PROJECT MANAGEMENT FOR ENGINEERING AND CONSTRUCTION

PROJECT MANAGEMENT FOR ENGINEERING AND CONSTRUCTION
2nd Edition

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Dedication

This book is dedicated to
George Pudlo and Victor Hoffman.
These individuals, through their accomplishments,
have demonstrated what it takes to be the "best"
in project management.

Contents

Preface

A "Project" can be defined loosely as an item of work which requires planning, organizing, the dedication of resources and the expenditure of funds, in order to produce a concept, a product, or a plant. The second edition of ***Project Management for Engineering and Construction*** focuses on "Plant Projects," all of which require design engineering, the purchase of materials, and their installation.

Almost all companies have personnel who are trained, skilled and dedicated to the execution of their projects. The individuals who lead these efforts are called project engineers and/or project managers. Supporting these project managers are such personnel as design engineers, procurement personnel, contracts officers, estimators, cost engineers, planners, construction managers and a variety of technical specialists.

In many cases, the type, size and complexity of projects vary greatly and, therefore, the skills and experience of project engineers, project managers and support personnel can, similarly, vary in capability.

The major factors which are essential for the successful execution of projects are:

- Cost Management

Many projects have cost as the number one objective. This requires the project to be completed within budgeted cost. Adequate business skills of the project manager are essential to meet this objective.

- Time Management

To meet the "cost objective," the efficient management of time is essential. This means that the predetermined schedule, upon which the cost estimate was based, must be met.

• <u>Human Resources</u>

Of all the resources required for plant projects, the people resources are the most difficult to manage. Inter-personnel skills and the effective motivation of people, at all levels, are essential for successful project execution.

• <u>Communications</u>

A formal and informal structure of effective communications is absolutely essential for successful project execution. In addition to a lack of people skills, many organizations form barriers to project success. These **"barriers"** are generally referred to as the Matrix Interface Conflicts **(MICs).** The conflicts or bamers are caused to departmental jealousies, rivalries and failure by management to create a "culture" where "project consciousness" and ***esprit de corps*** are common to all personnel. The 'Total Quality Management" programs sweeping industry are an attempt to solve these problems.

The second edition of ***Project Management for Engineering and Construction*** includes a new chapter on Personal Performance, Company Culture and Project Leadership for the 1990's. This chapter deals with improving communication and removing bamers for effective project management channels.

In addition, a new chapter on contract planning essentials addresses "tricks of the trade" for developing contract strategies, defining responsibilities and addressing various forms of contracts including reimbursable, fixed-price and target contracts..

Hopefully, ***Project Management for Engineering and Construc-***tion will provide the tools readers need to complete their projects on time and within budgets.

James A. Bent
Albert Thumann

1
The Project Management Approach

CONTENTS

Effective project management for engineering/construction projects is essential in today's very demanding business environment. A successful project management approach requires the development of business skills and involves establishing controls and monitoring progress to ensure that the project meets the performance specification requirements and is completed on time and within budget. The purpose of this book is to provide the detailed information needed to properly manage engineering construction projects, both large and small.

THE PROJECT MANAGER

The Project Manager can be described by the activities he or she is responsible for and the skills which are required. The project manager may be employed by the owner, engineer or contractor, and is responsible for the overall direction and management of the project activity.

Typical activities of the project manager include initiation of the project, project scheduling, project start-up, project control, contractual strategies and financial planning. Theproject manager acts as the key catalyst to stimulate effective communication and coordination between design, procurement and construction activities. The project manager ensures that the project is completed within budget, on schedule and meets the technical and construction quality objectives.

To effectively implement a project, the manager should possess the following:

- Business Expertise
- Technical Expertise
- Management Skills
- Leadership Qualities
- Effective Communication Capability

Business Expertise. The Project Manager is essentially a "business man" and must ensure that the project is executed in strict accordance with the Project Objectives. In the majority of projects, the number-one project objective is Cost. On such projects, the technical details required and schedule considerations should be consistent with the budget for the project. It is vital that design and construction engineers execute their work with full realization of financial impact, and it is the responsibility of the Project Manager to ensure this "financial execution."

Business expertise can be divided into the following:

1. Estimating/Cost Control
2. Planning & Scheduling
3. Economic/Risk Analysis
4. Purchasing
5. Contract Management
6. Analytical Skills

The above work categories may be carried out by other specialists, but it is the Project Manager's responsibility to "direct" these activities and ensure that the work quality is adequate.

Technical Expertise. The project manager should have a broad-based technical background to ensure that the project is properly staffed and that the client's objectives have been defined to enable the project to be completed with quality and "constructability" as prime objectives.

Management **Skills.** The project manager should have basic management skills including:

1. Good Decision Making
2. Competent Planning (Project Execution Plan)
3. Creative Organizing
4. Realistic Delegation
5. Follow Up on Delegation
6. Effective Communication
7. Adequate Common Sense

Leadership Qualities. An effective leader has the ability to bring about "people changes," and to persuade/motivate them to a work performance which they would not normally attempt. Good leadership qualities generally depend upon:

1. Liking People.
2. Being an Educator (With the use of "empathy")
3. Having an attitude for action
4. Desire to excel (To be "the best")

5. Experience (To determine "cause and effect")
6. Taking Risks (With appropriate analysis)
7. Sensitivity and Self Esteem
8. Being Honorable (Lack of trust is very "destructive")
9. Outstanding Leadership can lead to Inspiring Individuals
10. Patience and perseverance.

Effective Communication Capability. This is generally achieved with the following skills:

1. Understanding basic human behavior
2. Writing: structure, style, discipline
3. Reading: speed and retention
4. Speaking: eyes, hands, voice, presence
5. Listening: the "communication gap"

DEVELOPING PROJECT OBJECTIVES AND EXECUTION PLAN

In order to ensure that the project meets the performance specification and financial requirements of the client, it is important that specific qualifying objectives be established as soon as possible. The first part of defining the scope is to determine the division of responsibilities between the client, contractor and subcontractor. Figure 1-1 illustrates the responsibility determination which needs to be made for an engineering, procurement and construction project. It is important to include a design criteria and an abbreviated key date schedule when scoping the project. Schedule considerations are outlined in detail in Chapter 3.

DEFINING THE SCOPE OF WORK[1]

More than any other segment of the project documents, the scope of work is the key to a project's success. It must contain a precise description of the project, defining the proposed work as completely as possible. The scope of work must give company management, the project team, and the contractors, a clear picture of

[1] **How to Manage Successful Construction Projects, Thomas W. Dickson. Reprinted from *Plant Engineering*, March 27, 1987. © By Cahners Publishing Company.**

Figure 1-1. Responsibility Determination for
An Engineering and Construction Project

Activity	Client	Contractor	Submntractor
1. Survey of Site Location and Soil, Contour & Elevation (Soil Report)			
2. Site Preparation			
2.1. Clearing			
2.2. Fill			
2.3. Removal of Obstruction			
2.4. Excavation			
3. Permits (Environmental/Regulatory)			
4. Construction Utilities			
4.1. Water			
4.2. Steam			
4.3. Air			
4.4. Electric Power			
5. Furnish Construction Temporary Facilities			
5.1. Roadway, Railspur. and Docking Facilities for Receipt and Unloading of Materials			
5.2. Security Service			
5.3. Construction Parking			
5.4. Access			
5.5. Laydown Areas			
5.6. Field Office			
5.7. Warehouse			
5.8. Camp Facilities (Overseas Location)			
5.9. Temporary Design Office (for major			
6. Design Engineers			
6.1. Electrical Engineers			
6.2. Mechanical Engineers			
6.3. Piping			
6.4. Process Enaineers			
6.5. Civil/Structural Engineers			
6.6. Architectural Engineers			
6.7. Instrumentation			
7. Purchasing			

(continued)

Activity	Client	Contractor	Subcontractor
8. Expediting Purchase Equipment			
9. Equipment Inspection			
10. Transportation Management			
11. Contracting			
12. Start-up Engineering Commissioning			
13. Spare Pans			
14. Operating Manuals			
15. Furnish & Install Charge & Materials			

what is required of them, the services each will provide, and the type of support each can expect from the plant or the company.

The scope of work has a twofold function. It is an internal contract with the company's management on the project's objectives and the basis for prebid conferences with potential contractors. For this reason, the scope of work should be developed with input, review, and approval by company management, engineering, maintenance, and operations.

In addition, the scope of work is a public source document for prospective contractors that delineates construction details and the level of management required to perform the work. This section should, therefore, be written in a positive tone that will encourage successful contractors to become contributing members of the integrated project team. Regardless of the type of project, the scope of work must contain certain kinds of information (see accompanying Figure, "Defining the Scope of Work") Figure 1-2.

MINIMIZING PROJECT RISK[2]

Once the Division of Responsibilities and Scope of Work are defined the project risk will be minimized. One of the key elements for a project's success lies in the project manager's ability to identify and equitably distribute risks during project development.

