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2) CONTROL OF CONSTRUCTION COSTS DURING CONSTRUCTION,

by David H. Foo

Thesis submitted to the Falculty of the Graduate School of the New Jersey Institute of Technology in the partial fulfillment of the requirements for the degree of Master of Science in Management Engineering 1981

APPROVAL SHEET

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ABSTRACT

Title of Thesis: Control of Construction Costs During Construction

David H. Foo, Master of Science in Management Engineering, 1981 Thesis directed by: Dr. John M. Ciborski, Special Lecturer

The construction of a major project requires a vast amount of time, money, material and human resources. Proper coordination of these elements into an array of activities is crutial to the success of the project if it is to be built on time and within budget. As technology advances, the complexity of the project increases, however, the resources to build them remain finite, and therefore, the project manager must seek methods to improve control on the construction project.

This thesis provides an overall view of the relatively new and rapidly expanding field of cost engineering. Cost engineering may be defined as that field of engineering practice where engineering judgement and experience are utilized in the application of science principles and techniques to the areas of cost estimation and cost control. Cost estimation and cost control will be the main subject of this thesis.

Although this area has tremendous impact on the economics of private industries and the government, cost estimating and cost control has usually underestimated. Virtually all decisions to construct a facility is based on economics, inturn, the economic study is based on the accuracy of an estimate. Once management has committed itself to the project, cost control protects its decision and holds expenditures within budget by constant monitoring and appraisal of cost performance of those responsible for executing the project.

The text will provide the reader with the basic understanding of the nature of construction costs, the types and importance of estimates, budgeting procedures and implementation of a cost control system.

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CHAPTER 1.

INTRODUCTION

A. The Problem of the Construction Industry¹

The most profound recent developments in construction are the increasing size of its many projects and organization, the increasing technological complexity of such projects, more complex interdependicies and variations in the relationships among its organizations and institutions, and proliferating regulations and demands from the government. At the project level, management has just begun to integrate design, procurement, and construction into one total process. There are now and will continue to be shortages of resources, including materials, equipment, skilled workers, and technical and supervisory staff. There will be more and more government regulation of the safety of design and field construction methods, environmental consequences of projects, and personnel policies at all levels. Management must also cope with new econmonic and cultural realities resulting from inflation, energy shortages, changing world development patterns, and new social standards. These trends have been accelerating and will probably continue into the future. Figure 1-1 summarizes some of the elements that are involved.

Clearly, economic difficulties and increasing shortages of materials and other resources play a major role in the problems now facing today's projects. In spite of continuing economic problems, there is an on going need for the



FIGURE 1 - 1

construction industry to expand and improve its capabilities and its scope of perations to meet changing and, in the long run, growing demands for its services. Now more than ever, planning and control of the resources required to successfully accomplish today's increasingly complex projects remain among the most difficult and perplexing management responsibilities.

The purpose of this thesis is to review the various problems of the construction industry and the responsibilities of project management and to show through the use of cost control procedures, complex construction projects can be constructed in a proper and orderly fashion, within budget and on schedule.

1. Lefkoe, The Crisis in Construction, Washington D. C.: Bureau of National Affairs, 1970, pages 24-32

CHAPTER II

The Nature of Construction

A. Characteristics of the Construction Industry

The construction industry has many characteristics common to both the manufacturing and service industries. Certainly, as in other manufacturing, there ar physical produsts, and are often of considerable size, cost and complexity. But in other ways, construction is more like a service industry because it does not accumulare significant amounts of capital when compared with industries such as steel, transportation, petroleum and mining. Also as in other service industries, success or failure in construction is by far more dependent on the quality of its people rather than on its technologies protected by patents or by the sheer availibility of capital factors.

Construction is highly fragmented and sometimes divisive, yet few industries can mobilize its resources more quickly. Each of its elements - designers, contractors, regulators, consumers, suppliers, craftsment - can be highly skilled in its own area, yet there is little general perspective on how all the pieces fit together.

The construction industry is very custom-oriented, yet this orientation also means that the industry is slow to respond to the benefits of mass production. It has been observed that the construction industry is almost completely incentive oriented. If there is little programmatic activity, it is likely that there is little in-

centive for investing in it. This reluctance to invest probably results in part because advances in construction tend to develop from innovation or "better ideas." Most of these cannot be protected by either secrecy or patents, and therefore, disseminate rapidly through the industry. Thus, there is little incentive for one firm to invest heavily in new developments that can be expected to benefit its competitors.

Construction has amplified reaction to basic business and economic cycles. The consequent instability of demand dominates everything. Often, there is too much work in some regions while others at the same time are suffering localized recessions. Major problems recur in funding both the large and small projects, and these difficulties can be aggravated by government fiscal and social policies.

B. Types of Construction Projects¹

Construction intersects all fields of human endeavor, and this diversity is reflected in its projects. Designers of hospitals interacts closely with medical professionals to best serve the needs of patients. The design and construction of refineries, factories and power plants require that the builders be more knowledgeable of the related industrial technologies than the manufacturers and utilities that operate them. It is difficult, if not impossible to neatly catergorize so great a spectrum of projects. For the scope of this paper, the writer will limit the scope of projects to the industrial sector.

B.l. Industrial Construction

Industrial construction represents only 5 to 10 percent of the market, but it has some of the largest projects and is dominated by some of the largest engineering and construction firms. There projects include petrochemical plants, fossil-fuel and nuclear power plants; mine development and other facilities essential to our utilities and basic industries.

Both design and construction require the highest levels of engineering expertise (from the civil, chemical, electrical, mechanical and other disciplines) and typically all phases of the project are handled by the same firm on a negociated design - construct or "turnkey" contractual arrangement, with considerable overlap between design, procurement, and construction. The design constructors must be intimately familiar with the technology and operations of the facility from the owner's point of view and often they hold some key patents for advanced process technologies therein. In the Western free enterprise countries, most of this work is privately financed.

The major factors in industrial construction generally consist of large amounts of highly complex mechanical, electrical, process piping and instrumentation work. This work tends to be very labor intensive, thou some of the largest hoisting and material handling equipment is also required.

B.2. Residential Construction

Residential construction includes single family homes,

multiunit townhouses, garden apartments, high-rise apartments and condominiums. The later, in particular, are technologically less closely related to residences than to certain types of nonresidential building construction, described below, and are sometimes incorporated as part of multipurpose commercial developments. They are classified from the users's point of view.

Although largely financed by the provate sector, the supply and demand for residential construction are heavily impacted by government regulation, fiscal policy and the state of the economy. There are a few very large firms, but as a rule the low campital and technology requirements in this sector of the industry mean than it is characterized by a large number of small firms. Demand instability, among other things, causes a high rate of businrss failures. Designs are generally done by architects, home designers, or builders themselves, and construction is ususally handled by either independent contractors or developer-builders. Whether in single units or in large developments, traditional construction has been field labor intensive, with on-site hand fabrication and installation of literially thousands of pieces per dwelling unit. In recent years, however, there has been a growing trend towards industrialization and factory mass production of at least some major components, and even of complete modular homes.

B.3. Building Construction

Building construction produces structures ranging from

small retail stores to urban redevelopment complexes, from grade schools to complete new universities, hospitals, churches, commercial office towers, light manufacturing plants and warehouses and so forth. Although labor and materials are similar and interchangable with those of residential construction, the scope and technology of these structures are generally much larger and more complexes.

Most of these structure are financed and built by the private sector of the economy. Design is typically coordinated by architects working together with engineering specialists for the structural, mechanical and electrical items. Construction is usually coordinated by general contractors, we in turn, subcontract substantial portions of the work to specialty firms.

B.4. Heavy Construction

Heavy construction includes many of the structures industry knows best: dams, tunnels, bridges, airports, highways pipelines and so forth. Both the design and construction phases of the heavy construction is primary the domain of civil engineers, though almost all disciplines of engineering play important roles. The construction phase is much more equipment intensive characterized by fleets of large earthmovers, cranes, and trucks, working with massive quantities of basic materials such as earth rock, steel timber and pipe. Another major distinction is that many construction projects are publically financed. Typically, design is either by or under contract with a

public agency with competitive open bidding. Construction contractors here usually require greater expertise in engineering, geology, than did those in the residential and building construction.

C. Uniqueness of Each Job

Because of the advance of technology and the wide diversity of government regulations, industrial construction projects are complex undertakings. Through the years, the magnitude of the project in capital cost and resources has grown almost expontially. Even a structure of modest proportions involves many skills, materials and literially hundreds of different operations. The assembly process must follow a natural order of events which, in total combination, constitutes a complicated pattern of individual time requirements and restrictive sequential relationships among the many segments of the structure. The advance of technology has created more and more fields of narrower and narrower technical specialties.

To some degree, every construction project is unique and no two jobs are quite ever alike. In its specifies, each structure is individualized to suit its environment, performance requirements or characteristics and designed to meet specific specifications or owners preferences. The construction process is subject to the influence of highly variable and sometimes unpredictable factors. The construction team, which includes architects, engineers, trademen, subcontractors, and material vendors, changes

from one job to the next. All of the complexities inherent to different construction sites, such as subsoil conditions, surface topography, weather, transportation, material supply, utilities and services, local subcontractors, and labor conditions are an inate part of construction.

Seldom is there a job operation that can be performed in only one manner. Almost invariably, there is more than one possible way in which to accomplish a given item of work. Basically, the choice is made after evaluating the time and cost characteristics of the feasible alternatives.

As a consequence of the circumstances just discussed, industrial construction projects are typefied by their production. The use of factory produced modular units may diminish this individuality somewhat, but it is unlikely that field construction will ever be able to adopt itself completely to be the standardized methods and prosuct uniformily of assembly line production.

D. Environmental Factors^{2,3,4,5}

For the past several years, there has been special emphesis on environmental cleanup thoughout our society. New laws and attitudes did much to reduce total pollutant loadings to the environment, and the ways of doing business have changed as a result.

The environmental law framework within which the siting and construction of facilities now occur consists of a complex collection of federal, state and local laws and

regulatory programs and the judicial review of agency decision making. The laws have programs have been designed separately, overtime, to achieve a variety of social objectives, which range from the broad protection of public health, safety, and welfare to the specific protection of discrete and critical environmental features such as wetlands to current efforts to manage growth. Other laws and programs in this framework have been designed to improve government decision making, to control various types of pollution, and to more rationally allocate land and other resources for diverse social purposes.

Some measure of environmental control has been also brought about by the use of state laws and derivative local ordinances to influence the design and siting stages of project management. These powers have been implemented by zoning, noise, building, health and other ordinances. As a result, the uses of municipal land and the design, setback, and other features of structures have been regulated with significant implications for local and regional environments. Implementation of this comprehensive approach to environmental control now significantly affects the siting of major industrial and energy facilities, the design of such faciliteis, and if their operations will produce any objectionable effluent. The construction process itself and the subsequent operation of such facilities.

For example, the Federal Noise Control Act of 1972 which is a national effort to control noise pollution at the source of emmission, empowered to the EPA to list pro-

ducts for subsequent regulation by emmission standards. Among the types of products to be regulated are "construction equipment" along with transportation equipment, motors and electrical equipment. Although the EPA lacks authority under the Act to establish ambient standards for noise levels in the general environment, it has undertaken research to determine levels of noise intensity and frequencies necessary to protect health and welfare, which will be of use to those states and municipalities seeking to improve their performance in establishing acceptable ambient levels of noise, in accordance with their "police powers."

The implications of this bureaucratic approach to noise pollution for land use and the development of constructed facilities will depend to a considerable extent on the site-related requirements for ambient noise levels that are ineffect and enforced by state or local authorities. Therefore, for facility construction and operation, the matrix represented on Figure 2-1 now represents the noise control framework to be considered by project developers and management in Siting, scheduling, and designing their new developments. The figure also includes reference to other governmental authorities with noise control programs of relevance.

The first wave of pollution control programs were enacted at the federal level and are now beinng rapidly overtaking in significance by a second wave of new programs at the state level designed to bring about more coherent

	Stage of Development of Project		
Authority to Control Noise	Construction	Cperation	
EPA: National Standards for Equipment Emissions per Noise Control Act of 1972	Construction Equip- ment, Trucks, Motors, etc.	Electrical Equip- ment, Motors, etc.	
OSHA: Cn-site ambient Levels for Worker Exposure per 29 USCA 651 and other laws	Construction Workers	Facility Employ- ees	
State and Local Govt's: Off-site Ambient le- vels for Public Expo- sure per Codes and Ordinances	Various Parameters: time, site, fre- quency and/or intensity of noise, etc.		

Figure 2 - 1. Major Noise Control Requirements Applicable to the Siting, Construction, and Operation of a New Industrial Facility.

and rational approaches to land and coastal resource management.

State management of land and coastal regions is presently the most critical aspect of environmental law for the siting of industrial and other major constructed facilities required to meet social needs. Although the siting problem may be diminished as a result of energy conversation measures and economic conditions that reduce the need for certain facilities, the problem will remain a significant one for environmental decision making.

