different units by the respective unit prices. The owner should define the methods of field measurements before awarding the contract. This type of contract format can be performed in different forms such as single or multiple contracts.

2.2.3 Cost Plus

Under this type of contract the owner agrees to pay to the contractor his actual direct costs of doing the work plus a stipulated percentage for overhead and profit. This is in many ways the most favourable type of contract for a contractor since, although he cannot make any exorbitant profits, he is at least assured of not incurring a loss [Goldsmith, 1988]. This type of contract can also be performed in either single or multiple contract forms.

Since there is a wide variety of contracting strategies that can be implemented in the construction industry, covering all contracting forms is beyond the scope of this thesis. In this thesis, the emphasis is on the lump sum type contract with a single contractor.

2.3 PROJECT PARTIES

All parties involved in any construction project (owner, contractor and engineer) are interested in developing a project control system. In establishing a project control system, every organization should account for certain interests depending on the type of the organization.

Fig. 2.2 shows the basic construction format. The owner enters into two separate contracts with an engineer and a contractor. These contracting parties in turn enter into a contract with their subcontractors or sub-consultants.

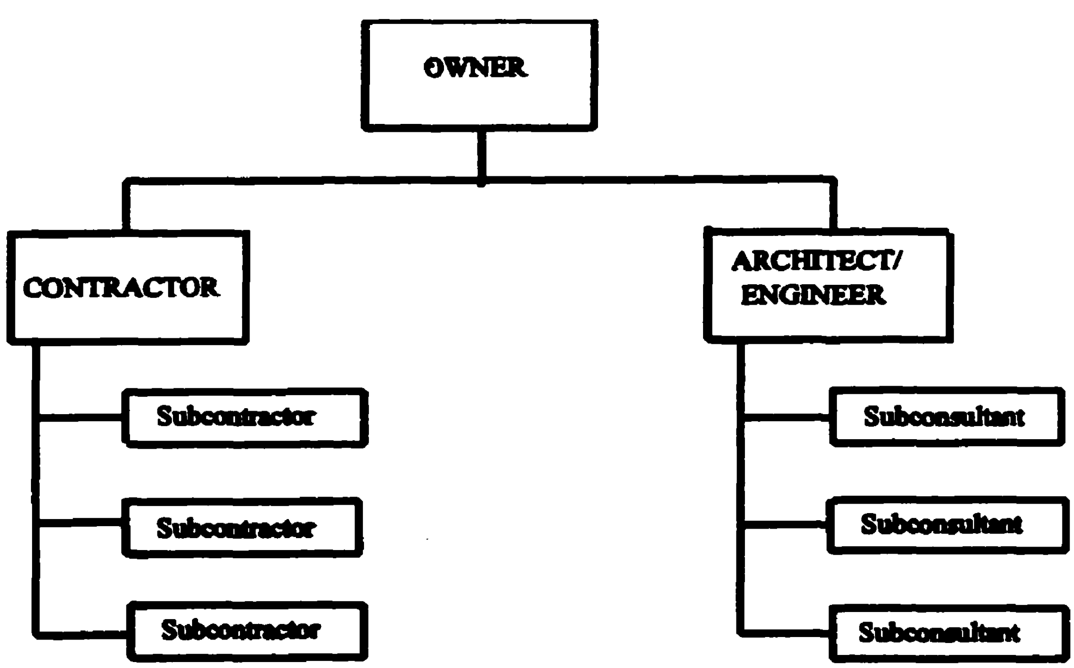


Fig. 2.2 Basic Construction Formats

2.3.1 Owner

The owner is the person or entity identified as such in the agreement. The term owner means the owner or the owner's authorized agent or representative as designated to the contractor in writing, but does not include the consultant [CCDC2,1994]. The owner finances the project and inherent the property after completion. From an owner perspective, he or she must have assurance that the project will be delivered on time, on budget and with the desired quality and is suitable for the intended use.

The level of involvement in a construction project and the level of control exercised by the owner depend on several factors. The skill of the owner is one major factor. In a knowledgable owner organization, where construction professional staff are available, the owner will exercise more detailed control than a non-knowledgable owner. In this work, only knowledgable owners are considered. The contracting strategy is also another factor that determines the level of control assumed by the owner. In a cost plus contract, the owner controls and verifies all the contractors expenditures. Also, in a unit price contract, the owner should review and measure all quantities of work performed. In a lump sum contract, which is considered in this work, the owner controls the general progress of work.

The owner may require to know what he is paying for in each progress payment. Therefore, the project control system must be designed in such a way as to provide the owner with the baseline schedule and regular updates of actual schedule performance. Also, an agreed upon method must be established for work measurement purposes so that no conflict arises during the processing of progress payments. In most contracts, owners establish scheduling guidelines which include mobilization date, completion date and key milestone dates to correspond with expected delivery dates.

For income and sales tax purposes, owners may require a project cost data in a certain format. For example, most owners require the Goods and Services Tax (G.S.T) to be identified separately on all progress payments.

The project life cycle is also a factor affecting the level of control exercised by the owner. This is discussed in details later in this chapter.

2.3.2 Engineer

The terms engineer, consultant and architect are used interchangeably. The consultant is the person or entity identified as such in the agreement. The consultant is the architect, engineer or entity licensed to practice in the province or territory of the place of work [CCDC2, 1994]. The engineer designs a facility for the owner that is suitable for the intended use and also cost efficient. The engineer usually also assists the owner during the construction phase to deliver the project on time and on budget.

In order for a project control system to be effective in an engineering organization, it must begin during the planning and budgeting of the work and continue during the conceptual and detailed engineering phases. If these phases are part of a contract where engineering, procurement, and construction overlap, engineering project control should be integrated with procurement and construction project control. The project control system is also affected by the project life cycle and the project format.

2.3.3 Contractor

The contactor is accountable to both the owner and the engineer to construct the building according to the specifications, drawings and applicable codes. The contractor is also responsible to deliver the project on time and with the expected quality.

Every construction firm is interested in a highly detailed project control system. Such control system should include detailed schedule and tracking reports on daily basis because the contractor controls all subcontractors and coordinates their activities. Also, a construction firm should keep all cost data in a historical data base so that this information can be used for the planning of future projects. The control system established by the contractor always depends on the contractual relationship between the contractor and the owner.

2.4 PROJECT STAGES (Project Life Cycle)

A construction project occurs over several stages during which a changing level of effort is required to complete each stage. The most important milestone in a project life cycle is fund approval. This milestone is considered to be a Go / No-Go decision for the entire project. Therefore, the project life cycle can be viewed as the pre-fund phase which consists of planning activities and the post-fund phase which consists of execution activities. For the constructor, the vital milestone is the tender award. This is when he / she becomes involved in the project.

Fig. 2.3 shows a "not to scale" diagram indicating the total effort that is required by all the project parties during the four distinct stages of a project [Wideman, 1995]. It should be noted that the level of effort exercised by each party in each stage of the project life is highly dependent on the contracting strategy. In this study, a single lump sum contract format is considered. Fig. 2.3, also, shows a diagramming indicating the ability to control the outcome of the project and how it relates to the different stages of the project life. It is clear that this ability declines as the project approaches its completion.

The following is a discussion of the four main stages of the project life cycle.

Conceive: This is the beginning of the planning phase. During this stage, preliminary drawings and block diagrams are produced in order to develop a general concept. As the scope is better defined, budgets and preliminary schedules are used to establish an economic study for the project. Although this stage requires minimal project control effort, it still has to be completed within pre-established deadlines. In this stage, the owner provides the architect with information such as funding limitations, design criteria and the intended use of the facility. The architect uses this information to develop the proposed concept.

Develop: In this stage, the project is further developed with additional engineering and drawing work. Additional engineering and economic studies are carried out to develop a better budget, schedule and cash flow profile. In this stage, the final budget approval is received and the level of effort builds up which requires extra project control effort. In this stage, both the architect and the owner build work teams. These work teams work together to exchange information and make decisions that help in establishing a more detailed design and feasibility study.

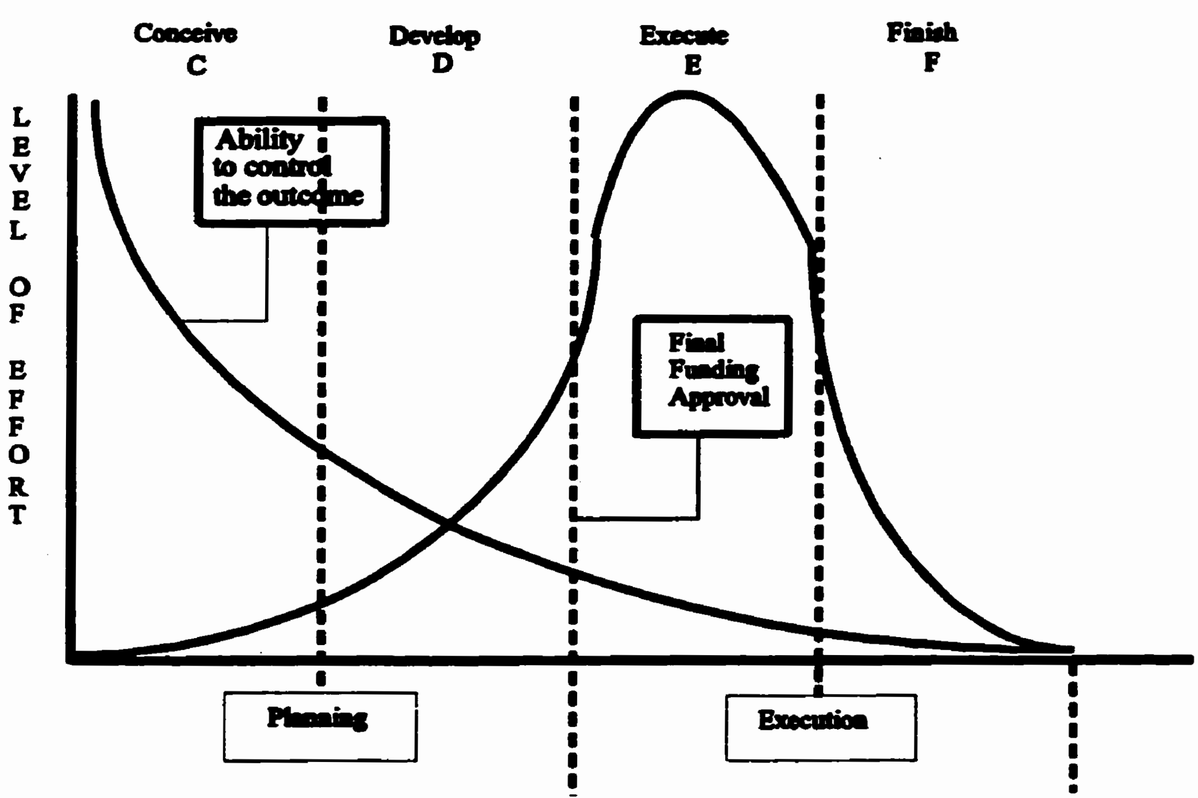


Fig. 2.3 Project Life Cycle

Execute: In this stage, a considerable amount of effort is expended and the project reaches the highest level of expenditure. Most of the engineering, procurement and construction are completed in this stage. The physical project is produced to the scope, cost, time and quality requirements. The scope is defined through the final approved set of drawings, the cost is established through a tendering process and the time and quality requirements are built into the specifications and contract documents.

This stage requires the most considerable amount of project control. An extensive control work for cost, schedule and quality should be planned and implemented. In this stage, the architect produces the final drawings and work with the owner to tender the project. The contractor also in this stage joins the project team as a key player. The contractor has the highest share of project control and the owner and the architect also increase their control levels to be able to monitor the work progress.

Finish: In this stage, the project is completed. Turnover, commissioning and training are the final steps. Receipt of final progress payment constitutes a completed project, not withstanding any future warranty work. The owner, architect and contractor carry out their final inspections. The contractor submits the final commissioning reports, manuals and warranties. The architect produces the final certification and the owner observes and participates in the process. The owner also reviews the documentation, then processes the final payment. In this stage a low level of control is exercised by all parties.

Table 2.1 shows the level of control exercised by the three main project parties in the different stages of the project life cycle. It should be noted that in this table, a knowledgable owner and a single lump sum type contract are considered.

STAGE	STEP	OWNER	ARCHITECT	CONTRACTOR
	Concept	M	L	N/A
CONCEIVE	Scope	M	L	N/A
	Budget	H	L	N/A
	Feasability	H	M	N/A
DEVELOP	Design	M	H	N/A
	Approval	H	H	N/A
	Final Design	L	H	N/A
EXECUTE	Tendering	M	H	M
	Construction	H	M	H
	Final Inspection	M	M	H
FINISH	Commisioning	M	M	M
	Certification	L	L	L

H: High, M: Moderate, L: Low

Table 2.1

It is important to understand the life cycle concept of a project because the level of the project control process must be compatible with the level of effort at each stage. Since the execution stage requires the most considerable amount of project control, this work investigates the different techniques that can be employed during this stage of the project life cycle.

2.5 THE SCOPE OF THE THESIS

Due to the wide diversity and great complexity of the construction industry and in order to have meaningful results of this research, the investigator placed bounds to identify the research area and the scope of this work. A single lump sum type contract is considered as the contracting strategy.

Also, a knowledgable owner who exercises a reasonable effort of project control is considered in this work. The execution stage of the project life cycle where all contracting parties increase their control efforts is also considered in this thesis.

2.4 THE CONTROL PROCESS

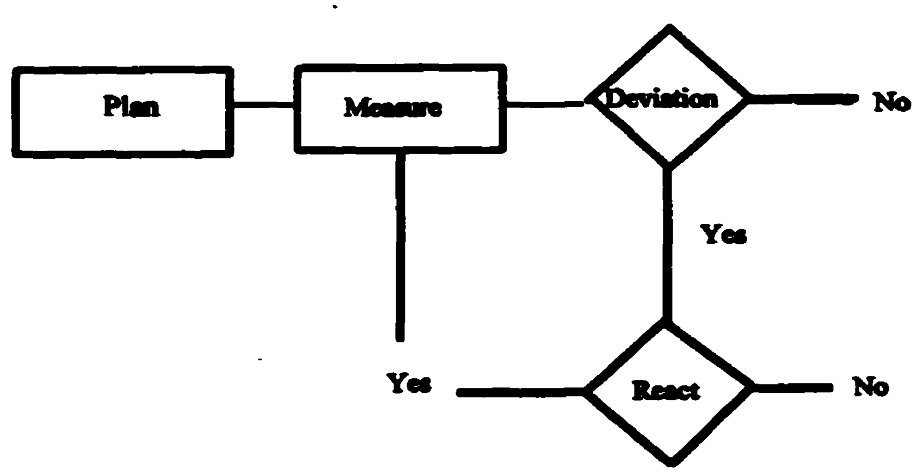


Fig. 2.4 Project Control Process

Project control, like any other control system, must follow a basic logical sequence. There must be (1) a plan, (2) a method for measuring performance, (3) a test for deviation of performance from the plan, and (4) a decision and reaction process based on (3). Complete project control is achieved when the project manager controls the three control functions: cost, schedule and quality. Project control is comprised of determining the standards for each function, measuring the performance, testing for deviations and reacting to deviations [McKim, 1990].

Fig. 2.4 shows the basic control process for any control function [Mckim, 1990]. This control process can be described as a reactive control process, however, it can also be extended to include a proactive control process by building forecasting techniques into the process. The control process should be able to answer the following questions: What is the project outlook ? Is it improving or not ? If not, what are the major factors controlling the project planned performance ? And finally what can be done as a corrective action to put the project back on track ?

The following three chapters are the result of an exploratory study of the most common principles of control techniques used in the construction industry to control the three main functions: cost, schedule and quality, through the different stages of the control process.

CHAPTER 3

COST CONTROL TECHNIQUES

Cost is a basic control function which should be included in any project control system. With the increase in size and complexity of construction projects, construction managers are faced with the need to have greater understanding of all their projects economic aspects. This will enable them to implement a greater degree of control, not only over the day-to-day cost of work which they manage, but also over the wider aspects of their work in general.

Fig 3.1 shows the cost control process. The basic control process which is shown in Fig. 2.4 is utilized to develop this cost control process. The cost control process is divided into two phases: reactive control and proactive control. In the reactive control phase, the cost control system is planned, executed, measured and the deviation determined if any. Also, a corrective action is usually taken if there is any deviation. In the proactive control phase, the project controller forecasts the cost performance.

In this chapter, the various cost control techniques which can be used at the different stages of the cost control process are studied. Section 3.1 discusses the planning levels for cost control whereas section 3.2 discusses the different techniques that can be used to measure and control cost progress. Section 3.3 investigates cost performance analysis and finally section 3.4 discusses reporting and also acting on cost performance which is of greater significance.

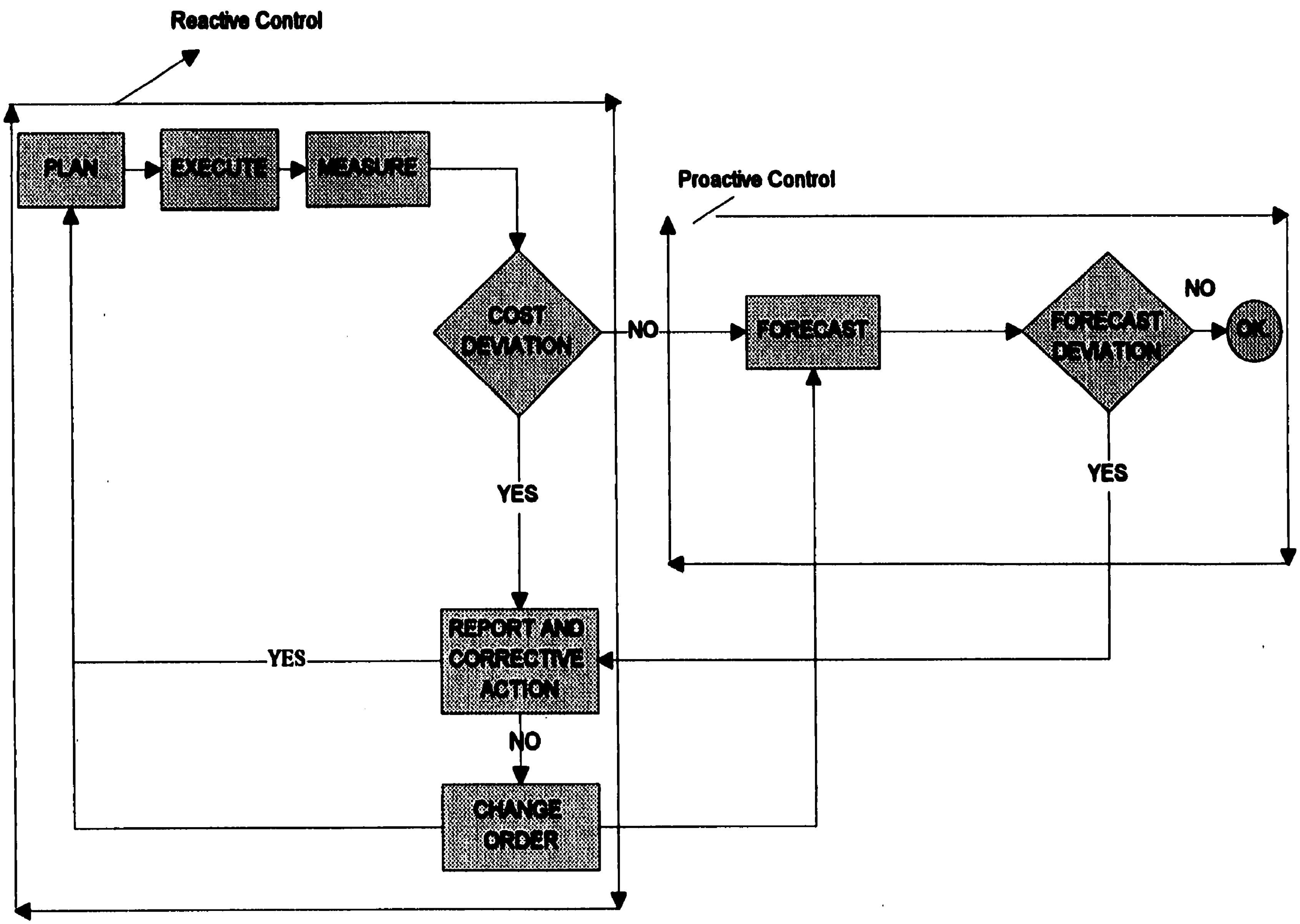


Fig. 3.1 Cost Control Process

3.1 LEVELS OF COST CONTROL PLANNING

Cost control planning should start as early as possible in the project life cycle. The ability to influence the final costs of a project diminishes as the project advances through each successive stage. **Fig. 3.2** shows this relationship graphically for the execute and finish stages of the project life cycle. It appears from this graph that the project team can influence the total cost much better in the final design stage than in the final inspection stage. This section discusses the different levels at which a baseline plan can be established.

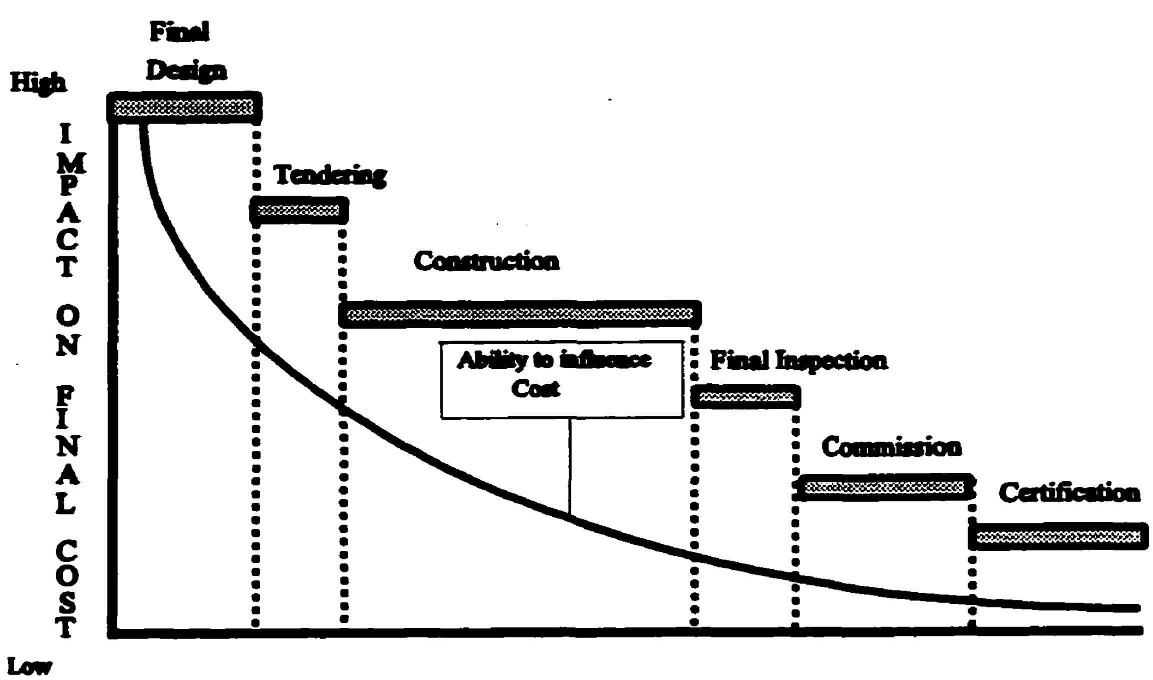


Fig. 3.2 Ability to Influence Final Cost of a Construction Project

3.1.1 Budget Baseline and Budget Allocations

Project budgeting is the first cost control technique that is used to control the cost of any construction project. The budget baseline level of control is mostly used in an owner or architect / engineer organization. It is sometimes used with the contractor organizations as a secondary control. The budget baseline is generated through the estimating process. Planners within the owner and the architect organizations must develop a cost estimate for the project whether or not the design documents are complete. As the project becomes better defined, the estimates are updated to reflect the new information. In a fixed price contract, this estimate is critical because it provides all quantity, cost and productivity targets used for the budget baseline.

The budget baseline level of control has several advantages. It provides analytical methods and procedures, and establishes a reference point to monitor and control project costs. It also serves as the basis for the owner in the provision of funds as well as the disbursement of progress payments. The budget baseline also provides a baseline from which forecasts and trends can be developed. It is important to mention here that budgets are treated as flexible rather than fixed plans, which can be adjusted when the appropriate conditions warrant such action.

3.1.2 Work Packages Costing

A work package as defined in the Construction Industry Institute Publications, is a "well-defined scope of work that terminates in a deliverable product or completion of service."[November, 1988]. Each package may vary in size, but it must be a measurable and controllable unit of work to be performed. To complete a work package, one or more tasks are performed. Thus, a work package may encompass the work of more than one crew.

Breaking the budget baseline into budgeted work packages is a good cost control planning technique because it allows construction professionals to have better control of the project's components. The benefits of work packages are not limited to the projects under control only. Work packages also provide a structure that facilitates a continuous planning cycle and controls future projects through accurate historical cost data base.

A work package should also be large enough so that the scope of work could be competitively bid and contracted for by itself. **Fig. 3.3** shows a sample work package costing sheet. The work package level of control can be used within the organizations of an owner, engineer or contractor.