The project manager should define responsibilities of each project participant as illustrated in Figure 1-3.

[2] Participant Cooperation Eases Project Risk Management. R.S. Madenburg and M.C. Humphre, *Power*, June 1986.

Figure 1-2. Defining the Scope of Work

This document must contain a precise description of the project, defining the proposed work as completely as possible. The scope of work defines what is required of all parties in the project, the services that each will provide, and the type of support each can expect from the plant or company. The scope of work should always contain certain types of basic information.

Brief description of the plant where the work will be performed

Historical outline of developments that have led to the decision to proceed with the project

General description of the project and its objective–a technical definition of the project that includes project characteristics, design criteria, and building descriptions

Location of project

Project organization

List of services to be provided by the plant (engineering office space, water, electricity, etc.), procedural control, and work coordination

Duration of project

Brief description of construction practices and labor market in area

Initial engineering and purchasing schedules

Type of contract required for contractors

Detailed drawings, sketches, and specifications that describe the project or work required

Procedures. schedules, quality requirements, performance reports, and final report required from contractors.

Figure 1-3. Responsibilities of Project Participants Are Defined by Roles in Operation

Owner owns the physical **plant, furnishes or** arranges financing, provides site and access, acquires permits and licenses, uses project tax benefits and cash flow, and contracts for all necessary goods and services. By default, the owner assumes all risks that have not been assigned to or assumed by others.

Architect/engineer provides preliminary engineering and detailed design, specifies and may procure major engineered items, and may provide construction-management services.

Constructor furnishes materials and equipment not procured directly by the owner or engineer and erects the facility as designed by the engineer.

(continued)

Process vendor provides the process technology, may furnish equipment, supervises equipment and plant startup and performance testing, guarantees process performance, and supervises the training of operations personnel.

Operator operates and maintains the plant, coordinates acquisition of fuel and feedstock supply, disposes of wastes, and provides operational review of facility design.

Suppliers furnish fuel and utilities as specified for quantity and quality. Usually the owner or operator will require a "put-or-pay" contract which unconditionally guarantees the supply of fuel or feedstock to the project for a specified term.

Product purchaser buys the items produced by the project–for example, steam and electricity. A single purchaser may enter into a "take-or-pay" or "take, if tendered" agreement with the facility owner, or the product may be placed on the commercial or consumer open market.

Financier provides for full or partial funding of the project, which may involve construction and take-out financial rating, and represents the project in the solicitation of stock or bond offerings. A financier may have a limited ownership interest in the project.

Insurance underwriter insures the nonspeculative risks–those risks where there is a chance of financial loss but no chance of gain.

Risks are those situations or events arising during the execution of a project which may adversely affect its financial success. Risks may be either inherent or artificial. Inherent risks are those that arise from the nature of the project. They are usually allocated according to each participant's role. Artificial risks arise from the relationships between participants and from attempts to transfer risks among them without sound reasons.

IDENTIFYING RISKS

Certain inherent risks are controllable and should be assigned to the participants who are best able to exercise control over the situation. Other inherent risks are beyond the control of any participant. The following lists some of the major areas where inherent risks are found:

- Engineering.
- Codes and regulations.
- Construction.

- Schedule.
  Site conditions.
- Labor.
  Operations.
  Casualties.
- Financing.

Allocating risks to participants who are best able to control events is illustrated in Figure 1-4.

Figure 1-4. Allocate Risks to Participant Best Able to Control Events

Risk Element	Responsible Party: Owner	Engineer	Constructor	Process vendor	Operator	Mitigation method
Engineering, construction related:						
Process technology selection	P[1]	S[2]		S		Preproject analysis
Design of system involving new technology		S		P		Contingency allowance
Design errors and omissions		P				Insurance
Design chances	P	S		P		Contingency allowance
Ambiguous specifications and plans		P	S	S		Contingency allowance
Mechanical completion		S	P	S		Contingency allowance
Completion by date certain	S	S	P	S		Contingency allowance
Unknown site conditions	P	S	S			Preproject analysis and contingency
Unilateral owner-directed changes	P					Contingency allowance
Natural disasters	P				S	Insurance
Court injunction, war, or civil disturbances	P					Contingency allowance
Patent infringement		S	S	P		Contingency allowance
Coordination of subcontractors and suppliers			P	S		Contingency, related project experience
Labor disputes	S		P	S		Contingency, related project experience
Labor productivity			P			Contingency, related project experience
Changes of law	P	S	S	S	S	Preproject analysis and contingency
Inability to meet performance specifications		S	S	P		Contingency allowance
Operations related:						
Selection of O&M contractor	P					Preproject analysis
Higher than expected O&M cost	S			S	P	Contingency and contractual incentives
Changes in supply and character of fuel	P				S	Preproject analysis

(continued)

TABLE 14 (continued)

Risk Element	Responsible Party: Owner	Engineer	Constructor	Process vendor	Operator	Mitigation method
Process performance		S	S	P	S	Contingency
Change in price of utilities	P				S	Contractual incentives
Chanaes in environmental, health, and safety regulations	P				S	Contingency allowance and preproject analysis
Availability of plant	S				P	Insurance, contractual Incentives
Natural disasters	P					Insurance
Increases in taxes	S				P	Contingency allowance
Increases in insurance premiums	S				P	Contingency allowance
Poor management and operations					P	Contractual incentives
Financial related:						
Changes in tax laws	P					Contingency allowance opinion of tax counsel
Financing availability, cost, arbitrage	P		P	P		Preproject analysis
Inaccurate cash-flow projections	P	S				Contingency allowance
Changes in interest rates	P					Contingency allowance
Adverse IRS determination	P					Preproject analysis
Revenue shortfalls from general economic factors	P					Contractual incentives

[1]P = Primary responsibility [2]S = Secondary responsibility

Engineering. The engineer is responsible for exercising the skill and diligence that is normally rendered by a reputable professional engineering firm under the circumstances. Mistakes resulting from a failure to perform to this standard are commonly termed "errors and omissions." These can result in costly change orders, damage to equipment, or injury to persons.

Engineering errors and omissions are controllable by the engineer, who should assume responsibility for this risk. However, the potential financial exposure arising out of this risk is much greater than the revenue normally available from the engineer's work. The engineer's fees will usually not exceed 5-8% of the total cost of the project, while the damages resulting from an engineering error may well exceed the total project cost. This exposure is reflected in the high premiums for professional-malpractice insurance, and it is included in the rates charged for engineering services.

Mistakes can occur even though the engineer is not negligent. Historically, this has been the owner's risk because the engineer is obligated only to perform with ordinary engineering skill and diligence. Therefore, the owner should determine whether the engineer will be willing to guarantee the work. If so, the remedy to the owner is clear. In most cases, however, engineers will limit responsibility to reperforming the defective engineering only. They will not assume liability for any resulting loss or damage. Furthermore, engineering guarantees are not insurable—professional liability insurance will cover only actual negligence.

To enable the engineer and other project participants to work at the lowest reasonable price, the owner should require that each participant indemnify the others from exposure to lawsuits arising from his work. Whenever something goes wrong on a project, all participants are named in the resulting lawsuits, regardless of any actual participation in, or responsibility for, the claimed wrong. This arrangement, called "cross indemnity," causes the participant who is at fault (or who has contractual responsibility in the matter) to bear the burden of defending the other participants and of paying any resulting damages. An owner should not contract with any participant refusing to agree to such an indemnity.

An exception to the above approach occurs when the owner agrees to furnish a "wrap-up" program, which insures all participants. Such a program can result in significant cost savings. Wrap-up programs usually do not include professional-malpractice insurance for the engineer or other participants rendering professional services. If a wrap-up program is used, the owner should avoid assigning risks to participants who are covered under the program. Otherwise, the desired cost savings will not be realized; in fact, project cost will be greater because of duplication of insurance coverage.

Codes and regulations. The engineer is responsible for the application of the proper technical codes and for facility-safety and environmental regulations. To identify applicable regulatory requirements, the engineer will probably consult with an industrial underwriter during the development phase of the project. Additional consultation with environmental, health and safety, and building officials at the local, state, and federal levels is essential. The engineer must also rely heavily on working experience with similar projects, as well as on research and sound judgment, to define the applicability of codes to the project. Overkill through the application of inappropriate codes and regulations increases project costs without adding value.

Construction bid prices are directly dependent on the contractor's perceived abilities to forecast, assess, and manage those elements of exposure that are directly under its control. Normally, construction cost overruns are attributable to inaccurate estimation of construction requirements. Inaccurate estimates result from inadequate or premature scoping of the project. For example, design or specifications may be inadequate; vendors and contractors may not be committed to fixed-price contracts; or contingency allowances, engineering changes, or site conditions may not have been adequately foreseen.

Fixed-price construction affords the owner and financier some protection against cost overruns by placing responsibility for construction, as specified in the engineer's design, on the construction contractor. However, the contractors bidding on fixed-price jobs normally assess the risks and add a contingency factor to their bids. For risks that are within the contractor's control, contingency amounts will be at a minimum. For risks that are beyond the contractor's control, contingency amounts can approach the full cost of occurrence of the risk. The owner pays for the risk whether it occurs or not. If the risks no not occur, the contractor realizes more profit.