Facility siting is a highly complex process, involving construction firms, interest groups, and numerous authorities at all levels of government. Measured in terms of environmental quality indicators, the process is largely ineffective for ensuring appropriate siting and design decisions. In the process, builders of the private sector, as well as the agencies of the public sector, employ siting methods that are essentially opportunistic, in that the methods of site selection are designed primarily to identify paths of least resistance from interest groups, irrespective of the environmental consequences associated with the sites under consideration.

Each of the numerous federal, state and local authorities involved in the siting process in turn applies its narrowly drawn criteria to its permit and review procedures, in order to accomplish its limited objectives. Local zoning and health boards, state wetland and wildlife commissions, state siting and public work boards, the Army Corps of En-

gineers, the Environmental Protection Agency, and various other authorities with pollution control and other relatively narrow objectives are encountered by developers a and interest groups in multiple review contexts. Each employs its own calculus or method of decision making, designed to ensure that its own mandate and objectives will be satisfied.

E. Litigation and protest^{5,6}

Projects are implemented by activities in the several sequential stages of conception, planning, siting, design, construction, and operation of the completed facility. Each stage requires different levels and types of resources or inputs; for example, manpower, funds, time, facilities, and equipment, materials, and natural resources. The facility that emerges from the construction stage, and indeed the construction process itself, brings about social, environmental and other affects, or outputs, which can be designed direct and indirect, primary and secondary, beneficial and detrimental, measurable and unmeasurable.

Whether one uses a nuclear power plant, airport or a housing development, several basic classes of effects or outputs from both construction and facility operation stages are apparent. These include effects on the following:

 Ecology: sedimentation, erosion, landscape change, wildlife habitat change, groundwater and runoff changes, air and noise pollution, etc.,

2. Economy: Private property values, taxes, insurance rates,

etc., local and regional community jobs, development and commerce, services and tax base, etc.;

- 3. Regional and Community Quality of Life: esthetics, congestion and traffic, population migration, open space and recreation, odors, human health health (physical, psychic), etc.; and
- 4. Social and Political Factors: changes in residents and life styles, changes in social opportunities and sociopolitical characteristics, changes in municipal systems for education, water supply, energy, solid waste disposal, etc..

Now that the inputs and outputs have been briefly discussed, a simple flow chart for project planning can be developed (see Figure 2-2). The implementation of each project will depend on numerous decision makers in both the public and private sectors, and at various jurisdictional levels of the public sector (state, local, regional and federal). These decision makers function as controls on any project essentially in two ways, as depicted in Figure 2-3 by controlling inputs of resources, eg, public agencies and private sector sources of manpower and funds for planning, design and construction; zoning and other land use or natural resource authorities; federal and state legislatures whose enactments may be essential to the availibility of other project inputs of resources; project management itself, and (2) by controlling the effects or outputs, eg, the courts by means of preliminary or permanent injunctions or awards of compensatory damages; federal agencies such as





the DOT, EPA and other state counterparts who engage in standard setting, regulation, and enforcement regarding project externalities; the courts again as judicial reviewers of such agency determinations; project management; insurers; building and health authorities; and others who can brong about project redesign to abate or ameliorate specific externalities. To further develop this framework, some of the major influences on project planners and management must be determined. These influences (depicted in Figure 2-4) generally include the following:

 Land and other resource availability or input information;

2. Project technical and economic feasibility information; Actual and potential effects or output information; and 3. 4. Information from what can for convience be called operational institutional values, comprised of the common law, legislation, economic and social policy, developer and management policies, and other given values that have been recognized and accepted by project management as of the time any specific decision is made regarding further project development. This includes diverse and sometimes conflicting laws and policies, eg, the National Environmental Policy which fosters conservation and rational use of resources and HUD Housing Programs which fosters subsidization and dispersing housing.

Now to complete this general model, the social dynamics brought about by a construction project must be considered



further: specifically, the responses of individual citizens and organized interest groups to perceived resource commitments and project effects (Figure 2-4). These responses can be manifested through institutional procedures for changing the laws and policies (operational-institutional values) such as the community master plan, which influence decision makers, lenghy process requiring extensive aggregration of voters and generally undertaken in order to influence future projects, not the particular project that provoked the response.

Alternatively, responses can be manifested through formal, adversarial procedures to challenge decision making, eg, aggravated citizens can go to court or appeal zoning decisions to appeal boards, disturbed environmentalists can intervene in agency proceedings or seek judicial review of agency decision. Finally, a variety of nonformal adversarial procedures can be employed to feedback responsess to decisionmakers, such as demonstrations, town meeting, or campaigns.

The analytical framework for project management does not provide answers, but can be used for several purposes: to ensure that a fuller perception of planning, design, and decision making responsibilities is developed for specific projects; to depict the interrelationship of resources, effects, institution and citizens; to develop management and project alternatives, and to assess and grapple with the dynamics of impacts of specific projects before construction conflict.

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- 3. Zeltmann, Environmental Standards Need Cost/Benefit Analysis, Mechanical Engineer, February, 1978
- 4. Dolgin an Gilbert, Federal Environmental Law, New York: West Publishing Company, 1974, pages 1212-1230
- 5. Baram, Environmental Laws and the Siting of Facilities, Cambridge, Mass.: Ballinger Publishing Company, pages 33-37
- 6. O'Brien, Construction Delay: Responsibilities, Risks and Litigation, Boston, Mass.: Cahners Book International, 1976, pages 139-158
THE NATURE OF THE CONSTRUCTION COST AND PROBLEMS OF RISING CONSTRUCTION COSTS

3.A. Labor Costs^{1,2}

The construction of a facility is a complex process of managing money, time, material and manpower. Unlike other industries which are usually capital intensive and own a sizable amount of physical assets, the construction industry is highly labor intensive. The construction industry reflects its concern over labor costs through cost control procedures. Depending on the type of construction, anywhere from 35 to 60% of construction costs is labor, where the remaining portion is mostly material costs, followed by engineering and overhead costs.

Estimating the money componet of labor costs is more difficult than any other industry. Reasons for this situation include the scope and variety of the work involved, the craft structure of labor unions, and the regional and local autonomy of labor and employer collective bargaining units. There are literally thousands of different wage rates, fringe benefits, insurance rates, and work rules, and there are exceptions to almost all of them. Superimposed upon them are federal, state, and local laws, taxes and special programs such as wage and price control.

3.B. Labor Productivity³

In contrast with the money component of labor costs, productivity is much more difficult to estimate. Many of the factors influencing labor productivity are highly quan-

titstive in nature, and great deal of experience and judgment is needed to develop the type of quantitative information that is required. However, the productivity component also offers the contractor by far the greatest opportunity to control his labor costs, assuming that he has some basic understanding for the factors that influence this variable in the equation.

3.C. Job size vs productivity

Job size, in the terms of the estimated number of manhours required to complete the project, can have significant impact on labor productivity, as illistrated in Figure 3-1. This figure assumed that the job size upon which the base productivity was analyzed was 300,000 manhours. The figure shows how, as the job size increases above 300,000. the productivity decreases and, conversely, as the size will increase dramatically. This demand will have a twofold impact on local base productivity. First of all, the available local labor will be fully employed, therefore, the project has probably acquired a number of marginally qualified craftsmen and helpers, and lowering the overall productivity. Secondly, since there are so many job opennings available, turnover increases dramatically and disrupts overall activity (learning, curve, training, etc.) which results in lower productivity.

3.D. Direct hire vs subcontract labor productivity There are essentially only two ways a prime contractor



can erect a plant in the field: either by hiring all the craftsmen and supervising them himself (direct-hire), or by giving each identifiable piece of work to a specialist subcontractor.

Most subcontractors have a fairly close knit and highly experienced work force, and consequently, they work more efficiently and have a higher productivity than the direct hire. Also, the subcontractor is an expert in his field, whereas the prime contractor is an overall construction expert and does not tend to have the same degree of expertise in each specific area as the specialist.

Although the end result is higher productivity for the subcontractor, it does not necessarily mean a lower labor cost or lower project cost. The local area must have sufficient competent subcontractors to allow good competitive bids to be received. Also, subcontracting creates some duplication is supervision, temporary facilities and construction equipment and tools. The decision to go subcontracting or direct hire can only be made after factors such as these are considered and analyzed.

3.E. Regional Variations

Apart from environmental and other effects discussed bellow, two factors related more directly to labor cause considerable regional variation in productivity. These include (1) the training, experience, and skill of local labor force in the various crafts, and (2) the work rules which are negotiated between employers and unions. These factors can cause productivity in some parts of the country to be more than double than in others. When working overseas, they can be even mor significant. Other things being equal, labor costs will vary accordingly.

Clearly, for both estimating and control, a contractor working in more than one area must take regional variations into account. This is generally done by establishing base productivity levels for various crafts or activities in one region and applying index multipliers to ratio the base to other areas. If properly documented, a contractor's records will be the bes source for developing such multipliers. Otherwise, he will be obligated to rely upon the experience of others as reflected in published sources. Precautions for this situation are mentioned briefly later on.

The amount of training and experience is certainly varies from worker to worker even within a single craft in a local area. Formal distinctions are drawn between "apprentice" and journeyman, but of course there are wide ranges within these. Although the estimation usually cannot forecast which craftsmen will work on which tasks, this factor that is very much subject to control by project management. Within the prescribed work rules, good superintendents can apply selective hiring, firing, and assignment of craftsmen in order to improve productivity. On a grander scale, contractors can actually set up their own training programs to enhance the skills of their employees. This has happened on many large overseas projects and is now being done in several "open shop" areas in the United States.

3.F. Environmental Effects

The environmental effects productivity on many levels. The weather, terrain, topography, and similar natural phenomena have obvious implications which need not be labored here. The physical locations and working conditions of individual craftsmen can be equally significant. These include height above grade, heat, noise, light, constrictions, stability of work station, dust and several others. Clearly, the productivity of an ironworker laborring outdoors during the Illinios winter would be different from one working in sourthern California sunshine. A carpenter erecting small form panels for an outside wall on the tenth story of a building would most likely produce less than if he were working in an on-site shop assembling the same panels into large ganged forms which would then be hoisted into place by a crane.

Estimators generally take environmental conditions into account in preparing their estimates. Thorough preplanning can minimize the impact of many of these problems. Careful scheduling of outdoor preparations with respect to seasons can help reduce weather effects, as can the appropriate use of enclosures. Through layout of construction facilities can offset the effects of difficult topography, A good comparative analysis of alternative methods of accomplishing specific operations can provide on-site working conditions conductive to higher productivity.

For controlling labor costs, management can also have considerable influence on the environmental effects on labor productivity.

3.G. Learning Curves 5,6

The basic principle of the learning curve is that skill and productivity in performing tasks improve with experience and practice. For example, the tenth of ten identical concrete flooring pours should take less time and be done more skillfully than the first.

Consider the example learning curve shown in Figure For estimating purposes, the curve should be in-3-2A. tegrated through the number of units to be constructed, here defined as n, to obtain the total numbric of workerhours required. Graphically, this may be expressed as the shaded area under the curve. Dividing the total number of worker-hours by the number of units gives the average worker-hours required per unit as shown by w on Figure 3-2B. This is the number that should be used for estimating. Note that if the number of units is greater, as shown by n', the average worker-hours per unit should be less, as shown It is therefore not sufficient simply to take avbv w'. erage figure from one project and apply them directly to similar operations on a project being estimated.

For cost control purposes, management should recognize that worker-hours required for the first few of a number repetitive operations should be expected to be higher than the average given by the estimator. However, as the operations continue, the worker-hours per unit required should drop below the estimated average so that the actual completed average is less than or equal to the estimated average. The concept is illistrated on Figure 3-2C. Another





important important feature of the learning curve that should be recognized for control is that if repetitive operations are interrupted or otherwise interferred with, an "unlearning curve" effect takes place which can cause the estimate to be exceeded. This is shown in Figure 3-2D. Therefore, for controlling labor costs, it is generally good practice to provide continuity of work on repetitive operations.

3.H. Work Schedule^{7,B}

Work schedule here refers to using variations on straight time only, scheduled overtime, or multishift work for accomplishing project objective. Note that scheduled overtime refers to the situation where operations are regularly scheduled to exceed the normal 8-hour, 40-hour week. It does not refer to the occasional use of overtime to finish operations that could not be completed in a normal workday, such as finishing concrete pour that took longer than expected.

The section on the money component of labor dealt with strictly financial aspects of work schedules. This section will focus mainly on the productivity side, but will also show how the two are combined for the total labor-cost impact.

Placing field construction operations of a project on a scheduled overtime basis reduce effectiveness of craft labor due to fatigue, increased absenteeism, attraction of less qualified workers, disruption of daily operations, reduced work pace and increased accident rates. This, combined with the 50 to 100 percent increase in labor costs reflected in

overtime should provide sobering second thoughts to owners and contractors in hoping to save time and money by putting projects on scheduled overtime.