	WORK PACKAGE	**COSTING FORM**	
Title:————	————	————	**Date:**————
Code:————	————	————	**Revision No.:**———
Responsibility:———	————	————	————
Scope			
	COST	**DATA**	
Budget	**Expenditures**	**Changes**	**Cost at Completion**

Fig. 3.3 Work Package Costing Form

3.1.3 Cost Breakdown Structure (CBS)

The Cost Breakdown Structure (CBS) is one of the most powerful techniques available for controlling a project. It involves a level-by-level hierarchial segregation of the project's components into a set of budgeted items. There are different levels of a project cost breakdown which can be used. The first level is the facility level where the construction project is broken down to several facilities serving different purposes. The second level is a Functional Element Breakdown which breaks down the project further into components that relate exclusively to a part of the project that serves unique functions (e.g. excavation, concrete, finishing, ...etc.). The third level is the Work Item level. With the work item CBS, as the name suggests, the project is broken down into very detailed budgeted and controllable activities (e.g. formwork, reinforcement steel, cast-in-place concrete,...etc).

It is important to mention that the CBS dollar value should add up to the total construction contract value. If the contract includes Cash Allowances or Contingency Allowances, it is recommended that they be included as an item within the CBS of the project. Including these allowances within the CBS will ensure better cost control of the expenditure of these allowances. These allowances are usually included in the CBS at the Functional Element level. Contingency Allowance is a dollar amount allocated within the overall project budget to be used in dealing with any unforeseen condition. Cash Allowances, on the other hand, are amounts allocated towards specific activities, but the full extent of the work is not fully determined at the time of the tender. Although this level of control is mostly used within the contractor organization, it can also be used within the owner organization. **Fig. 3.4** shows a sample of CBS.[Construction Industry Institute, September 1987]

3.1.4 Cost Coding

The cost coding structure is the framework upon which the cost control system is built. It provides a common language of identification and communication to be used by all those involved in project cost control. It can be used to identify and refer to the various components at the different levels of control such as Budget Baseline, work packages or cost breakdown structure. A good and accurate cost coding system is one which simplifies the task of referring to the items to be coded. The coding system should provide a wide range of characteristics which can be used to define the subject to be coded. The coding system should also have the ability to accommodate future additions to the list of items without the need to alter the basic coding structure.

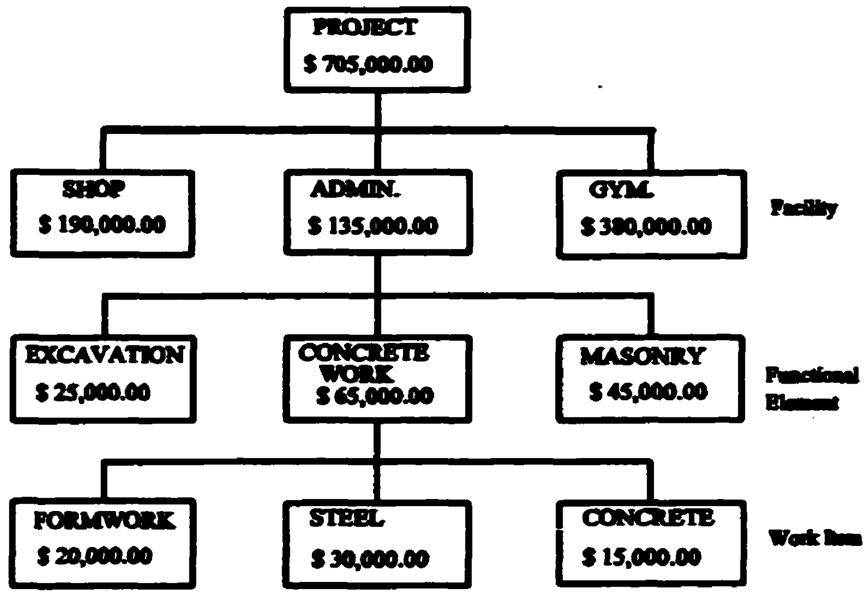


Fig. 3.4 Sample Cost Breakdown Structure

The cost coding structure should correspond with the cost breakdown structure. Fig. 3.5 shows an example of cost coding structure. The lowest element level of CBS is called the cost account. This is comprised of the facility, functional elements and work items. Each cost account is assigned a cost code. The cost code may consist of a four or five digits numeric code or a combination of numeric codes and alphabetical characters.

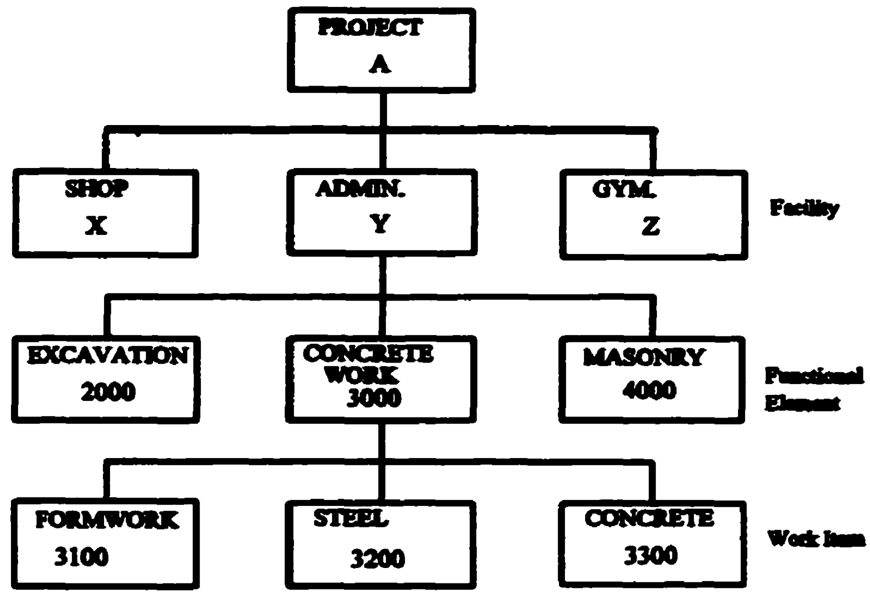


Fig. 3.5 Sample Cost Coding Structure

Fig. 3.6 shows an example of the cost code for the concrete work item. In order to have a coding system that is easily remembered, most computerized cost control systems use a coding system that is similar to the Master Format Index System or the Construction Standard Institute format.

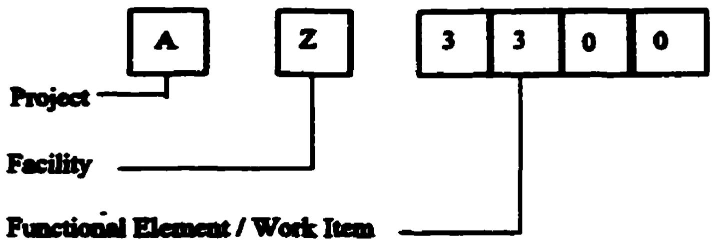


Fig. 3.6 The Cost Code for the Concrete Item

3.1.5 Unit Costing

Unit costing is usually used as a cost control technique in construction firms. By using a unit cost form, it becomes possible to compare unit costs from week to week to monitor and analyze any sudden changes. Also, comparing the weekly unit costs to preset standard unit costs helps to control the cost on ongoing basis.

3.1.6 Dual-Entry as a Cost Control Technique

As mentioned in the literature, the dual-entry system is widely used in business bookkeeping worldwide. This system can also be used successfully in cost control planning. Dual-entry means that one cost entry in cost control is recorded and the cost is allocated to two accounts in two separate columns called "debit" and "credit", so that the sum of credits is equal to the sum of debits. Dual entry reduces the number of data entries and provides an automatic balancing of accounts through debit / credit entries. It is believed that the best application for this technique is in the contractor organization.

3.1.7 Cash Flow

In all construction projects, there is capital flowing out from the investor's resources at various stages of the project in the expectation that, sooner or later more cash will flow back into these resources (government projects excluded). Movements of cash, either into or out of the project account, are referred to as cash flows. Income or receipts are known as positive cash flows. In the cost control planning stage, a cash flow projection plan should be developed for all contracting parties.

When a contract is awarded, the contractor may be asked to submit an estimate of progress payment requirements over the life of the project. The owner then determines a realistic schedule of anticipated cash flows. This process assures the contractor prompt payment and eliminates any potential disruption due to shortage of funds. The anticipated cash flow schedule enables the owner to determine his / her long term investment options that yield higher rates of return and coordinate the maturity of investments with the contractor's anticipated payment requests.

3.2 MEASURING AND CONTROLLING COST PROGRESS

After cost control planning is completed, the cost of any construction project should be controlled and measured throughout the various phases of construction until the project is completed. The following is the result of an examination of several measuring and controlling techniques that are used in the construction industry.

3.2.1 Cost Ratio

Every construction project includes some activities or tasks which take place over a very long period of time during construction, or are continuous over the life of the project. These tasks are budgeted on bulk allocation of dollars rather than on the basis of production. Examples of these types of tasks are contract administration, mechanical and electrical rough-in and quality assurance. The best control technique to measure these tasks is the cost ratio which is calculated using the following formula:

$$\textit{Percent Complete} = \frac{\textit{Actual Cost to Date}}{\textit{Estimated Cost of Completion}}$$

[American Society of Civil Engineers, 1987]

The disadvantage of this technique, however, is that it does not give early warning of potential cost overruns. This technique can be used in both an owner and contractor organizations to monitor the performance of those tasks that take place over a long period of time.

3.2.2 Earned Value

The earned value concept is used to measure the progress of a combination of unlike work tasks or a complete project. The earned value is based on the amount of work completed which is measured by the percent complete method described earlier in Article 3.2.1. A project "earns" dollars as progress in the various cost accounts is made. Earned value is also referred to as the Budgeted Cost for Work Performed (BCWP). For a single cost account, earned value can be expressed by the following equation:

$$\textit{Earned Value} = (\textit{Percent Complete}) \times (\textit{Budget for that Account})$$

Similarly, the earned value concept can be used to summarize multiple accounts and calculate overall progress. The equation is as follows:

$$\textit{Earned Value} = \frac{(\textit{Earned dollars all accounts})}{(\textit{Budgeted dollars all accounts})}$$

The above form of earned value can be used to measure performance using a Cost Performance Index (CPI):

$$CPI = \frac{\textit{Earned dollars}}{\textit{Actual dollars}}$$

If CPI is > 1.0 , it is favourable because the account is earning at a rate faster than actual expenditures. The earned value technique is mostly used within the contractor organization.

3.2.3 Cost Variance (CV)

Cost variance is a technique used to measure the cost overrun or underrun of the budget established for the work accomplished to date based on the earned value. CV is calculated as the difference between budgeted cost of work performed (BCWP) and the actual cost of work performed (ACWP) at any point over the life of the project.

$$CV = (BCWP) - (ACWP)$$

Where the Actual Cost for Work Performed (ACWP) is the actual cost for completed work items, including the completed part of work items in progress at a given data date.

If CV has a (-) value, the cause should be identified and a corrective action should be taken. The causes could be technical problems requiring allocation of extra resources or inaccuracies in the original estimate of work. Causes may also be due to lower productivity or unexpected increase in material, labour or equipment costs. Cost variance is mostly used within a contractor organization, however, some owners use this technique.

3.2.4 Control Change Orders and Budget Variances

A change is any modification to the original contract documents and the contractual agreements between the contracting parties (e.g. specification drawings, scope, working hours, access, ...,etc). Such modifications impact the contract cost. Cost control includes monitoring cost performance to detect variances from plan, ensuring that all appropriate changes are recorded accurately, preventing incorrect changes from being included in the cost baseline and informing appropriate stakeholders of authorized changes[PMI, 1996].

A major source of change is a change in the scope of work originated by the owner. The designer is another source for changes relating to design coordination errors, unforseen conditions and new regulatory requirements. Site personnel may participate in initiating changes such as those related to existing site conditions, relocation of services to avoid interference, ...etc.

3.2.4.1 Impact of Changes on Cost

A change made while work is in progress may cause cost increases attributable to a combination of factors. The interruption aspect of the change may cause lower productivity. A potential delay might occur between the time a hold is placed on the work to be changed and new instructions are received. Equipment, labour and material used to remove or modify existing work also contribute to the extra costs due to changes.

3.2.4.2 Costing Changes

Several techniques are employed for costing changes. Price adjustment may be negotiated before starting work changes. If the contract, however, includes unit prices for additions or deletions, unit prices may be used to arrive at a price for these changes. Historical data may also be used as a guideline in pricing changes. Finally, the contractor may be asked to proceed with a change and price the work based on time and material.

3.2.4.3 Controlling Changes

In order for cost control to be efficient, all project participants should take steps to familiarize themselves with all the reasons which may cause a change to arise and they should also be aware of the consequences of these changes. Changes should be resolved in a timely fashion as they occur. Delaying resolutions to changes may cause unnecessary disruption to the construction process. Once a change is recognized, the architect should issue a Change Notice. This document is used to describe the scope of change and it requires the contractor to respond whether or not there are any cost implications associated with the change. **Fig. 3.7** shows a change control procedure that is being followed in the construction industry.

Change orders should be documented on specific forms. These forms should be designed to indicate the number of changes issued to date, original contract value, revised contract value, reason for change and the necessary approvals. **Fig. 3.8** shows a sample change order form.

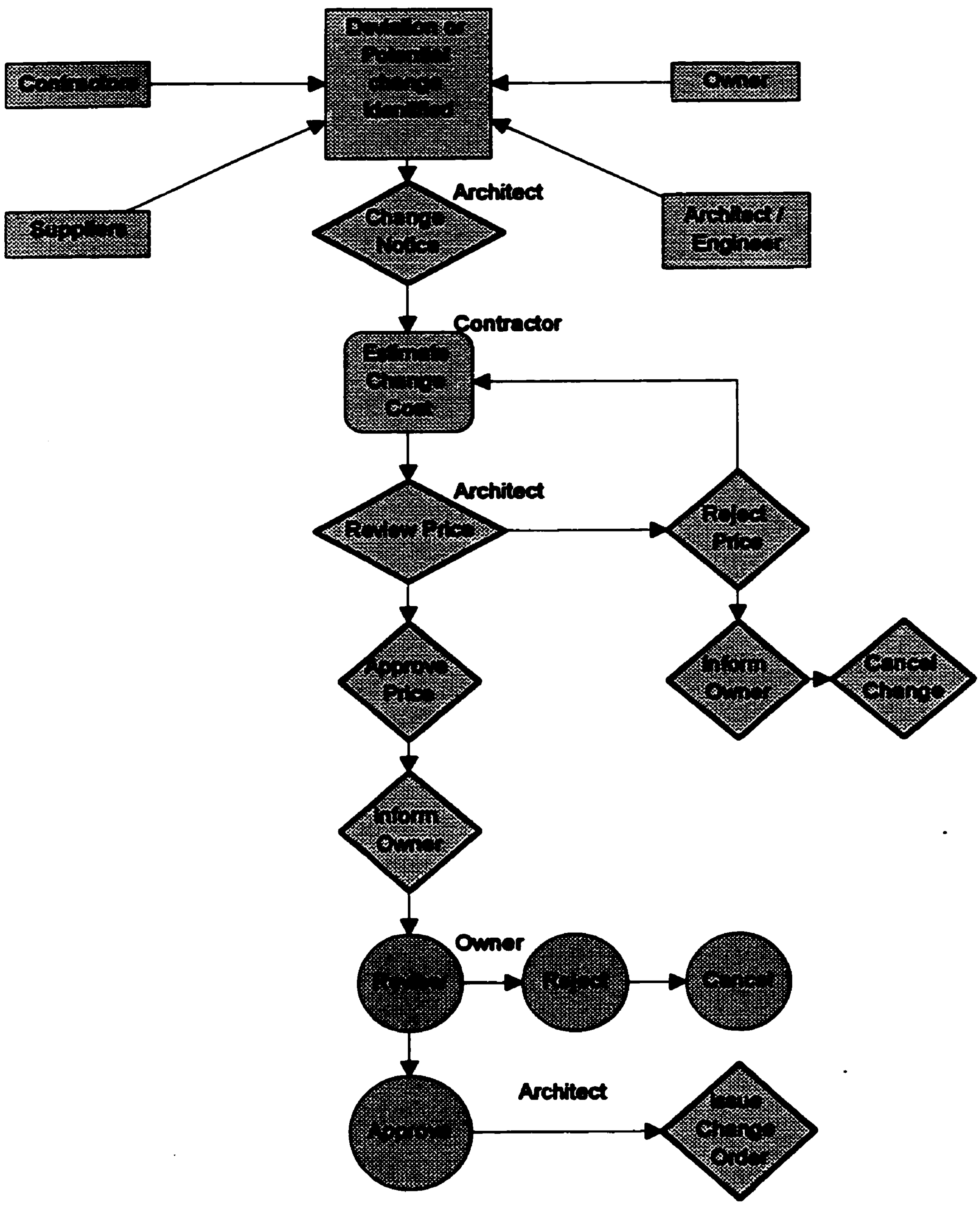


Fig. 3.7 Change Order Control Procedure

ABC Architect .

123 University Ave.

Waterloo, Ontario

L3A 3K7

CHANGE ORDER FORM

Issue Date ______________________

Project Number ______________________

Contractor ______________________

Project Name ______________________

Change Order # ______________

Original Contract Amount $ ______________

Change Order Approved to Date $ ______________

Amount this Change Order $ ______________

Revised Contract Amount $ ______________

Description of Change ______________________________

____

Reasons for Change ______________________________

____

Approvals

Owner ______________ **Date** ______________

Architect ______________ **Date** ______________

Fig. 3.8 Sample Change Order Form

3.2.5 Measuring and Controlling Progress Payments

There should be a direct relationship between the amount of payments made to the contractor and the physical progress accomplished in the construction site. Such payments should be made with care and in a controllable fashion and should not result in undue risks being assumed by the owner. The payment certifier should visit the construction site before processing the payment certificate to verify that the progress being claimed on the payment request matches the actual site condition.

Before the start of construction, the contracting parties should agree to a type of measurable performance plan against which performance can be measured to support progress payments. The most common approach used in the construction industry is the " schedule of values". The schedule of values is a cost-loaded breakout of estimated construction costs that corresponds to the project work breakdown structure. It should include, however, items such as cash allowances, contingency allowances and mobilization. The schedule of values is initiated by the constructor and then verified by the owner or his /her representative. Once agreed upon, the schedule of values is used throughout the construction phase to calculate the value of physical performance in the construction site. When submitting the schedule of values for payments, it should include other information such as percent complete to date, amounts previously certified and amounts claimed for the current payments. **Table 3.1** shows a sample of schedule of values.

The schedule of values control approach is normally equitable for both contracting parties. However, contractors sometimes tend to "front-load" the schedule of values in order to reduce their risk or improve their cash flow. Front-loading is assigning higher dollar values to earlier work tasks and offsetting them by lower dollar values to later tasks. This strategy may introduce potential risk to the owner and should be avoided.

The application for payment is done in the form of a payment certificate (invoice) which summarizes the information in the schedule of values. **Table 3.2** shows a sample of a payment certificate.

Item Description	Contract Value	Completed To Date		Previously Billed		This Billing		Balance to Complete
	Amount	%	Amount	%	Amount	%	Amount	Amount
0100 General								
0105 Mobilization	$5000.00	90	$4500.00	20	$1000.00	70	$3500.00	$500.00
Subtotal	$5000.00		$4500.00		$1000.00		$3500.00	$500.00
0200 Site Work								
0215 Excavation	$10000.00	80	$8000.00	10	$1000.00	70	$7000.00	$2000.00
0220 Landscaping	$ 4000.00	0	0.00	0	0.00	0	0.00	$4000.00
Subtotal	$14000.0		$8000.00		$1000.00		$7000.00	$6000.00
0300 Concrete								
0305 Rebar	$3000.00	15	$450.00	5	$150.00	10	$300.00	$2550.00
0310 Formwork	$7000.00	15	$1050.00	5	$350.00	10	$700.00	$5950
0315 Concrete	$4000.00	10	$400.00	0	0.00	10	$400.00	$3600.00
Subtotal	$14000.0		$1900.00		$500.00		$1400.00	$12100.00
0900 Finishes								
0905 Drywall	$3500.00	0	0.00	0	0.00	0	0.00	$3500.00
0910 Painting	$1500.00	0	0.00	0	0.00	0	0.00	$1500.00
Subtotal	$5000.00	0	0.00	0	0.00	0	0.00	$5000.00
Total Contract	$38000.0	38	$14400.00	7	$2500.00	31	$11900.0 0	$23600.00

Table 3.1 Sample Schedule of Values

Application For Payment	**Project # 96110**
ABC Development	**Computer Lab.**
300 University Ave.	**Date : July 31st 96**
Waterloo, Ontario	
L2N 3K5	**Appl. # 2**
1- Original Contract Value	**$38,000.00**
2- Authorized Changes to Date	**$0.00**
3- Contract Value to Date	**$38,000.00**
4- Total Progress	**$14,400.00**
5- Holdback	**$1,440.00**
6- Total Progress Less Holdback (4 - 5)	**$12,960.00**
7- Less Item 6 From Previous Application	**$2,250.00**
8- Net Amount Payable this Application (6 - 7)	**$ 10,710.00**

Table 3.2 Sample Certificate of Payment

3.3 COST PERFORMANCE ANALYSIS

Monitoring the actual cost at every stage of the project does not alone ensure that the performance will proceed according to the plan. It is also important to analyze the situation so that the appropriate action can be taken if needed. The control techniques which were discussed so far, can be considered as a reactive approach to control problems. This performance analysis method, however, can be considered as a proactive control approach which enables the construction team to anticipate any future problems. The following is an investigation of the analysis techniques which are used in the construction industry.

3.3.1 Trend Analysis

Trending is a comparison of actual versus planned degrees of completion for a project over a given period of time used to determine whether the overall rate of project performance is increasing, decreasing or remaining the same. If the cost progress trend is decreasing or remaining the same over a certain period of time, an action should be taken to analyze and improve the project progress or to indicate the problem areas impeding the project progress. The cost trend analysis is performed at certain time intervals such as weekly or monthly.

One of the analysis techniques that is used to develop the project cost trend is variance analysis. Variance analysis in simple words is comparing current performance with the planned performance. Cost variance and schedule variance are the two items mostly used to measure the cost performance and develop cost trend analysis.

Cost variance (CV) was introduced and defined earlier in this work. Schedule variance (SV) is the difference between the project budgeted cost of work performed (BCWP) and the project budgeted cost of work scheduled (BCWS) at any point in time or data date.

$$(SV) = (BCWP) - (BCWS)$$

Fig. 3.9 shows the cost variance and the schedule variance plotted on the cost performance graph.

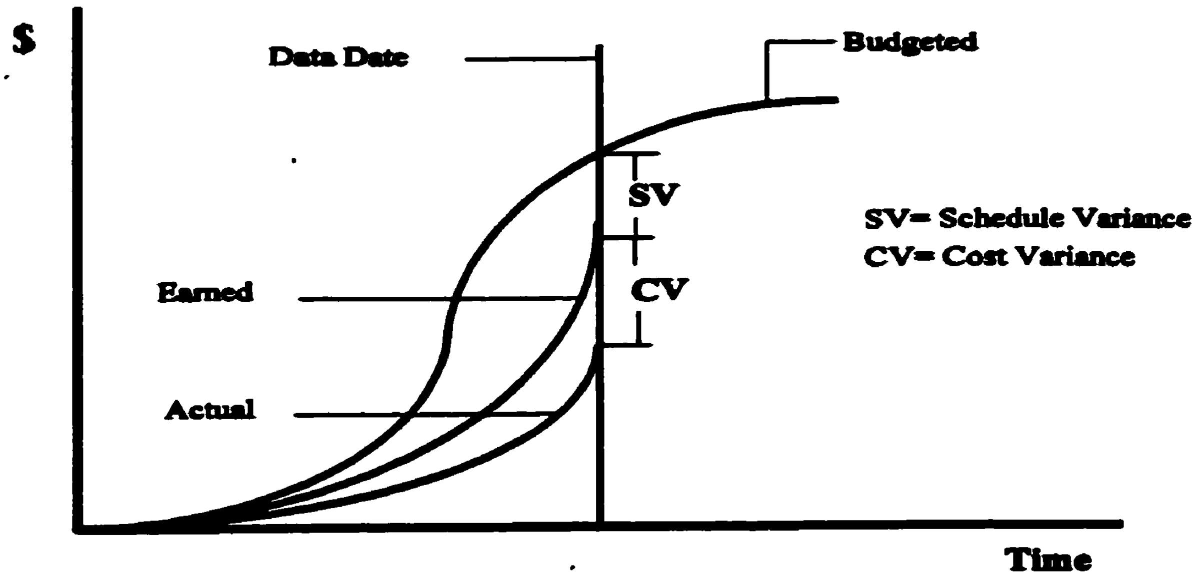


Fig. 3.9 Cost and Schedule Variances

Fig. 3.10 shows the cost variance trend for a project. It can be seen that the cost performance in the first month was not favourable as the contractor lost $1000. The cost trend in the second and third months shows an improvement from the first month and the current status was $1500 favourable. Using this trend analysis graph, it may be concluded that the projected variance for the following month is + $3000.