In the reality of the marketplace, however, a contractor who prices each and every risk into a bid will not win the job, since other contractors may be willing to accept some risks in order to secure the work. In today's highly competitive construction market, owners are able, therefore, to shift substantial uncontrollable risk to contractors with virtually no price impact. If a contractor does not have the financial wherewithal to overcome the occurrence of a substantial risk event, the owner may have to assume the resulting additional cost. To prevent this strategy from backfiring, an owner should assign to the contractor only those risks that are within the latter's control. This includes taking the time to ensure that construction bidding documents are complete and unambiguous.

If the owner desires to minimize the duration of the project by "fast tracking '—starting construction before design is complete—

a form of cost-reimbursible construction contract should be used, and should include bonus/penalty incentives to motivate the contractor's performance. **A** hybrid form of contract may also be used, where the contractor fixes the price of those elements that can be estimated while the balance of the work is performed at unit rates or cost reimbursible subject to performance incentives.

Schedule. Delays in the completion of a project result in increased interest and overhead expenses, a general escalation of construction costs, and lost revenue from lack of production. Delays can result from such conditions as poor design or construction management, inadequate scheduling estimates, labor strikes or slowdowns, unanticipated site conditions, delays in delivery of equipment, or defective equipment. Completion of project milestones on schedule is essential, since meeting debt-service requirements usually depends upon the generation of revenues on a predictable and timely basis.

The project schedule must be realistic. If construction is broken up into packages in an attempt to maximize competition and the use of local resources, the schedule must be sufficiently detailed to promote the proper coordination and interfacing of the various contractors. This often requires the services of a construction manager who understands the construction process and how to manage and coordinate contractors.

Site conditions. The risk of unknown site conditions can be minimized by making a thorough geotechnical evaluation of the site during the project-development phase. Engineers and constructors must protect themselves against exposure to risk resulting from subsidence, dewatering problems, compaction, archaeological finds, nonrecorded obstructions, and other unknown conditions, by prequalifying the site with assumed site conditions.

If the owner allocates the risk of site conditions to the construction contractor without furnishing sufficient information on surface and subsurface conditions, or if information furnished is disavowed by the owner, contractor contingencies will be at a maximum. This is a risk that is uncontrollable, and thus is best assumed by the project owners as a part of the speculative risks of the venture. Contingency amounts will then be within the control of the owner, thereby avoiding any cost increases for the risk of conditions that may not arise.

Labor. Because the financial impact of a labor dispute can be so serious, it is essential that the constructor and construction manager have a thorough understanding of site labor conditions, local work rules, and craft jurisdictional policies. Labor risks can be minimized by negotiating a project work agreement with local craft and by coordinating labor jurisdictional areas among the various crafts prior to the start of work.

Work stoppages and labor disputes are frequently attributable to the actions of the construction contractor. The construction contract should specify no relief for labor actions that could have been avoided or that do not actually impact the contractor's ability to complete the work as scheduled. Likewise, stoppages that are beyond the contractor's control should be shouldered by the project owner.

The project owner should determine when the contractor's labor agreements will expire. He should also decide whether to assign the risk of wage increases to the contractor, or assume it himself in order to minimize contingency pricing.

Operations. After construction and acceptance testing, operational risks—the possibility that the facility will fail to provide expected levels or revenue—become the area of major concern. Events and conditions that can affect the flow of revenue during operation include improper operation, poor maintenance, disruption or changes in the character of the fuel supply, employee work stoppages, natural disasters, condemnation by a public authority, or changes in health, safety, and environmental regulations.

For a state-of-the-art facility, performance is the most pertinent concern. The facility may fail to perform as specified despite proper design or workmanship, because the process itself is not viable or cannot be scaled up as anticipated. This is the entrepreneurial risk that is usually assumed by the owner of the technology.

Casualties. The construction or operation of the facility can be disrupted by casualty occurrences or force majeure events: fire, flood, tornado, earthquake, or accident. These are the nonspeculative risks that are usually covered by liability or property-damage insurance. The owners must coordinate the insurance coverage of each participant and specify detailed insurance requirements so that there will be no unintended gaps. In addition to property-damage insurance, the owner should consider procuring business-interruption coverage for the loss of revenue or increased costs resulting from loss or damage to equipment and structures.

Financing. The financing entities must be assured of the timely repayment of project debt, both interest and principal. The cost of financing the project will vary in proportion to the financier's perception of such assurances, as well as financial market conditions. For proven technology, a nonrecourse debt (not backed by guarantee) may be available at near prime rates. Anything less than a full feeling of assurance will raise the financing rate or require some form of independent guarantee or collateral. Additional areas of major financing risk include adverse IRS determination of tax benefits, revenue shortfalls resulting from the general condition of the economy (such as double-digit inflation or reduced product demand), lack of credit-worthiness or experience history of project participants, and availability of insurance.

Other project risks can be artificial and unnecessary. Such risks may be introduced into the project through ambiguous contract language, poor communication among project participants, failure on the part of some participants to meet contractual obligations, poor contract administration, or improper coordination of contractual obligations such that essential work is not performed. Artificial, or contractual, risk is also introduced through the use of onerous contract terms which require a participant to accept an unmanageable risk, or it may arise because there are too many parties to the contract, or the parties are incompatible. In addition, a participant may assume certain risks contrary to intent or without realizing it. Statutory or common-law assignment of liability may be unanticipated or improperly addressed, or the party who has accepted the risk may lack sufficient assets to make good on its obligations.

Managing risks. The first step in risk management is to reduce or mitigate it to the greatest degree possible. Start by segregating the speculative risks from the nonspeculative risks. Recall that nonspeculative risks are those that threaten loss and offer no potential for gain—such as natural disasters or other casualty loss—and are generally insurable. Speculative risks offer the risktaker economic gain in return for effective performance and proper risk management. Good management and prudence are the risktaker's insurance against loss.

To minimize the impact of uncertainties, project participants must recognize risk elements, understand risk accountability, know how to manage risk effectively, and be able to share risk equitably through the contractual process.

A clear definition of each participant's role and responsibilities is essential when assigning risks. This is especially true in situations where one party may assume multiple roles, as in the case of an engineer/builder/operator, or where financing agreements dictate who assumes the various responsibilities. All too often the task of role definition is overlooked in the initial enthusiasm and accelerating momentum of the project. Role definition is a complex task that requires much thought and the input of all potential participants. It can serve to identify many of the project risks and provide a basis for risk allocation that has the support and acceptance of all project participants. Figure 1-4 broadly outlines each participant's responsibilities.

Any exposure to risk must be commensurate with the benefits to be derived from participation in the project. The role-analysis process should result in a careful and rational determination of which participants are best suited to assume each specific risk. It is essential that the participant who can best control the outcome of an event or task be assigned responsibility for any associated risks. Even so, there is a trend among owners to shift risk indiscriminately to other participants. Yet if any risks are assigned without regard to a participant's ability to control them, the project may be needlessly jeopardized.

Naturally, each participant will want to protect his own interests. A governmental owner does not want to obligate the tax base and wants the project to be totally self-sufficient; the engineer and constructor want to receive reasonable compensation for their services; the financiers want to be assured of timely payment of principal and interest. However, risk mitigation is a give-and-take situation. If the project is to have optimum chance of success, all parties must see a potential financial gain equal to their risk exposure.

Use the following guidelines and Figure 14 to assist in making a rational allocation of project risks among the project participants:

(1) Allocate sufficient risk to participants to motivate them to perform properly.

(2) Consider the degree of control over the risk to be allocated

when assigning risk responsibility.

(3) Consider the participants' abilities to control risks allocated to them.

(4) In general, allocate risks of a national or international character (such as a currency devaluation or an oil embargo) primarily to the project owner.

(5) Share mutually dependent risks on a preselected, rational basis, rather than overlapping. This will prevent conflict and inadvertent assumptions of loss because of inability to determine fault.

Once risks are at their minimum, the next step is management. Each participant should approach each risk situation aggressively and in a manner that will reduce the probability of its occurrence and/or minimize its impact should it happen. Techniques for risk management include:

- Obtain firm price quotations from vendors and contractors for all major engineered items.
- Perform sufficient preliminary engineering during project development to clearly define scope and identify inherent risks.
- Assign risks prudently by means of appropriate contractual formats. Various formats range from fixed-price- through full-cost-reimbursible- to incentive-type contracts.
- Dedicate specific contingency budgets and reserve margins to each risk area.
- Use outside consultants to evaluate risk, identify potential cost impacts, and develop contingency plans.
- Investigate the reputation and financial stability of all project participants.
- Conceptualize the project thoroughly so that all objectives and restraints are understood by all participants.
- Make certain that no risk, unless purposely shared, is included in more than one participant's scope of responsibility.
- Re-evaluate potential risk situations as the project progresses.