Scheduling projects on a multishift basis can avoid some but not all of the ill effects of scheduled overtime. This assumes, of course, that the shifts themselves do not run on scheduled overtime basis. Neverless, multishift work does occur a financial preminum, and it can introduce productivity problems as well.

When shifts are regularly rotated, the natural body rhythms of the workers are continuously disrupted and the workers are therefore kept well below their peak efficiency. The effect is not unlike that caused by the frequent changes of time zones encountered. Body functions affected include temperature, kidney activity, hormone activity, and corticosteroid production. Some adjustments can effectively take place within 1 or 2 days, but others may take several months.

Although research is not conclusive, but some studies indicate that some people are day people and others are night people, and people actually perform much better when there work fits their physiological schedule. Therefore, it would appear that multishift-work could be more productive if (1) shifts were not regularly rotated, and (2) an effort were made to match employees to the shift on which they would be likely to perform the best.

3.I. Management⁹

Possibly the most difficult of all componets to analyze

is the interrelationship of labor and management. This alone can produce orders of magnitude variations in labor productivity. Factors involved include such things as management philosophy, motivation and morale, safety polocies, employee participation in planning, incentives and rewards, relationship with union locals and many others.

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CHAPTER IV

Measurement of Construction Costs 4.A. Integrity of the Estimate^{1,2,3,8}

No single management function plays a more important role in the financial success of the company than estimating. The secret competitive bidding process that characterizes the industry emphasizes the need for accurate estimates.

There are numerous methods and levels of accuracy for preparing an estimate for a construction project. Each method has its appropriate applications and limitations, but it is important to recognize and emphasize that all estimates are approximations based upon judgment and experience. As a project progresses from conceptual stage through the design stage, several types of estimates are required as a project evolves. Estimates and in turm become the reference standard for cost control when the project is executed. Estimates may be categorized as one of the following types:

Order of magnitude estimate- This is the least accurate of all the types. It is not based on flowsheets or equipment lists but is derived through the applications of scale up ratios and escalation factors to the known cost of a similar facility. It is usually not well enough defined to justify a capital appropriation (except for very small projects), and mainly serves to guide decisions as to whether or not further engineering work should be done.

<u>Study estimate</u> This cost estimate is prepared from minimal flowsheet data with the costs of many sections

arrived through factoring. The expected accuracy is 30% of the actual fixed investment. This estimate's purpose is to provide management with a "ballpark" figure with which to justify (or not) further engineering work.

<u>Budget estimate</u> - This estimate is propared from well defined process flow diagrams, detailed equipment lists, and current, valid site information. Its usual range of accurracy is 20%, precise enough for initial budget approval. It should always should be done for larger projects.

Project control estimate- This represents the most detailed estimate, and is based on bid-issue drawings. Its purpose is to provide an accurate document against which to control expenditures. Usually, upon completion of the control estimate, any significant variances from the authorized estimate should be published and acted upon by management.

4.B. Special Factors in the Estimate^{1,3,9}

Several aspects of construction cost estimate warrant special attention because they become relevent to the manner in which cost control is carried out.

<u>Allowance for extras</u>- Every project entail extra construction costs, the amount depending in the complexity of the project, specific site conditions and numerous other considerations. To offset possible cost overruns, allowances must be made for unforeseeable conditions, mistakes on drawings and ommissions. The amount of the allowance should be based on the nature of the work to be performed and historical data. It may be added to the total estimate as a lump sum or broken down and added appropriately to the separate construction categories.

Use of cost indices- Before applying cost indices, it is important to understand how they are derived, their limitations and the difference in the basic methods. Indices may not consider factors such as productivity, changes in technology, competitiveness of contractors and geographic and demographic base. Both prices and productivity can radically bary around the country (or the world) due to market conditions and other special factors.

Escalation- Funds to compensate for the inflationary trend of the economy and its effect on the cost of material and labor should be included in every estimate. Before an estimate is submitted for approval, it should contain provisions for revisions to labor contracts, escalation clauses in contracts and purchase orders, and other potential price increases.

Design modifications- With the possible exception of the utilities section, most areas of a new facility will need to have changes made during startup it the system is to meet operating criteria. Generally, such changes will consist of minor additions and revisions, and so require only a minimal allowance in the estimate.

<u>Contingency</u>- This fund should be based on the rating of the estimates validity. This is determined from the type of estimate that has been prepared, the reliability of the historical data that has been used, and the accuracy attributed to the equipment price data. If the estimated cost of a major portion of the process equipment has been based on written or oral quotations (rather than on factoring), and the budget estimate on well developed process and instrument diagrams, the contingency applied should be less than 20%, and most realistically about 10%.

There are no steadfast rules on how much to assign to contingency, however, the decision is an important one which will depend on the company practice and the economic climate.

4.C. Standards³

In the previous section, the importance of an accurate estimate was discussed, however, an estimate is only as good as the information which was used to develop the estimate. Therefore, acquisition and maintenance of data plays an integral part of estimating.

The estimating methods for virtually all of the components of an estimate produce quantities in one fashion or another. In order to arrive at these costs, standardization of costs is a common practice used by the industry. Standard costs may be defined as the costs of standard outputs or consumption for plant or men under specified conditions of environment, where unit costing is used to evaluate the cost per unit. For example, if 9000 cubic yards of concrete is to be poured, the cost of material may be on a per foot basis and manhours associated with the erection of the piping) and associated equipment, but will not have detailed information for the costs of constructing access roads for a particular site. A standard cost file can be developed from the company's historical files or form published data. Some examples of cost data sources are as follows:

Feedback from projects

purchase orders

engineering contracts

wage rates

engineering manhours/productivity

labor manhours/productivity

etc.

Literature

Standard building materials

wage rates

Manufacturers published price lists Union agreements (wage rates and benefits) Vendor contracts Affiliate contacts and feedback Published indexes

Surveys

Having established from published or previous historical data, a cost index may be used as a mechanism for converting these costs to present day costs at a given location. These indexes are really factors representing a comparison or cost ratio between the latest cost data available and the equiva\$1.00 per cubic yard and the labor in manhours is .25 manhour at a rate of \$15.00 per hour in the gulf coast region.

Standard costs would be developed for direct material, construction labor, contractor engineering and services and other indirect costs. For direct material, engineered equipment (vessels, pumps, furnaces, etc.) should be distinguished from bulk materials (piping, concrete, wiring, structural steel, etc.). There is also a third category of delivered and erected equipment, such as storage tanks or field fabricated vessels, involving both material and labor as a single lump sum subcontract cost.

Construction labor cost data falls into two categories: direct hired labor and subcontract labor. Direct hired labor is hired and paid directly on a per hour basis to the worker by the main contractor. Consequently, the data required involve wages, payroll burden, and productivity. Subcontractor labor works for a subcontractor of the main contractor and his costs are normally quoted on a fixed unit price or lump sum which often includes material costs. Contractor engineering and services involves not only wages, burdens, and productivity data, but also data on overhead costs which represents the contractors costs of running his business.

The development of a standard cost file will rely heavily on the experience and the peculiarities of the business which the contractor may be involved in. For example, a petrochemical engineering firm will develop a database that will provide detailed information on piping (cost of material



lent standard cost data. The cost engineer or estimator has analyzed the feedback data (such as a purchase order from a recent project) and arrived at an average ratio which is called a location cost indes.

Several important points should be noted at this time about the use of standard cost and indexes:

- by using indexes, the standard or base costs never have to be changed, only the indexes change
- the indexes can be updated as often as necessary, however because of the volitile nature of the material costs in most locations, quarterly review and reinsurance of the indexes is necessary
- the indexes must be tied to a time frame, preferably as close to present day of the time of estimate preparation as possible

The same approach conceptually followed for material can be used for developing indexes for engineering, construction labor and indirect costs. An escalation factor can be used to commence. The standard cost file is an one time effort and remains fixed. With routine updating the file will remain a valuable source of information.

4.D. Estimate coding^{3,4,5,6}

One area that is often overlooked despite its importance is the documentation of the estimate basis and details. Estimate coding and documentation will insure that the estimate will be fully utilized. In the preparation of an estimate, there are multitudes of work categories and classes in the

construction of a project. Therefore, in order to maintain some semblance of the categories involved, the costs must be segregated. As discussed in later sections, the contractor will want to segregate costs to keep track of where and how he is spending money. He will want to compare these costs with the costs in the control estimate. This segregation is referred to as a code of accounts, or when it is used during project execution, the construction code of accounts.

Figure 4-1 is a sample code breakdown for a typical process unit. As you can see, codes are broken down into various cost levels where each level becomes progressively more detailed. The primary code level represents the cost of an entire process unit where there are more than one unit involved in the project or the code can also be used to accumulate costs for large geographic areas such as on-site, offsite and so forth. The primary code is the first one or two numbers in a code and immediately tells the reader to what unit or what area the time belongs.

The secondary or main code in our example is the one that immediately follows the primary code and indicates the major cost category (labor, material, indirect, etc.). The tertiary code and the codes that follow (subcodes and detailed codes) are the heart of the code of accounts. The first two digits can be allocated to a specific material category such as piping. The third digit can then be piping valves or piping flanges. Depending on the amount of detail required and the capacity of the accounting programs,

AREA		MAIN		<u>SUB</u>		DETAIL		
¢۵	Name	lio.	Name	No.	Hame	110.	Name	lio.
	On-sites Off-sites Utilitics	01 02 03	Labor Material Subcontract	1 2 う	Excavation Concrete Str. steel Equip. and mach. Electrical Instruments Pibing Paint and insul. Buildings Indirect	0 1 2 3 4 5 6 7 8 9	Hand excav. Mach. excav. Trenching Backfill Formwork Rebar Four found. Four slab	001 002 003 004 100 101 102 103
	Example:	01 Onsite	- 1 Labor		1 - Concrete	100 Formwork		

or labor for setting on-site formwork

additional numbers or digits can be used to get further level of detail.

4.F. Documentation of estimates 3,5,6

The estimate is a text of information where the information can be used in future estimates, and therefore must be detailed and the clarity is essential. The estimate should be able to convey a clear, precise and comprehensive basis of its origins and present a clear presentation of the details themselves.

Six relatively easy steps should be carried out to accomphish the documentation of an estimate:

- standarized forms
- write down all calculations and assumptions
- date all calculation sheets
- document basis concisely and clearly
- emphasize neatness
- maxamize computer usage

Standarization of sheets provides a consistent looking detail sheets and promotes discipline and consistancy for the estimator and the department. The estimator should be encouraged to write down all calculations and assumptions in the course of preparing the estimate to document its origins. Dating calculating sheets eliminates possible problems of trying to reconstruct the sequence of events. Maximization of use of computer usage promotes better utilization of an estimators time to thought processes rather than be utilized in manual number manipulations. A project is a dynamic, moving operation and so are the costs associated with the project. Therefore, it is important to document what the basis for the estimate was at the cut-off time. Listed are some of the more important estimate basis information that should be included in the estimate documentation:

- scope basis at cout-off date
- assumed project schedule
- source of material purchases
- detailed design basis (local design codes, etc.)
- escalation rates assumed
- contracting approach
- labor source/rates/productivity
- contingency basis

4.G. Quality Control Risks⁷

Quality control risks lie at all points of the spectrum from the moment the designer designs a structure up and through the erection and construction of that structure. For example, a design error not discovered by a checker could be released into the system, bid packages released, subcontractors selected, and the project well underway or even completed before the error was detected. At this stage many manhours and concomitant costs have already been generated.

If quality assurance checkpoints are established at stategic locations throughout these phases, some costs usually can be avoided. Even greater savings can be experienced if approblem is avoided that otherwise would lead to litigation.

Before we go any further, lets consider what the term

quality control means. First it refers to a collection of systems or techniques for discovering, reporting, and preventing product (or process) defects. Second, it refers to a department or staff group within the company (and usually related to the inspection department) that plans and analyzes quality control procedure, while the inspection department performs the actual inspection. There is no denying that quality control is closely related to inspection, however, one goal is to lower the number of inspections by improving the reliability of the product (or process) since inspections are costly also.

The problems of how to reduce and control errors are uniquely difficult in the architectrual/engineering and construction industry. Projects in the construction industry are much more complex and unwieldy than they were only a few years ago. More suppliers are in the picture, new and varied materials are on the market, making both the design and construction activities more difficult. Strikes are continuing and making jobs even more difficult. With burgeoning technology on one hand and the management-worker confrontations on the other, there is far greater change that errors and omissions will occur.

Among the first tasks to complete when instituting the quality assurance audit procedure is to analyze the function performed by each individual or group in a firm (ie job description of fucntional outline for each position). While each job may involve varing degrees of complexity and require highly subjective judgments or esoteric background, they must

all be described clearly before an analysis of inherent error potential of the jobs can be made.