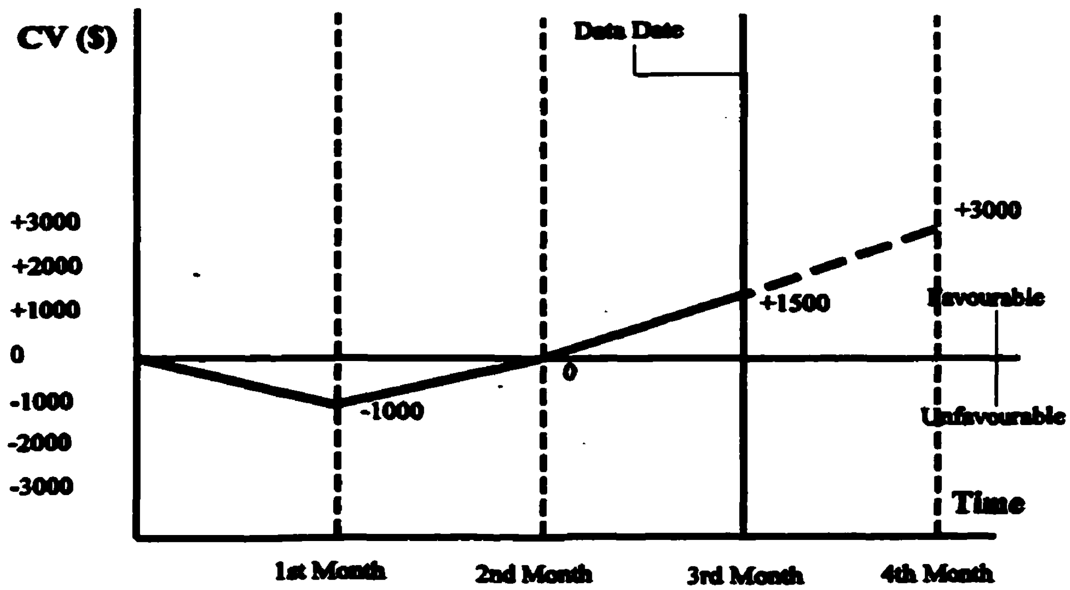


Fig. 3.10 Cost Variance Trend

It should be mentioned that variance analysis is not meant to be used alone. Variance analysis should be examined in coordination with contributing factors such as poor initial estimates, technical difficulties, ...etc. Trend analysis can be used in an owner, architect or contractor organization. However, in a contractor organization it is performed in a more detailed format.

3.3.2 Forecast Analysis

Cost forecasting is an attempt to predict the future cost performance of the project by utilizing the past and current performance of the project costs. Although there are various forecasting techniques available, no two techniques produce the same results. It is recommended that more than one technique be used to provide a range of possibilities. Three different forecasting techniques are examined below.

The first technique assumes that the cost from the data date froward will perform at planned rates whether or not these rates have performed well at this point.

$$FAC = (ACWP) + (BAC - BCWP)$$

Where (FAC) is Forecast At Completion, (BAC) is Budget At Completion which is the Total Baseline Cost (BCWS) of a project or work package.

The second technique assumes that the rate of progress prevailing to date will continue to prevail.

$$FAC = (BAC) \; / \; (CPI)$$

The third suggested technique is probably the most difficult one to perform. However, it is the most precise and accurate technique. This technique requires a careful and objective reassessment of all the work that remains to be done to complete the project and the uncommitted costs relating to this work. It also requires the collection of subjective information in the regular course of other work and an examination of trends and indicators. The forecaster simply uses all the information that may be available to make the projection. Forecast analysis can be used in any type of organization.

3.4 REPORTING AND ACTING ON COST PERFORMANCE

This stage can be considered a very important stage of the cost control process. Cost reports must be simple, accurate and timely. They should not contain useless information or irrelevant details. Cost reports should assist the project team in recognizing the problem and enable them to determine how and where a corrective action should be taken. The following is an explanation of various reports that are used in the construction industry.

3.4.1 Cost Performance Report

In this report the cost performance is measured for each work package separately and then summed for the overall project performance. Variances are calculated for the current period and also from the start of the project and up to the time of the report. The report also shows overruns, underruns and predicted costs at completion. **Table 3.3** shows a sample cost performance report. This report enables the project team to determine the problem at the work package level. A corrective action for cost overruns may include changing the scope of work, selecting different materials or adjusting the baseline budget.

3.4.2 Project Budget Status Report

This table is used for senior management staff in an owner organization. It provides them with general information regarding the budgeted costs for the different categories of the project. It also includes the contingency and the its expenditures . The revised budget for the project (forecast at completion) can then be calculated. **Table 3.4** shows a sample of this report [Ahuja, 1994].

3.4.3 Cash Flow Reports

Fig. 3.11 and **Fig. 3.12** show the monthly cash flow report and a cumulative cash flow respectively in an owner organization. The reports include a comparison of the planned vs. actual cash flow. These reports help the owner predict the cash flow requirements. Since the amount of money paid to the contractor corresponds to the physical progress accomplished, these reports also help the owner in evaluating the overall contractor's performance.

3.4.4 Corrective Actions

All construction team members should be trained and experienced to respond to cost deviations in the appropriate manner depending on the circumstances. A corrective action that is usually taken by the owner to deal with cost deviation is changing the scope of work. Change of scope may include accepting an alternative material or equipment at an affordable price. Scope change may also include eliminating a portion of the work to reduce the overall cost of the project. A corrective action by the contractor may include eliminating overtime work by increasing the labour force that are paid regular pay. If a corrective action is not feasible, then the project budget should be altered to accommodate the new requirements.

Project : Expansion to ABC Facility

Report Date : July 31st, 1996 Report # 3

COST PERFORMANCE REPORT

ITEM	Current Period					Cumulative to Date					At Completion		
	Budgeted Cost		Actual Cost for Work Performed	Variance		Budgeted Cost		Actual Cost for Work Performed	Variance		Budgeted	Forecast At Completion	Variance
	Work Scheduled	Work Performed		Schedule	Cost	Work Scheduled	Work Performed		Schedule	Cost			
1000 General Condition	$0.00	$0.00	$0.00	$0.00	$0.00	$10,000.00	$10,000.00	$12,000.00	$0.00	$2,000.00	$10,000.00	$12,000.00	($2,000.00)
2000 Site Work	$8,500.00	$0.00	$0.00	($8,500.00)	$0.00	$9,400.00	$1,200.00	$2,200.00	($8,200.00)	($1,000.00)	$26,200.00	$26,200.00	$0.00
3000 Concrete	$14,500.00	$16,500.00	$13,700.00	$2,000.00	$2,800.00	$17,700.00	$16,500.00	$13,700.00	($1,100.00)	$2,800.00	$19,500.00	$17,200.00	$2,200.00
4000 Masonry	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$7,700.00	$7,700.00	$0.00
9000 Finishing	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$1,600.00	$1,600.00	$0.00
15000 Mechanical	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$1,900.00	$6,300.00	($4,400.00)
16000 Electrical	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$2,500.00	$2,500.00	$0.00
Total	$21,000.00	$16,500.00	$13,700.00	($4,500.00)	$2,800.00	$37,100.00	$27,700.00	$27,900.00	($9,300.00)	$3,800.00	$69,400.00	$73,500.00	($4,200.00)

Table 3.3 Cost Performance Report

Work Package	Original Budget	Breakdown of the Original Budget			Remainning Contingency		Forecast At Completion
		Base Construction Budget	Consultant Fees	Original Contingenc	(+)	(-)	
2000 Site Work	$5,000.00	$4,000.00	$800.00	$200.00		($150.00)	$5,150.00
3000 Structural	$24,800.00	$20,000.00	$3,800.00	$1,000.00	$200.00		$24,600.00
9000Finishing	$21,400.00	$17,000.00	$3,600.00	$800.00	$300.00		$21,100.00
15000Mechanical	$7,350.00	$6,000.00	$1,000.00	$350.00		($200.00)	$7,550.00
16000Electrical	$4,650.00	$3,500.00	$950.00	$200.00		($100.00)	$4,750.00
Toatal	$63,200.00	$50,500.00	$10,150.00	$2,550.00	$500.00	($450.00)	$63,150.00

Table 3.4 Sample Project Budget Status Report

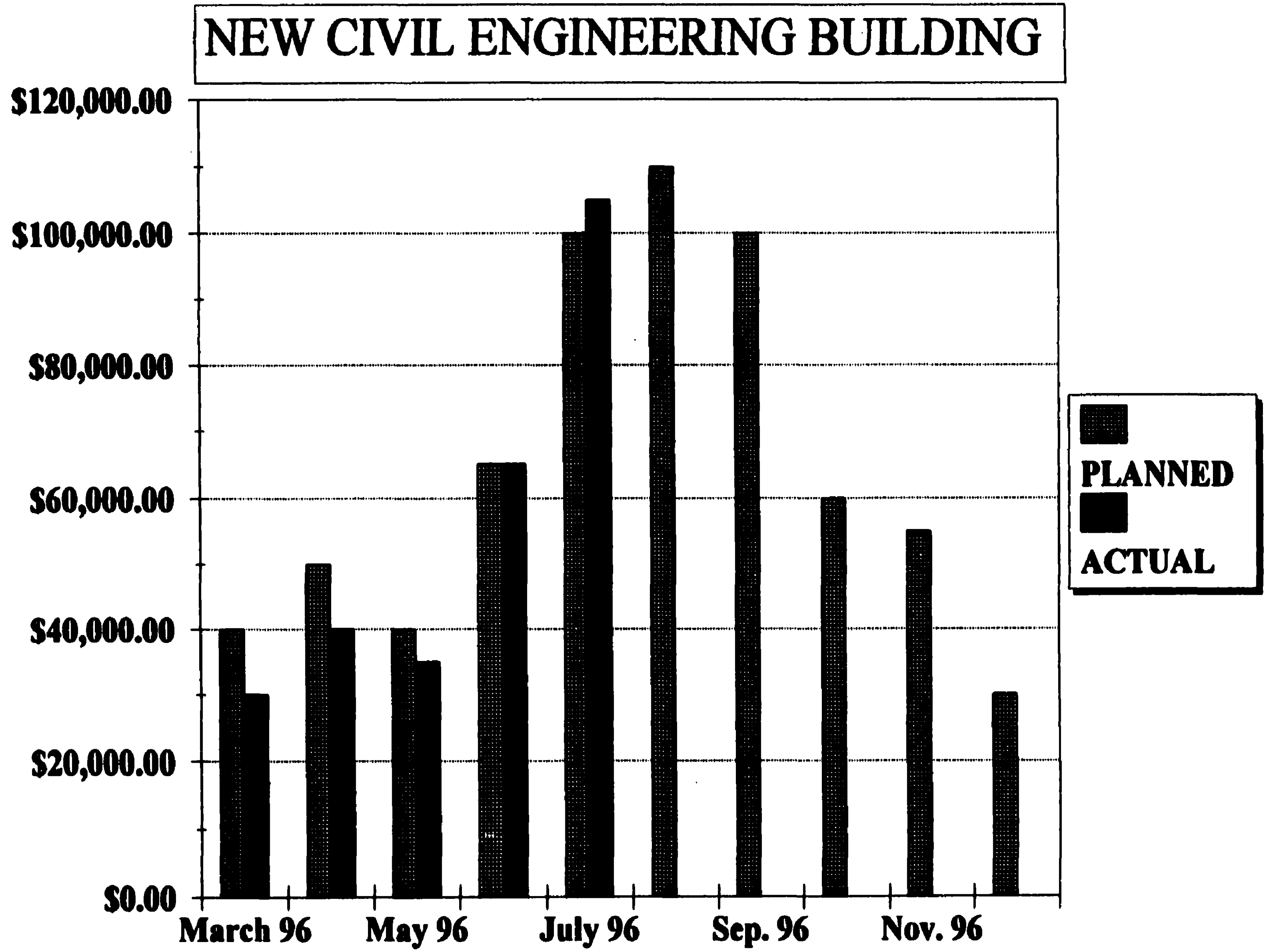


Fig. 3.11 Sample Monthly Cash Flow Report

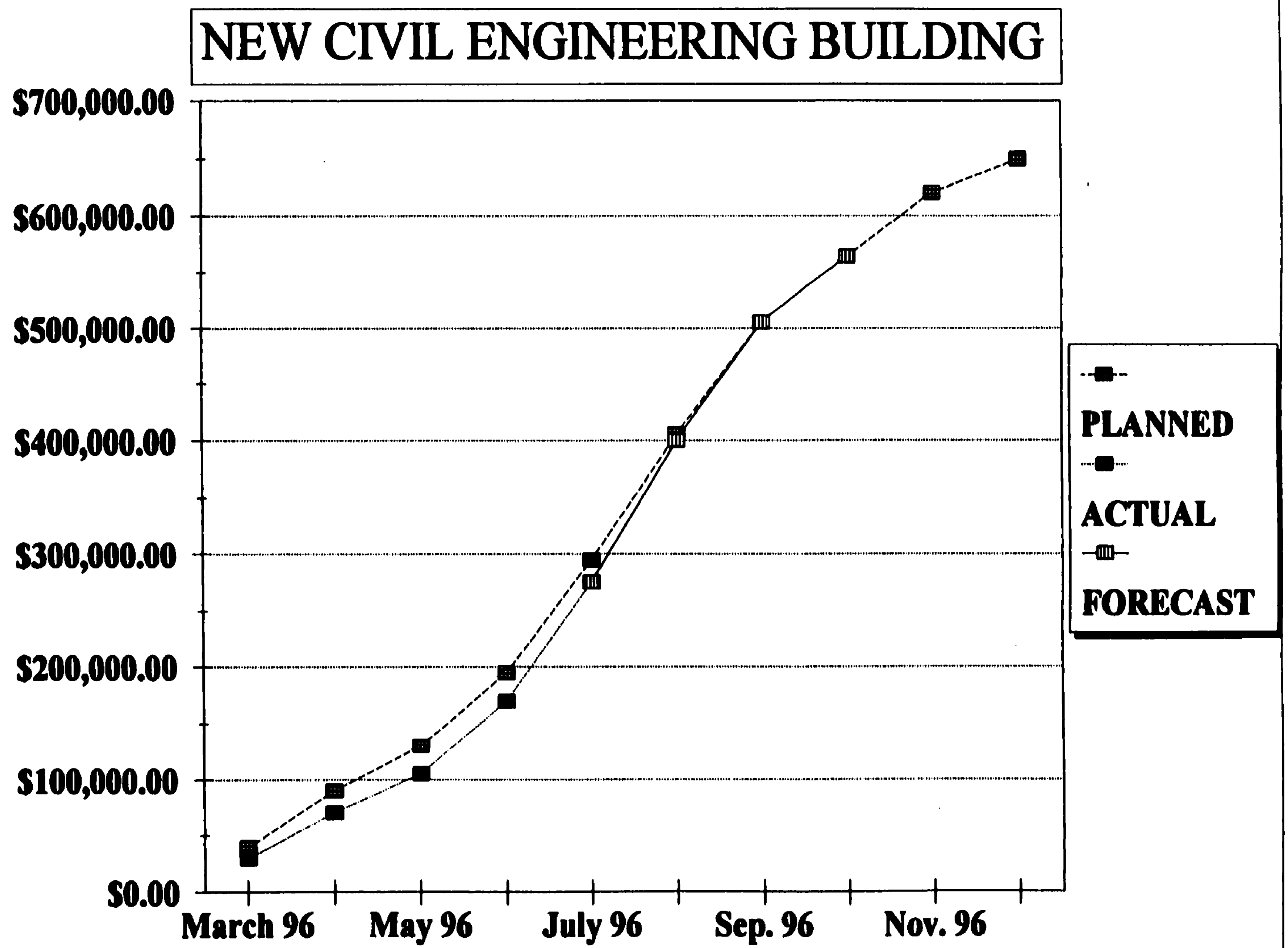


Fig. 3.12 Sample Cumulative Cash Flow Report

CHAPTER 4

PLANNING AND SCHEDULING CONTROL TECHNIQUES

The time factor is of almost the same significance as cost to all parties involved in a construction project. The total cost of a project will increase if the project is to be completed in a very short period of time. This cost will also increase if the project is drawn out over a very long period.

Planning and scheduling are control functions that construction professionals use to control and direct construction projects in order to complete those projects in a timely manner and consequently in a cost effective way. Planning and scheduling integrate the various tasks of the project within an interdependent time sequence. Fig. 4.1 illustrates the project planning and scheduling control process.

It is clear from this figure that the scheduling control process follows the same sequence which was explained earlier in chapter two for the entire project control process. In this chapter, the different schedule control techniques that are used to measure, analyze, report and direct schedule performance in construction projects will be discussed.

Section 4.1 discusses the first stage of the schedule control process which is planning for schedule control. Section 4.2 discusses the most common schedule control techniques that are used in the second stage of the schedule control process which is measuring. Section 4.3 investigates the proactive approach to schedule control while section 4.4 studies reporting and corrective actions to schedule deviations.

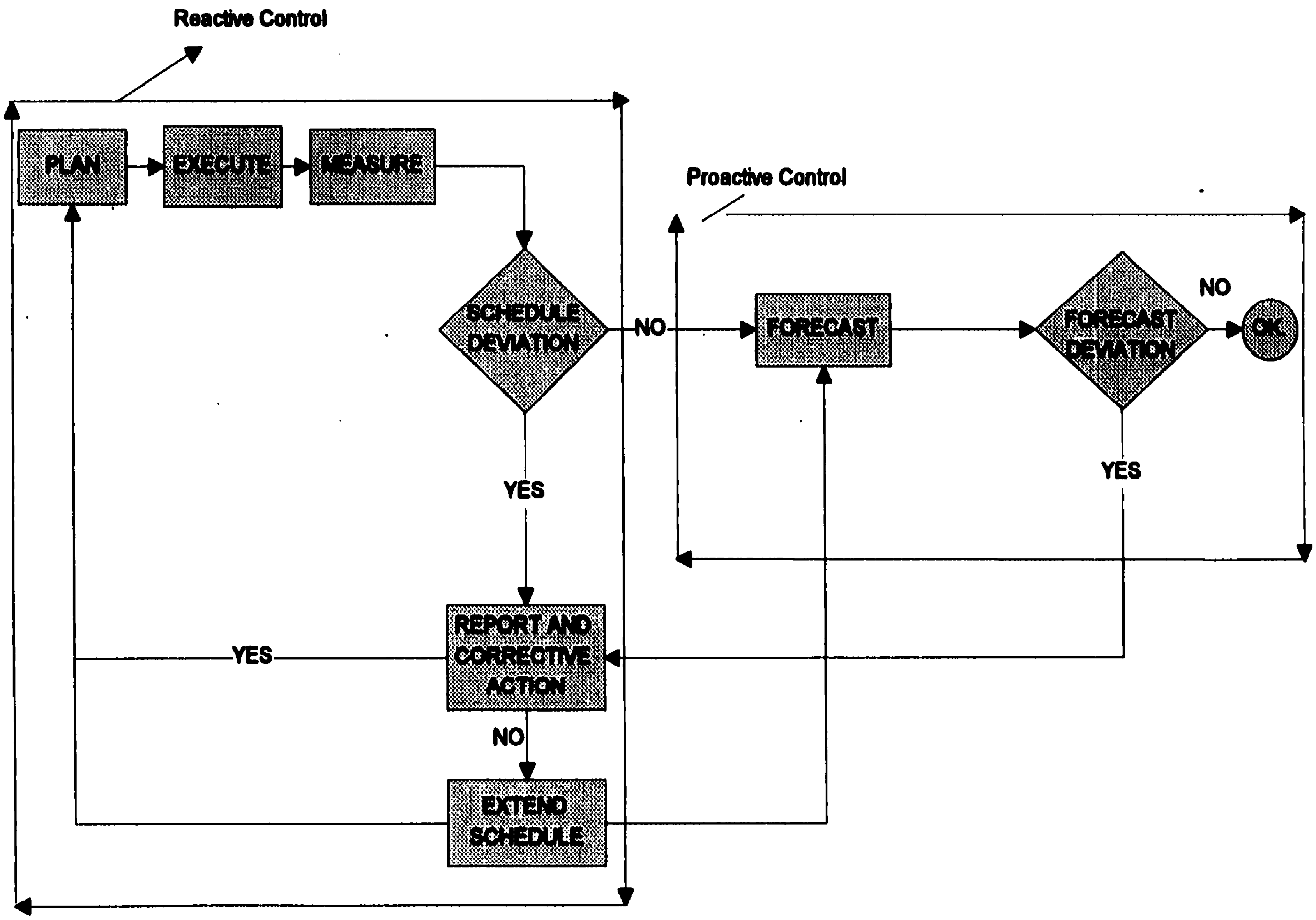


Fig. 4.1 Schedule Control Process

4.1 PLANNING FOR SCHEDULE CONTROL

The first step in the planning and scheduling process is to establish the baseline plan. The project plan is an essential document for the project activities because it covers the project from initiation through completion. Therefore, project planning can be defined as the establishment of the project activities and events, their logical relationships and interrelations to each other, and the sequences in which they are to be accomplished. A schedule can then be generated by adding start time, finish time, durations and constraints to each activity.

Several techniques are used in planning and scheduling construction projects. The following is a discussion of various techniques that are used to establish a baseline plan and schedule in order to measure, track and redirect the project progress.

4.1.1 Work Packages

Similar to the use of work packages costing as a cost control technique, work packages are also used as a planning and scheduling control technique. The project is divided into groups or packages of tasks whose completion is required in order for the total project to be completed. The work package is performed by a single organization unit (crew, shop, subcontractor, ...etc) and is the base for short interval planning and scheduling. The effective use of work packages throughout the construction of a project eliminates information lags among different phases, duplication of data capture and redundancy or inconsistency of data. Work packages can be used by all construction parties; however, in construction firms, a more detailed level of control is usually required.

Fig. 4.2 shows a Work Package Catalog Form. This form includes all the related information that help in the planning and scheduling control. Each work package catalog contains the following information:

- **Work Package Identifiers**: These are the work package title and work package code.

WORK PACKAGE
CATALOG

Work Package Title : ____________ ____________

Work Package Code : ____________ ____________

Responsibility : ____________ ____________

Scope :

Engineering
Deliverables

Critical Equipment and Material

SCHEDULE DATA

Duration	Preceding Activities	Succeeding activities

Fig. 4.2 Work Package Catalog Form

- **Responsibility:** This names the person or the firm responsible for the work.

- **Scope:** This includes all elements of the work package and detailed description of the package's boundaries.

- **Engineering Deliverables:** These list the drawings, specifications and procedures required by the contractor to complete the work package.

- **Critical Permanent Equipment and Materials:** These include all materials and equipment to be delivered and incorporated within the work package. They also indicate critical items which have a long delivery-lead time.

- **Schedule Data:** This includes duration, preceding event and succeeding event.

4.1.2 Work Breakdown Structure (WBS)

Similar to the use of cost breakdown structures as a cost control technique, work breakdown structures (WBS) are also used as a schedule control technique in the construction industry. The development of a (WBS) involves dividing up the project into controllable parts suitable for schedule control. These parts are converted into schedule activities where one or more activity comprise one element of the (WBS). It should also be noted that if the project is broken down into overly broad elements, it is difficult to define the logical relationship that may exist between these elements. The work breakdown structure should be performed in a manner that enables the construction team to determine and specify the relationships between work activities. WBS is a more detailed level of control. It is mostly used in a construction organization. It is important, however, that it is used as a communication tool between all parties in a construction project.

4.1.3 Bar Charts

A bar chart is also called Gantt Chart since it was developed by Henry L. Gantt. It is one of the most widely used planning and scheduling techniques. A bar chart is a graphical presentation of project activities shown in a time-scaled bar line but with no links between the activities.

4.1.3.1 Definitions

Activity Duration: It is the length of time from the start to the finish of an activity in any time units chosen for the project. It may be in hours, days, weeks or months. The estimation of an activity's duration depends on various factors such as type and quantity of work, the available resources, working hours and environmental factors that affect the work.

Milestone: It is an event of major significance in achieving the project objectives. Examples of milestone events are the start of the project, completion of the project, key dates for delivering major equipment.

4.1.3.2 Code Structures

A framework is established to communicate the schedule information to the team members. For each activity or work item, a great deal of data is received, stored and processed. The development of an adequate code structure increases the efficiency of transferring and communicating these data. The code structure should be hierarchial in format to permit expansion to various levels of detail and the summarization of data at any level.

4.1.3.3 Schedule Levels

The parties involved in any construction project have different interests and expectations of the project schedule. The home office or the top management staff of any organization are interested in a summary level schedule whereas the site personnel are interested in a more detailed schedule. It is, therefore, important to have a schedule with different levels. These levels are explained below.

Level 0 : This level includes the entire project as one task with start and finish dates.

Level 1 : This schedules the project into its major components. For example, in a high rise building, every floor is considered as one task.

Level 2 : Each floor is divided into east and west wings.

Level 3 : This divides each wing into major components such as concrete, finishing, mechanical and electrical.

Level 4: This further divides each major component into sub-components.

4.1.3.4 Developing a Bar Chart

The first step in preparing a bar chart is to develop the schedule levels that correspond to the needs of all the participants in the project. A list of the activities shown on the schedule have to be developed for each level and a brief description assigned to each activity that appears on the bar chart. The duration of each activity is then estimated taking into consideration all factors which could affect the duration. Each activity is assigned an identification code for future tracking. An appropriate time scale is selected which can be in days, weeks or months. The logic in which the construction activities are carried out is then developed. The various milestones within the project life should also be determined. Having all the above information, a bar chart schedule could be generated.