Commercial insurance is available to protect project participants from the economic consequences associated with nonspeculative risks. Insurance policies vary in terms of coverage, and should be closely scrutinized to see just what is being insured, both in terms of the actual property or persons protected and the events being insured against. Figure 1-5 outlines insurable risks and applicable coverages.

Warning: Do not overinsure. Insurance is intended solely to protect project participants from catastrophic financial losses. Deductibles and limited cost sharing with the underwriters will keep premiums low while providing needed protection. Contingency allowances should include insurance deductibles. Overuse of insurance as a mechanism to reduce risk increases project costs without benefit.

Project insurance requirements must be coordinated with experienced financial advisors, and must be consistent with the overall exposure of the project participants.

Figure 1-5. Insurance Covers Losses from Nonspeculative Risks

Exposure	Insurance coverage
Repair or replace damaged equipment	Property damage/Builder's risk/Transit
Pay for continuing expenses and lost revenue while repairs are being made	Business interruption
Pay for continuing expenses if procured equipment is delayed by an insured peril	Contingent business Interruption/Extra expense
Protect against legal costs and judgments to third parties	Comprehensive general liabilitv
Provide funds if a contractor or vendor fails to perform within the scope of this responsibility	Performance and payment bonds
Pay for project expenses resulting from uncontrollable circumstances	Cost overrun/Delayed opening
Pay project equity participants if tax credits are recaptured by IRS because facility is destroyed	Investment-tax-credit recapture
Modify the plant to meet specified performance guarantees	Efficacy*
Pay debt service while plant operates below specified performance levels	Efficacy*
Pay for damages caused by engineering errors or omissions	Professional liability
Injuries to employees	Workers' compensation

*Efficacy insurance market is limited, with large deductions and high premiums

COORDINATION PROCEDURES

In order to keep a project on schedule it is important to develop document and action schedules which define every drawing, specification and equipment purchase and indicate time for client approval and status of activity. Typical guidelines for developing procedures and controls for drawings and equipment are illustrated in Figures 1-6 through 1-7. Chapter 7 includes additional controls such as Figure 7-2, Engineers/Drawing Status Report.

These documents should form a basis for weekly review meetings with all those responsible for the work. Any slippage of activity should be noted at the meeting and discussion should center on how to bring that activity up to the current schedule.

To expedite client approval a time period of ten working days after receipt of drawings should be stated for client comments. If comments are not received within this period, client approval is assumed.

Another key element is to define who should receive documents and which engineering or construction group needs to review the material. The coordination procedure may also cover other items such as contract agreements, contractural relationships and subcontractors. Proper planning and control procedures developed at the start of a project are essential for its success.

Figure 1-6. Outline for Coordination Procedure
For Engineering/Construction Projects

1. Design Basis
   This section outlines basis for design including ***applicable references*** to client specifications, scope of work documents and applicable codes.
2. Responsibility Determination - Refer to Figure 1-1
3. Drawings, Specifications and Models
   - 3.1. It is important to determine early which phase of the project will utilize a scale model instead of drawings.
   - 3.2. A section of the administrative procedures should detail what type of drawings will officially be issued for client approval. Typical key drawings requiring client approval are: Heat & Material Balances, Process Flow Diagnosis, Plot Plans, Piping & Instrument Diagrams (P & I.D.s), Electrical On-Line Diagramming, Building General Arrangements and Preparation Drawings. A period of ten working days after receipt of draw-

ings should be indicated for client comments. If comments are not received within this time period, approval is assumed.

3.3. Similar to paragraph **3.2,** client approval on specifications should be detailed.

3.4. The administrative procedures should outline distribution of drawings and specifications to the client's

3.5. A simple drawing and specification numbering system should be outlined. In addition, a consistent numbering system for equipment, piping, etc., should be stated.

3.6. **It** is also advisable to indicate the size of drawings to be used and title how the drawing title block will be displayed.

4. Manufacturer's Drawings & Purchase Orders

4.1. A section of the procedures should address bid evaluation requirements for equipment.

4.2. Each purchase order for equipment will require manufacturer to submit specified drawings and details. Certain drawings will require approval prior to fabrication.

5. **Scope of Work Changes**

5.1. Any change which affects the scope of work needs to be in writing. It is important that the effect of the change on schedule and price be documented to the client before work proceeds.

6. Monitoring and Control Documents

A combination of reports and controls insure that the project management objectives are met. Depending on the complexity of a project additions or deletions from the below control documents should be made.

6.1. Schedules: A key date schedule indicating major milestones in engineering **and/or** construction progress should be issued and updated as changes are made. In addition, a detailed schedule of design discipline **and/or** construction activity is required.

6.2. Equipment status control: Delivery of equipment greatly impacts on the overall schedule. Amonthly control should be prepared indicating required and actual dates for equipment quotations, purchases and delivery. (Refer to Figure **1-7)**

6.3. Drawing and Specification Control: All drawings and specifications should be listed. Next to each drawing and specification scheduled start and completion dates should be indicated. Actual start and completion dates and each time the drawing is revised should also be so detailed.

6.4. Progress Control: A summary of engineering and construction progress should be issued monthly. This control usually includes information on schedule, cost forecasts and any change affecting the project.

7. Distribution of Documents
   Administrative procedures should indicate distribution of letters, drawings, specifications, etc.

8. Correspondence Procedures
   8.1. In general, all correspondence shall indicate Job No. and include a consecutive number for each type of correspondence. A typical heading is as follows:

   Subject: Project No. ____________________
   Client's Name ____________________
   Letter Subject ____________________
   Letter No. L-100

   8.2. All conference and telephone conversations to be confirmed.

9. Security
   9.1. It is important to define any special security measures including who has access to information, client confidentiality and other procedures which must be implemented.

To build "quality" into a project, organization is a demanding task and requires good coordination and communication from all participating groups and individuals. Communication skills of the project staff are essential. Two organizational approaches have governed most engineering-construction projects, namely the Matrix/ Departmental Approach and the Team Approach.

THE MATRIX/DEPARTMENTAL APPROACH

This organizational method in its simplest form has each department physically separated from each other. Individual members of a design discipline, for example, electrical department, can work on many small projects at a time. Information flows down from either the chief department head or his assistant to members of the department. Figure 2-1 illustrates typical project organization using this approach.

The assigned project manager needs to be the key catalyst in making sure that project objectives, schedules, budgets and information between the many groups are will communicated and coordinated. The advantage of this organizational method is the economic utilization of the design/service groups on many small projects at the same time. The primary disadvantage is that communication and coordination of information may be hindered since departments are physically separated and information flows down through design/ services supervisors. Allegiance of personnel is primary to the department for which they work. This loyalty to the department rather than to the project sometimes causes friction between departments on a project. For example, coordination of the physical location of ducts, piping and electrical wireways may involve three departments. It is critical that compromises be made so that there are no interferences between routing of ducts, piping and electrical wireways. Many times a change in scope of one department impacts on another' department's work. Unless these departments have a good communication link, delays and cost increases could easily arise.

There are greater inefficiencies/conflicts between design, purchasing and construction groups in the matrix/departmental organization than there are between the industrial design groups. Many companies have formed "small projects departments" to reduce the problems of the matrix organization. With the matrix organization, authority/responsibility/accountability is diffused. The project manager becomes a coordinator rather than a decision maker.

THE TEAM APPROACH

The team or task force approach is highly recommended for larger projects. In this case, key members of each department are physically located in the same area. Information flows directly within the project team as indicated in the organization chart, Figure 2-2. The departmental managers act as a resource to the project team. The main advantage to this organizational structure is that it improves communication and coordination among members of the task force. Primary allegiance is to the project and not to the department. When the project is completed, the task force is dissolved and members return to the department. The primary disadvantage is that expertise among members of the department is not shared as much because other members of the department are not physically available. Also on smaller projects there may be more wasted time. The individual assigned is only working on one project at a time and when there is a delay in an activity the individual may not have any productive work.

There are many variations in the above organizational structure that can improve efficiency. If there are several smaller projects of a similar nature a task force can be formed to simultaneously work on these smaller projects. The "small projects" task force will gain experience on working efficiently on more than one project and yet be part of a team. The team members will get to know and understand how other members work and become more effective in communication and coordination. Another organizational structure is a hybrid between the department and team approach.

Part-time specialists are physically located with their department while members of the task force are physically located with the project team. Specialists can be brought in and out of projects only as required by the associated project engineer.