The question to ask in each case is: which characteristic of the piece, or activity, it is substandard, will or will not cause malfunction? More over, which task performed by the professional, if omitted or performed incorrectly, could expose the firm to liability? This procedure helps in determing which tasks deserve special attention and monitoring. There is much more to the question, however. Guidelines are required to show monitoring is justified. If records are kept and analyzed, this can be accomplished in two ways.

<u>Frequency</u> by error category is one consideration; if a task historically involves frequent or even periodid errors or ommissions, it deserves monitoring.

<u>Severity</u> of the consequences is an even more important consideration in determining nor only which tasks should be monitored, but by how much and how often they need be observed.

With the description of each job completed, and the quality critical tasks of each job identified and evaluated, still other questions should be answered. After it has been decided which tasks and which products must be checked, then who should perform the tasks, how throughly should the items be checked, and how should the check be indicated as having been accomplished? As errors are found, how should they be treated? When and by whom will the corrective action be performed?

As the questions are answered and check procedures developed, they are formalized in a procedure manual familar to both the worker and the supervisor involved. Further, these procedures form the basis for periodic audit of the functions by quality assurance auditor, who assesses conformity to these procedures.

An important benefit of quality assurance given little recognition up to now lies in the area of cost advoidance. As illistrated in Figure 4-2, the earlier error or potentially significant quality problem can be detected and corrected, the less compounding costs will be generated. Benefits of quality assurance program can far exceed the costs if properly conceived and administered.



FIGURE 4 -2

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CHAPTER V Control of Construction Costs

5.A. Elements Modeled^{1,2,3}

The flowchart in Figure 5-1 models the operations, flow of information, and decision-making process characteristics of a feedback control system appropriate for a medium to large sized engineering construction project. General objectives for an information-feedback system may be stated as follows: 1. To provide an organized and efficient means of measuring, collecting, verifying and quantifying data reflecting the process and status of operations on the project with respect to schedule, cost, resources, procurement and quality: 2. To provide standards against which to measure or compare progress and status. Examples of standards include CPM schedule, control budgets, procurement schedules, quality control specifications, and construction working drawings.

3. To provide an organized, accurate, and efficient means of converting the data from the operations into information. The information system should be realistic and should recognize (a) the means of processing the information (eg., manual vs computer), (b) the skills available, and (c) the value of the information compared with the cost of obtaining it. 4. To report the correct and necessary information in a form which can best be interpreted by management, and at a level of detail most appropriate for the individual managers or supervisors who will be using it.

5. To identify and isolate the most important and critical

information for a given situation, and to deliver the infor- ' mation to the appropriate parties: and 6. To deliver the information in a timely fashion so that necessary corrective action may be taken on those operations.

Although this flowchart applies to the conventional design and construction processes where the two phases are largely separated, a control system of this type can be used where there is strong interplay between all aspects of the system: concept, design, procurement and construction. This approach is especially prevailent in the large heavy industrial projects.

5.A.l. Components

In the flowchart, the project is initiated according to a predefined plan (box 1) and operations get underway (box 2). The plans also become reference standards for control purchases (box 5). As the operations continue, external factors (box 3) such as recently imposed standards or newly available materials in design, or bad weather, strikes, procurment delays, foundation excavation problem, or even unexpectedly good conditions on site, may cause the course of operations to differ from the plan, or may provide opportunities for improving on the plan. The operations underway generate indicators or progress (quantities in place, elapsed time, money expended, or resources consumed) which may be measured (box 4) and fed as data into a system (box 6) to produce information for decision makers. This information processing system refers to plan-decision makers. This information processing system refers to planned standards (box 5), such as schedules and budgets, to show deviations, variences, and trends. This information is analyzed and made available through reports (box 7), which may be stored for future reference (box 8), or given to engineering managers and supervisors for their further analysis and decision making (box 9), or both. They combine and compare this information with their own knowledge, experience, policies, and other quantitative and qualitative information and judgment (box 10) in order to produce new or modified plans for continuing and controlling the project operations (box 11).

5. A.2. Feedback

This is a feedback control system, and it operates continuously throughout the life of a project. Associated with it is a feedback time. Ideally, the time through parts 4, 6, and 7 should be short as possible so that engineering managers and supervisors can receive accurate and up to date information in time to make decisions and formulate plans of action so as to have maximum impact in controlling those operations which are generating the information in the first place.

On a small project, it is impossible to short circuit the path from box 2 to box 9 and provide direct feedback. A master builder who works with his own tools in constructing custom suburban homes is a common example of this. If something is wrong, he knows about it immediately.

On a large project, such as the design and construction

of a rapid transit system or a nuclear power plant, direct feedback to the decision makers of all information on all activities is no longer possible. One needs a staff and an organized system to measure, process, analyze, and report the most important information to the decision makers. In engineering design and construction, this staff consists largely of scheduling and cost engineers. Neverless, the goal remains to provide feedback to decision makers in minimum time for maximum impact in controlling operations. Needless to say, however, it is here that the industry experiences some of the greatest difficulties.

A major need in project planning and control is significantly to improve and expedite the operations represented by boxes 4, 5, 6, and 7 on the flowchart in order to help resolve these difficulties and improve the quality of information available to decision makers. On larger projects, some improvements are being made through computer applications. Indeed, like a neighborhood power outage on a cold winter night, it almost takes a computer failure to dramatize the extent to which such projects are coming to take their computers for granted.

5. B. Status and Progress 1,3,6

Numerous measures can be taken to determine the progress or status of operations on a project. Quantities of work units in place can be physically surveyed and compared with those shown on drawings. Elapsed time can be compared with the estimated activity or project durations. Money committed

or expended can be compared with the estimated.budget. Resources usage can be plotted versus expected requirements for labor, materials and equipment. Finally, an experienced professional project manager can simply apply his judgment to estimated the percentage completed on individual activities or on the project as a whole.

Each of these measures has its advantages and disadvantages. For example, field measurements may be more accurate than judgment estimates of percentage complete, but it is expensive to use a surveying crew to obtain these data. Judgment inturn, can reflect qualitative factors, not evident in the quantities themselves.

5.C. Nonlinear relationships^{1,3}

In applying such measures, it is important to recognize nonlinear relationships among them. For example, there may be a nonlinear relationship between quantities in place and elapsed time. To illistrate, if the bulk of the work is scheduled to be completed earlier in the activities scheduled duration, then when the time is 50 percent elapsed, the work might actually and correctly be 60 percent complete. Similar nonlinear relationships apply among the other measures. The time and money is expended on materials, for example, might be only loosely related to the actual time those materials are used.

When comparing the expenditure of labor resources overtime, one can also often recognize nonlinear "learning curve" effects.. Learning curves relate time, resources consumed

and quantities produced. The basic principle was discussed in earlier sections.

5.D. Source of Data 1,3,4

Data reflecting status and progress some from numerous sources. In the formal information system, sources include labor, and equipment, time cards, purchase orders, invoices, field quantity reports, quality control reports, and so forth. In all cases, accuracy, timeliness, and completeness are important. Human considerations are particularly essential at this point if good management information is to be produced.

In addition to the formal sources, there are numerous other inputs to management, some of which short curcuit most regular steps. If there is an serious accident on the job, the superintendent of project manager is told about it almost immediately.

5.E. Information Processing^{1,3}

In concept, information processing systems take progress and status data, compare them against reference standards such as budgets or schedule, and convert the results to information needed by the managers and supervisors on the project. As stated in the objectives, the level of detail, the variety and the frequency of the reports to be produced should be appropriate to the people who will use them, should be feasible for the means of processing the information, should recognize the skills available, and should realistically assess the value of the information compared with the cost of obtaining it. Finally, the system should be fast, efficient and accurate.

Several related subsystems are needed fully to plan and control projects. Examples include activity and resource scheduling and control, cost engineering, materials procurment and tracking, and quality control. Each of these systems are important, but if fully intergrated into one system, the sheer volume of data would dominate and obscure the vital information that is needed from any one of them. An interrelated modular system is thus essential. That is, each subsystem should be largely self sufficient, but it should be logically coordinated and compatible with others.

In summary, an information processing system for project planning and control should recognize that there are many subsystems involved in the process, and it should further recognize the interrelationships among those subsystems.

5.F. Reporting^{1,3,5}

Reporting can take many forms, ranging from conversations and telephone calls through tabulate presentations of cost information and graphical presentations on bar charts, cumulative progress curves and CPM diagrams, to up to the minute reports from computers, and so forth. Certain basic principles should guide each of these, however, if the reporting is to be effective for control purposes.

Regardless of the form, in order to be effective for control purposes, a complete report should have five main compon-
ents:

- Estimates: either total to date, or this period, that provide a reference standard against which to compare actual or forecast results;
- 2. Actuals: what has already happened, either this period or to date figures;
- 3. Forecasts: based on the knowledge at hand, what is expected to happen to the project and its elements in the future;
- 4. Variences: how far actural and forecast results differ from those which were planned or estimated; and,
- 5. Reasons: anticipated or unexpected circumstances that account for the actual and forecast behavior of the project and its operations, and especially that explain significant variences.

5.G. Selectivity and subreporting^{1,3,4}

One of the objectives stated previously was to report the correct and necessary information in a form which can best be interpreted by management and at a level of detail most appropriate for the individual managers who will be using the information. Selectivity and subreporting are important here. Since time is among their scarest resources, construction managers and supervisors simply cannot afford to wade through piles of extraneous data to obtain the information they need. The project manager should have summary reports as well as logically coordinated detail reports to back them up.

5.H. Variences^{1,3}

Reports for control purposes should calculate variences to show which operations are relatively more in need of attention than others. Varience is used here to mean a deviation from a planned or budget item. The variences, in turn, should be expressed in both relative (percentage) and absolute (quantities, dollars, etc.) terms. For example, it is more important for a manager to focus attention on a \$100,000 operation which an absolute varience of plus \$2,000 (overrun) and a relative varience of plus 2 percent, or a \$10,000 operation with a relative varience of plus 15 percent and an absolute varience of \$1,500. With both types of variences on hand, the manager can apply his judgment as he thinks best.

5.I. Forecasting and trending^{1,3,7}

If management is to have clear vision ahead and be able to anticipate problems before they arise, reports must look to the future as well as document the past. Forecasting and trending are two means by which this is done. In network-based schedule and resource control. The network logic itself provides a vehicle for determing what effect a change in one operation will have on the project as a whole. Procurment and tracking systems should be similarly designed so that a superintendent does not arrive at work one morning to find that a critical 6-month lead time item of equipment to be installed that day has not even been ordered yet. Related principles apply to her systems.

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CHAPTER VI

Cost Control Tools

6.A. The estimate and the budget

The control or budget estimate is the main tool of the cost engineer for control of costs during the construction phase of a project. This estimate is a detailed prediction of the project execution plan. It reflects not only the schedule, but also the physical and economic conditions under which the project will be executed. The estimate must be in <u>suffi</u>cent detail to permit actual project performance to be measured against it on an item by item basis.

The budget must be available when needed. For example, if an important long-delivery piece of equipment must be ordered early in a project, then the estimate for that piece of equipment must also be prepared early and be on hand for comparison with the vendors' bids when they are opened.

Since a project entails a large number of items and categories, it is necessary to segregate the costs to keep track of where and how it is spent, and therefore, a code of accounts must be developed. For example, even what seems to be the most logical approach and best thought out design, modifications will be needed as work progresses. It is always be necessary to make changes during the execution of any engineering/construction project. For effective cost control, it is necessary to alter the project budget to reflect changes as they occur, and the best way to do this is with a formal change order system. By use of an change order system, each change will be documented and incorporated in to the project budget and be kept up to date.

The cost engineer must take the following three important steps in the office before construction gets underway:

- 1. Set up a code of accounts to accumulate field costs;
- Recast the budget to insure that there is a budget allocation for every cost code and that the field manhour budgets reflect the actual designed material quantities to be installed; and
- 3. A procedure for measuring progress and percent complete is established.

6.A.l. The code of accounts

The first step for the cost engineer is to set up a code of accounts suitable for the project. In most cases, most contractors have established a standard cost code that covers most cost elements, however, the standard code might need some modifications to suit the requirements of a particular project. For example, an owner of a proposed facility might have special accounting and tax requirements to be met, therefore, the code of accounts should be tailored to meet two requirements:

- 1. Provide cost data necessary for cost control; and
- 2. Provide a cost history satisfactory for tax requirements.

The code should be kept as simple as possible, and the control estimate, if not orginally prepared by code, must be broken down to provide a budget for each cost code.

Many contractors use codes similar to that described in the previous section (standards vs control procedures). This seven digit code provides the following breakdown which is satisfactory for cost control:

- The first two digits indicate the physical area of work; large projects are frequently divided into geograph areas for administrative and cost control purposes.
- The third digit indicates the prime cost element: labor, material subcontractor, etc..
- The fourth digit is used to divide the prime elements into significant subdivisions.
- The fifth, sixth and seventh digits are available for segregating construction details to the extent desired for management purposes.