There are usually duration adjustments and activity overlapping in order for the entire schedule to fit the required overall time frame. Fig. 4.3 shows a sample bar chart schedule. Each schedule normally includes other information such as the name of the company, the project and the project manager. Although Fig. 4.3 can be considered as a level 4 schedule, it can be filtered to produce a level 2 schedule that includes three summary tasks, washrooms, ramps (A) and (B) and the elevator shaft. This schedule also includes one milestone which is mobilization / start.

PROJECT MANAGER : MOHAMED ATTALLA, P.ENG.

BARRIER FREE
UNIVERSITY OF

ID	Task Name	Duration	Start	Finish
1	Mobilization / Start	0d	1/2/96	1/2/96
2	**WASHROOMS**	**29d**	**1/2/96**	**2/9/96**
3	Washrooms 2nd, 3rd flo	19d	1/2/96	1/28/96
4	Door Operators	5d	1/29/96	2/2/96
5	Electric Work	5d	2/5/96	2/9/96
6	**Ramps (A), (B)**	**39d**	**1/2/96**	**2/23/96**
7	Cutting & Demolition	4d	1/2/96	1/5/96
8	Concrete / Steel	5d	1/8/96	1/12/96
9	Screens	20d	1/15/96	2/9/96
10	Railings	15d	1/15/96	2/2/96
11	Finishes	10d	2/12/96	2/23/96
12	**Elevator Shaft**	**68d**	**1/15/96**	**4/17/96**
13	Excavation	5d	1/15/96	1/19/96
14	Concrete / Backfill	5d	1/22/96	1/26/96
15	1st Floor Shaft	10d	1/29/96	2/9/96
16	2nd Floor Shaft	10d	2/12/96	2/23/96
17	3rd Floor Shaft	10d	2/26/96	3/8/96
18	Finish	10d	4/4/96	4/17/96
19	Piston	5d	3/11/96	3/15/96
20	Roofing	7d	3/18/96	3/26/96
21	Elevator Installation	15d	3/18/96	4/5/96
22	Commissioning	5d	4/8/96	4/12/96

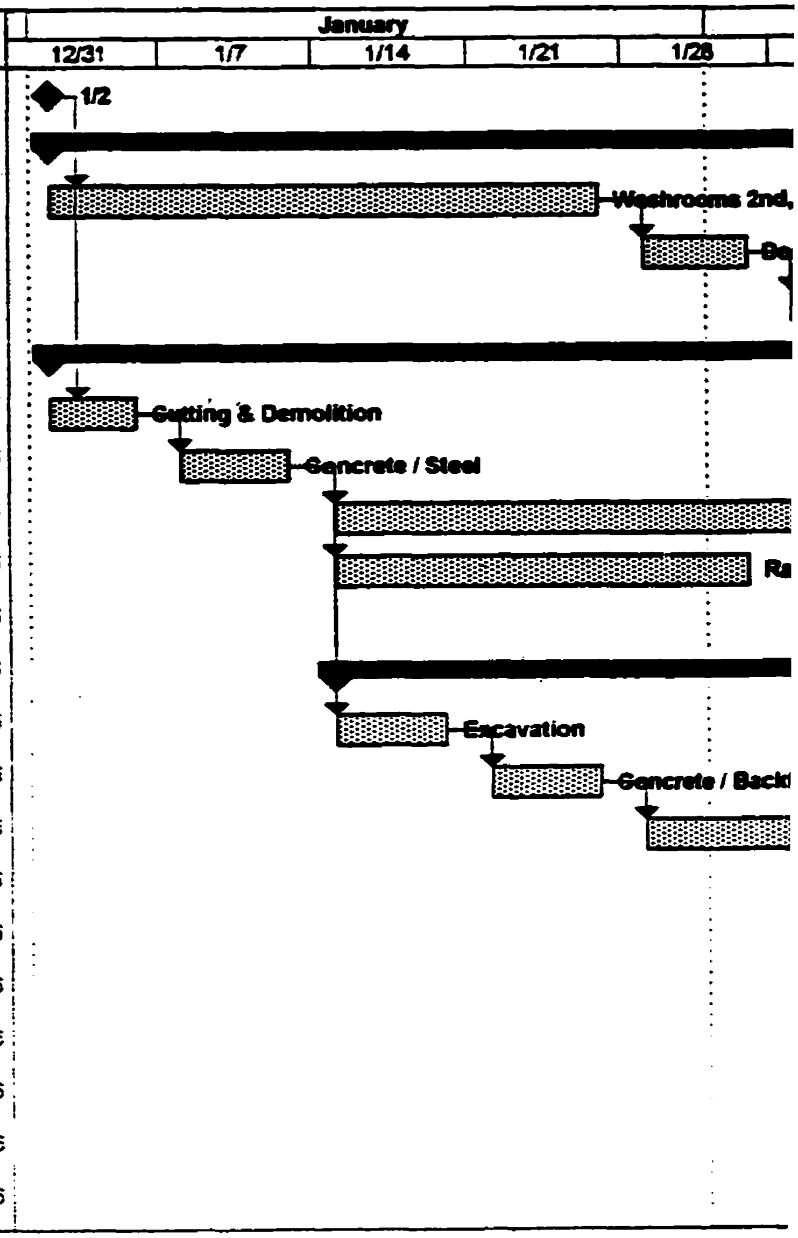


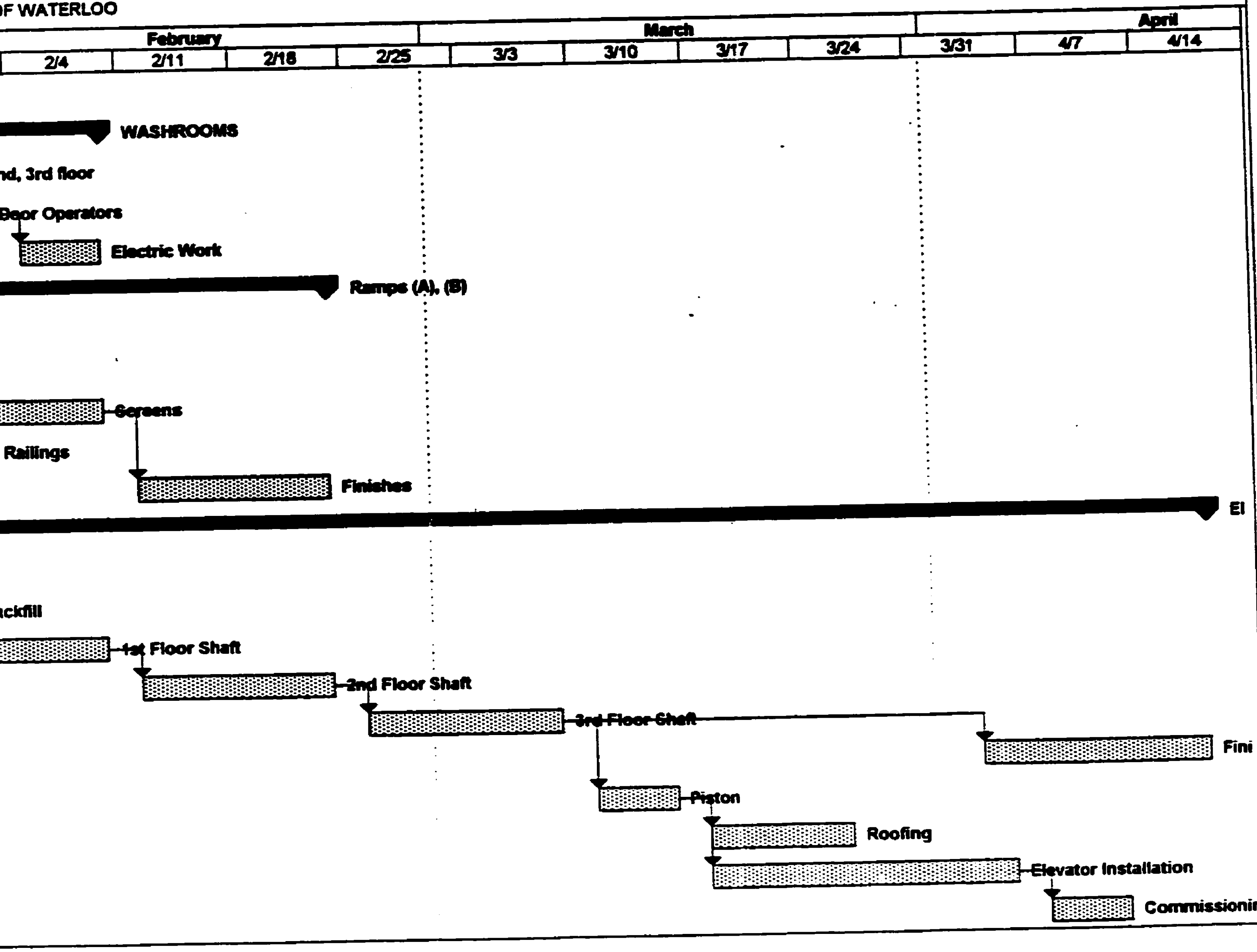
Fig. 4.3 Sample Bar Chart Schedule

Project: Barrier Free Facility
Date: 11/20/96

Task — Milestone — Rolled Up Task
Progress — Summary — Rolled Up Milestone

EE FACILITY
F WATERLOO

ABC ARCHITECT
XYZ CONSTRUCTION



Rolled Up Progress

4.1.3.5 Advantages and Disadvantages of the Bar Chart Technique

One of the major advantages is that, almost anyone can look at a bar chart schedule and decipher its meaning. On the other hand, the bar chart schedule can be very difficult to prepare, particularly if there are numerous and complex relationships between the tasks that make up the schedule.

4.1.3.6 Baseline Schedule

A baseline schedule is normally developed prior to the start of any construction project to demonstrate the anticipated sequence, durations, and interdependencies for all the activities constituting the project. The most important part of this schedule is that it represents the construction team agreement and plan of work in order to meet the project finish date, and it also serves as the basis for project schedule control.

The baseline schedule can be changed or modified during the course of construction due to unexpected conditions. It is used to assess the project program and identify problem areas during construction.

4.1.4 Logic Diagrams

A logic diagram is sometimes termed a network. It is a graphic description of a project. There are two basic types of logic diagrams.

4.1.4.1 Activity on Arrow and Activity on Node Diagrams

Activity on Arrow (AOA) is a diagram made up of arrows and nodes. Words are written on the arrows to represent tasks. The nodes are circles that represent events. The Critical Path Method (CPM) is based on the AOA diagram.

Activity on Node (AON) is also made up of arrows and nodes. The nodes are depicted with a circle or with a box and they represent tasks. The precedence method (PM) is based on the AON logic diagrams.

4.1.4.2 Critical Path Method (CPM)

It is a graphical presentation of a planned sequence of activities using an arrow diagramming technique. It shows the interrelationship of the elements comprising a project to determine the length of a project and to identify activities, events and constraints which are used on the critical path. It is also used to determine early start and finish, late start and finish and the floats.

The critical path is the particular sequence of activities in a CPM network that has the least total float and is the longest path in the network. Therefore, the critical path is a chain of critical activities. Any delay in the duration of a critical activity causes a correspondent delay in the completion of the project.

One of the principal benefits to be derived from the preparation of a CPM logic diagram is that its preparation requires detailed analysis of the project which enables the project team to develop a better understanding of the project as a result of this detailed analysis. Fig. 4.4 shows a CPM using an arrow diagram (AOA). The critical path in Fig. 4.4 is presented by darker arrows. It links a chain of critical activities and each has FF=0. This diagram also includes four dummy activities that are referred to as (D).

4.1.4.3 The Precedence Method (PM)

The Precedence Method (PM) is used in the construction industry. This is a method of constructing a project network diagram using nodes to represent the activities and connecting them with arrows that show the dependencies [PMI, 1996]. A network is drawn after all activities and their relationships are defined. A precedence diagram developed for a particular project is used as a means

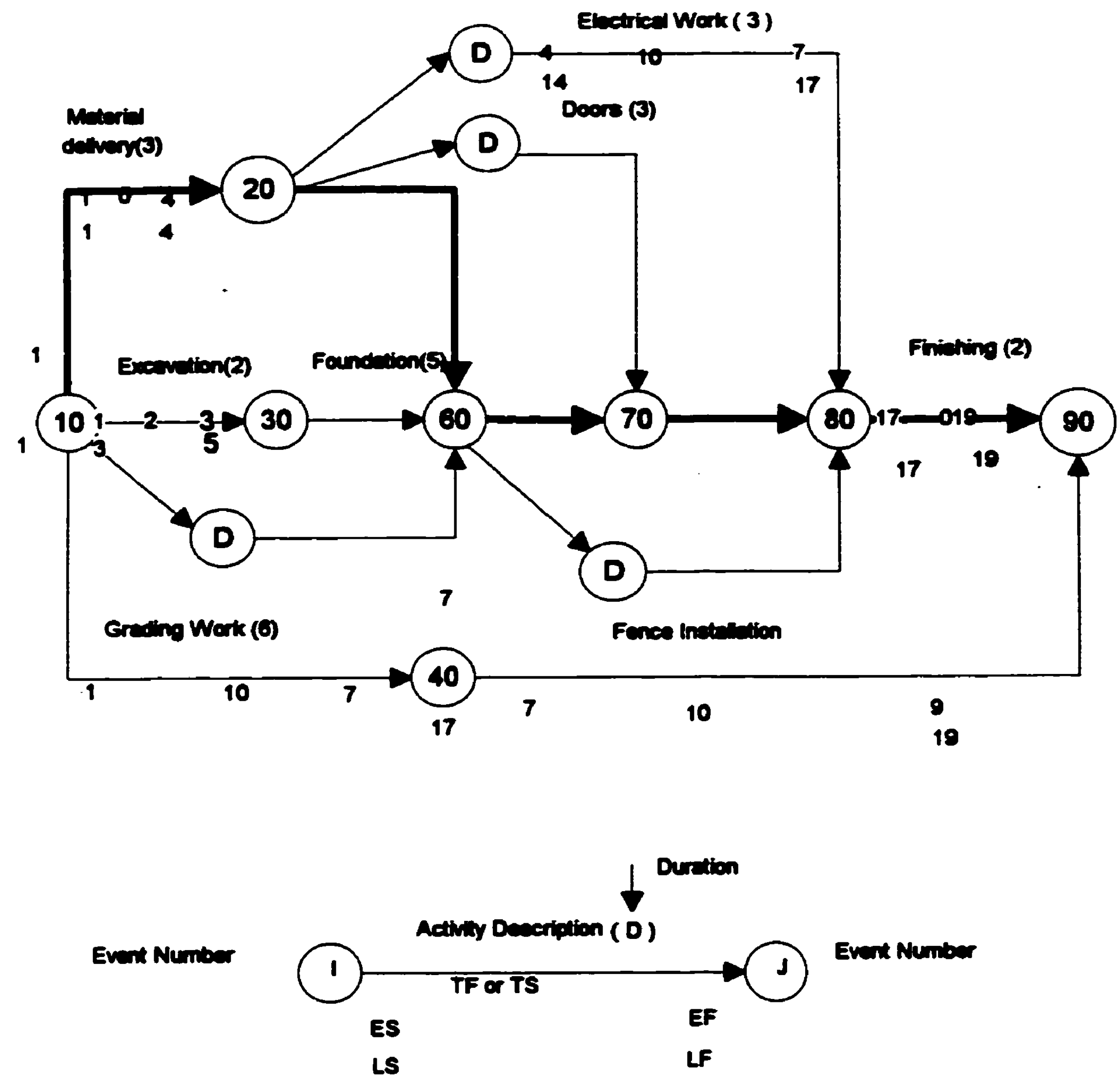


Fig. 4.4 C.P.M using Arrow Diagramming

of communicating the work sequences among the project participants and is also used as a means of monitoring schedule performance.

Fig. 4.5 shows a sample (PM) diagram. This figure includes a logical presentation of the activities relationships using precedent diagramming. Each activity is presented by a box which includes the activity's name, identification number, duration, start date and finish date. The critical activities are also identified by a darker presentation on this diagram.

4.1.4.4 Program Evaluation and Review Technique (PERT)

The network methods described previously do not provide a measure of uncertainty associated with the estimate of a particular milestone in a project. PERT is a statistical treatment of uncertain activity performance time. It assumes a variability in activity durations based on a variability in production rates. PERT focuses on events (nodes) that must occur prior to the successful completion of a project. PERT requires four estimates for activity duration: the Optimistic Time (To), the Most Likely Time (Tm), the Pessimistic Time (Tp) and the Expected Mean Time or Expected Duration (Te).

Optimistic Time (To) : It is the minimum estimated time required for an activity to be performed repeatedly under similar conditions.

Most Likely Time (Tm) : It is the estimated performance time for an activity that would most frequently be most achieved or be most probable to happen under a number of repeated similar conditions regarding activity completion.

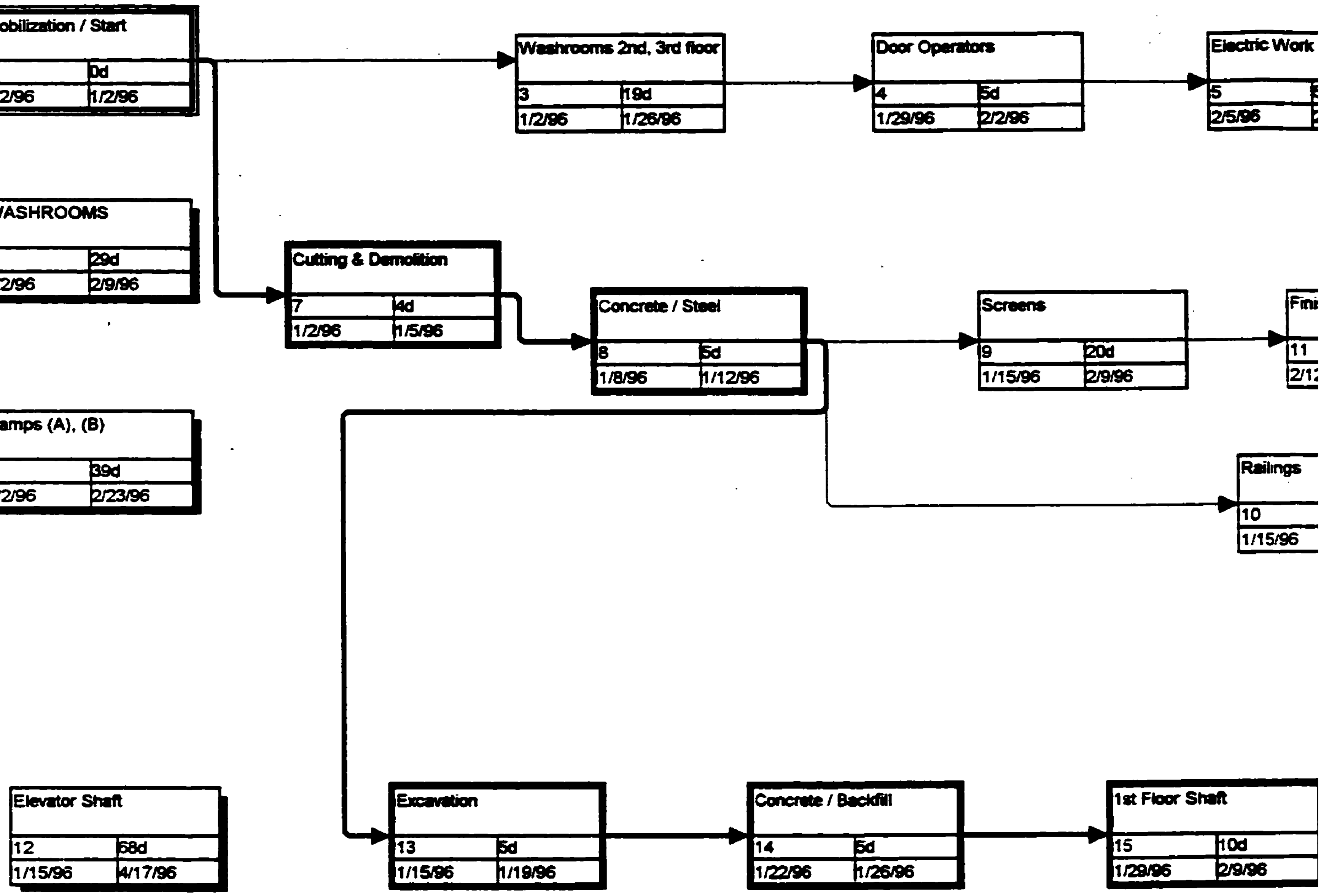
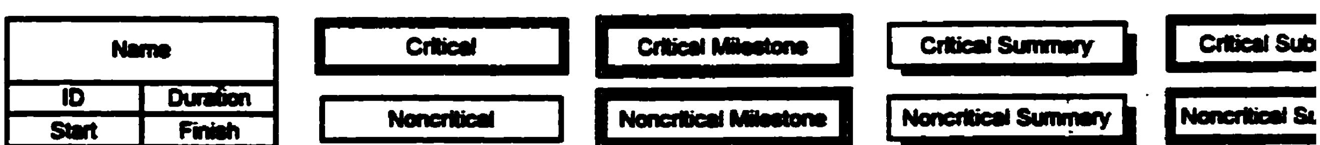
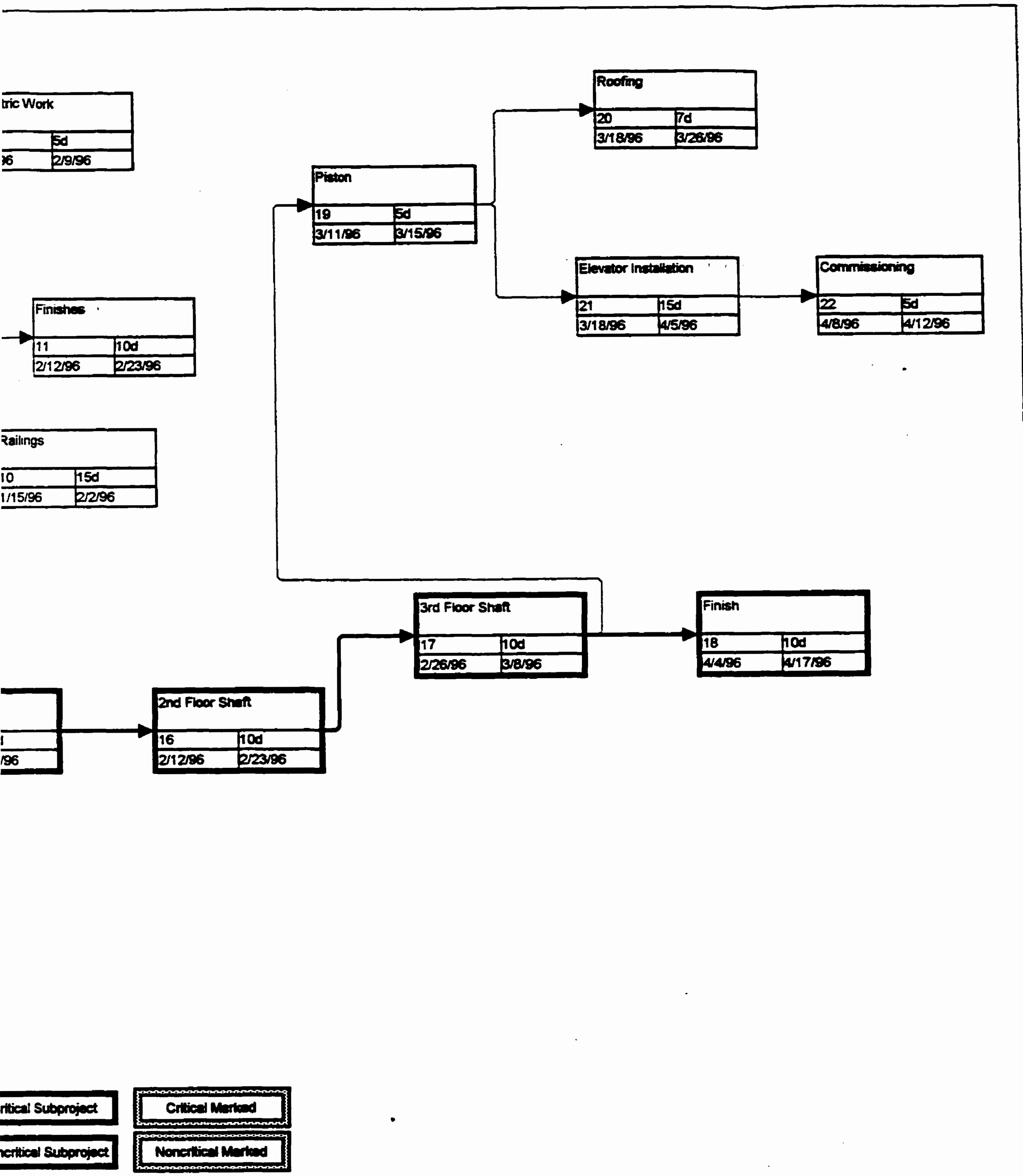


Fig. 4.5 Sample PM Diagram





tric Work
5d
96
2/9/96
Roofing
20
7d
3/18/96
3/26/96
Piston
19
5d
3/11/96
3/15/96
Elevator Installation
21
15d
3/18/96
4/5/96
Commissioning
22
5d
4/8/96
4/12/96
Finishes
11
10d
2/12/96
2/23/96
Railings
10
15d
1/15/96
2/2/96
3rd Floor Shaft
17
10d
2/26/96
3/8/96
Finish
18
10d
4/4/96
4/17/96
2nd Floor Shaft
16
10d
2/12/96
2/23/96
/96
ritical Subproject
Critical Marked
ncritical Subproject
Noncritical Marked

Pessimistic Time (Tp) : It is the maximum estimated time required for an activity to be completed when an unusually bad condition is experienced.