ASSIGNING TEAM MEMBERS

The project manager needs to have a keen understanding of the project's objectives in order to make sure the right organization

Figure 2-1. The Department Organization

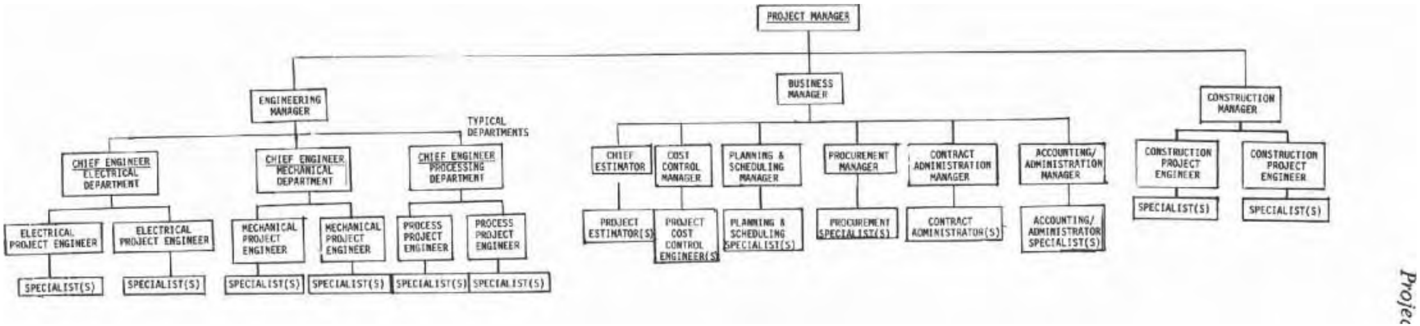
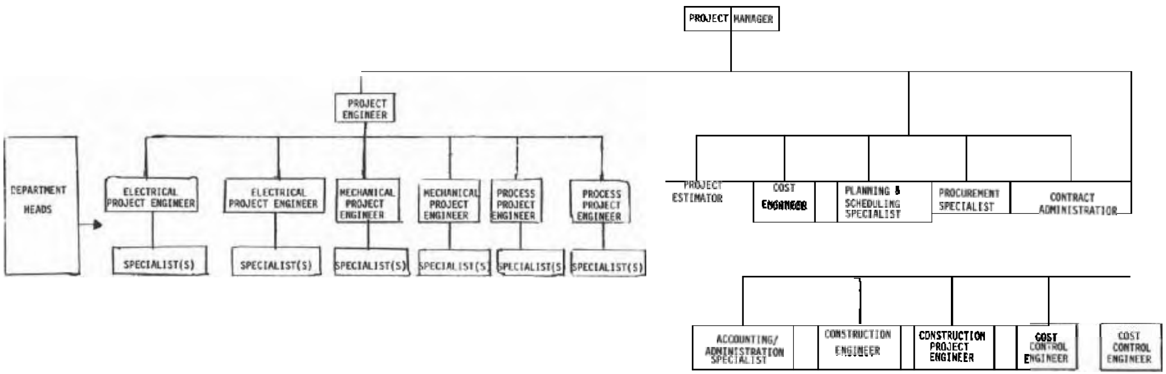


Figure 2-2. The Task Force Organization



structure is chosen. In addition, a particular project may require stronger expertise in one area. For example, the constmction of a chemical process plant would need a different team make-up than the construction of a cogeneration facility. The project manager must make sure that he works with the departmental managers to get the best possible individual assigned. Major revamps, shutdowns, and turnarounds will generally require the highest quality of personnel.

It is also essential to have a representative from the constmction and cost department on the engineering team. Constructability, access, lighting requirements and difficult site conditions must be taken into account at the beginning of the design engineering portion of the project. Impacts of design changes on the project cost must also be carefully monitored.

INFLUENCE OF SCALED MODELS

Coordination can be enhanced with the use of scaled models. The decision to use scale models should be made early in the project. Factors which influence using a scaled model include:

- Degree of piping, ductwork or electrical work in a given area
- New or retrofit constmction
- As a training tool for construction and startup

Scaled models force communication and eliminate many construction problems.

PROJECT STAFFING

Once the key dates have been established, the overall staffing can be determined. The number of manhours is estimated based on the design basis and scope of work. Depending on the number of weeks allowed to complete a project will determine the number of engineers/designers and draftsmen required. The obvious problem in staffing is how to keep the staff as small as possible to minimize overhead yet meet the demands of the overall schedule. Staffing options include:

1. Working overtime
2. Hiring job shoppers
3. Increasing permanent staff

4. Utilizing computer-aided design systems which reduce drafting and designer hours.

The staffing requirements may influence the final schedule. For example, if a project is cost-plus the client may not want to authorize working overtime or using job shoppers since they are paid premium salaries. Thus, staffing and scheduling need to be analyzed together.

Construction staffing is discussed in Chapter 3.

BUILDING AN EFFECTIVE TEAM

To build a quality facility within budget and time[1] limits, project managers need an integrated team that can work toward a common goal. **A** genuine team does not happen spontaneously, however, but is built according to certain ground rules. (Refer to Figure 2-3).

The goals of team building are to increase the cohesiveness and effectiveness of a functional work unit (FWU) within the organization while also creating opportunities through which individuals can derive satisfaction and pride in their work. Team building efforts are typically directed at a combination of three primary areas:

- Task accomplishment: solving problems, clarifying goals, establishing priorities, planning activities, allocating tasks, and using resources effectively.
- Team relationships: building and maintaining effective interpersonal relationships (between supervisors and subordinates and among colleagues and peers), improving communications, understanding and managing the team's group dynamics, clarifying mutual role expectations, and managing conflicts at interpersonal, team, and interunit levels.
- Team relations with other organizational FWUs (or external groups): clarifying the functions that must be performed by interdependent FWUs (for example, when the purchasing group must operate within the quality assurance criteria specified by production groups). It is important to ensure the efficient coordination of these functions, to identify demands being made on the FWU by "outside" individuals or groups,

[1] **How to Manage Successful Construction Projects, Thomas Dickson. Reprinted from *Plant Engineering*, March 27, 1987. ©1987 by Cahners Publishing Company.**

Figure 2-3. How to Build a Successful Team

An integrated project team is necessary to a successful construction project. Building such a team takes commitment on the part of the plant engineer, who will have to exercise certain management traits:

- Provide candid, frequent, and timely communications on job cost and schedule status, procurement problems, labor problems, organizational problems, personnel problems, etc.
- Accept questioning and penetration into job details, problems, and recommendations.
- Accept involvement in project decision making such as approval of contractor's personnel assigned to the job, suggestions, and construction techniques.
- Accept direction for change if, after discussing the subject, the project team issues such direction.
- Participate in the necessary meetings designed to develop and improve the team relationship and to establish a satisfactory level of trust.
- Determine if there is a better way of carrying out a given construction operation (managerial, operational, or clerical) and plan to study, explore, and develop potentially better ways.
- Allow the project team to operate without too much control from the home office. The home office role should be that of a consultant, providing help when required and setting overall policy. The project team should be able to handle independently the filed purchasing requirements, job cost accounting, preparation of progress reports, and in general exercise the necessary job control prerogatives.
- Understand that changes may occur as the job progresses and expect the project team to manage them.
- Develop plans for turning over various parts of the facility at different times to permit staggered check-out and operator training. Project personnel must be cooperative with engineers who are assigned to check out the facility installation and operation, and be willing to make frequent field engineering changes.
- Coordinate procedures for plant personnel to begin operations in some areas while construction is continuing in adjacent areas. Prepare to work under restrictions that may be imposed by plant management (such as "off-limits" areas, cleanliness, standards, parking locations).
- Maintain control of public relations matters such as publicity, news releases, and statements about jobsite conditions, etc.
- Be concerned continually about the impact of illegal strikes and slowdowns, and other restrictive practices, on the job cost and schedule. Expect contractors to protect their companies' interests aggressively, even to the extent of taking risks or illegal action.
- Develop "team building workshops" to develop skills in communication and breakdown barriers between departments.

and to determine whether and how to respond to those demands.

The project manager who stresses the dynamics of team building can also demand and expect a high standard of quality from his own team and from the contractors doing the work.

An individual experienced in human resource development gives the task force guidelines on how they can become more effective. The workshop leader discusses subjects such as "general semantics" and why communication breaks down. An effective way to show the group the power of effective communication is to give them a problem which tests their "working together" skills.

INTERRELATIONSHIP BETWEEN OWNER, DESIGNER AND CONSTRUCTOR

Many projects are complex and require several teams interacting together. For example, the owner may have a team as well as the constructor. The project manager has the overall responsibility of direction and management of the project team. This relationship is determined by the contract teams and conditions. There certainly may be variations on the organization and structure, but one element is clear; namely the project manager must be the focal point to insure coordination, communication and overall project management.

3
Fundamentals of Scheduling

(CRITICAL PATH METHOD [CPM] OF SCHEDULING)

CONTENTS

HISTORICAL BACKGROUND

CPM scheduling was developed in the late 1950's. It was introduced to the industry as a tool to improve planning and scheduling of construction programs. Concurrent with industrial development of CPM, the U.S. Navy introduced a similar method of scheduling called PERT. PERT is an acronym for Program Evaluation and Review Technique. The Navy developed this method to evaluate and monitor progress of the Polaris Missile Program. The major difference between CPM and PERT is that PERT is a more probabilistic approach that lends itself to activities for which there is little or no historical experience, whereas CPM uses historical information for establishing durations. Subsequent development led to a considerable amalgamation of the two methods.