6.A.2. Recasting the budget

The second step for the cost engineer is to recast the manhour budget to reflect the actual designed material quantities instead of the original estimated quantities. The recasted budget is calculated by multiplying the budget manhour rates by the actual quantities. The recast budget is to be installed at budget productivity, and is to be used as a yardstick for measuring field achievement. The recast budget is to be used for:

- 1. To provide realistic manpower objectives for the field superintendents
- 2. To calculate labor productivity;
- 3. To forecast actual costs;

- 4. To prepare a realistic schedule; and
- 5. To weigh the various construction activities for calculating overall percent complete.

The budget cannot be established until the completion of design engineering, and this is usually well after the start of construction. Therefore, the initial budget must be based on forescasted quantities form sampling and early takeoffs, and the budget is adjusted as better quantity data is supplied.

6.A.3. Calculation of percent complete

The third step for the cost control engineer is to set up procedures for measuring construction progress. Progress is usually summarized and reported as percent complete. Most contractors have standard procedures, however, the standards may be modified to some extent to suit pecularities of specific projects.

The percent complete is a very useful tool for project management, and in many companies, it is the only criteria of progress reported to upper management.

In the later part of the text, examples of various report formats will be examined and methods of calculating percent complete will be shown.

6.B. Feedback (reports)

To control a project, two elements must be continuously monitored by the project manager: (1) performance measured against time, and (2) performance measured against cost. For

a construction project, time is measured against a schedule and the costs are usually measured by expenditure of manhours. Currently, the number of reports available to the project manager range from the simple bar graphs and "S" curves to the complex CPM, PERT and network analysis project control systems. Each system has its unique features and its own place in cost control. In this section, we will review some of the reports that are currently available to the project manager. It is important to emphasize that none of these reports alone can be used for total control of a project, however, as a team of reports, project control can be achieved within certain bounds.

6.C. Bar Charts

A bar chart graphically describes a project consisting of a well defined collection of tasks or activities, the completion of which marks its end. An activity is a task or closely related group of tasks whose performance contributes to the completion of the overall project. A typical activity noted in a bar chart for a building project could be "escavate foundation."

A bar chart is generally organized so that all activities are listed in a column at the left side of the diagram. A horizontal time scale extends to the right of the list, with a line corresponding to each activity is drawn between its corresponding scheduled start and finish times along its horizontal line. A simple bar chant for construction of a small. building is shown on Figure 6-2.



WORK ACTIVITIES

CONCRETE FOUNDATION STRUCTURAL STEEL FRAME METAL ROOF DECK BUILT UP ROOF EXTERIOR CONCRETE BLOCK WALLS PAINT EXTERIOR PAINT INTERIOR CONCRETE SLAB FLOOR FLOOR TILE PLUMBING PIPING PLUMBING FIXTURES ELECTRICAL CONDUIT ELECTRICAL WIRING ELECTRICAL FIXTURES ELECTRICAL CONNECTIONS SUSPENDED CEILING EXTERIOR DOORS WINDOWS INTERIOR DOORS TRIM & MILLWORK INTERIOR CONCRETE BLOCK WALLS CERAMIC TILE AIR CONDITIONING UNIT AIR CONDITIONING DUCTWORK

FIGURE 6 - 1



Bar charts differ in the way they show planned progress on the horizontal scale, in the way they report progress, and in numerous details of a diagramatic style. Three of the more common types of bar charts are discussed below. They will be labeled types I, II and III.

6.C.l. Type I, Linear Time-scaled for Planning; Linear Progress for Reporting

Type I, a common form of a bar chart, assumes that progress on a activity is a direct linear function of elapsed time. Therefore in plynning, no attempt is made to show the physical percentage completion at any point on the bar representing the activity. The basic form is the open bar shown on Figure 3-3a.

In order to report progress, a parallel bar is sometimes placed immediately below the plan bar, and is initially open also. Then, as the job progresses, it is shaded in direct proportion to physical work done (not necessary elapsed time). This is shown on Figure 6-3b. Alternatively, a narrow shaded reporting bar could be superimposed on an open bar, as shown on Figure 6-3c. Other variations are also used. Note that the current physical progress, a work function, does not necessarily coincide with the current to reporting date, a time function. By comparing the shaded reporting bar with the open plan bar and with the current date, one obtains only a rough indications of whether the activity is behind or ahead of schedule.

The example in Figure 6-3b shows that 5 months were ori-

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TYPE I BAR CHARTS



ginally scheduled for the activity and that 60 percent of the time has elapsed. However the shaded bar reports that only 50 percent of the physical work has been completed. On first appearance, it may seem that the activity is about one-half month, or 10 percent behind schedule. This may or may not be true. It is quite possible that the bulk of the resource hours and dollars was scheduled to be expended during the latter half of the activity's duration, as shown in Figure 6-3c. In this case, the activity may actually be on or ahead of schedule. On the other hand, if the bulk of the effort has been planned as in Figure 6-3b, the activity may be much more than 10 percent behind schedule. The point is, the Type I bar chart accurately reflects activity status only when cummlative progress is indeed a direct linear function of time. This knowledge is important in advoiding serious misinterpretations of the diagram.

6.C.2. Type II, Time-scaled for planning, Time-scaled for reporting

Type II bar charts by scheduling an activity with the same kind of open bar that was shown in Figure 6.3-3a for Type I charts. However, an important difference is that planned cumulative progress percentages (interms of physical work completed, man-hours expended, etc.) are written at the end of each basic time interval (day, month, etc.). A convention must be established so that they are consistantly written either above or below the bar, as shown on Figure 6.3-4a. This progress need not be uniformly linear, and can be distributed







as shown in Figure 6.3-4b.

Progress may be reported on Type II bar charts by using either of the graphical conventions explained for Type I, however Type II graphs are shaded to show actual time worked on the activity. Figures giving the actual percentage cumulative progress are written on the opposite sides of the bar from the planned progress.

Comparison of actual and planned percentages is used to evaluate the status of the current activity, so it is essential that these figures be writeen on the diagram to show more vividly what happened on activities which are already complete.

6.C.3. Type III, Time scaled for planning, variable progressscaled for reporting

Type II bar charts start by representing an activity with a horizontally divided open bar such as that shown in Figure 6-4a. Planned percentage progress figures are written at the end of each basic time interval above the bar. The example shows that 50 percent of the work is planned to be performed in the last 2 of the 5 months scheduled for the activity.

When the activity gets underway, work completed is reported by shadeing in alternating areas in the lower and upper portions of the bar, one for each basic time interval worked. The segments are shaded in proportion to the physical work actually performed during the basic time interval compared with the scale for the basic time interval in the range being shaded. The reporting date is marked with an arrow or a heavy line on the calender scale for the bar chart. It is important to



(a) TYPE III PLAN BAR





TYPE III BAR CHARTS

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FIGURE 6 - 5

recognize that the scale of progress generally changes during each basic time interval considered unless progress is a direct linear function of time (see Figure 6-5b).

The major advantage of the Type III graphical representation is that it shows much more information than Types I and II, and can more accurately portray actual job conditions. A possible disadvantage is that some of its implications are more difficult to understand at first and may require considerable explanation.

6.C.4. Advantages and limitations of bar charts

Bar charts have a number of advantages over other scheduling systems. Their simple graphical from results in relatively easy general comprehension. This, in turn, has led to their common acceptance and widespread use as a good form of communication in the industry. Since bar charts are fairly broad planning and scheduling tools, they require less revision and updating than more sophisticated systems.

However, because of their simplicity and generality, bar charts have several limitations. As the complexity of a project increases and the number of activities increase, the number of bars increase and become very cumbersome. If several sheets are required, logical sequence of activities are not expressed in the diagram. Lastly, although the bar chart is a good planning and reporting tool, it is difficult to use it in forecasting and is therefore limited as a control tool. With due regard to these limitations, the bar chart is neverless continue to be a valuable asset to project management.

6.D. Bell and "S" Curves

Like bar charts, Bell and "S" curves can express some aspects of project plans. Once the project is underway, actual progress can be plotted and compared with that which is planned. It is then possible to make projections based on the slope of the actual curve. Such projections, however, should neither be made nor interpreted without a good understanding of the reason for deviations, if any, from the planned progress, and the current and future plans of the project management.

6.D.1. Visual impact

The visual impact of "S" and Bell curves may be influenced by changing the horizontal or vertical scales. Most of the figures in theis section have equal vertical scales. A larger horizontal scale will flatten or elongate the curves. A larger vertical scale will increase the slope and the peaks and valleys, which may be desirable for the dramatic affect.

A basic "S" curve (Figure 6-6a) is drawn on a grid with a horizontal axis showing percentage calender time from 0-100 percent. Any single activity, group of activities, or overall project expressed in the form of an "S" curve must start at (0,0) in the bottom left hand corner and must be complete at the right hand corner at (100,100). The shape of the curve between 0 percent and 100 percent can be an indicator of comparative performance and efficiency.

The simplest "S" curve is a straight line as shown in Figure 6-6a curve A. An "S" curve shows cumulative values

from 0-100, and its shape shows the rate of progress or loading at each point in time. In reality, it is rarely feasible to apply full loading instantly and maintain a constant load throughout the time span. Usually, there must be an initial lead in period for movilization before peak effort can be appled and tail-off period towards the end. In Figure 6-6a, curve B, shows a typical symmetrical "S" curve which has an equal buildup and tail-off.

If planned manhour and progress curves are prepared at the start of a project and actual manhour expenditure and progress recorded at each reporting date, any deviation from the plan is visible. Even more important, schedule slippage in one area can be easily trended to evaluate the potential impact upon the schedule of other areas.

6.D.2. The Bell Curve

The bell curve is derived from the "S" curve and shows the amount of vertical movement of the "S" curve (the rate of progress or loading, Figure 6-6b) for a finite interval of time. In the case of straight line "S" curve, the slope or loading is constant indicating a constant effort throughout the total period. Thus, the derived Bell curve is also a straight line. The shape of the curve is normally the most efficient and hence the most desirable when related to manpower loading. It may not be necessary be so for dollar expenditures to the latest possible date.

The loading curve developed from a symmetrical "S" curve shows the conventional Bell shape with a symmetrical peak con-



(a)



siderably higher than average. This indicates a lower rate at the beginning and end with the maximum rate during the central period.

6.D.3. Symmetry

"S" curves are not usually symmetrical. They may be front end loaded or back end loaded as illustrated in curves C and D in Figure 6-6c. An actual "S" curve might follow any shape with in a grid, but will probably fall between the extremes of the two "S" curves shown. The closer the "S" curve is to the 45 degree straight line, the greater is the degree of resource leveling that has been achieved, and the greater the theoretical efficiency.

6.D.4. Periodic reporting

At each reporting period, physical completion for each activity is recorded. This physical completion is multipled by the activity weighting. The sum of these multiples give the total physical percentage completion for the overall discipline. Physical completion and manhour expenditures are plotted on the same form with the planned progress curve. A comparison between the planned percent complete, and the percent manhour expenditure will quickly show the productivity and performance trend. It is then possible to forecast overall completion and over-all manhour expenditure.

This method of developing planned progress "S" curve is a basic method. Many variations can be done manually or by computer with networks and bar charts.

6.D.5. Manpower forecasting

Figure 6-7 shows how curves can be used to forecast manpower requirements. Normally, the planned progress curve is prepared after the manpower requirements have been determined and leveled to even out the peaks. However, sometimes during the progress of a job, when the end date has been fixed, and progress and manhour expenditures have varied from the initial plan, it is necessary to redetermine the manpower requirements to meet the original schedule. The steps are as follows; 1. The current position is the end of the actual progress

- completion is realistic.
- 2. From this point extend a revised planned progress curve approximating to the shape of the previous planned "S" curve and meeting the required completion point.
- 3. Note the cumulative percent completion required at the end of each month on the revised planned progress curve.
- 4. Tabulate for each monthly reporting period the required percent to be completed per month which is the difference between the cumulative numbers noted under 3.
- 5. To predict the number of men required per month, take the total forecast hours based upon productivity and performance to date. Multiply the total hours by the percent to be completed per month and divide it by the hours worked per month. This will give the number of men required per month.
- 6. Review the number of men required thus calculated and even out the numbers if there are large differences on a month



to month basis.

7. Confirm that the number of men indicated can realistically applied to the job. If the number indicated is greater than can be obtained or realistically applied to the job, then the scheduled will have to be extended. Alternately, if more men are available and can be applied to the job than is required, it may be possible to reduce the schedule.

6.D.6. Master project schedule

Figure 6-8 shows a typical bar chart master project schedule. Chart complete dates and relationships between the various major activities are expressed as a percentage of calender time to mechanical completion.