Expected Duration (Te) : It is a statistically weighted estimate of the anticipated duration for an activity. It can be obtained using the following formula:

$$Te = \frac{To + 4\,Tm + Tp}{6}$$

The activity Standard Deviation (D) can be obtained as follows:

$$D = \frac{Tp - To}{6}$$

The activity Variance (V) $\quad V = D^2$

As explained above, PERT permits calculation of the probability of completing the project at specified times. However, the computed values of early event times and of probabilities for attainment of events at specified times are based solely on the durations of tasks that are on the critical path.

4.2 MEASURING AND MONITORING SCHEDULE PROGRESS

The different techniques of creating a baseline plan and schedule for the different activities in any construction project were discussed in article 4.1. The construction team needs to measure and monitor periodically the progress of these activities. This can be considered the second stage in the schedule control process. The following is an explanation of the most common techniques used to measure work progress.

4.2.1 Activity Units Completed

This technique is usually used with a quantifiable activity such as concrete, steel, excavation, ...etc. This measure is presented in percentage of completion based on units of work completed to date. It can be obtained by the following formula:

$$\textit{Percent Complete} = \frac{\textit{Actual Units to Date}}{\textit{Total Forecast Units}} \times 100$$

The advantage of using this technique is that it is accurate and easily audited. When using this technique, the total forecast units have to be updated whenever a change order is incorporated into the work. This technique can be applied in both an owner and contractor organizations.

4.2.2 Incremental Milestones

This technique is similar to the activity units completed and it is also based on percentage of completion. However, it is not based on the activity level but rather on the major milestone level. It is used when the effort required to determine the completed units for each activity is not justifiable. It is also used when the activity includes sub-tasks that must be handled in sequence. This technique is useful to top management and senior staff because it enables them to monitor the performance of the project in a generic format. It can be used in all types of organizations.

4.2.3 Start / Finish

This technique is applicable to activities that do not have intermediate milestones or when the effort required to perform the activity is difficult to estimate. With the Start / Finish technique, start is assigned 50 % and finish is assigned 100 %.

4.2.4 Manager Judgement

This is a subjective technique and is usually used for relatively minor activities where more discrete techniques can not be used.

4.3 SCHEDULE PERFORMANCE ANALYSIS

After using the previously mentioned techniques to measure the progress of different activities, the project participants can use the measured data to analyze the schedule performance and consequently take the appropriate corrective action if a deviation is detected. The following discussion provides several techniques for analyzing schedule performance.

4.3.1 Progress Curves "S Curves"

S curves are widely used in the construction industry by both owners and contractors. The information provided by the baseline schedule and plan are used to plot the time-phased progress plan against its respective percent of completion. Usually, two curves are plotted for each project, one uses the late start dates for each activity and the second uses the early start dates for each activity. Using the actual measured data enables the project team to plot a third curve representing the actual progress.

Using the S curve shown in **Fig. 4.6** enables the project team to successfully analyze the schedule performance. The ideal project progress is usually when actual performance is maintained between the late and early curves. If the actual performance occurs outside these boundaries, the performance should be studied and a corrective action taken.

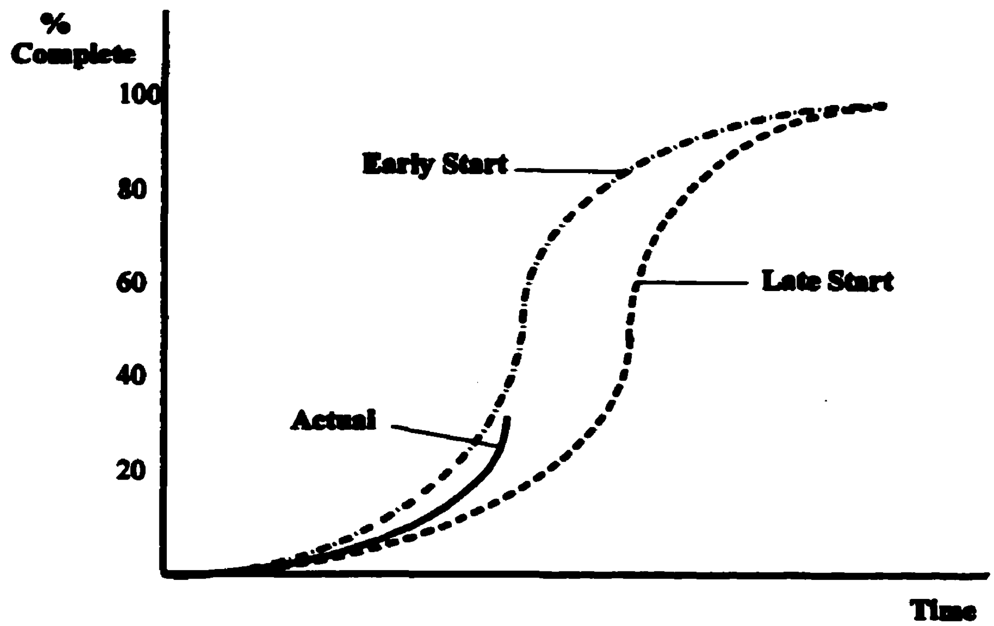


Fig. 4.6 Typical (S) Curve

4.3.2 Time Variance

Variance analysis is widely used in the construction industry. Variances can be obtained by comparing planned man hours versus actual man hours or planned percent complete versus actual percent complete. **Fig. 4.7** shows a schedule performance analysis graph based on time variances for planned percent complete versus actual percent complete. In Fig. 4.7 the project achieved 30% complete at a later date than the planned date, the time variance equals dt.

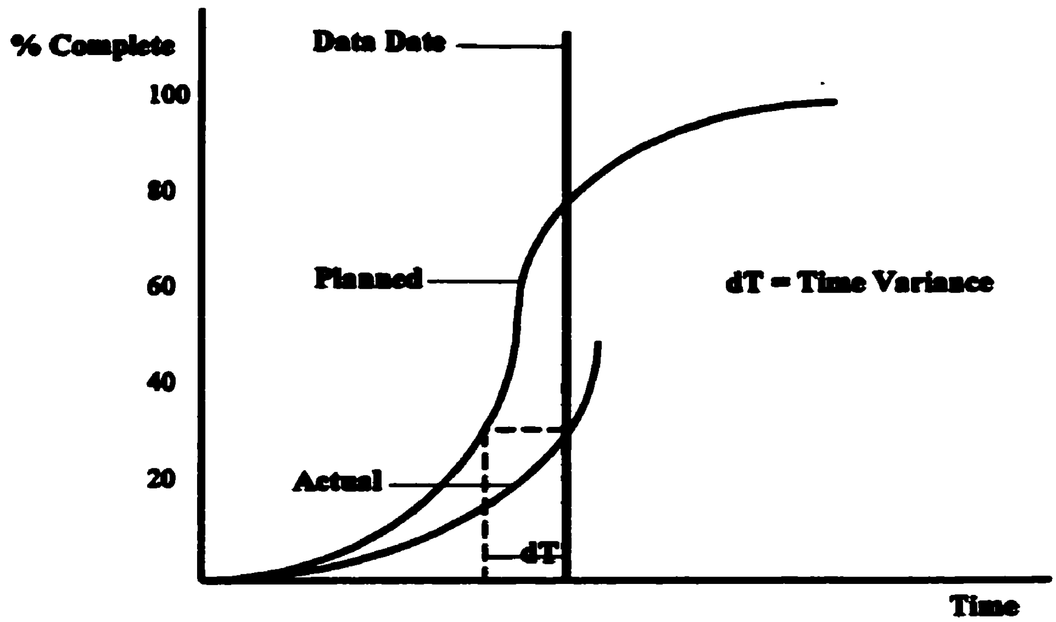


Fig. 4.7 Schedule Performance (Time Variance)

4.3.3 Time Variance Trend and Forecast

Time variance can be used to develop a trend and a forecast analysis for the schedule performance of any project. Fig. 4.8 shows a sample time variance trend and forecast for a construction project. A positive time variance means the project is ahead of the planned schedule and a negative time variance means the project is behind the planned schedule.

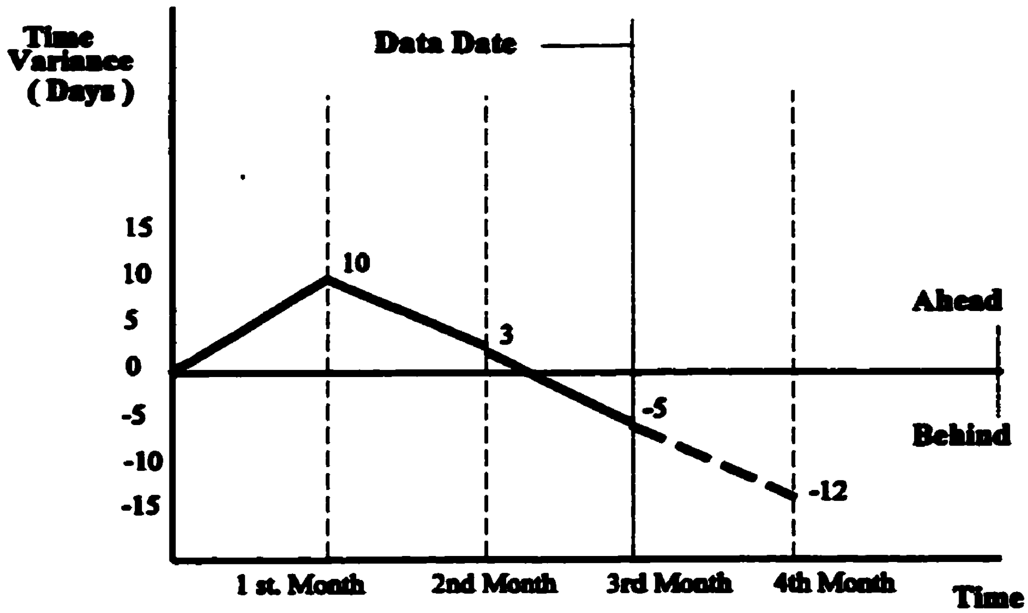


Fig. 4.8 Time Variance Trending and Forecasting

As shown in Fig. 4.8, in the first month the project was 10 days ahead of schedule, whereas in the second month it was only 3 days ahead of schedule and in the data date it was five days behind schedule. This trend can be used to forecast an anticipated time variance of (-12) days at the next update. However, this forecast analysis may not be correct because there are usually other factors affecting the project throughout its life cycle which have to be considered when forecasting the schedule performance.

4.3.4 Analysis Tree

As it was mentioned in the above article, each data has significance in itself. The forecaster, however, should take a combination of various data in order for the total situation to be closely analyzed. For example, if the Schedule Performance Index (SPI) is less than 1.0, this is certainly a problem (SPI = BCWP / BCWS). However, the (SPI) alone does not point to the cause of the problem. When the Total Float (TF) is introduced into this analysis, a better evaluation of the cause of the problem can be obtained. **Table 4.1** shows an analysis tree with the possible combinations using the (SPI) and (TF).

TF > 0 —	**SPI > 1.0 —**	**Ahead of schedule on critical path; more work being done than planned.**
	SPI = 1.0 —	**Ahead of schedule on critical path ; some shortfall in work on non-critical activities.**
	SPI < 1.0 —	**Ahead of schedule on critical path ; significant shortfall in work on non-critical activities.**
TF = 0 —	**SPI > 1.0 —**	**Critical path on schedule ; more work being done on non-critical activities than planned.**
	SPI = 1.0 —	**Critical path on schedule; total work volume is as planned.**
	SPI < 1.0 —	**Critical path on schedule; shortfall in work on non-critical activities.**
TF < 0 —	**SPI > 1.0 —**	**Critical path activities behind schedule; total work more than planned indicating excess attention to non-critical activities.**
	SPI = 1.0 —	**Critical path activities behind schedule; total work volume as planned meaning too much attention to non-critical activities.**
	SPI < 1.0 —	**Critical path activities behind schedule; total work less than planned; need more overall effort.**

Table 4.1 Analysis Tree (TF and SPI)

4.4 REPORTING AND DIRECTING SCHEDULE PERFORMANCE

Three stages have been discussed so far within the schedule control process ; the baseline plan, measuring schedule progress and analyzing schedule performance. It was discussed earlier in this work that it is unlikely for the actual activity durations to be exactly as planned or for the actual construction sequence to be exactly as depicted in the logic diagram. There may also be additions or deletions to the scope of a construction project which affect the schedule. Therefore, it can be concluded that, there is an immediate need for regular updating, reporting and directing the project schedule which is the fourth stage within the schedule control process.

In addition to the analysis graphs which were presented previously, the following are various reporting tools that can be used to communicate schedule information among the project team members.

4.4.1 Percent Complete Report

This report presents the percentage of completion of each activity at the data date. It can be presented in both tabular format or bar chart format. **Table 4.2** shows a percentage of completion report in a tabular format and **Fig. 4.9** shows a percentage of completion report in a bar chart format.

4.4.2 Tracking Report

Schedule progress tracking report is one of the most useful reports that is widely used within the construction industry. It compares the actual physical schedule progress to the baseline schedule. This assists the project team to identify the problem areas and take action as necessary.

Fig. 4.10 shows a tracking report in a bar chart format. In this report, each bar is divided into two horizontal bars. The bottom one is representing the baseline schedule while the top portion is further divided into two spaces. The dark portion represents the actual progress achieved whereas the rest represents the remainder of the task. A quick analysis of this schedule enables the project team to evaluate the progress of each individual task.

4.4.3 As-Built Schedule

Fig. 4.11 presents an as-built schedule in a logic diagramming format. An as-built schedule includes the actual start and finish dates of each activity. It is a very essential tool for schedule control. It provides the actual history of construction activities and can be used to forecast the schedule performance for similar activities. The as-built schedule is also a very valuable tool that can be used in cases of disputes. In Fig. 4.12, tasks in progress have a slash whereas the completed tasks have a full cross. It can also be noted that a completed critical task is removed from the critical path.

4.4.4 Activity Crashing and Activity Overlapping (Corrective Actions)

Activity crashing and activity overlapping are two techniques used as corrective actions in cases of schedule slippage.

Activity crashing is completing an activity in less than its normal duration. To completely crash an activity is to complete that activity in the least possible time by means of working extended hours and multiple shifts and by committing to it all the resources that can be used to reduce the task duration. It is recommended that the cost implications of crashing an activity be evaluated before proceeding with crashing this activity.

Overlapping activities means to introduce lead or lag time to two interrelated activities so that they share some time frame without affecting the construction sequence and thus result in time gain.

ID	Task Name	Act. Start	Act. Finish	% Comp.	Act. Dur.	Rem. Dur.
1	Mobilization / Start	1/2/96	1/2/96	100%	0d	0d
2	**WASHROOMS**	1/2/96	NA	88%	29d	4d
3	Washrooms 2nd,	1/2/96	1/28/96	100%	19d	0d
4	Door Operators	1/29/96	2/2/96	100%	5d	0d
5	Electric Work	2/5/96	NA	56%	5d	4d
6	**Ramps (A), (B)**	1/2/96	NA	87%	33.94d	6.06d
7	Cutting & Demo	1/2/96	1/5/96	100%	4d	0d
8	Concrete / Steel	1/8/96	1/12/96	100%	5d	0d
9	Screens	1/15/96	2/9/96	100%	20d	0d
10	Railings	1/15/96	NA	73%	11d	4d
11	Finishes	2/12/96	NA	70%	7d	3d
12	**Elevator Shaft**	1/15/96	NA	38%	28.73d	47.27d
13	Excavation	1/15/96	1/19/96	100%	5d	0d
14	Concrete / Backf	1/22/96	1/26/96	100%	5d	0d
15	1st Floor Shaft	1/29/96	2/9/96	100%	10d	0d
16	2nd Floor Shaft	2/12/96	NA	50%	5d	5d
17	3rd Floor Shaft	NA	NA	0%	0d	10d
18	Finish	NA	NA	0%	0d	10d
19	Piston	NA	NA	0%	0d	5d
20	Roofing	NA	NA	0%	0d	7d
21	Elevator Installa	NA	NA	0%	0d	15d
22	Commissioning	NA	NA	0%	0d	5d

Table 4.2 % Complete Report in a Tabular Format

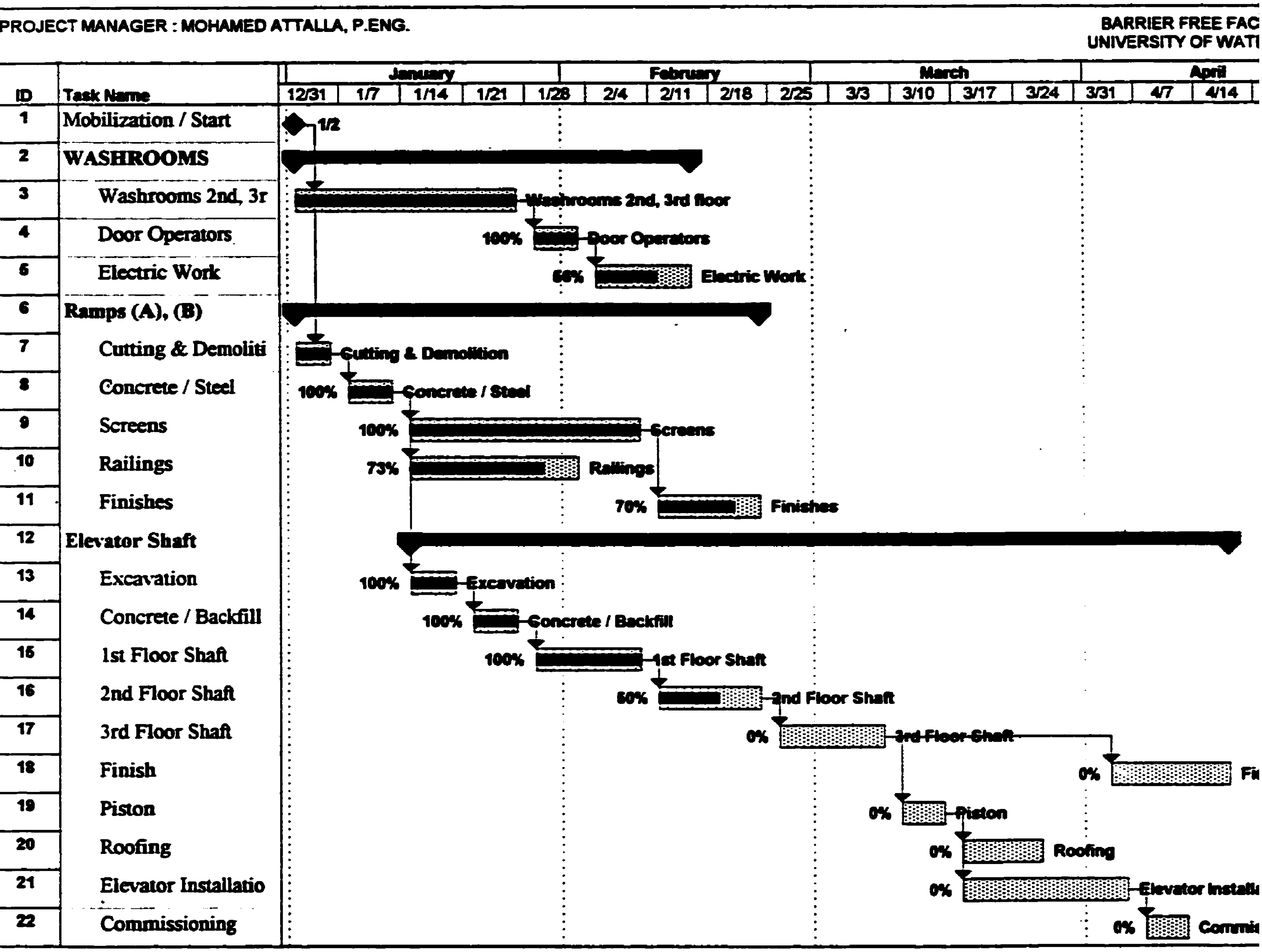
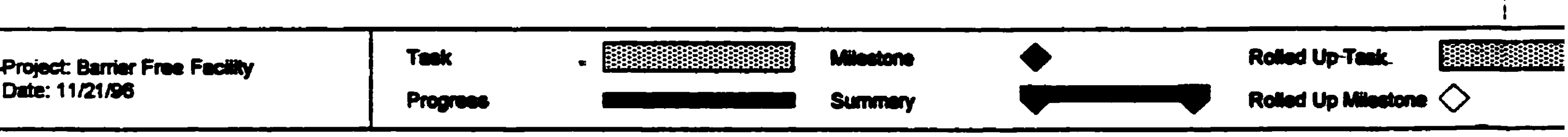


Fig. 4.9 % Complete Report in a Bar Chart Format



EE FACILITY
F WATERLOO

ABC ARCHITECT
XYZ CONSTRUCTION

pril			May				June				July				August		
4/14	4/21	4/28	5/5	5/12	5/19	5/26	6/2	6/9	6/16	6/23	6/30	7/7	7/14	7/21	7/28	8/4	8/11	8/18

Finish

Installation

Commissioning

Rolled Up Progress

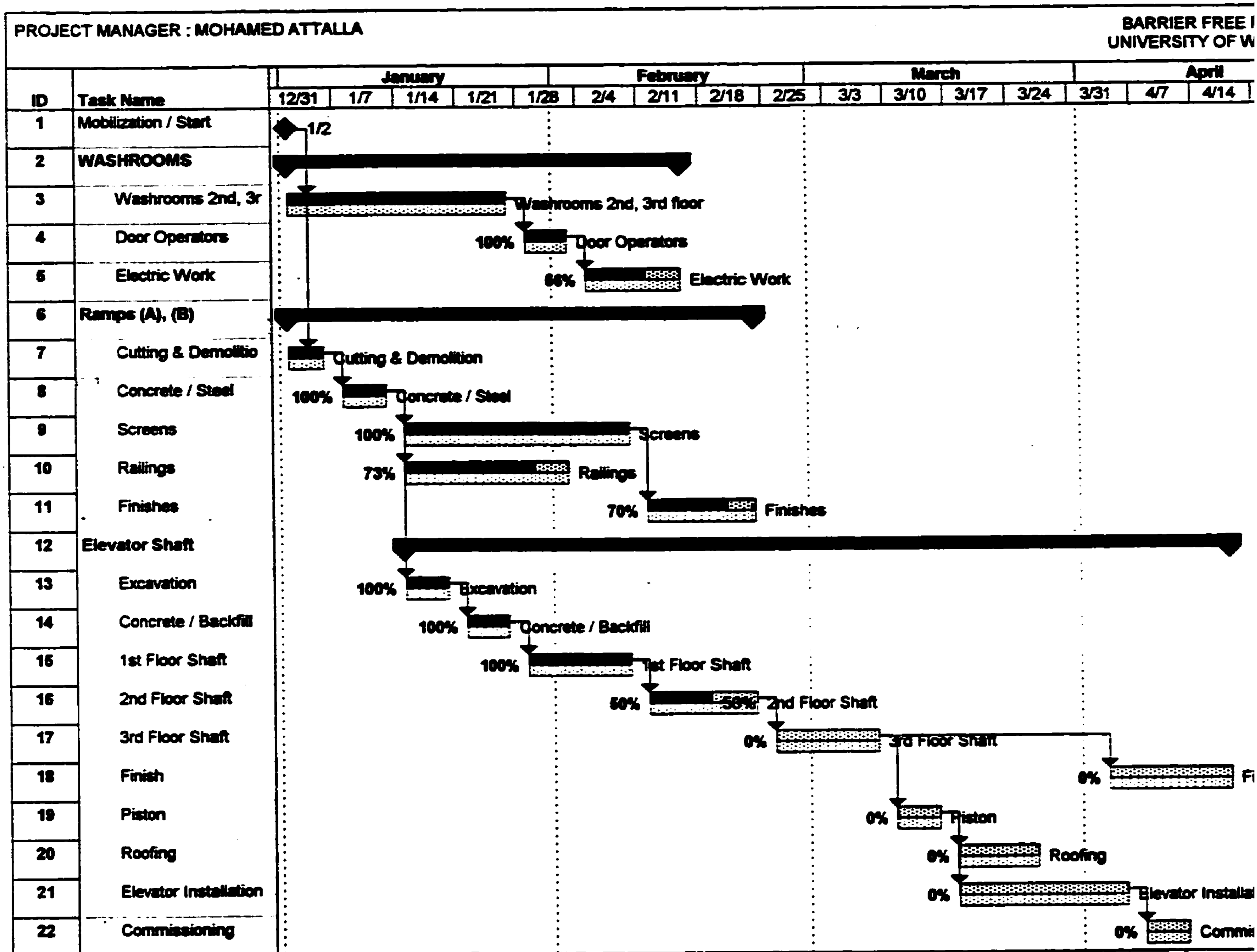


Fig. 4.10 Tracking Bar Chart Report

Project: Barrier Free Facility
Date: 11/21/96

Critical — Task Progress — Milestone
Critical Progress — Baseline — Summary
Task — Baseline Milestone — Rolled Up C