It was not until 1967 that James Kelly developed the techniques of CPM as used today. He used digital computer techniques developed by Rand Corporation and applied them to a complex construction project for DuPont Corporation. This resulted in completion of a project well ahead of schedule.

OBJECTIVES OF CPM

Figure 3-1 lists the objectives of CPM scheduling. As seen from the figure, CPM can be used as a logic tool for decision-making. It provides a means for planning, scheduling, controlling and presenting alternate courses of action. It also provides a visual means of communication to Project Management and an organized approach to implement a schedule program. CPM scheduling can be carried out manually or with a computer program.

A major problem with the CPM computer programs can be the number of activities. Very large networks became the norm during the 1960's. Size, not quality, became a dominant factor and computer scheduling methods became more important than the scheduling program itself. Theory replaced practicality and, as a result, quality of scheduling deteriorated.

It was not until the mid-1970's that a proper balance of computer method and size of networks was achieved. Experience has shown than 10,000/20,000 activity networks are costly, unmanageable and inefficient. Careful prior evaluation of criticallity and networks with a maximum of 5,000 activities have proven effective.

Figure 3-1. Objectives of CPM

Plan	Communicate
• Schedule	• Organize
• Control	• Implement

TERMS AND DEFINITIONS

Figure 3-2 lists terms and definitions of typical CPM schedules. Brief definitions of each are covered with further explanations to follow.

Figure 3-2. Terms and Definitions

Activities (arrows)	An item of work, with or without its duration.
Nodes (events)	Start and finish points of an activity.
Arrow Diagram	A Network showing a logical sequence of activities and events which are graphically shown as arrows and nodes.
Restraints	Limiting activities that prevent other activities from starting. They are ***non-time consuming*** and are referred to as "dummy" or dependent activities.
Critical Path	The longest duration chain in a Network.
Early Start **(ES)**	As implied this is the earliest time that work can begin on a given activity.
Late Start **(LS)**	The latest time that a given activity can start without affecting the overall project duration.
Early Finish **(EF)**	The finish achieved by starting a given activity at its Early Start and achieving the estimated duration of that activity.
Late Finish **(LF)**	The latest time that an activity can finish without affecting the overall Project Duration.
Float	Spare time available to activities not on the **Critical** Path.
Total Float	The amount of spare time available to an activity if all ***preceding*** activities are started as early as possible and all ***following*** are started as late as possible.
Free Float	The spare time available to an activity when all activities in the chain are started as early as possible.

ARROW DIAGRAMS VS. PRECEDENCE DRAWINGS VS. TIME-SCALED DIAGRAMS

Figure 3-3 shows three methods of drawing **CPM** diagrams. Each has its pros and cons.

Arrow Diagramming, at present, seems to be the most popular method. This probably stems from the fact that it was the first method to be developed and computerized. It is also easier to associate with time and flow of job activities.

A major difficulty to arrow diagramming is the "dummy" activity. Learning the significance and proper usage of "dummies" requires time and experience. The arrow diagram is also cumbersome to modify.

The second method is Precedence Diagramming. As shown, the activities are on nodes. Length and direction of the arrows have no significance as they indicate only the dependency of one activity on another. This method is commonly referred to as "Activity-on Node."

This method has received wider acceptance over recent years. Its primary advantage is that it eliminates "dummy" activities. It is also easy to modify. Since there are no events in the "Activity-on-Node" diagrams, it is difficult to use milestones in the network; therefore, visual aspects of precedence networks are poor. As there is no dateline, it is also very difficult to view overall status.

Both methods are acceptable, however, arrow diagrams continue to have the slight edge because of early acceptance and familiarity.

The third method, showing a time-scaled network, is just a more "visual" tool of the arrow diagram. It is not designed as a tool for detailed control, but a technique to present overall schedules to management. It gives a quick and simple picture of the schedule as it relates to time, activity interfaces and criticality.

SIMPLE NETWORK

Figure 3-4 illustrates a simple network of an arrow diagram. There are three activities: **A,** B and **C.** They can be defined as follows: A is the beginning activity; B follows A but cannot begin until A is complete; and C is the final activity following the completion of B. As shown, there is a logical sequence of work starting from left to right.

Figure 3-3. CPM Drawing Methods

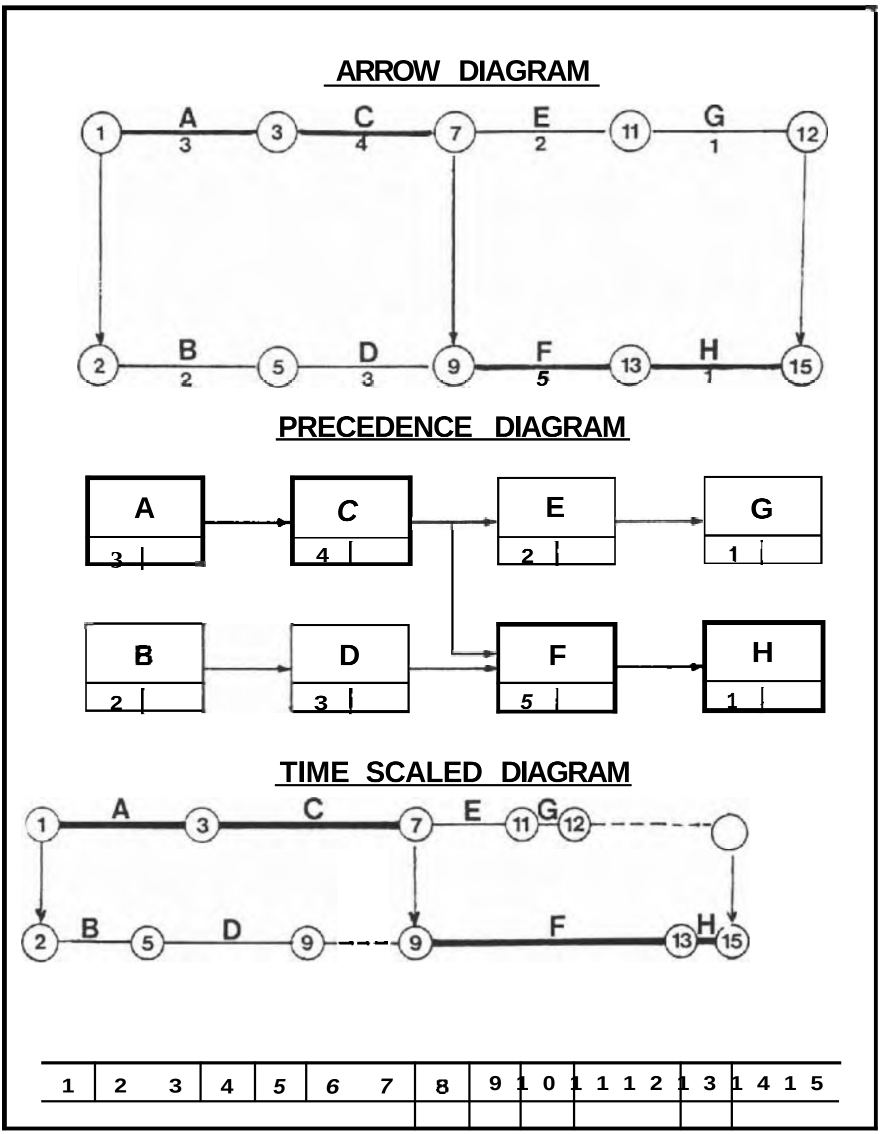
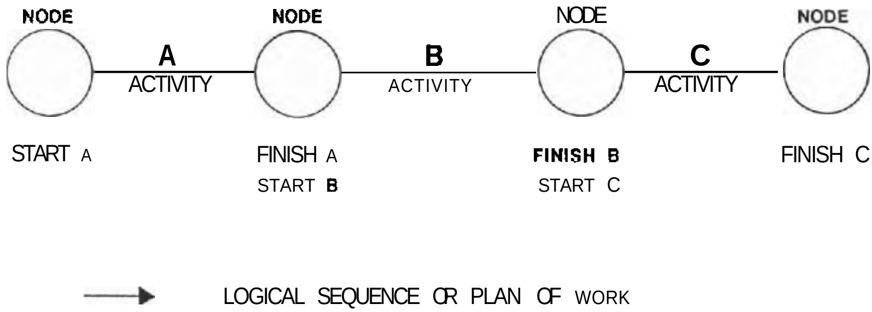


Figure 3-4. Simple Network



Problem **3-1**: Network Development

In order to develop a network, the following example illustrates the steps involved. Given the data as indicated in Figure 3-5, draw an appropriate network.

Activities must follow in a logical sequence.

Analysis

First, read through the given data and note that this in a nine-activity network. Activity A is the first activity and Activity I is the last.