Superimposed on the bar chart are "S" curves for various activities to construct a small commerical building discussed earlier in this section (see Figure 6-8). The relationships between the "S" curves matches the relationship between the corresponding activities in the bar chart. Whereas the bar chart shows specific start and finish dates for activities, the "S" curves show required rates of progress and cumulative completions at various stages of the project.

The shape of the"S" curves, their relationship to each other, and their position with regard to overall project completion fall within a fairly narrow band for all projects. For example, procurement, engineering and material delivery all should be essentially complete at 50 percent, 70 percent and 80 percent points, respectively. Little is to be gained by starting construction much earlier than at the 30 percent





point. If any one of these curves moves significantly out of its place, then the overall schedule will be affected. The typical relationships between these "S" curves and their position in the overall project completion provide excellent data for preliminary planning. Also the curves help to check the realism of any detailed plans developed for a specific problem.

6.E. Quadplot

Quadplot permits the project manager to know how the project stands currently and in what direction it is headed. The method is adapted from a concept used earlier in the aerospace industry.

Because of the practical limitations of the scale of the "S" curves, it is difficult to judge performance accurately. Quadplot overcomes this difficulty by relating the ratios of the cost and schedule performance to the planned progress. This is the keystone of the Quadplot concept and provides a readily visible means for trending the project.

At the end of each review period, a point is plotted, the coordinates of which represent the cost performance and the schedule performance to date. These coordinates are developed from the cost ratio and the schedule ratio.

The y-axis represents the cost variables. Projects on budget are plotted on the origin, projects under budget are plotted above the origin and those over budget are plotted below.

Likewise, the x-axis represents schedule progress. A

project right on schedule will be on the origin. Those ahead of schedule will fall right of the origin, and those behind will fall to the left.

As the successive points are plotted for the project, the following relationships become evident. If the project status point falls in the upper right hand quadrant, the project is under-budget, ahead of schedule. If it falls in the lower right hand quadrant, the project is over-budget and ahead of schedule. These relationships are shown in Figure 6-10.

6.E.l. Ratios, performance

Although the term budget is used frequently, quadplot does not relate expended manhours to the budget hours except at the inception and at the completion of the project. Generally, we are speaking of "cost" ratios and "cost" performance during the life of the project. Control of manhours with respect to the approved budget must be done by conventional means.

The "cost coordinate" is determined by dividing the actual hours used to date by the current projection for total hours required, by dividing that quotient by the planned percent complete and then subtracting this figure from 1. This last calculation is necessary to preserve the quadrant relationship described above.

Cost rations. % of total project manhours used planned progress in %

Cost coordinate= 1- cost ratio

Time period	% proj. mhr. used	Planned % progress	Cost ratio 1 ÷ 2	Cost coordinate 1 ÷ 3
1	6.8	6	1.133	(.133)
2	19.7	20	.985	.015
3	38.5	39	• 987	.013
4	60.8	59	1.031	(.031)
5	79.0	76	1.037	(.039)
6	88.5	89	•994	.006
7	94.0	96	•979	.021
8	99	100	•990	.010

DETERMINATION OF COST COORDINATES

DETERMINATION OF SCHEDULE COORDINATES

وميطا خمار فيضجها خبار بالاجوال كالأحمار وينبغ عديب

Time period	Actual % progress	Planned % progress	Schedule <u>ratio</u>	Schedule <u>coordinate</u>
1	6.2	6	1.033	.033
2	21.4	20	1.070	.070
3	39.6	39	1.015	.0151
4	47.2	59	•969	(.031)
5	73.7	76	•970	(.030)
6	90.1	89	1.012	.012
7	96.5	96	1.005	.005
8	100	100	1.00	.000



The "schedule coordinate" is calculated by dividing the physical percent complete to date by the planned percent complete and subtracting 1, again to preserve the quadrant relationship.

Schedule ratio= Actual physical progress in % planned progress in %

Schedule ratio = schedule ratio - 1

Figure 6-9 shows how the cost and schedule coordinates are determined for a sample project for eight measuring periods. These coordinates are then used to plot the Quadplot chart for the project (Figure 6-10).

When a project has just begun, there is latitude for a larger deviation from the planned conditions than later on when there is a lesser chance to apply corrective action. To represent this graphically on the Quadplot diagram, a target circle is drawn at the end of each period to depict the maximum limit of prudent permissible deviation at that time.

6.E.2. Target circle

With each successive period, the diameter of the target circle is progressively reduced to reflect the desired varience limit. For the purpose of the sample project, a figure of 2 percent ratio deviation has been indicated at the completion if the job, (see figure 6-11).

The quadplot chart in itself does not identify what is



Figure 6 - 11

wrong, however it provides a "red flag." The project manager should investigate what is wrong and what must be done to correct the problem. This method offers a very simple way to spot possible performance shortcomings, however, it is important that an analysis of the problems be done by personnel familiar with the job.

6.E.3. Performance point

The location of the performance point in the quadrant is significant, but probably not so much so as the direction of the vector drawn from the previous performance point. Figure 6-12a shows several possibilities for performance analysis. In general, a vector upward and towards the right indicates improving performance. A vector downward and to the left indicates an unsatisfactory performance.

In each case, some of the conditions influencing vector direction are uncontrollable, while others are controllable. Figure 6-12b indicates some of the conditions catergorized by controllability.

When considering performance of all disciplines together, the good performance of one section may compensate for poor performance of another. This condition would lead to possible wrong conclusions. It is best to separately chart the performance of each major activity. This is done by providing the same type of information at the section level as was outlined previously for the overall project: scope of work, plan of execution, schedule milestones, man-hour budgets and "S" curves for the activity.



a- Improving schedule performance, cost performance steady b- Improving cost performance, schedule performance steady c- Deteriorating cost performance, schedule performance steady d- Deteriorating schedule performance, cost performance steady



e- Cost and schedule performance deteriorating f- Cost and schedule performance improving

g- Cost performance improving, cost performance deteriorating h- Schedule performance improving, cost performance deteriorating



i- Long vectors: a long vector represents a relatively great change in performance. Vectors at project start tend to be longer than later on in the project.



j- Short vectors: A short vector represents a relatively small change in performance. A short vector at the end of a project will be more significant than an equal vector at the beginning of the project.

-Lack of information -Work done out of sequence -Shortage of personnel -Corrective action not effective -Indecision by project personnel	-Petter than planned per- formance -Timely decisions -Innovative approaches to execution -Good planning -Good communication -Few changes -Good followup for correc- tive act on
Uncontrollable Factors: -Indecision by non-project personnel -Tight schedule for work	Uncontrollable Factors -Conditions better than assumptions -Generous schedule for
-Generous budget for man- hours imposed	-Generous budget for man- hours imposed
Behind Schedule - Under Budget	Ahead of Schedule - Under Eudget
Behind Schedule - Cver Budget	Ahead of Schedule - Over Budget
Controllable Factors -Excess manpower on job -Lack of information -Foor productivity -Poor manpower forecasting -Poor planning/compliance to plans -Recycling of work -Excessive changes -Indecision by project personnel- -Lack of communication on -Corrective action not effective	Controllable Factors -Work done out of sequence -Excessive manpower on job -Poor productivity -Foor manpower forecasting
Uncontrollable Factors -Indecision by non-project personnel -Excessive or late changes -Tight schedule for work -Tight budget for manhours	Uncontrollable Factors: -Generous schedule for work -Tight budget for manhours

Cost Performance

Figure 6 - 12b

Some typical controllable and uncontrollable factors to be used in analyzing project performance

Schedule Performance

6.F. Network planning techniques

Practical applications of network planning techniques began in 1958 with the introduction of the critical path method (CPM) and the program evaluation and review technique (PERT). Originally, there were differences between CPM and PERT, however, the differences between CPM and PERT have largely disappeared over the years since their introduction. For this reason, and others to be discussed, the general phase "network techniques" is a better description.

Both CPM and PERT require that a project be broken down into component activities which can be represented in the form of a network diagram showing their sequential relationships to one another. Both use the "arrow diagram" where the network lines are represented activities and network modes are events that represent the points in time at which activities may be commenced or are completed. Both require time estimates for each activity which are used in calculations to determine project duration and scheduling data for each activity. These calculations are used to determine which activities must be kept on schedule, if the project duration is to be realized and which activities have extra time.

Although both used a network diagram, CPM was an activity oriented system, and descriptive labels are applied to the arrows in the diagram. PERT is an event oriented system, and descriptive labels are applied to the nodes of the diagram. In CPM, only a single time estimate is applied to each activity, where PERT allows multiple time estimates.

6.F.l. Fundamental of network based planning and scheduling

The backbone of the network based planning network is a graphic model of the project. The basic component of this model is the arrow. Each arrow represents one activity in the project. The tail of the arrow represents the starting point of the activity and the head represents the completion. The length of the arrow has no significance (unless the network is timescaled).

The arrows are arranged to show the plan or logical sequence in which the activities of the project are to be accomplished. The intersection of two or more activity arrows is termed an evented. All activities leading into an event must be completed before any of the activities leading from the event can be started.

The resulting logical flow chart is a network of arrows containing all activities which are required to complete the project. This flow chart is generally referred to as the arrow diagram.

For example, consider the small commerical building discussed earlier. The activities representing the work involved in this construction project as shown in Figure 6-13. The network representing logical sequence of activities is shown in Figure 6-13. Mode numbers are added for each event in this network. These numbers have notsignificance except that they separately identify each event. Unlike a bar chart, this network plan shows the interrelationships between all activities in the project.

The preparation of the network provides three important
FIGURE 6 - 13



advantages:

- 1. A disciplined method of preparing the plan;
- 2. A method of considering the project in detail; and
- 3. A graphic record of the plan which is useful for exchanging opinions and constructive criticism of the plan.

At this point, no time dimension has been introduced, and therefore, the next step is to add the time dimension to the network.

The time estimate for an activity is usually referred to as the activity duration and is shown below the arrow. The network for the small commercial building with activity times assigned is shown on Figure 6-14. When the activity durations have been added, the project duration can be computed.

The first step in the computation is the calculation of early event times or forward pass calculation. This calculation is best illustrated by reference to the network for the building which is shown on Figure 6-15 with the early event time calculation already completed.

From this example, it can be seen that the early event time is equal to the preceeding early event time plus the duration of the preceeding activity. When two or more activities converge at the event, then the early event time is the latest of the event times calculated.

Using this procedure, the calculated early event time for the last event (event 200) is 88 days. The significance of this is that based on our logical sequence and time estimates, the shortest time in which this work could be completed is 88 working days.



FIGURE 6 - 14



FIGURE 6 - 15

The second step in the computation is the calculation of late event times, or backward pass calculation. The late event time is defined as the latest time at which an event may be reached without delaying the computed project duration. These late event times are calculated by working backward through the network from the final event. The late event time is equal to the late event time of the following event less the duration of the following activity. Where two or more arrows converge (at the tail end), the late event time is the earliest of the calculated times. This calculation is illustrated on Figure 6-16.

The Critical Path determines the length (duration) of the project. It is the longest chain (accumulative duration) or path of activities through the network. The critical path is identified as the path which passes through all the critical events. On the example network, the critical path is shown on Figure 6-17.

The computation of the project duration can be summarized by the following three rules:

- The early event time is the latest of the possibilities at the convergence of arrows (head end);
- 2. The late event time is the earliest of the possibilities at a convergence of arrows (tail end); and
- 3. The short project time is the result of the longest path, which is the critical path.

6.E.2. Time scaled networks

Using the early and late dates calculated for each act-



FIGURE 6 - 16



FIGURE 6 - 17

ivity, time scaled networks can be prepared if required. Figure 6-16 shows a time scaled network for the example building with all activities plotted on an early start basis. Note that this time scale network is similar to the original bar chart (Figure 6-2) except that restraints are shown. Figure 6-17 shows all activities on an early start basis and identifies the critical path.

It should be noted that in order to draw a time scaled network, decisions are require to establish the schedule dates for all activities which are not on the critical path. These activities must be scheduled within the available slack.

6.F.3. Slack/Float

It is important to note that the time that is identified as slack is related to the entire network and not to unique activities. The use of slack to schedule activities according to project needs is a shared responsibility. Consider for example "erect structual steel: in Figure 6-17 nodes 5 to 10 takes 25 days instead of 5 days to complete, the result would be that the activity "metal roof deck", nodes 10 to 25, would need to be completed in 3 days, or the completion of the project on time would be in jeopardy. Float on this activity would be 0.

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CHAPTER VII

OTHER COST CONTROL TECHNIQUES

A. Supervision¹

Front line supervisors are the key people in any costreduction program for the simple reason that in most cases they have direct control over more than half of their companies' operating costs. It's the supervisor who deals directly with the people who earn the wages, who build the product and who waste the materials.