Page

E FACILITY
WATERLOO

ABC ARCHITECT
XYZ CONSTRUCTION

	May					June				July					August			
4/21	4/28	5/5	5/12	5/19	5/26	6/2	6/9	6/16	6/23	6/30	7/7	7/14	7/21	7/28	8/4	8/11	8/18	8/25

Finish

lation

nissioning

		Rolled Up Critical Progress		Rolled Up Baseline	
		Rolled Up Task		Rolled Up Baseline Milestone	
Critical		Rolled Up Task Progress		Rolled Up Milestone	

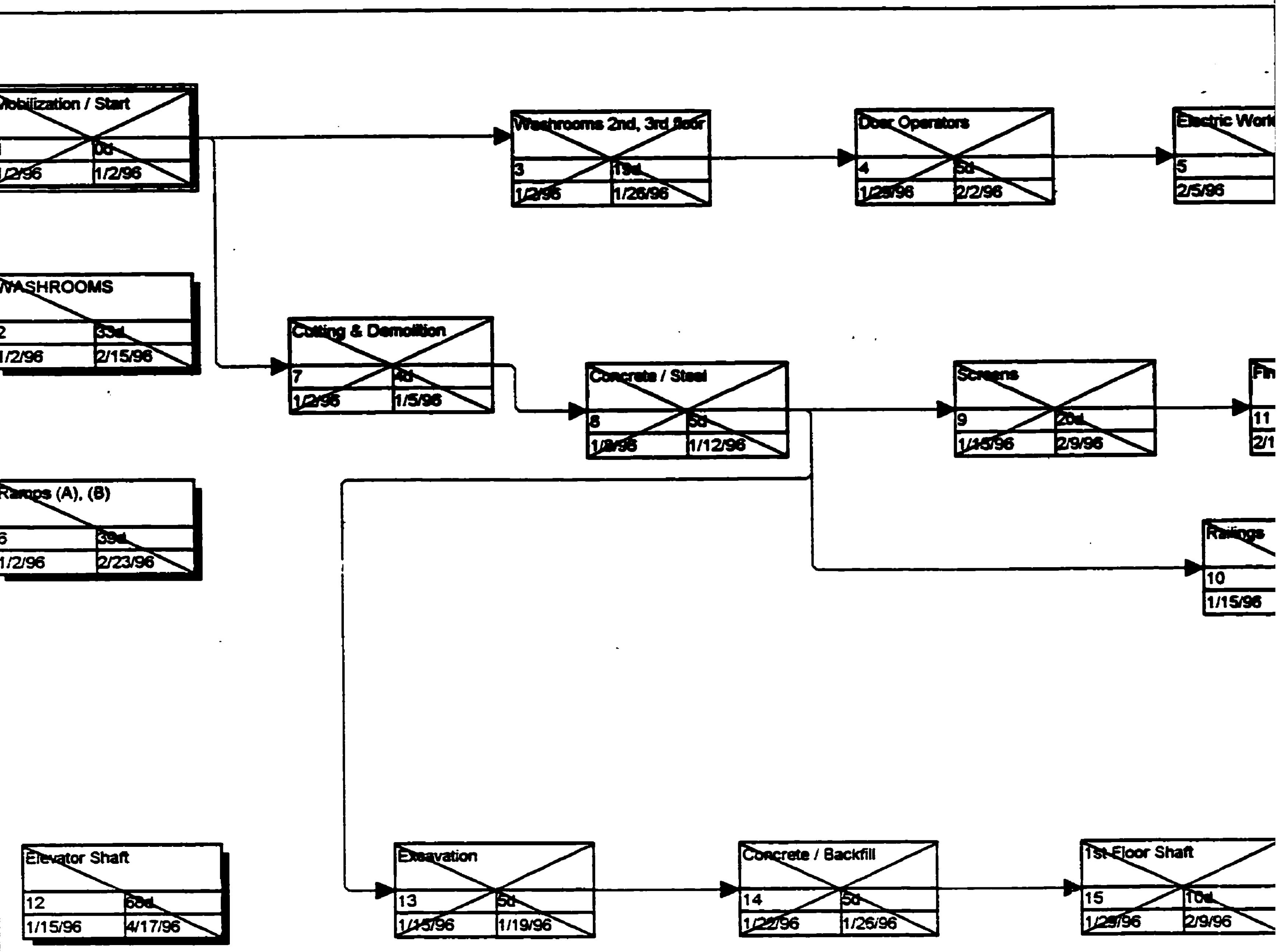
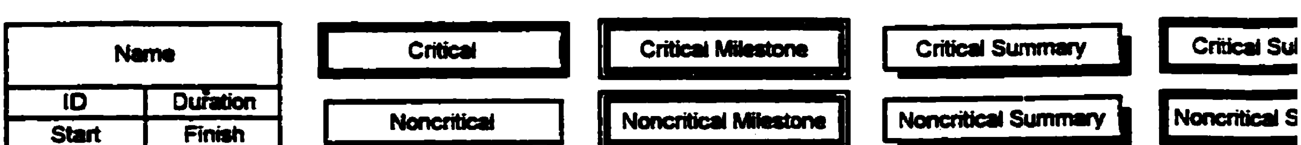
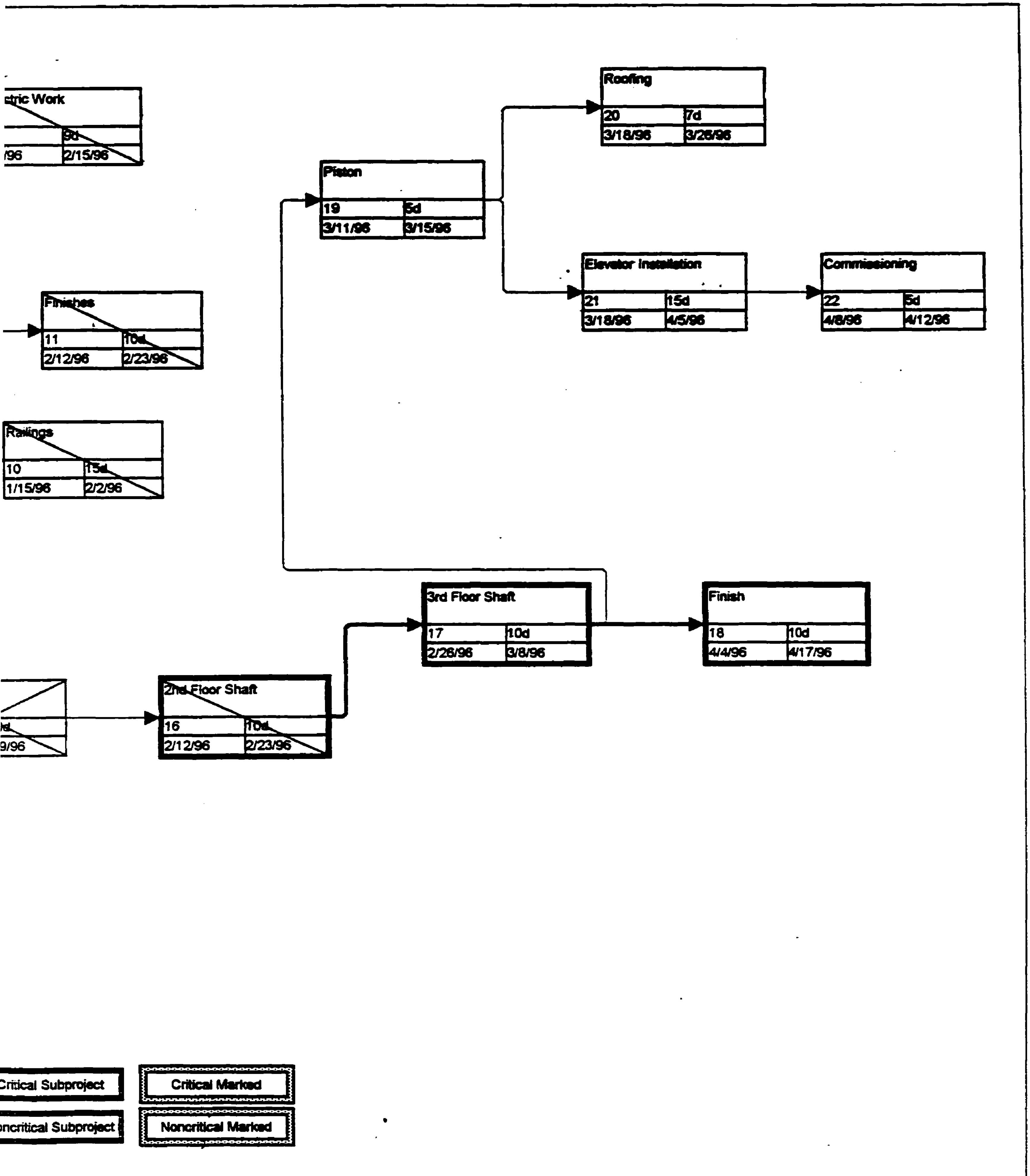


Fig. 4.11 As - Built Schedule (Logic Diagram)





ctric Work
9d
/96
2/15/96
Roofing
20
7d
3/18/96
3/26/96
Piston
19
5d
3/11/96
3/15/96
Elevator Installation
21
15d
3/18/96
4/5/96
Commissioning
22
5d
4/8/96
4/12/96
Finishes
11
10d
2/12/96
2/23/96
Railings
10
15d
1/15/96
2/2/96
3rd Floor Shaft
17
10d
2/26/96
3/8/96
Finish
18
10d
4/4/96
4/17/96
2nd Floor Shaft
16
10d
2/12/96
2/23/96
9/96
Critical Subproject
Critical Marked
ncritical Subproject
Noncritical Marked

CHAPTER 5

QUALITY CONTROL

Quality facilities enhance the safety, productivity and environment of the people and economic activities they serve, and are achieved through a process of planning, design, construction, operation and maintenance that must work effectively at all stages. In construction, quality is obtained though conformance to adequately developed requirements, requirements clearly stated to set forth the characteristics which the constructed facility must have to serve its users well.

An essential precondition for assuring construction quality is getting the requirements right and stating them clearly and accurately in the drawings and specifications to be followed by the construction team. The owner, engineer and contractor, being the three major parties involved in any construction project, have different roles and interests in controlling quality. Owners pay for a facility to be built within certain expected parameters of quality. Engineers and architects produce complete, clear and accurate drawings and specifications. They also set the quality parameters that meet the owner's expectation. Contractors supply material, labour and equipment in accordance with the quality parameters.

In this chapter of the thesis, the third main control function, quality control, is defined and the development and implementation of quality systems are studied. For the purpose of this work, however, the emphasis is on the process of inspecting and testing workmanship and material for general compliance with the specifications and contract documents.

The quality control process should follow the control process outlined in Fig. 2.4. Fig. 5.1 shows the quality control process.

In this thesis, all of the control functions are discussed within the execution stage of the project life cycle since most of the efforts spent on project control are being exercised during this phase. The quality control process is also discussed within the execution phase of the project life cycle. After the design is completed, both the owner and the architect develop their plans for the quality control process. Once the contract is awarded, the contractor develops his own quality process which responds to preset requirements by the contract documents. The project team then establishes the overall control process for the entire project. This process is discussed in more details in the following pages.

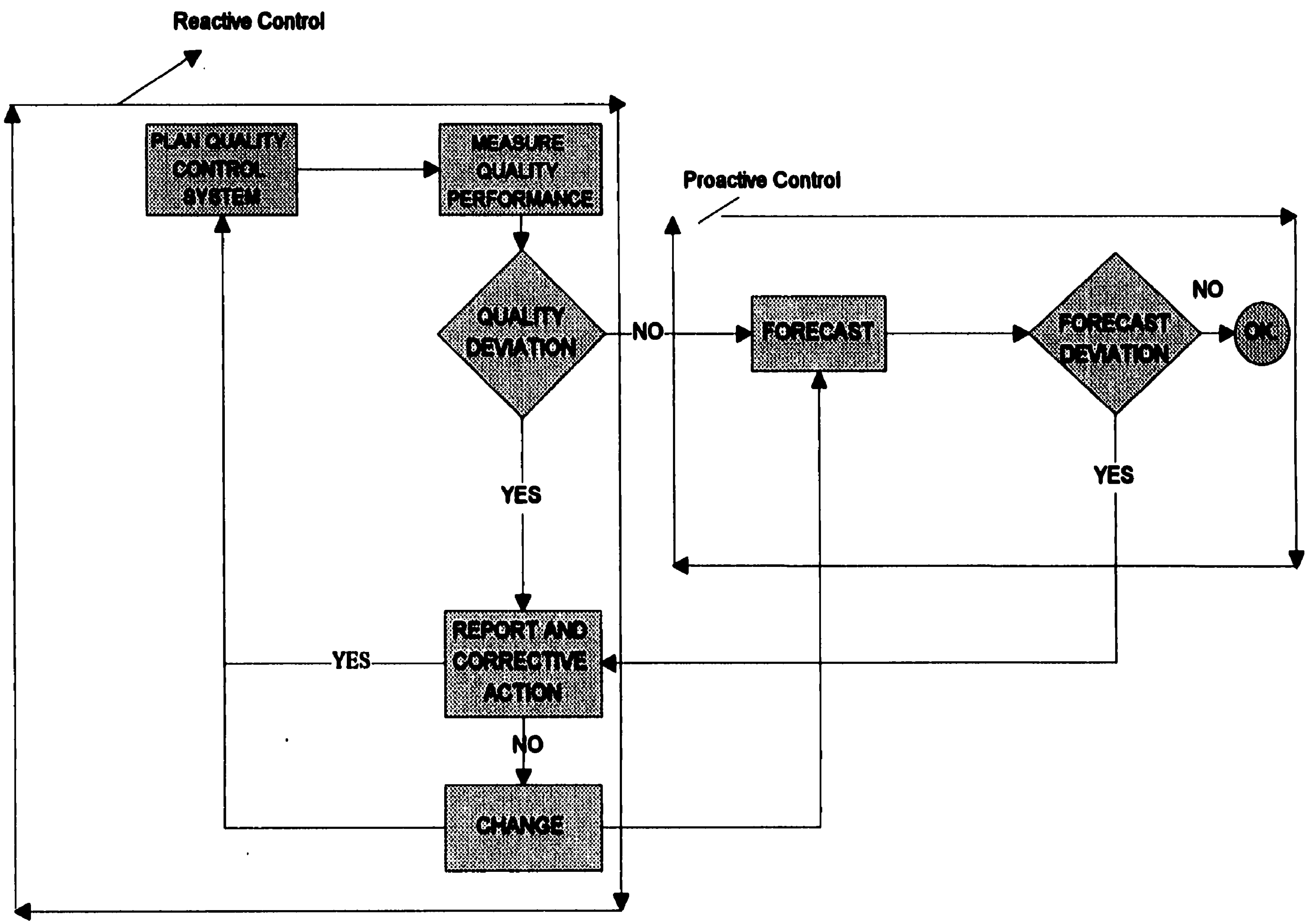


Fig. 5.1 Quality Control Process

5.1 DEFINITIONS

According to the dictionary, **quality** means "a degree of excellence and superiority in kind." The literature provided different definitions for the term quality. The American Society of Civil Engineers manual defined quality as "the totality of features, attributes and characteristics that bear on ability to satisfy a given need: fitness for purpose and meeting the requirements." The American Society for Quality Control termed quality "a systematic approach to the search for excellence."

Also, in the literature there were no generally accepted definitions of the terms quality assurance and quality control, and the two are used interchangeably by many practitioners within the construction industry. One definition of **quality assurance** is "a structured approach to business management and control, which enhances the ability to consistently provide products and services to specifications, program and cost." It was observed, however, through interactions with construction professionals that the term quality control is more frequently used in the construction industry, and thus the term quality control was used in this study. The term **quality control** is used to describe all those planned or systematic actions undertaken to provide adequate confidence that a product, process or service conforms to established requirements. These actions include inspections, tests and evaluation of services.

5.2 PLANNING A QUALITY SYSTEM

The first step in the quality control process is to plan the quality control system. Setting up a quality system is likely to be one of the most important steps in a construction project life. The implications for project performance are very real. Quality planning involves identifying which quality standards are relevant to the project and determining how to satisfy them [PMI, 1996].

A quality system can be considered the documented expression of the project quality policy. It should be noted that, each organization (owner, architect or contractor) usually has its own preestablished quality system. This system, however, should be modified to meet the specific requirements for the individual project.

5.2.1 Quality Standards and Specifications

The first step in the planning of a quality system is the preparation of clear and tight specifications for the project. The architect and the sub-consultants are responsible for putting together and finalizing these specifications. The interviewees indicated that, at this stage, the architect, owner and sub-consultants form teams of specialists to review the specific requirements for various sub-systems such as mechanical, electrical and architectural. Those teams usually meet with authorities having jurisdictions to discuss and clarify unique conditions.

The architect and the sub-consultants should incorporate the specific requirements of the owner teams and authorities having jurisdictions into the project specifications. The successful preparation of the specifications highly contributes to the overall success of the project. It eliminates any future disputes with local authorities or conflict with the owner expectations which in turn may result in extra costs or time delay.

The consultant also builds the specifications according to the standards and applicable codes. In Canada, the Standards Council of Canada is the coordinating body of the National Standards System, a federation of independent organizations working towards the improvement of standardization in the national interest. The National Standard of Canada is a series of standards which have been approved by the Standards Council of Canada. Also, the Canadian Standards Association (CSA) is engaged in approvals of products and services. The CSA standards are used widely by industry and commerce and often adopted by municipal, provincial and federal governments in their regulations.

5.2.2 Responsibilities and Quality control Organization Structure

It is necessary that the project team determines its policy and develops its objectives and goals. Policy can be defined as the direction in which the team wishes the project to move. Objectives and goals are the actions that have to be taken in order for the project to move into the required direction. A quality system can function effectively only if it is part of the overall control system created to achieve the required objectives in accordance with the defined policy.

Quality system standards require responsibilities to be clearly defined by management. People with a delegated responsibility for quality must have the authority to stop and reject poor work and take action to prevent repetition. Training is also an essential requirement for staff engaged in inspection.

In the construction industry, quality organizations are set up to meet the requirements of a specific contract. These organizational structures need to be defined on organizational charts backed up by a text defining responsibilities of key people. In a construction project, the owner, engineer and contractor are each given a role in controlling quality. It is also required that verification activities in all construction stages be carried out by companies independent of the construction or consultant firm. The independent role of the verifier is a mandatory requirement. This implies that verification of one's own work is unacceptable although there are grey areas.

Fig. 5.2 shows a typical quality control organization structure for a construction project. This figure shows the different players who are involved in controlling quality in a typical construction project. Due to the complexity and diversity of the relationships between those involved in quality control, it was not possible to present the quality control structure in a hierarchial format. This investigation reveals that those key players interact with each other during the construction operations to communicate certain information and receive feedback.

5.3 MEASURING QUALITY PERFORMANCE

The second stage of the quality control process is to measure quality performance, document and report compliance with or deviation from the quality requirements. These quality measurements take place through a series of inspection and testing by qualified professionals.

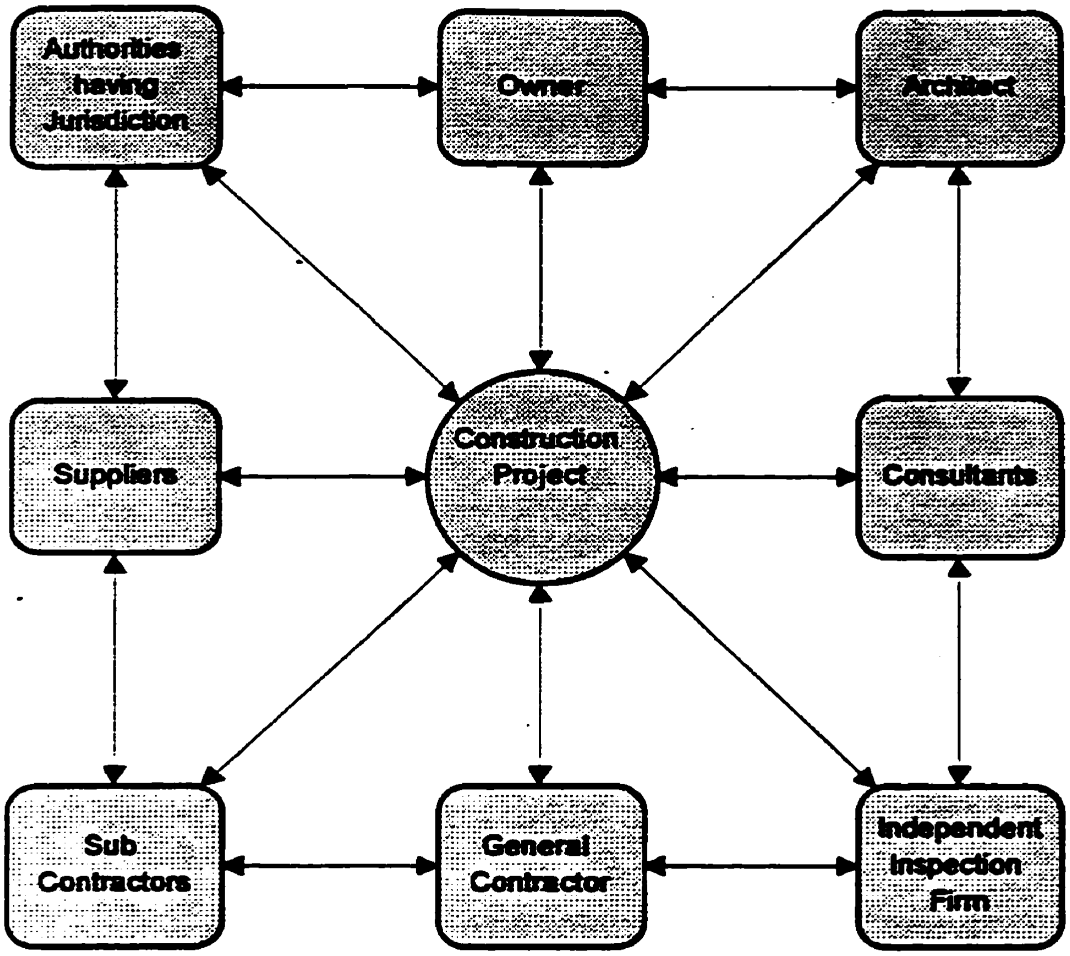


Fig. 5.2 Quality Control Structure in Construction Projects

5.3.1 Inspection and Testing

Inspection is an important means of controlling conformance to requirements and is an essential part of any quality control system. The value of inspection, however, has limits and over-inspection wastes the owner's resources, increases the construction costs and creates adversarial relationships among the construction team. The resources available for inspection must be deployed effectively and are most productive when all the project parties accept the value and relevance of inspection or testing. To assure this effective deployment and acceptance, the owners together with their consultants should develop integrated inspection plans for their construction projects. These plans should be reviewed with the constructor prior to commencing construction. These plans should also have input from the independent inspection organizations and from authorities having jurisdiction. The plan should include criteria for acceptance and rejection of work.

Although the contractor is not generally involved in formulation of the plan, it is important that the contractor understands the contents of the plan and recognizes that the engineering, construction and inspection and testing organizations concur with it. The integrated plan helps to assure the uniformity of inspections from one inspector to another and reduces the frequency of office consultations to review standards for acceptance of work.

Engineering tools and procedures that utilize modern electronics, computers and other new technologies are being used as inspection and testing tools in the construction industry. By using these tools, the task of inspection can be accomplished quicker as less labour is used, and more reliable information about the quality of construction in place become available. Computers and communication technology enhance both the contractors' and owners' abilities to review inspection data and monitor construction performance. A computer based building automation system, for example, enables the owner to have full control of the facility from a central location and also inspect, commission and verify the performance of all the equipment in the building from the same central location.

5.3.2 Documentation

A quality system can not function effectively unless it is communicated effectively among the project team members. This effective communication is carried out through an effective documentation system. Documentation can be defined as "any recorded information describing, defining, specifying, reporting or certifying activities, requirements, procedures or results."

5.3.2.1 Quality Manuals

The purpose of a quality manual is to provide an adequate description of the quality control system while serving as a permanent reference in the implementation and maintenance of that system. A typical quality manual includes information such as the company's philosophy and organization. It also includes the project quality assurance.

5.3.2.2 Standing Instructions and Procedures

It is one of the most essential management tasks to ensure that those responsible for executing the work are aware of the scope of their work. A quality system standard requires that this be achieved by the establishment, maintenance and implementation of documented procedures and instructions. Instructions can be defined as "the written and / or spoken direction given in training." Procedure can be defined as "a document that specifies or describes how an activity is to be performed."

5.3.2.3 Site Instructions

The instructions and procedures discussed in the previous article were related to procedural and organizational matters. There is another type of instructional document required to provide help and support to those responsible for executing the work. Very often, site personnel face a situation where the requirements are not clear. The engineer or the concerned party usually issues site instructions as a clarification to the extent and quality of work required. Site instructions do not usually change the prescribed quality or extent of work and neither do they have an impact on cost.

5.3.2.4 Document Control and Records

All of the quality control system documents are subject to change. If these changes are not controlled, the system will break down. It is important for every construction organization to have a documented procedure which identifies the persons responsible for the original preparation and approval of documents and which ensures that subsequent changes are reviewed and approved.