Figure 3-5. Network Development Problem

Given:

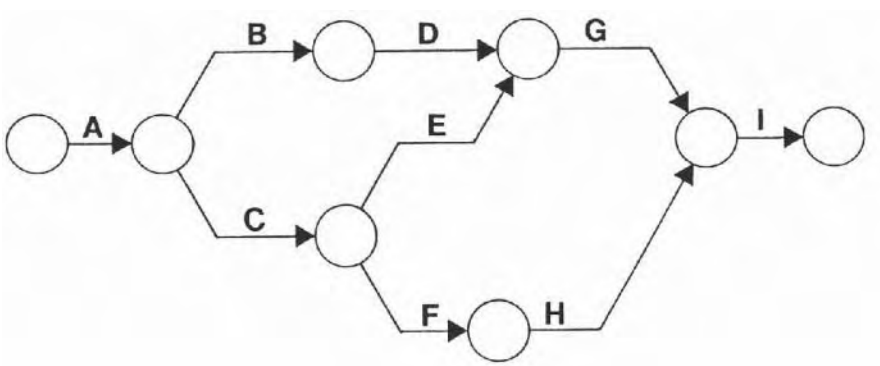
1) Activity B follows activity A
2) Activity A is the beginning activity
3) Activity C follows activity A
4) Activity C precedes activities E & F
5) Activity D follows activity B
6) Activity G follows activities D & E
7) Activity F precedes activity H
8) Activities G and H precede activity I
9) Activity I is the last activity

Draw the appropriate network.

Figure **3-6** shows the completed network diagram. Networks become more complex as activities are added and durations are established for each activity. Activity durations can be in days, weeks, or months; therefore, it is essential to determine from the outset the time scale. Logical sequence and durations for each activity can be determined by past experience or by work content in relation to available resources. This determination should evolve from consultation between the scheduler and appropriate construction and engineering personnel. It is important that an operating group concur with the schedule development, accept it as their schedule, and make a commitment to operate as per the plan and schedule. Work sequence can then be checked and durations assigned to each activity.

Figure 3-6. Network Development Solution

SOLUTION

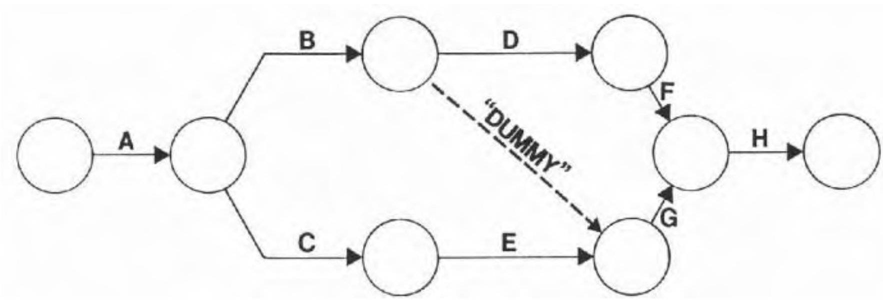


LOGIC TIES

In a given network, it is common to encounter logic ties with no durations. These are called "dummy" activities and are added to the network to portray all predecessor relationships in a graphical form. As well as being called dummies, these can be referred to as restraints.

Normally, Activity G would begin with Activity E's completion, however, the activities have been defined to restrain Activity G's start until both B and E are completed, as illustrated in Figure **3-7.**

Figure 3-7. "Dummy" Restraint Network



Problem 3-2: Network Workshop

The following example illustrates the relationship between *Activity Definition, Durations and **Dummy** Restraints.* Given the network as shown in Figure 3-8 with the durations in days already established, determine the *Critical Path.*

Analysis

The *Critical Path* as defined earlier is the longest duration chain in a logic network and it determines the total project/network duration.

Figure 3-9 illustrates the Critical Path solution. The heavy lined activities on the Critical Path are called Critical Activities. Now that the Critical Path has been determined, analysis of the network can begin.

CALCULATIONS FOR EARLY START (ES)

In analyzing a network, the first item to be evaluated is the Early Start (ES) of each activity. This is accomplished by taking what is called a "Forward Pass" through the diagram. **A** "Forward Pass" is exactly what is implied. Starting with the first event or at day 0, then following the direction of the arrows and adding the durations of each activity defines the ES of the following activity. In network analysis, this number can be enclosed in a square above the Event (Node).

Figure 3-8. Network Workshop

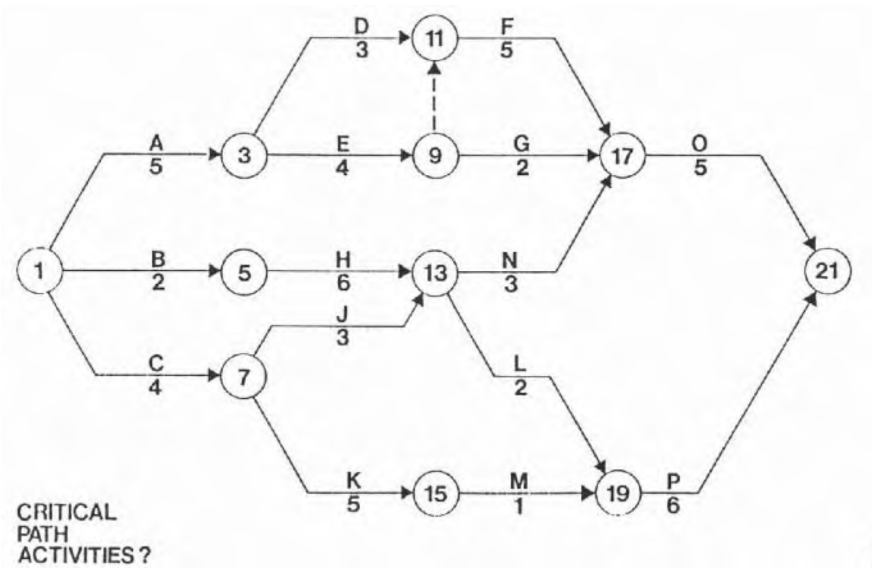
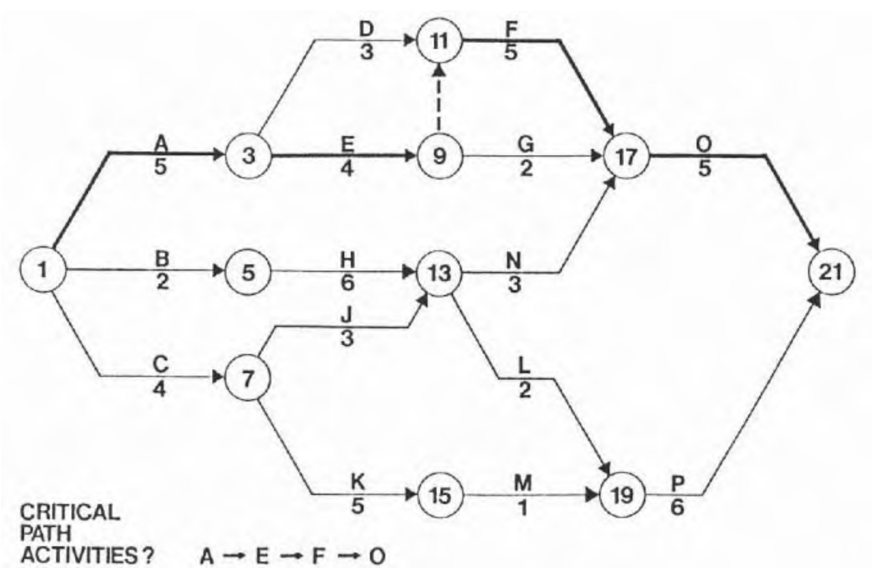


Figure 3-9. Network Workshop Solution



Problem **3-3:** Early **Start**

Given the data on Figure 3-9, calculate the Early Start of each activity.

Analysis

Working through the network it is noted that in several cases more than one activity enters a node. Since the longest path is to be determined, the ***largest number*** coming into the node should have been used in the calculation. The solution as illustrated in Figure 3-10 has a total project duration of 19 days.

CALCULATION PROCESS FOR LATE FINISH (LF)

Examination of Figure 3-10 reveals that at event 21, the Late Finish of Activities O and P has also been defined. This is a vital figure in order to calculate LF for all other activities. LF is calculated by the method known as "Backward Pass." To implement the "Backward Pass," start at the last event using the Late Finish and follow the arrows backward through the network subtracting durations to the beginning event. This then determines the LF of each activity in the network. For network analysis, this calculation will be enclosed in a circle.

Problem **3-4: Late** Finish

Given the data on Figure 3-10, calculate the Late Finish of each activity.

Analysis

Referring to Figure 3-11, working through the network again, several nodes show more than one Late Finish, since more than one activity is involved. In this case, the ***smaller*** of the numbers will be used because the Late Finish of the subsequent node has already been established. This is easy to see at Nodes 3, 11 and 9.

Figure 3-12 summarizes the results of Figures 3-10 and 3-11, so further analysis can be made. Numbers in squares show Early Start while numbers in circles show Late Finish.