The quality and quantity of supervisors have direct effect on worker productivity. As shown in figure 7 - 1, worker's productivity increases as the number of supervisors increases, however, labor costs also rise due to increased supervision. The amount of supervision on a job depends on the number and experience of the field labor. In some regions, it will be necessary to train the field hands because of scarcity of a particular craftmen, and consequently, more one on one supervision is necessary and labor costs increase as a result.

Front line supervisors will insure quality control, promote work simplification by reducing bottlenecks, and streamlining material handling and be a liason between the field hand and project management.

B. Substitution

The theoretical minimum cost of a project is set during the conceptual phase of the project. The conceptual phase of the project leads into the detailed



FIGURE 7 - 1

1.06

engineering work which culminates in the process flow diagrams which specify the equipment's duties, sizes, capacities, cumbers and so forth. It is also here where the cost control engineer is a key figure to save project dollars. In the review of the estimate or budget estimate of quantities and materials used, the cost control engineer should be alert to overdesign and substitution.

For example, platforms and stairways for a petrochemical plant may be designed too wide for its intended use. Therefore a smaller design may be utilized to save on material dollars and labor manhours. Substitution of a piece of material or reduction in quantities may be another way of reducing costs. For example, a cost engineer may reccommend that combined footings for several pieces of equipment by combining them in one area to save on concrete. Futher, pipe racks designed with building deflection requirements may use beams of lesser design since deflection may be more tolerated than by a building. These are only examples, however, as shown, the cost engineer is in an unique position to review the entire process, where the design engineer is limited to his particular area of expertise.

C. Prefabrication

Proper planning should utilize prefabricated equipment and materials as much as possible. A review of the specific site conditions and modes of transportation available will provide the necessary information whether prefabrication is

feasible or not. Prefabrication is ideal because:

1) fabricated pieces of equipment are ususally constructed under ideal conditions where the craftsmen are more productive and there is less material waste, and therefore cheaper than field labor to erect;

 the quality and performance of the fabricated equipment is usually tested and assured to meet all specifications;

3) special tradesmen or assembly procedures are necessary for field fabrication of the equipment;

4) field erected equipment are prone to site conditions, weather, available equipment, and so forth, and therefore lower worker productivity and waste of material may prevail;

5) field erected equipment usually needs more planning and supervision to construct;

6) more quality control procedures and inspections are necessary for field erected equipment which will increase overall costs;

7) field erected equipment usually takes longer to build, therefore, valuable time and (manhours) resources are used up which may be utilized in some other area of construction; and

8) profabricated equipment may be schedule to be delivered within a specific time frame when needed.

The primary requirement for a prefabricated piece of equipment is the transportation available to the site and

the associated handling. Because of the size and weight of a particular piece of equipment, it cannot be shipped by truck, but can be shipped by rail. If the job site has a rail depot, it is feasible to have this particular piece of equipment prefabricate. If there is no rail depot, it may be necessary to break down the piece of equipment into two or more pieces for easy shipment by truck. Secondly, the site must have the storage area and handling equipment to handle a bulky piece of equipment. If not, it may be necessary to rent additional cranes or hoisting equipment. Lastly, the engineer should be aware of any specific assembly procedures which may require the expertise of special tradesmen groups or the like. D. Contingency ²,⁵

One of the most controversial and least understood items in every estimate is contingency. In a strict sense, contingency is an allowance for a possible or unforeseen occurance. The interpretation of this definition varies considerably from company to company and from estimator to estimator, with a net result of a broad range of application. Unfortunately, there is no common definition within cost engineering for contingency and it becomes necessary to question each estimate with regard to the basis for contingency before one can understand the significance and the accuracy of the estimate. Perhaps the best approach to defining contingency in the cost engineering sense is to rewiew in detail the reasons that contingency is added to an estimate (normally contingency is a bottom line addition, expressed as a percentage of the subtotal of all costs in the estimate).

Below lists the majority of reasons that contingency is included in estimates. We will discuss each of these in more detail, but first we need to examine why contingency is needed. Money is added mainly because the estimator feels that, without the additional money, the total estimate for the project is below the cost that he predicts or feels would be the final actual cost.

- inadequacies in scope definition
- inadequacies in estimating methods
- cover escalation
- cover soft areas
- decrease chances of overrun
- untried process

D.1 Inadequacies in Scope Definition

In reality, the final scope of a project is not defined until the building is completed. Between that time and the time the project is first concieved, there is a period of project development during which the project is in a constant state of change, with definition becoming clearer and more stable as time passes. This is an increase or improvement in scope difinition and the accuracy of the estimate increases accordingly. Since changes occur throughout a project life cycle, at any given time when an estimate is being made, the scope at the time of the estimate is by definition incomplete. Since future changes to the scope, intiated in the main by the owners, are unknown in both numbers and in cost, the estimator has no means of estimating the cost of the future changes. To cover the cost, the estimator adds a contingency allowance based on historical data. The amount of contingency will depend on the time in the development of the project and the past performance of the owner's process and project engineers with regard to iniating changes. The amount can vary form as high as 30 to 50% for very early estimates to as little as 2 to 3% for projects in their final stages of execution. Contingency to cover inadequacies in scope definition is probably the most common and valid reason for adding money to an estimate.

D.2 Contingency for Estimating Methods

This contingency covers money for items not covered by the estimating methods in use by the company's cost engineering department. These are items that are known to be required but that may not be defined in enough detail, or the method itself may not be sufficiently comprehensive to pick them up. Consequently, an estimating allownance or contingency must be added.

A contingency to cover inadequacies in estimating methods can and should be advoided whenever possible. This can normally be accomplished by developing an estimating method (instead of an allowance) to cover the missing item in question. This approach not only will improve the

accuracy of the overall estimate, but will also increase greatly the effectiveness of the estimate as a control tool.

The amount of contingency to be added to cover inadequacies in estimating method depends on the track record of the owner's estimating methods and historical records. The amount to be added is normally in the range of 1 to 10%. D.3 Contingency for Escalation and Soft Areas

Often, a contingency or allowance is added to an estimate because the estimator or management lacks confidence in a particular part of the estimate. These soft areas are places where there appears to be insufficient information or where experience has shown that there is a high degree of variability, such as labor productivity, geographic/ regional factors and so forth. As in the case of escaltion, this type of contigency should be advoided whenever possible, where the soft area should be firmed up by seeking additional information and putting oneself in a better position to predict the most probable cost.

D.4 Contingency for Decreasing Chances of an Overrun

Often a contingency will be added to minimize the possibility of an overrun. For example, if a normal 10% contingency when added to an estimate prepared at a certain time in the development of a project statistically results in a probably of one chance in five that the estimate will overmun by more than 10%, management may want to increase the odds that there will not be an undesireable overrun. They

can do this by adding a bias contingency or artificially creasing a high estimate. The amount to be added to get a desireable probability can be determined by statistically analyzing similiar estimates. The addition of a bias is not a reccommended practive, since it creates an estimate that is not a realistic prediction of job execution. This high estimate can project an overly pessimistic opinion of a job and may promote unwarrented money spending.

D.5 Contingency for an Untried Process

In cases where the project estimated is a new and untried process, the process engineers may have some genuine concerns regarding the capability of the design basis equipment to fully meet the design criteria. For example, suppose when a plant is finally built and being started up, there may be a need for additional pumping capacity or heat exchange. Because this new design, the designer can't be certain of the actual requirement, but history shows that abnormal additions or changes are often needed during both the detailed design and start up. To cover this uncertainty resulting from inexperience, a process contingency is sometimes added. The amount of this contingency is usually determined by some kind of risk analysis. Based on what modifications are necessary and probabilities, the estimator calculates what contingency needs to be added to cover these possibilities.

E. Protection Against Contingency

In the previous section, contingency is a common phenomena in estimating procedures of a construction project. At some point in time, the project manager and other managers of upper management must review these contingencies to decide whether or not these risks associated with these contingencies are acceptable or not.

The risk associated with contingency can have a very large range and there may be no limitations. Risk may be defined as the uncertainy that exists as to the occurance of some event. Generally, we are concerned with an event which causes economic loss. The economic loss may take many forms, such as the loss of property by physical perils such as fire or explosion, defect in design, scheduling delays, accidents and so forth. Risk, unlike probability, is a concept in relative variation, whereas, probability refers to the long run chance of occurance, or the relative frequency of some event. Since probability operates by the law of large numbers, the individual seldom has a sufficient number of exposure units to reduce his risk significantly through the operation of the law of large numbers.

Once management has defined all of the risks associated with a particular project, management must evaluate and assess all those risks and its effect on the project. As the economic loss associated with each risk increases, management must decide whether to assume the risk, transfer the risk, or utilize a loss-preventive activity.

E.1 Assuming the Risk

This method is perhaps the most widely used of all the ways to handle risk. Many of the risks faced by project management are of small magnitude with respect to economic loss or loss of property. Project management is willing to assume the risks since they feel that the cost of insuring a particular operation or utilizing a loss-preventive activity is too costly. In turn, project management may address this problem by creating a "contingency" budget to cover certain contingencies in hopes that those risks will be of equal or lesser value than the budgeted amount.

E.2 Transferring or Shifting the Risk

In the transfer method, one individual pays another to assume the risk that the transferor desires to escape. The risk bearer agrees to assume the risk for a price. The risk of loss is often the same to the transferee as it was to the project manager of the project. The risk bearer, however, may have superior knowledge concerning the probability of loss, and thus may be in a better financial position to assume the risk than the transferor. Neverless, the risk still exits.

Transferring the risk will usually, but not always, utilize some form of insurance. For example, on every job, the employer will subscribe to some type of accidental and property insurance to provide coverage for loss due to fire, accidents and so forth. In another case, project management may have contracted a job that requires a certain type of expertise that he does not have at the time, therefore, the project management may subcontract that protion of work out to transfer his risk bearer is not willing to assume the risk, and therefore pays another party to assume his risks.

E.3 Utilizing Loss-Prevention Activities

It is sometimes erroneously believed that loss prevention is "good insurance". However, while the loss prevention activities normally produce a reduction of the probable losses and alleviate the severity of the loss, they do not affect the degree of risk. For example, at a job site, a resident engineer may incorporate procedures to reduce or minimize losses due to theft. Although the loss preventive measures were successful to reduce the thefts, the risk of theft is still there. Utilizing losspreventive activities is a good method of reducing the probability of occurance, however, as conditions present itself, it should not be used entirely as insurance against risk.

E.4 Evaluation of Risk

To recognize the various exposures to loss is one of the most difficult and complex tasks a project manager must face, and he mustwork hand in hand with the risk manager of the company. A construction site of substantial size offers almost limitless opportunities for loss, and the project manager, along with the risk manager, is expected to make an evaluation of all of them. He must also recognize that there are many types of losses other than

these of physical peril, such as losses from legal lia-

bilities, union agreements, etc.

There are countless losses that may happen, but some would be of no particular problem if they did arise. Other losses, however, could bankrupt the firm if they should occur. The project manager and the risk manager of the company should first study the records of past losses, if any, and then consult the loss experience of other firms to compile some sort of data base. Once the exposure is recognized, the next step is to estimate the size and frequency of the loss. Once the probability of loss has been estimated, the project manager is in a good position to decide the best method of handling the risk.

Risk, as faced by the project manager may be one of ac Make. four kinds. They are:

I	high	risk/high	loss
II	high	risk/low	loss —

- little or no risk/high cost III
- IV little or no risk/low cost

These are depicted in Figure 7-2

In most cases, the project manager will be willing to assume the risks associated with type IV risk, simply because of the degree of risk involved and the issure of economics. Because of the reasons of economics, the risks associated with type II risk might also be acceptable. In types II and IV, the losses will usually be covered in part or in whole by some excess in the budget. Types I and III risk will usually need more than a cursory review by management and will probabily require an evaluation by

(HIGH RISK, LOW LOSS)	생. 영국 (HIGH RISK, HIGH LOSS) 아이아이아이아이아이아이아이아이아이아이아이아이아이아이아이아이아이아이아이			
Degree of Economic Loss					
(LOW RISK, LOW LOSS)	(LOW RISK, HIGH LOSS)			

management to review the alternatives. In almost all cases, Type I will require some sort of insurance which will cover in part or whole of the probable loss along with, if possible, some loss preventive activity. Type III risk, must be decided on its own merits from job to job, on its uniquesness, degree of risk, degree of probable loss and so forth to decide which form or combination of risk transfer/retention should be made.

In all of the above types of risk, the project manager must decide whether to insure in whole or in part or review other methods of reducing the risk.