Document control should also keep track of all site visit reports issued by the owner, consultant, independent inspection firms, authorities having jurisdictions and the contractor's staff through a proper filing system.

This step can be considered the most significant step within the measuring stage of the quality control process. In this step, the result of quality measures is documented, reported and communicated to the project team members. It also becomes apparent in this step whether or not the delivered material, equipment or workmanship meet the quality requirement.

5.4 CORRECTIVE ACTIONS

The last stage of the quality control process is to take a corrective action when deviations in quality performance occur. To prevent the reoccurrence of faults, prompt and effective actions should be taken to identify and correct the causes. Defective work can have many sources such as incorrect or lack of work instructions including documents, faulty materials, tools or methods and human error.

Responsibilities should be clearly defined so that in a case of defective work, action can be taken at once through the proper channels. The cause of the defect must be found and corrected, otherwise the same problems may be repeated. Documentary evidence of all corrective actions and the reasons for them should be retained.

Corrective actions may include modifications to the design, specifications or working methods. Corrective actions may also include enforcing compliance with the specifications which may require repair or rework. Repair can be defined as the process of restoring a non-conforming characteristic to an acceptable condition even though the item may still not conform to the original requirement. Rework can be defined as the process by which an item is made to conform to the original requirement by completion or correction.

The quality concepts discussed earlier in this chapter were found suitable for both new construction and reconstruction projects. It was also found that every organization develops its own quality system and employs it in both types of construction. This study, however, revealed that other control functions may be useful in controlling reconstruction projects. A detailed analysis of these findings will follow in chapter six.

CHAPTER 6

RECONSTRUCTION VS. NEW CONSTRUCTION ANALYSIS AND COMPARISON

This chapter analyzes and presents the results of this research. Thirteen successful interviews were conducted with construction professionals from thirteen different organizations. This sample of thirteen organizations is a good representation of the three main parties involved in any construction project; the owner, architect and contractor. Those representatives provided the research with factual information and knowledgable opinions about the control and performance of forty different projects.

Due to the confidentiality of the data, each project was given an identification number from one to forty, and the organizations were also given an identification number from one to thirteen. The data gathered were grouped and analyzed using the Empirical Mathematical approach. When the mathematical approach was not available due to the nature of the data, textual descriptive analysis was used.

6.1 PROJECTS INFORMATION

Certain criteria were established to select projects for this study. Since one of the objectives of this research was to perform a comparison between reconstruction and new construction projects, data were obtained for a number of projects in both environments. This information was used to establish trends for the performance of these projects. Also, in reconstruction projects, a criteria was established that all projects should be implemented within or in the vicinity of an existing fully occupied and fully operational facility throughout the construction period.

Measures were taken to reduce the impact of the wide diversity in the construction industry and eliminate the effect of external factors that may have a negative impact on the comparison of the collected data. To this effect, most projects were selected in the same geographical area that being Southern Ontario, and all had the same building type that being institutional with the exception of one project which was commercial. Furthermore, all project formats were strictly lump sum except one project which was turnkey. Thus, the impact of external factors such as weather conditions or different codes or jurisdictions was greatly reduced. This selection criteria resulted in the selection of about forty projects out of forty five which were originally recommended by the survey participants.

The survey included twenty five reconstruction projects and fifteen new construction projects. **Appendix 3.1** includes the profile of the surveyed projects.

6.2 PERFORMANCE FACTORS

The optimum objective of any construction manager is to finish the project on time, within budget and to the expected quality standard. This statement simply indicates the three main functions that determine the success or failure of any construction project.

An effort was made to develop a quantifiable measure that enables the construction team to measure the degree of success or failure of any construction project, and also establish a bench mark to compare the performance of different projects.

This section discusses cost and schedule performance. It also discusses the overall performance of construction projects. Quality performance will be discussed later in this chapter.

6.2.1 Cost Performance Factor (CPF)

The variable Cost Performance Factor (CPF) was developed to be used as a means of measuring cost performance of construction projects and to establish a bench mark to compare the cost performance of different projects.

This cost performance factor utilizes the cost overrun as the basis for measuring cost performance. This approach was derived from the general practice in the construction industry and was also confirmed by the different construction professionals that were interviewed. The construction industry considers cost overrun an indicator of poor cost performance of a construction project.

The Cost Performance Factor can be obtained using the following formula:

$$CPF = \frac{\partial C}{\text{original contract value}} \times 100 \qquad \textit{Formula [1]}$$

Where ∂C is the total value of change orders issued during the project life. **Appendix 4.1** includes the calculations of the CPF for the surveyed reconstruction projects. These cost performance factors were multiplied by 100 as an adjustment factor to produce numbers that are easy to handle and to present. Appendix 4.1, also includes the calculated mean values and standard deviations (SD) of the cost performance factors for reconstruction projects.

Appendix 4.2 includes the CPF calculations for the surveyed new construction projects. Appendix 4.2 also includes calculations of the mean value and standard deviation (SD) of the CPF for new construction **projects. Table 6.1** summarizes these findings and presents the calculated values for both construction environments

RECONSTRUCTION		NEW CONSTRUCTION	
CPF	SD	CPF	SD
19.9	18.37	4.55	4.3

Table 6.1

It is obvious from Table 6.1 that new construction projects have better cost performance history at a mean value of 4.55 and SD of 4.3 than reconstruction projects in occupied buildings which tend to have a higher cost overrun rate at CPF mean value of 19.9 and are more volatile at SD of 18.37.

6.2.2 Schedule Performance Factor (SPF)

Schedule performance factor is another variable created to measure the schedule performance of construction projects and establish a bench mark for comparison purposes.

SPF utilizes schedule slippage as the basis for measuring the schedule performance of a construction project. There is an agreement among construction professionals that schedule overrun is a good indicator of schedule performance and consequently of the overall project success.

SPF can be obtained by the following formula:

$$SPF = \frac{\partial S}{\text{original duration of the project}} X\,100 \quad \text{Formula [2]}$$

Wher ∂ S is the total time delay during the project life. Appendix 4.1 includes the calculations of

SPFs for the selected reconstruction projects. These numbers were also multiplied by 100 to obtain manageable and meaningful numbers. Appendix 4.1, also, shows the calculations of the mean value and standard deviation of the SPFs for reconstruction projects.

Appendix 4.2 includes the calculations of SPFs for new construction projects. These calculations were used to arrive at a mean value and standard deviation of SPFs for new construction projects.

Table 6.2 summarizes the findings of this research in regards to schedule performance. These findings prove that reconstruction projects have a higher tendency for schedule slippage at SPF mean value of 22.28 and are more volatile at a standard deviation of 26.15 . New construction projects, on the other hand, are more stable at SPF mean value of 12.55 and standard deviation of 14.15.

RECONSTRUCTION		NEW CONSTRUCTION	
SPF	SD	SPF	SD
22.28	26.15	12.55	14.15

Table 6.2

6.2.3 Project Performance Factor (PPF)

Project Performance Factor was established in an attempt to define a quantifiable measure for the overall project performance and also to create a bench mark for future comparison studies. Initially, the intention was to include a quality performance factor in PPF. It was discovered, however, that the combination of CPFs, SPFs and the obtained quality performance factors would result in non-manageable numbers. Therefore, a combination of CPF and SPF only was utilized to obtain an indication of the overall performance of the project. Quality performance will be discussed separately in this chapter.

PPF can obtained by using the following formula:

$$PPF = \frac{CPF + SPF}{2} \qquad \textit{Formula [3]}$$

Information gathered in the survey assisted in assigning weighting factors to the various control functions. The participants were asked to assign weighting factors to the cost, schedule and quality functions. The obtained data were grouped and tabulated.

Appendix 4.3 tabulates the opinions that were expressed in the interviews. **Table 6.3** summarizes the findings and includes the obtained mean values for these weighting factors.

CONTROL FUNCTION	COST	SCHEDULE	QUALITY
WEIGHTING FACTOR	37%	28.9%	34.1%

Table 6.3

As seen in Table 6.3, schedule and cost obtained relatively close weighting factors. The above formula was, therefore, used in this research to obtain PPF.

It is recommended that this approach be followed in future research. However, it is advisable to gather future data on a project by project basis and also group the data for engineers, owners and contractors separately.

Appendix 4.1 and 4.2 include the calculations of PPFs for both new construction and reconstruction projects. Appendices 4.1 and 4.2, also, show the mean values and standard deviations for both reconstruction and new construction projects respectively.

Table 6.4 concludes the findings of this research that pertain to performance factors and their standard deviations.

Table 6.4 shows that PPF gives the same indications of the projects performance as CPF and SPF. This research reveals that the cost performance of reconstruction projects is 20% of the cost performance of new construction projects. Additionally, the schedule performance of reconstruction is about 50% of the schedule performance of new construction. These measures indicate that improving the cost performance of reconstruction will yield better results and will also contribute to the improvement of the overall project performance.

RECONSTRUCTION						NEW CONSTRUCTION					
CPF	SD	SPF	SD	PPF	SD	CPF	SD	SPF	SD	PPF	SD
19.9	18.3	22.3	26.2	22.9	17	4.5	4.3	12.6	14.2	9.2	9

Table 6.4

6.3 COST AND SCHEDULE OVERRUN ANALYSIS

In the previous section performance factors were obtained and a comparison study conducted between reconstruction and new construction projects. Schedule overruns were utilized as a means of measuring the project performance. In this section an attempt was made to determine and identify the reasons that mostly contribute to schedule and cost overruns in both construction environments. A preliminary investigation identified nine reasons which may contribute to cost or schedule overruns. This section is an attempt to determine the significance of each reason.

6.3.1 Cost Overrun

The answers provided in section 2.4 of the questionnaire were grouped and tabulated and mean values were obtained. While the questionnaire was structured to obtain factual information in a numeric format, details of the specific elements that can contribute to cost overruns were obtained in the interviews.

Appendix 5.1 shows the contributing factors to cost overruns in reconstruction projects in occupied buildings. It appears that the notorious contributor to cost overruns is unforeseen existing site conditions at a mean value of 52.8%.

Responses from the participants indicated that removal of concealed hazardous materials such as asbestos is a major element of unforeseen existing site conditions. Concealed services such as piping or duct work and inaccurate as-built drawings are also major elements of unforeseen site conditions.

Appendix 5.1 also shows that scope changes and design coordination contribute to cost overruns. It was reported that during reconstruction in occupied facilities, the end users very often discover during the construction process that the proposed design does not support the intended use of the facility which triggers a massive amount of change orders.

Appendix 5.2 shows the contributing factors to cost overruns in new construction projects. Unlike reconstruction projects, unforeseen site conditions are not the highest contributors to cost overruns. The appendix illustrates that the scope of work changed by the owner was the highest contributor.

6.3.2 Schedule Overrun

One of the objectives of this research was to investigate the reasons for the delays of construction projects, especially in reconstruction of occupied buildings. The participants were asked to assign a percentage to each factor that contribute to the overall delay of the project. These percentages were grouped and mean values were obtained to assess the contribution of each item to the schedule overrun.

Appendix 5.3 demonstrates the findings. Unforeseen existing site conditions was reported as the biggest contributing factor to schedule overruns in reconstruction projects. This was followed by scope and design change.

Appendix 5.4, on the other hand, shows that the critical factor which causes schedule delays in new construction is the change of scope by the owner followed by weather conditions. The impact of existing site conditions in new construction projects is not of great concern at only 15.5.

Table 6.5 summarizes the findings of this research and tabulates the reasons for cost and schedule overruns in both construction environments.

This study revealed that the cost and schedule performance of reconstruction projects are sensitive to the same factors to some degree. Therefore, it is recommended that control techniques should be developed to eliminate or reduce the effect of these factors in order to achieve significant improvements in reconstruction projects.

CONTRIBUTING FACTORS	RECONSTRUCTION		NEW CONSTRUCTION	
	COST	SCHEDULE	COST	SCHEDULE
Unforseen existing site conditions	52.8%	47.8%	21%	15.5%
Scope change by owner	16%	13.3%	52%	47.1%
Design change	13%	13.4%	23.6%	16.7%
Schedule problems	1.2%			
Procurement problem	2.6%	11.6%		4.4%
Design coordination	10.8%	7.6%	3.4%	3.3%
Regulatory requirement	3.6%	.7%		7%
Weather conditions				6%
Poor performance by contractor		5.6%		

Table 6.5

6.4 CONTROL TECHNIQUES

The following pages are an attempt to investigate the use of conventional control techniques in both construction environments and compare the performance of new construction to reconstruction projects under the utilization of conventional control techniques. The obtained data was also analyzed to identify those techniques which are associated with relatively successful projects.

6.4.1 Cost Control Techniques

This section investigates the use of conventional cost control techniques in both new construction and reconstruction projects. This section also explores other cost control techniques that may be used in reconstruction projects to enhance their performance.

A comprehensive literature review led to the identification of eleven different control techniques. Those techniques can be considered the most commonly used cost control techniques. The participants were asked to identify which of the eleven techniques were used to control the cost of their projects. Furthermore, they were given the opportunity to share their experience with the researcher and provide other techniques.

The questionnaire indicated that seven cost control techniques were most frequently used, and those are presented in **Appendix 6.1** together with the number of occurrences for each interviewed organization. The result is summarized in **Table 6.6.**

Table 6.6 shows that Budget Baseline and Cost Breakdown Structure are the most frequently used levels of planning for a cost control system. Also, in the execution and measuring steps of the cost control process, the following techniques were reported as the most frequently used techniques: Unit costing, Cost variance, Cash flow analysis and Schedule of values. Surprisingly, no forecasting techniques were reported in the surveyed projects.

CONTROL TECHNIQUES	Total No. of Occurrences
Budget Baseline	22
Cost Breakdown Structures	19
Unit Costing	14
Earned Value	5
Cost Variance	21
Cash Flow Analysis	15
Schedule of Values	23

Table 6.6

In an attempt to identify the cost control techniques that contributed to the improvement of the cost performance of the project, the most frequently used cost control techniques were classified into groups C1 and C2. **Appendix 6.2** illustrates the surveyed projects and their respective cost control techniques together with their cost performance factors.

This work revealed that projects associated with group C1 experienced better cost performance than projects associated with group C2.

Group C1: [Budget baseline, Cost breakdown structure, Schedule of values, Cost variances]
Group C2:[Work packages, Unit costing, Cost ratio]

Groups C1 and C2 above indicated that planning the cost control system at the budget baseline and CBS level render better results than projects that utilize work packages as the only level of cost control planning. They also indicate that better cost performance is associated with the utilization of schedule of values and cost variances as cost control techniques to measure the performance of the cost and identify any deviation from the original cost. On the other hand, the use of unit costing and cost ratios alone to measure and monitor cost performance did not render high cost performance.

Table 6.7 summarizes this information.

COST CONTROL	RECONSTRUCTION	NEW CONSTRUCTION
	CPF	CPF
C1	6.7	2.9
C1, C2	20.2	10.6
C2	37.2	

Table 6.7

It should also be noted that the CPF for reconstruction projects associated with group C1 has a mean value of 6.7 , whereas it is 2.9 for new construction projects. This indicates that new construction projects outperform reconstruction projects when the same conventional control techniques are utilized.

One non traditional cost control technique was indicated in the survey . It suggested that cash allowances may be utilized as a cost control technique to assist in reducing the cost overruns in reconstruction projects. Any undetermined scope of work at the time of tendering may be included in the contract through cash allowance. When the scope becomes more defined during the construction process, the owner is then able to solicit prices from vendors or subcontractors to carry out this portion of work under the supervision of the general contractor. This method can be applied to demolition work, rerouting of existing services or removal of hazardous material.

This process eliminates or reduces the painful and costly change orders. It is recommended that further research be conducted in this area to discover other cost control techniques. These new techniques could be utilized in reconstruction projects in occupied buildings in place of conventional control methods to reduce cost overruns.

6.4.2 Schedule Control Techniques

This section studies the schedule control techniques that are used in both construction environments. The literature review has determined eleven different schedule control techniques. The participants were asked to identify which schedule control techniques were used to control their projects. The results of the survey determined that six different schedule control techniques were mostly used to control the surveyed projects. The details of the results were included in **Appendix 6.3** and summarized in **Table 6.8.**

CONTROL TECHNIQUES	Total No. of Occurrences
Work Breakdown Structure	14
Bar Chart	27
C.P.M.	10
Percent Complete	25
Incremental Milestone	19
Time Variance	11

Table 6.8

Table 6.8 indicates that WBS is the most frequently used level of schedule control in the surveyed projects. Also, Bar Charts and C.P.M. are the most frequently used techniques for schedule control planning. In the measuring and monitoring steps of the schedule control process, Percent Complete, Incremental Milestone and Time Variances were most frequently used.

The schedule control techniques which were associated with a higher schedule performance were grouped as S1. On the other hand, the schedule control techniques which were associated with lower schedule performance rate were grouped as S2. **Table 6.9** summarizes these results and the details are included in **Appendix 6.4.**

Group S1: [Bar chart at the detailed activity level, Percent Complete, C.P.M., Incremental Milestone]
group S2: [Bar chart at the work packages level, Work Breakdown Structure]

Group S1 indicated that using both Bar charts at the detailed activity level and C.P.M. as the schedule control planning techniques yield better schedule performance. Also, the utilization of Incremental Milestone and Percent Complete as measuring and monitoring schedule control techniques result in achieving higher schedule performance.

Group S2 indicates that the project team used planning techniques, but they did not utilize any measuring or monitoring techniques. Therefore, it was not possible to identify any schedule deviations.

SCHEDULE CONTROL	RECONSTRUCTION	NEW CONSTRUCTION
	SPF	SPF
S1	7.17	6.6
S1,S2	20.72	15.9
S2	100	

Table 6.9

One successful non traditional schedule control technique was reported as an attempt to improve the schedule performance in reconstruction projects in occupied buildings. This technique is the integration of the operation schedule of the existing facility with the construction schedule. In large projects in occupied facilities, the owner is usually responsible for the procurement of some special equipment and their relocation from one place to another. The combination of this process with the construction schedule enhances the schedule performance significantly because it keeps all the parties informed of all the different aspects of the project.

It is recommended that further research be carried out to identify more techniques that can contribute to further enhancement of schedule performance in reconstruction projects in occupied buildings.

6.5 QUALITY PERFORMANCE

For the purpose of this research quality control was defined as the process of inspecting and testing workmanship and materials for compliance with contract specifications and the applicable codes. The intent of the study was to gather information pertaining to the quality performance of the project and use this information to conduct comparisons in a quantifiable fashion.

6.5.1 Quality Control Planning

As a result of some discussions with a number of construction professionals, three questions were included in part four of the questionnaire to examine quality control planning in the tested organizations. The intent of two of the questions was to examine whether a clear definition of management responsibilities towards quality as well as a quality control organizational structure were included in the project quality manual. The third question examined the involvement of independent inspection firms in the quality control plan.

All the surveyed organizations had established a quality control system. This system is usually modified to suit the specific needs of the individual project. The survey revealed that each organization utilized the same quality control system for both new construction and reconstruction projects.

Responses to the questionnaire indicated the following:

1. All reconstruction and new construction projects had the quality control organizational structure clearly defined.

2. Responsibilities of individuals towards quality were also clearly defined.

3. All the organizations interviewed do not have a quality controller position. It is the responsibility of the site superintendent or the project manager to oversee and coordinate the quality control process.

4. Independent inspection firms were also used to the same degree in both construction environments.

6.5.2 Measuring Quality Performance

A preliminarily investigation was conducted within the construction industry in an attempt to develop questions that provide a quantifiable measure to quality performance. The outcome of this preliminary study was the development of four quantifiable measures to quality performance of construction projects. Those four measures are the estimated cost for rework or repair, number of rework or repair requests, number of orders to comply by authorities having jurisdiction and number of users complaints. The interviewed organizations did not have sufficient data at the time of the survey in terms of rework, repair and orders to comply by authorities having jurisdiction. The available data, however, indicated that both new construction and reconstruction projects received almost similar directions from engineers and inspectors with authorities having jurisdiction.

Appendix 7.1 tabulates the obtained data for reconstruction projects and **Appendix 7.2** tabulates data for new construction projects. **Table 6.10** summarizes this data.

QUALITY CRITERIA	RECONSTRUCTION	NEW CONSTRUCTION
Cost of rework (Percentage of Total Cost)	1.6%	0.27%
No. of rework requests	7.4	1.3
No. of users complaints	7.8	1

Table 6.10

Table 6.10 indicates that reconstruction projects received more users complaints at a mean value of (7.8) complaint per project compared to new construction projects which received complaints at a mean value of (1) per project.

Table 6.10 also indicates that reconstruction projects experience higher cost for rework required at a mean value of (1.6 %) of the original cost of the project compared to (0.27%) within new construction projects.

The above information also indicate that reconstruction projects received more rework requests at a mean value of (7.4) request per project while new construction had a mean value of (1.3).

The above analysis helps to provide useful indicators which can reflect a true trend to the current quality performance of reconstruction projects as compared to new construction projects.

6.6 OTHER CONTROL FUNCTIONS FOR RECONSTRUCTION PROJECTS

Another objective of this research was to explore other control functions than cost, schedule and quality which can be managed in order to optimize the outcome of reconstruction projects in occupied buildings. The result of a brainstorming exercise with the interviewees was some fruitful information and knowledgable opinions regarding other control functions that may contribute to the success or failure of reconstruction projects in occupied buildings. This is not meant to imply that these functions are not of significance to new construction but rather that reconstruction projects are more sensitive to these factors.

6.6.1 Communication Control

Several interviewees cited communication control as the key to the success of reconstruction projects. The architect, owner and contractor are usually the three main players in new construction projects. There are other players in reconstruction projects, however, who become heavily involved and affected by the construction process. These are the facility users, facility operators and in most cases the public.

The involvement of these parties early in the process eliminates unnecessary hardship which could be caused by poor communication. Problems may be related to inadequate scheduling and coordination between the construction operation and the operation of the facility or the interruption of existing services to the building (water, power,...etc). A recommended technique is to conduct regular meetings with the users and operation staff in order to keep them informed and receive their feedback.

6.6.2 Scope Control

The scope definition and control of any project can determine whether or not the project is successful. In order to determine this, the end user's requirements and objectives must be known, quantified and documented. The relationship of the end product to those requirements can then be determined and can provide a measure of the project's success. Early documentation and communication of the scope to all parties increase the chances for success. The users, normally, in the vicinity of the construction work, observe the progress of construction. If their expectations are not built into the project, then a very lengthy list of change orders can be expected. Providing adequate as-built drawings for the existing facility also assists in developing a more precise scope definition.

6.6.3 Site Control

Proper and adequate site control is crucial to all construction projects. However, the unique characteristics of reconstruction of occupied buildings give site control more significance. Working within an occupied and fully operated facility makes reconstruction projects struggle for space. Space congestion introduces a variety of challenges. Available storage space and hoisting of material and equipment are examples. Also, access to the facility and sequencing of equipment are other constraints. Providing enough parking spaces or alternate parking for users is one of the major problems that faces reconstruction projects.

Site control in reconstruction environments should start in the preliminary planning stages of the projects. All of the above factors should be taken into consideration when laying out the extent of construction.

6.6.4 Safety Control

The construction industry is committed to safe practices either in a new construction or reconstruction environment. Every construction organization is responsible for establishing its safety management programs for construction projects in response to the Health and Safety Act and its regulations. Working in or in the vicinity of an occupied building imposes additional constraints for safe practices. These constraints come from two different sources. The first source is existing building components as it is likely that these components contain hazardous materials such as asbestos, PCB and lead . The second source is the occupants because their existence in the building imposes limitations on activities that produce odours, smoke or noise. These concerns should be included in the contract documents to avoid possible future disputes that may result in cost or schedule overruns.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Reconstruction projects are becoming increasingly more important as metropolitan cities face economic and space constraints to new or grassroots projects. Social and demographical factors also contribute to the increasing need for the upgrading and expanding of existing facilities.

Reconstruction projects in occupied buildings are different from new construction projects in many ways. Reconstruction projects involve work in or in the vicinity of an existing facility which imposes limitations on the owner, engineer, contractor, operator and user. These limitations include insufficient information about the existing facility, physical space limitations and operational limitations which make reconstruction projects unique because of the degree of freedom available to all parties.

7.1 CONCLUSIONS

The primary objective of this study was to investigate the use of conventional control methods in reconstruction projects in occupied buildings and conduct a comparison study between the project performance of reconstruction projects and the project performance of new construction projects under the utilization of conventional methods.

In order to achieve this objective, the most commonly used project control techniques were researched and reviewed. The three main approaches utilized in this study were a comprehensive literature review, informal discussions with construction professionals and observations based on the experience of the writer. The intent was to provide the reader with an insight and appreciation of the different project control techniques used to control the three main control functions which are cost, schedule and quality. The external factors which affect these control functions and which are part of the entire control system were also explored. External factors included project life cycle, project format and the project parties.

A questionnaire was developed using the researched principals of control techniques in order to obtain factual data to perform comparisons between the project performance in both construction environments.

Thirteen organizations participated in this research and provided valuable data pertaining to forty projects. It is believed that this sample of organizations and surveyed projects adequately represented the construction market. It is also believed that the appropriate data collection mechanism was used and that the data collected from the various organizations can be trusted. This statistical survey can , therefore, be described as exhaustive.

The use of conventional control techniques in both construction environments was investigated. The tested organizations used almost the same conventional control techniques to control the surveyed new construction and reconstruction projects.