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POTENTIAL CONTRIBUTION OF TECHNOLOGY

A. Prefabrication, Preassembly

Although not all types of construction lend themselves to standardiztion of components, standardization, prefabrication, preassembly will be playing an increasing role in construction in future years. As physical limitations are overcome (transportation, hoisting equipment, etc.), more and more construction projects will utilize prefabricated components to save construction time, labor manhours and material dollars. For example, in the petrochemical industry, construction of refineries require several "prill towers". Until a few years ago, prill towers were usually constructed in the field. Presently, most constructtion firms will have the prill towers shop fabricated in sections and then shipped to the field for final assembly. As in the past, the size and weight of the shop fabricated components will increase as these limitations are overcome through the use of more elaborate equipment and alloys. A discussion of the advantages of prefabricated, preassembled items was discussed under cost control tools.

B. Mechanization

Mechanization, or the improvement of labor productivity though the use of mechanical equipment and aids are always under constant improvement.

Engineers and designers are always reviewing certain manual tasks that can be automated to increase worker productivity and accuracy. With the onslaught advancement of computer technology and the miniturization of

various components, we will see various manual tasks give way to automation. As construction projects grow in size and complexity, technology will be asked to come along and review certain processes to save valuable labor manhours and schedule time. As discussed in the previous section, certain physical limitations will be overcome to build larger cranes, more efficient earth movers and so forth to take on larger projects and to promote more efficient operations. For example, although automatic welding machines were around prior to the construction of the Alasken pipeline, there was significant improvement in its design and its operation because of the size and complexity of the project.

Certain aids for the craftsmen will also be developed to make his job easier and less time consuming. We have seen this throughout the industry in the past (electric welders, electric hammers, etc.) and will continue so into the future.

There is no limitation in the area of mechanization except for the imagination of the engineer and the design and will probably see constant improvement in this area.

C. Design Developement

As in mechanization, there is no limitation in this area except for the imagination of the engineering and design personel. As new processes are developed, design developement will follow. Design development may include a few changes in the structural configuration to save material dollars, or the use of alloys to save weight, or the design change may be in the order which work is done to save labor manhours and construction time. Design development may be an entire new process which may make a smaller plant more efficient than its counter-parts to promote efficienty in its construction as well as its final operation. Design development requires input from all areas of expertise and needs strict coordination throughout its development.

D. Planning Procedures

As discussed in earlier sections, various planning and control tools are available to the project manager. Through experience the project manager becomes familiar with these various aids and recognizes the weaknesses as well as the strong points of these aids and he will custom tailor and refine each of these aids for his particular use and need. New planning procedures rarely occur, and more likely, new planning procedures are the application of exiting aids to a specific need. As new design development, mechanization and preassembly occur, new planning procedures are required, however, the basic guidelines stay intact. I am not saying that there will be no new planning procedures, I am saying that there will be constrant improvement of the various planning procedures and techniques as time goes on.

E. Behavioral Factors 1,2,3,7

Behavioral factors has been long recognize by all

business and engineering disiplines as an important factor within its organizational structure since it deals with large social groups and its relationship within the organization. The goals of the organization (planning, budgeting, decision-making, and control and reporting) cannot astray from the goals of the individual, or the system will fail. Success of any project, or of any business lies in its labor selection techniques, the training procedures which it uses to develop competent and efficient workers, and quality and quantity of supervision on the job, management and labor relations, and its organizational structure which it operates in. A short discussion of those areas is as follows:

Labor selection and training - Probably one of the most important factors in the success of the company is the labor selection and training techniques which it uses. The primary goal of the labor selection is to make a synergenetic fit between the task (or job) and the individual. The end result is that you will have a productive and efficient individual who is happy with his job. The initial step is to examine the job vacancies and define the job as to its activities, tasks, responsibilities and particular charateristics. Once the job has been reviewed, a review of successful employees who have or had held that position should be reviewed. The review should seek common traits and/or charateristics among all the successful employees. They may include physical charateristics such as height and

weight, or educational background, or job attitudes and so forth. Now that the job characteristics and individual charateristics have been defined, the two may be correlated and a potentially successful candidate for the open position has just been defined. Sighting or measuring for the individual charateristics may be sought by testing procedures, personal interviews, job application forms and so forth.

If there are certain weakness in the individual, they may be overcome by a training program. Training is a process that develops and improves skills related to performance, where the accepted goal of training is usually the achievement of a desired level of competence in the performance of a particular task or job. In addition, it is usually required that this training be accomplished as rapidly and efficiently as possible.

Despite the fact that job training should become one of industry's responsibilities, there are many companies which seem to do their best to advoid it. Industry, in general has attempted to get around the problem of training in two ways: (1) by hiring skilled or experienced workers on the assumption that training will be unneccessary, or (2) it hires inexperienced personnel to be trained by experienced employees with the belief that a worker who is experienced can train an unexperienced person even though he has no knowledge of training techniques, Althoughlearning can take place without effective training aids, it is uneconomial because it takes longer and does not permit the ineffictively trained worker to reach his maxium output.

When one is involved in the training of others, it is best that a number of basic fundamental considerations are necessary. The following can serve to enhance the training process:

- Motivation is not only desireable, but often neccessary accomplishment of training;
- The number of lessons to teach the individual must be considered judgement, and should not be arbitrarily or artifically set;
- 3. The amount to be learned in a lesson must be planned, where the unit learned should neither be too large or complex or simple;
- 4. Any training is practically never comprehensive or exhaustive, for example, a crane operator needs not to know the laws of statics and dynamics to operate a crane;
- 5. The task to be performed should be demostrated;
- 6. The demonstration should be followed immediately by participation of the trainee;
- 7. A discussion and question period should follow to clear up any misconceptions;
- 8. Ample and adequate practice should be encouraged;
- 9. Observable progress or feedback of learner's progress should be institued; and
- 10. A summary and review of the entire learning process should be made between the instructor and trainee so that what is learned meets the criterion of the standard.

Classification of the difference types of training situations is rather moot, however, since there are a number of different ways that they may be classified, for convenience, training experiences may be classified in terms of (1) purpose, (2) location, (3) trainee, and (4) technique. Such a classification is given below:

- I. Purpose of training experience
 - to impart knowledge (ie. orientation training)
 - to teach skills
 - to modify attitudes
- II. Location of training
 - on the job training
 - classroom
 - simulated work situation (vestibule training)
 - homestudy
- III. Trainee characteristics
 - Experience
 - 1. no prior experience
 - 2. moderate prior experience (refresher training)
 - 3. extensive experience
 - Job level
 - 1. non-supervisory
 - 2. supervisory
 - Number
 - 1. individuals
 - 2. groups

IV. Techniques used

- lecture
- work sample procedure
- role playing
- closed circuit TV
- programed instruction
- group discussion

F. Supervision and Management-Labor Relations

The role of leadership in industrial relations is gaining increased recognition. The quality and amount of supervision is an important factor with respect to worker's moral and productivity. The supervisor should be well organized, be cognizant of his job and know how it fits in the overall plan of action, and have all of the neccessary leadership qualities. The supervisor should be a good decision maker who has full support of his workers and must maintain close contact with his group. It is important that he is able to delegate authority, however, leadership is not an one-way affair, and it involves the interaction between the leader and the group.

The supervisor should spend more time planning, a greater degree of delegation of authority, be employee oriented rather production oriented and instilling motivation and pride of the group. Past studies indicated that apparent characteristics which differentiate high productivity groups from low productivity work groups are summarized below. The high productivity groups: 1. are under less close supervision from their supervisors;

- 2. place less direct emphesis upon production as the goal;
- 3. encourage employee participation in the making of decisions;
- 4. are more employee centered;
- 5. spend more time in supervision and less in straight production work;
- 6. have a greater feeling of confidence in their supervisory roles; and
- 7. feel that they know where they stand with the company.

It is very difficult to devise a list of specific recomendations for the successful leader because such a list must be general in nature, whereas most situations which confront the leader are specific. However, an attempt listing general qualities based on leadership actions is as follows:

- 1. a fair evaluation of work;
- 2. sufficient delegation of authority;
- 3. fair treatment for all;
- 4. be available to all employees; and
- 5. be able to discuss employee problems with employees.

A supervisor should advoid such common practives as the following:

- dependence upon superiority (ie. taking advantage of position);
- 2. simulation of knowledge;
- 3. interference with the subordinates work;
- 4. favoritism and discrimination;
- 5. public reprimands;
- 6. pettiness;
- 7. conflicting orders; and
- 8. superfluous orders.
- G. The Organization Structure 5,6

The organizational structure may be defined as the design of the structural hierchy within which defines the relationships between people and the lines of authority and communication. The organizational structured on a centralized or decentralized system, which consists of large or small staffs and uses various goals as part of the allocation process. A well organized company should have well defined lines of communication which are short between the levels of authority to promote timely and accurate information flow. The flow of information between the different levels should flow easily in either direction with little interference or "noise". Timeliness, accuracy and quality should be enherent qualities of the system. The organizational structure should reflect the organization's goals, and more importantly, the organizational's goals should be the same as those of the individuals.

H. Financial Development 8

Delays to project schedule occur in a number of ways. Of particular concern are those from procedural constraints imposed upon the project team by sources of investment finance. A well informed engineer should have a clear definition of financing and know the major considerations a banker looks at.

For the plant owner seeking funds to finance his project, there are several sources operating from a nation to an international scale. They fall into four main catergories, each with special charateristics of loan terms and fields of application. They are broadly as follows:

1. Commercial Banks - the more traditional source of capital funds charaterized today by relatively short loan periods and non-fixed interest rates. Although more expensive than other agencies, and advantage is the lack of commercial or political constraints in project implementation. 2. National Export Credit Programs - These exist to assist and encourage a country's exports of goods and services. Their functioning is based upon the special insurance and discount facilities made available to them by the government and central banks. Thus they are receptive to political influence and tend to reflect the current trade policies of their respective governments. Loans are at fixed interest rates over medium to long periods. They are generally tried to purchasing goods and services from the country of origin only.

3. National Aid Organizations - These are essentially government to government loans and are therefore subject to some political infulence. Loan terms vary but tend to soft (for long periods at very low interest rates). They are sometimes tried to supply of goods and services from country of origin.

4. International Agencies - These are international organizations employing resources contributed by governments of the participating countries, together with income from international bond issues and placements. Very long loan periods at very low interest rates may be made available to developing countries. Strict procedural rules require open competition for the supply of goods and services from member countries.

From the financing point of view, the shortest project schedule can be achieved when the owner pays cash for the plant, or borrows commercially. The need to obtain other
forms of institutional finance generally extends the time to complete the project for one or more of the following reasons:

- the time required to negotiate loan agreements;
- the protracted procedures for qualifying bidder which may have to followed; and
- the extra time required to evaluate competitive quotations and select vendors.

If the owner puts up enough cash to pay for front end engineering and possible to make down payments on critical equipment, the delays in obtaining finance need not significantly delay completion of the project. However, a delay is almost inevitable if engineering costs and down payments have to be financed.

Project financing constraints can seriously lengthen the project schedule. Thus, if sufficient money is not available for down payments on bought in equipment, the completion date for the plant will extend by an amount equal to the delay in placing the purchase order, even if the equipment is not on the critical path for delivery and erection. Delays in critical equipment have a cumulative effect. Not only is the project completion time effected directly, but the delay feeds back possibly into engineering.

The lender must often rely heavily on a projection. This is prepared by the engineer or is based on assumptions provided to him. For this reason, engineer and banker must work closely as a team. Members of this team must understand each other. There is an inherent equity risk in construction of any new venture and is not appropriate for a bank must analyze various financing risks and considerations and determine which are acceptable. After this determination is made, the bank will apply the various project financing techniques to shift any unacceptable or equity risks to another party.

Some concerns and risks a banker considers:

1. Completion - This is the question of whether the project will be constructed for the cost originally projected, and if there are overruns, who will pay. It also includes the questions , will the project work as to the original design? Will it produce the product according to original specifications with operating costs in line with the original economics.

2. Equity - How much equity cushion is in the project, ie. how much stockholders invested in it? The amount of equity will usually vary depending on the strength of undertaking provided by the sponsors or other financial parties.

3. Market - Is the output covered by sales contracts, how long will they run, what is the sales price, etc.

4. Project Risk - Will the project work over a continuous period of time and achieve expected levels of efficiency, etc.

5. Source of Supply - Does the venture have a contract covering the supply of the raw materials, etc.

6. Political Risk - This would include the risk of expropriation, inconvertibility and war insurrection. 7. Operator - The ability of the operator is also a very basic consideration in all project loans.

The question of completion and the project risk directly involve the engineer. For example, we need to know whether the project employes any new technology. Has it been build before? How difficult is it to operate?

Even if the financing is structured so that the completion risk is shifted to another party, we will need to consult with an engineer. The most obvious assumptions the engineer would include:

- 1. Levels of production and efficiency that can be achieved;
- Assumptions regarding total initial capital costs for the project;
- 3. Construction period during which the project is assumed to be built;
- 4. Capital expenditures required each year to maintain;
- 5. Reasonable assumptions for operating costs and expenses; and
- 6. Economic forecast analysis.

This could include the determination of breakeven levels for the project or a forecast revision based on new assumptions.

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