Three different performance factors were described in order to obtain a quantifiable measure and establish bench marks for comparison. These three factors are Cost Performance Factor (CPF), Schedule Performance Factor (SPF), and Project Performance Factor (PPF).

Using the above factors, the comparison study revealed that new construction projects tend to perform at a much better rate than reconstruction projects. Reconstruction projects have a higher tendency for schedule overrun and cost overrun.

This work also performed an analysis of the contributing factors to schedule and cost overruns in reconstruction projects. This analysis indicated that unforseen existing site conditions is the biggest contributing factor to both cost and schedule overruns followed by the change in scope of work or the design by the owner or engineer.

Two non-traditional techniques were reported in the interviews as a means of reducing cost overrun and schedule overrun. Cash allowances was reportedly utilized to control expenditures for the undefined portions of the scope of work at the tender time. Also, reported was the integration of the existing facility operation schedule into the new construction schedule in order to avoid any conflict during the operation, which may consequently cause major delays.

For the purpose of this study, quality control was defined as the process of inspecting and testing workmanship and materials for compliance with the contract specifications and the applicable codes. The tested organizations and the surveyed projects seemed to have the same quality performance for both new construction and reconstruction. However, this investigation indicated that reconstruction projects in occupied buildings tend to have more user complaints during the construction process which pertain to noise, dust, smoke and other safety related concerns.

The survey provided the participants with the opportunity to describe in a free format other control functions that may contribute to the success of reconstruction projects and also identify problems that are unique to reconstruction projects. The reported problems included lack of information about the existing facility, space limitations for construction operations, maintaining health and safety of the occupants, and the involvement of more players such as building users. Therefore, other control functions may include site control, communication control, safety control and scope control.

This research also gathered information related to assigning weighting factors to the three main control functions, cost, schedule and quality which may assist future researchers in this respect.

7.2 RECOMMENDATIONS

The literature search provided a large body of information on the subject of new construction projects. However, very little useable information regarding reconstruction projects in occupied buildings was found. This work could be considered a step in the direction of developing and documenting quantitative data and a body of knowledge on reconstruction projects in occupied buildings.

It is recommended that further research be conducted to develop more nontraditional cost and schedule control techniques in order to enhance the cost and schedule performance of reconstruction projects. The developed performance factors in this research can be used as bench marks to measure any improvement in performance.

This research identified four control functions that are critical to the success of reconstruction projects. These functions are safety control, scope control, site control and communication control. It is also recommended that future research develop a set of techniques in order to optimize the performance of these functions. The approach used in this study in assigning weighting factors to cost, schedule and quality control functions can also be followed to assign weighting factors to scope, site, communication and safety functions.

It is also strongly recommended that future research develop an objective model of the processes of designing, planning and controlling reconstruction projects in occupied buildings.

Since the owner is the most concerned party with scope definition, communication, safety and site control in addition to cost, schedule and quality, it is recommended that the proposed model be developed within the owner organization.

APPENDICES

APPENDIX 1

Part 1: Organization and Project Information

1.1 Type of your organization

- ❑ Owner ❑ Engineer/ Architect ❑ Contractor

1.2 Location of the project

- ❑ Southern Ontario ❑ Northern Ontario
- ❑ Western Ontario ❑ Eastern Ontario

1.3 Your position in your organization

- ❑ Owner ❑ Project Manager ❑ Contract Administrator
- ❑ Other, please specify ________________

1.4 Type of building

- ❑ Institutional ❑ Commercial ❑ Industrial

1.5 Type of project

- ❑ Interior renovation ❑ Upgrading Functional Performance
- ❑ Retrofit ❑ Expansion ❑ Phased replacement
- ❑ New Construction (Grassroots)
- ❑ Other, please specify ________________

1.6 Project format

- ❑ lump Sum ❑ Cost Plus ❑ Turn Key
- ❑ Other, please specify ________________

1.7 Subcontract format

- ❑ lump Sum ❑ Cost Plus ❑ Turn Key
- ❑ Other, please specify ________________

Part 2 Cost Control

2.1 Original contract value $ ___________

2.2 Used the following techniques as cost control planning tools:

- 2.2.1 Budget baseline ❑ Yes ❑ No
- 2.2.2 Work packages costing ❑ Yes ❑ No

2.2.3 Cost breakdown structure ❑ Yes ❑No
2.2.4 Unit costing ❑ Yes ❑No
Other, please specify ______________________________

2.3 Used the following techniques as tools for measuring, controlling and analyzing cost progress:

2.3.1 Cost ratio	❑ Yes	❑ No
2.3.2 Earned value	❑ Yes	❑ No
2.3.3 Cost variance	❑ Yes	❑ No
2.3.4 Cash flow analysis	❑ Yes	❑ No
2.3.4 Schedule of values for progress payment processing	❑ Yes	❑ No
2.3.5 Trend analysis	❑ Yes	❑ No
2.3.6 Forecast analysis	❑ Yes	❑ No

Other, Please specify ________________

2.4 Project final cost
2.4.1 Contract value at completion $ ____________
2.4.2 No. of change orders issued ____________
2.4.3 Change orders included the following percentage of the following items
* Unforseen existing site conditions % ___
* Scope of work changed by owner % ___
* Design change % ___
* Schedule problem % ___
* Procurement Problem % ___
* Design coordination problem % ___
* Other, please specify_________________________ % ___

Part 3 Schedule Control

3.1 Original duration of the project (to the date of substantial completion) _______ Month

3.2 The following techniques were used for schedule planning:

3.2.1 Work packages	❑ Yes	❑ No
3.2.2 Work breakdown structure	❑ Yes	❑ No
3.2.3 Bar chart scheduling at the detailed activity level	❑ Yes	❑ No
3.2.4 Bar chart at the work package level	❑ Yes	❑ No
3.2.5 Critical Path Method (C.P.M.)	❑ Yes	❑ No
3.2.6 Precedence Method (P.M.)	❑ Yes	❑ No
3.2.7 Program Evaluation and Review Technique (PERT)	❑ Yes	❑ No

Other, Please specify ______________________________

3.3 Used the following techniques as tools for measuring, controlling and analyzing schedule progress:

3.3.1 Percent complete ❑ Yes ❑ No

3.3.2 Incremental milestone ❑ Yes ❑ No
3.3.3 Progress curves analysis (S curves) ❑ Yes ❑ No
3.3.4 Time variance analysis ❑ Yes ❑ No
Other, Please specify ____________________

3.4 Project schedule outcome
3.4.1 Final duration (to the date of substantial completion) __________ Month
3.4.2 Please indicate the percentage that the following factors contributed to the slippage of the schedule:

- Unforseen existing site conditions %____
- Scope change %____
- Design change %____
- Procurement problems %____
- Design coordination problems %____
- Other, please specify____________________

3.4.3 Duration between substantial completion and final completion ______ weeks

Part 4 Quality Control

(For the purpose of this question, QC is meant to be inspecting and testing workmanship and materials for compliance with the contract specifications and the applicable codes)

4.1 Responsibilities of management towards quality control clearly defined ❑ Yes ❑No
4.2 Quality control organizational structure clearly defined ❑ Yes ❑No
4.3 Involvement of independent inspection firms ❑ Yes ❑No
4.4 Please indicate the estimated cost for rework or repair $ _______
4.5 Please indicate the number of documented rework or repair requests ____
4.6 Please indicate number of orders to comply by authorities having jurisdiction. ____
4.7 Please indicate number of users complaints _____
Other, Please specify ______________________________

Part 5 Control functions weighting factor

Please indicate weighting percentage for each control function as outlined in the example below

	Cost % ____	Schedule % ____	Quality %____	= %100
Example				
	Cost % _40_	Schedule % _30_	Quality %_30_	= %100

Part 6 Other control functions

Note (The information required in this section is very important for this research, your cooperation is highly appreciated)

This survey is based on three control functions, cost, schedule, quality. Please indicate below what other control functions should be considered for reconstruction projects control together with reasons for such functions and the appropriate techniques or tools to control it.

Control Function	Reasons	Control Tools

APPENDIX 2

Dear Sir

The Construction Engineering Group at the University of Waterloo is conducting a research in the area of construction projects control. We are interested in both the construction of new facilities (Grassroots projects) and reconstruction of existing occupied facilities. We would appreciate your participation in this research by permitting Mohamed Attalla (Graduate Student) to meet with your project management staff to discuss the attached survey.

We would like to inform you that, according to the research policies of the University of Waterloo , all the information provided in this survey will be kept strictly confidential. The outcome of this research will be made available to you upon your request.

If you have any questions please contact us at the above address. Thank you in advance for your cooperation.

sincerely

Professor: Robert McKim, Ph. D., P. Eng.
Mohamed Attalla, P. Eng. (Graduate Student)

APPENDIX 3.1
Profile of the surveyed projects

PROJECT ID	TYPE OF PROJECT	TYPE OF BUILDING	PROJECT FORMAT	LOCATION	TYPE OF ORGANIZATION	SIZE OF PROJECT	PROJECTS DURATIONS(M)
1	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$985,000.00	18
2	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$270,000.00	3.3
3	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$212,000.00	3.3
4	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$215,000.00	3.3
5	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$352,000.00	3.5
6	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$259,000.00	3.5
7	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$319,000.00	5
8	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$423,000.00	8.5
9	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$555,000.00	6
10	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$220,393.00	4.3
11	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$383,194.00	4.5
12	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$125,000.00	4.5
13	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$113,000.00	4
14	Reconstruction	Institutional	Lump Sum	Southern Ontario	Owner	$214,000.00	4
15	Reconstruction	Institutional	Turn Key	Southern Ontario	Owner	$44,951,930.00	18
16	Reconstruction	Institutional	Lump Sum	Southern Ontario	Contractor	$110,000.00	2
17	Reconstruction	Institutional	Lump Sum	Southern Ontario	Contractor	$115,000.00	2
18	Reconstruction	Institutional	Lump Sum	Southern Ontario	Contractor	$12,200,000.00	15
19	Reconstruction	Institutional	Lump Sum	Southern Ontario	Contractor	$250,000.00	5
20	Reconstruction	Institutional	Lump Sum	Southern Ontario	Contractor	$230,000.00	4.5
21	Reconstruction	Institutional	Lump Sum	Southern Ontario	Contractor	$140,000.00	4.5
22	Reconstruction	Institutional	Lump Sum	Southern Ontario	Contractor	$211,000.00	8
23	Reconstruction	Institutional	Lump Sum	Southern Ontario	Contractor	$221,870.00	3
24	Reconstruction	Institutional	Lump Sum	Southern Ontario	Arch.	$690,000.00	5
25	Reconstruction	Institutional	Lump Sum	Southern Ontario	Arch.	$26,483,218.50	34
26	New Construction	Institutional	Lump Sum	Southern Ontario	Owner	$4,985,023.90	11
27	New Construction	Institutional	Lump Sum	Southern Ontario	Contractor	$692,000.00	7
28	New Construction	Institutional	Lump Sum	Southern Ontario	Contractor	$498,000.00	6
29	New Construction	Commercial	Lump Sum	Southern Ontario	Contractor	$187,000.00	3.5
30	New Construction	Institutional	Lump Sum	Southern Ontario	Contractor	$1,590,877.00	6.33
31	New Construction	Institutional	Lump Sum	Southern Ontario	Contractor	$2,862,000.00	11
32	New Construction	Institutional	Lump Sum	Southern Ontario	Contractor	$8,550,000.00	20
33	New Construction	Institutional	Lump Sum	Southern Ontario	Contractor	$1,000,000.00	8
34	New Construction	Institutional	Lump Sum	Southern Ontario	Contractor	$730,000.00	6.5
35	New Construction	Institutional	Lump Sum	Southern Ontario	Arch.	$2,400,000.00	9
36	New Construction	Institutional	Lump Sum	Southern Ontario	Arch.	$8,025,000.00	18
37	New Construction	Institutional	Lump Sum	Southern Ontario	Arch.	$253,000.00	4
38	New Construction	Institutional	Lump Sum	Southern Ontario	Arch.	$1,329,906.00	6
39	New Construction	Institutional	Lump Sum	Southern Ontario	Arch.	$450,000.00	6
40	New Construction	Institutional	Lump Sum	Southern Ontario	Arch.	$2,880,000.00	12

APPENDIX 4.1
Performance Factors, Reconstruction Projects

PROJECT ID	Cost Performance			Schedule Performance			PROJECT PERFORMANCE FACTOR
	Original Cost	Final Cost	CPF	Original Duration	Final Duration	SPF	
1	$920,000.00	$985,000.00	7.1	10	18	80	43.6
2	$249,500.00	$270,000.00	8.4	3	3.3	10	52.8
3	$147,000.00	$212,000.00	44.2	3	3.3	10	27.1
4	$142,000.00	$215,000.00	51.4	3	3.3	10	30.7
5	$295,000.00	$352,000.00	19.3	3	3.5	16.7	18
6	$209,000.00	$259,000.00	23.9	3	3.5	16.7	20.3
7	$278,127.55	$319,000.00	14.7	4	5	25	19.9
8	$360,747.08	$423,000.00	17.5	5	8.5	70	43.8
9	$300,000.00	$555,000.00	85	4	6	50	67.5
10	$198,500.00	$220,393.00	11	4	4.3	8	9.5
11	$338,129.00	$383,194.00	13.5	4	4.5	12.5	13
12	$113,600.00	$125,000.00	10.6	4	4.5	12.5	11.5
13	$100,823.00	$113,000.00	12	4	4.5	12.5	12.3
14	$199,500.00	$214,000.00	8	3.5	4	14	11
15	$41,802,000.00	$44,951,930.00	7.7	18	18	0	39
16	$85,000.00	$110,000.00	29.4	2	2	0	14.7
17	$104,500.00	$115,000.00	10	2	2	0	5
18	$11,500,000.00	$12,200,000.00	6.1	13	15	15.4	10.8
19	$81,000.00	$250,000.00	208	2	5	150	179.3
20	$179,000.00	$230,000.00	28.5	4	4.5	12.5	20.5
21	$110,000.00	$140,000.00	27.3	4	4.5	12.5	19.9
22	$202,000.00	$211,000.00	4.4	4	8	100	52.2
23	$189,800.00	$221,870.00	16.9	3	3	0	8.5
24	$590,000.00	$690,000.00	17	4	5	25	21
25	$25,619,000.00	$26,483,218.50	3.4	28	34	21.5	12.5

APPENDIX 4.1

RECONSTRUCTION PROJECTS

- Cost Performance Factor (CPF)

CPF is calculated based on Formula [1]

CPF = 19.9 SD = 18.37

- Schedule Performance Factor (SPF)

SPF is calculated based on Formula [2]

SPF = 22.28 SD = 26.15

- Project Performance Factor (PPF)

PPF is calculated based on Formula [3]

PPF = 22.91 SD = 17.00

Project # 19 was not included in these calculations, since its data was out of pattern.

APPENDIX 4.2
Performance Factors, New Construction

PROJECT ID	Cost Performance			Schedule Performance			PROJECT PERFORMANCE FACTOR
	Original Cost	Final Cost	CPF	Original Duration	Final Duration	SPF	
26	$4,927,288.10	$4,985,023.90	1	15	11	0	0.5
27	$650,000.00	$692,000.00	6.5	6	7	16.7	11.6
28	$474,000.00	$498,000.00	5.1	5	6	20	12.6
29	$168,000.00	$187,000.00	11.3	3	3.5	16.7	14
30	$1,395,000.00	$1,590,877.00	14	6	6.33	5.5	9.8
31	$2,710,000.00	$2,862,000.00	5.6	7	11	57.1	41.1
32	$8,350,000.00	$8,550,000.00	2.4	18	20	11.1	6.8
33	$1,000,000.00	$1,025,000.00	2.5	7	8	14	8.1
34	$730,000.00	$745,000.00	2.1	6	6.5	8	5.1
35	$2,500,000.00	$2,400,000.00	0	8.5	9	5.9	3
36	$7,768,200.00	$8,025,000.00	3.3	15	18	20	11.7
37	$253,000.00	$265,000.00	4.7	4	4	0	2.3
38	$1,329,906.00	$1,460,000.00	9.7	6	6	0	4.8
39	$450,000.00	$450,000.00	0	5.5	6	9	4.5
40	$2,875,000.00	$2,880,000.00	0	11.5	12	4.3	2.1

APPENDIX 4.2

NEW CONSTRUCTION PROJECTS

- Cost Performance Factor (CPF)

CPF is calculated based on Formula [1]

CPF = 4.55 SD = 4.3

- Schedule Performance Factor (SPF)

SPF is calculated based on Formula [2]

SPF = 12.55 SD = 14.15

- Project Performance Factor (PPF)

PPF is calculated based on Formula [3]

PPF = 9.5 SD = 9.79

APPENDIX 4.3

CONTROL FUNCTION	ORGANIZATION IDENTIFICATION													Total	Mean
	1	2	3	4	5	6	7	8	9	10	11	12	13	Value	Value
Cost	35	40	50	50	45	35	X	33	20	33	33	X	33	407	37
Schedule	40	25	20	30	10	40	X	34	20	33	33	X	33	318	28.9
Quality	25	35	30	20	45	25	X	33	60	33	33	X	34	375	34.1

APPENDIX 5.1

CONTRIBUTING FACTORS TO COST OVERRUN

RECONSTRUCTION PROJECTS

CONTRIBUTING FACTORS	PROJECTS IDENTIFICATIONS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Unforseen existing site conditions	40	50	90	50	65	60	55	50	50	45	53	45	40	45
Scope of work changed by owner	10	0	0	10	10	20	20	30	10	15	13	17	10	10
Design change	20	25	0	20	5	0	5	0	10	20	15	11	20	21
Schedule problems	5	0	0	0	0	0	0	0	0	0	5	0	4	7
Procurement problem	5	0	10	0	10	0	0	0	10	12	0	0	0	0
Design coordination problem	20	25	0	20	10	20	20	20	10	8	5	7	16	10
Regulatoey requirements	0	0	0	0	0	0	0	0	10	0	9	20	10	7

CONTRIBUTING FACTORS	PROJECTS IDENTIFICATIONS											Total Value	Mean Value
	15	16	17	18	19	20	21	22	23	24	25		
Unforseen existing site conditions	45	30	100	65	80	10	10	100	35	60	38	1320	52.8
Scope of work changed by owner	20	70	0	5	10	30	30	0	20	20	20	400	16
Design change	10	0	0	0	10	30	30	0	45	20	9	326	13
Schedule problems	0	0	0	0	0	5	5	0	0	0	1	29	1.2
Procurement problem	0	0	0	5	0	5	5	0	0	0		66	2.6
Design coordination problem	25	0	0	20	0	10	10	0	0	0	23	269	10.8
Regulatoey requirements	0	0	0	5	0	10	10	0	0	0	9	90	3.6

APPENDIX 5.2

CONTRIBUTING FACTORS TO COST OVERRUN

NEW CONSTRUCTION PROJECTS

CONTRIBUTING FACTORS	PROJECTS IDENTIFICATIONS															Total VALUE	Mean Value
	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40		
Unforseen existing site conditions	20	18		40	47	40		25	25		20	15	17	30	20	317	21
Scope of work changed by owner	58	82	100	60	7	12	50	60	50	50	53	48	55	45	50	780	52
Design change	22				46	48	20	15	25	50	27	20	26	25	30	354	23.6
Schedule problems																	
Procurement problem																	
Design coordination problem							30					17	2			49	3.4
Regulatory requirements																	

APPENDIX 5.3

**CONTRIBUTING FACTORS TO SCHEDULE OVERRUN
RECONSTRUCTION PROJECTS**

CONTRIBUTING FACTORS	PROJECTS IDENTIFICATIONS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Unforseen existing site conditions		50	40	50	60	50	45	30	60	65	65	70	55	70
Scope of work changed by owner						25	20	30	20	15	16	20	15	30
Design change			20	25	20				20	15	15	10	20	
Procurement problem	50	50			20	25				5				
Design coordination problem			40	25			35							
Regulatoey requirements											4		10	
Poor Performance by Contractor	50							40						

CONTRIBUTING FACTORS	PROJECTS IDENTIFICATIONS											Total	Mean
	15	16	17	18	19	20	21	22	23	24	25	Value	Value
Unforseen existing site conditions		50	40	50	60	15	15	100	35	60	60	1195	47.8
Scope of work changed by owner						35	35		20	40	10	331	13.3
Design change			20	25	20	35	35		45		10	335	13.4
Procurement problem	50	50			20	10	10					290	11.6
Design coordination problem			40	25		5	5				15	190	7.6
Regulatoey requirements											5	19	0.7
Poor Performance by Contractor	50											140	5.6

APPENDIX 5.4

CONTRIBUTING FACTORS TO SCHEDULE OVERRUN

NEW CONSTRUCTION PROJECTS

CONTRIBUTING FACTORS	PROJECTS IDENTIFICATIONS															Total Value	Mean Value
	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40		
Unforseen existing site conditions	15	18		40	25	30		20	10		20	15	15	10	15	233	15.5
Scope of work changed by owner	45	82	100	60			50	50	45	50	55	50	60	30	30	707	47.1
Design change	20				25	20	10	25		50	20	20	10	25	25	250	16.7
Weather conditions	10				30	15			20				15			90	6
Procurement problem						15	20							10	20	65	4.4
Design coordination problem							20		5		5			10	10	50	3.3
Regulatory requirements	10				20	20		5	20			15		15		105	7

APPENDIX 6.1

CONTROL TECHNIQUES	ORGANIZATION IDENTIFICATION											Total No. of
	1	2	3	4	5	6	7	8	9	10	11	Occurrences
Budget Baseline	5	1	1	2	3	3	2		1	3	1	22
Cost Breakdown Structures	7	1	2		1	3			1	3	1	19
Unit Costing		1	2		4	3				3	1	14
Earned Value			2	2							1	5
Cost Variance	6	1	2	2	4	2				3	1	21
Cash Flow Analysis	3	1	1	2	1		1	1	1	3	1	15
Schedule of Values	8		2		4	3	2	1	1	1	1	23

APPENDIX 6.2

RECONSTRUCTION PROJECTS			NEW CONSTRUCTION PROJECTS		
PROJECT ID	CPF	GROUP	PROJECT ID	CPF	GROUP
1	7.1	C1	26	1	C1
2	8.4	C1	27	6.5	C1,C2
3	44.2	C2	28	5.1	C1
4	51.4	C2	29	11.3	C1,C2
5	19.3	C1,C2	30	14	C1,C2
6	23.9	C2	31	5.6	C1
7	14.7	C1,C2	32	2.4	C1
8	17.5	C1,C2	35	0	C1
15	7.7	C1	36	3.3	C1
16	29.4	C2			
17	10	C1			
18	6.1	C1			
19	208.6				
20	28.5	C1,C2			
21	27.3	C1,C2			
22	4.4	C1			
23	16.9	C1,C2			
24	17	C1,C2			
25	3.4	C1			

Projects 9 to 14 and 37 to 40 were not incorporated into this analysis because data pertaining to the utilized control techniques were not provided.

APPENDIX 6.3

CONTROL TECHNIQUES	ORGANIZATION IDENTIFICATION											Total No. of Occurrences
	1	2	3	4	5	6	7	8	9	10	11	
Work Breakdown Structure	4	1			4		1			3	1	14
Bar Chart	7	1	2	2	4	3	2	1	1	3	1	27
C.P.M.		1	1	2	1	1	1	1	1		1	10
Percent Complete	8		2	2	2	3	2	1	1	3	1	25
Incremental Milestone	7	1	2		2	3	1	1	1		1	19
Time Variance	4		1	2			1			3		11

APPENDIX 6.4

RECONSTRUCTION PROJECT			NEW CONSTRUCTION PROJECT		
PROJECT ID	SPF	GROUP	PROJECT ID	SPF	GROUP
1	80	S2	26	0	S1
2	10	S1	27	16.7	S1,S2
3	10	S1	28	20	S1,S2
4	10	S1	29	16.7	S1
5	16.7	S1	30	5.5	S2
6	16.7	S1,S2	31	57.1	S1,S2
7	25	S1,S2	32	11.1	S1,S2
8	70	S2	35	5.9	S1
15	0	S1	36	20	S2
16	0	S1			
17	0	S1			
18	15.4	S1,S2			
19	150	S2			
20	12.5	S1			
21	12.5	S1			
22	100	S2			
23	0	S1			
24	25	S1,S2			
25	21.5	S1,S2			

Projects 9 to 14 and 37 to 40 were not incorporated into this analysis because data pertaining to the utilized control techniques were not provided.

APPENDIX 7.1

Quality Performance, Reconstruction Projects

PROJECT ID.	COST OF REWORK	NO. OF REWORK REQUESTS	NO. OF USERS COMPLAINTS
1	3%	40	20
2	1%	5	2
3	2%	5	4
4	2%	5	5
8	3%	4	30
16	1%	1	2
17	1%	?	1
18	1%	10	?
19	0%	0	10
20	2%	2	2
21	2%	2	2
MEAN	1.6%	7.4	7.8

APPENDIX 7.2

Quality Performance, New Construction Projects

PROJECT ID.	COST OF REWORK	NO. OF REWORK REQUESTS	NO. OF USERS COMPLAINTS
27	0.4%	1	1
28	0.36%	3	2
29	0.2%	1	0
30	0.4%	1	0
31	0.4%	?	2
35	0%	0	0
36	0.1%	2	2
MEAN	0.27%	1.3	1

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