Figure 3-10. Calculation of Early Start

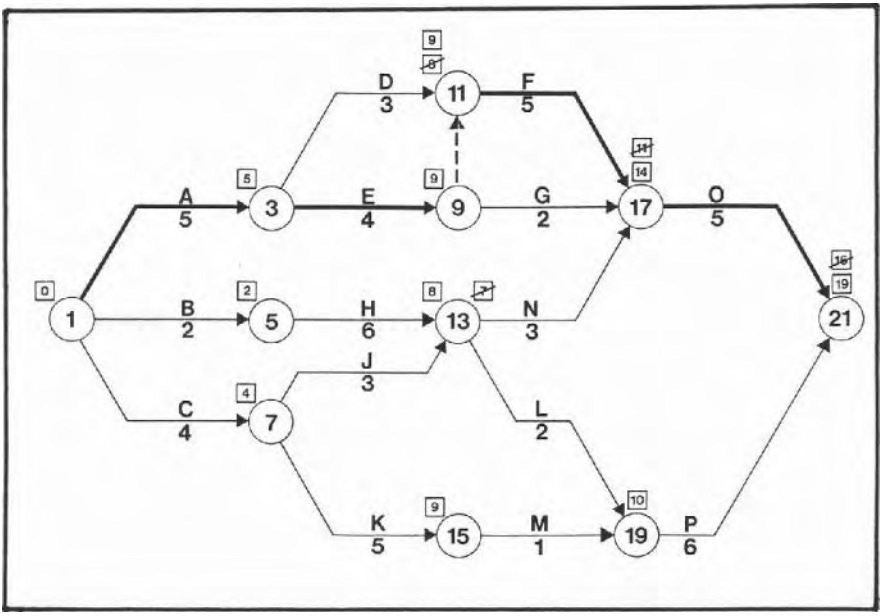


Figure 3-11. Calculation of Late Finish

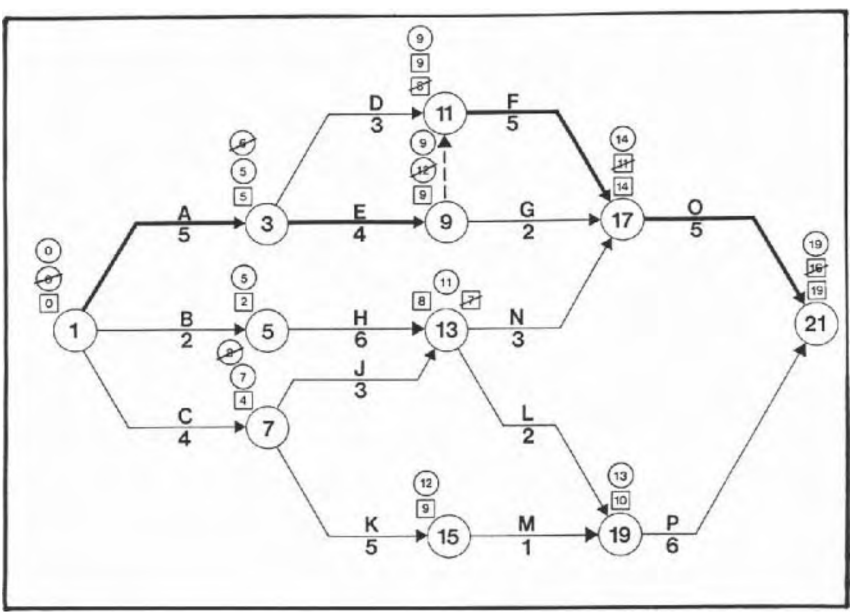
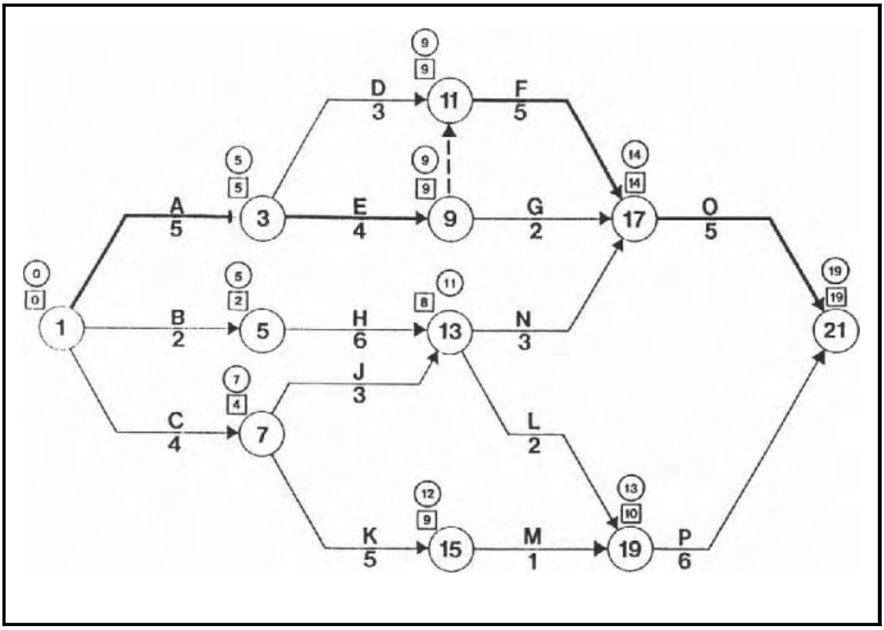


Figure 3-12. Summary of Results of Figures 3-10 and 3-11.



TABULATION SOLUTION OF DATA – EF AND LS

In order to make the calculations for Early Finish (EF) and Late Start (LS) of each activity, it is easier if the data is collected in a tabular form. Figure 3-13 also gives the formulas to calculate EF and LS.

Problem 3-5: ES and LS Calculations

Given the data of Figure 3-13, calculate EF and LS.

Analysis

Figure 3-14 lists Early Finish and Late Start by activity.

FLOAT AND ITS APPLICATION

The longest chain through the network was previously defined as the Critical Path and activities in the chain as Critical Activities. Obviously, the activities not on the Critical Path will have a certain amount of spare time by which they can be delayed and not affect

Figure 3-13. Tabulation Solution of Data

Activity Description	I	J	DUR	ES	EF	LS	LF			Critical Path
A	1	3	5	0			5			*
B	1	5	2	0			5			
C	1	7	4	0			7			
D	3	11	3	5			9			
E	3	9	4	5			9			*
F	11	17	5	9			14			*
G	9	17	2	9			14			
H	5	13	6	2			11			
J	7	13	3	4			11			
K	7	15	5	4			12			
L	13	19	2	8			13			
M	15	19	1	9			13			
N	13	17	3	8			14			
O	17	21	5	14			19			*
P	19	21	6	10			19			

Calculations for each activity

Forward Pass	= **Early Start (ES)**
Backward Pass	= **Late Finish (LF)**
Early Finish (EF)	= **ES + Duration**
Late Start (LS)	= **LF − Duration**

the project completion. This spare time was defined earlier as *FLOAT*. Critical activities are defined as those with NO FLOAT. As also noted from the Definition exhibit, there are two types of float in a network.

TOTAL FLOAT (DEFINITION & CALCULATION)

The first type of float encountered is Total Float. Total Float is defined as the amount of spare time available to an activity if all ***preceding*** activities are started as ***early*** as possible and all ***following*** activities are started as ***late*** as possible. It is calculated as follows:

Figure 3-14. Tabulation Solution of Data

Activity Description	I	J	DUR	ES	EF	LS	LF			Critical Path
A	1	3	5	0	5	0	5			*
B	1	5	2	0	2	3	5			
C	1	7	4	0	4	3	7			
D	3	11	3	5	8	6	9			
E	3	9	4	5	9	5	9			*
F	11	17	5	9	14	9	14			*
G	9	17	2	9	11	12	14			
H	5	13	6	2	8	5	11			
J	7	13	3	4	7	8	11			
K	7	15	5	4	9	7	12			
L	13	19	2	8	10	11	13			
M	15	19	1	9	10	12	13			
N	13	17	3	8	11	11	14			
O	17	21	5	14	19	14	19			*
P	19	21	6	10	16	13	19			

Calculations for each activity

Forward Pass	**= Early Start (ES)**
Backward Pass	**= Late Finish (LF)**
Early Finish (EF)	**= ES + Duration**
Late Start (LS)	**= LF − Duration**

$$\text{TF} = \text{LS} - \text{ES}$$

or

$$\text{LF} - \text{EF}$$

Consequently, from this definition it becomes obvious that TF for Critical Activities equals zero.

The network defined was a simple one and the Critical Path was easily identified, however, in complex networks, calculation of total float by activity may become the only way to locate the Critical Path.

Figure 3-15. Tabulation Solution of Data

Activity Description	I	J	DUR	ES	EF	LS	LF	TF		Critical Path
A	1	3	5	0	5	0	5	0		*
B	1	5	2	0	2	3	5	3		
C	1	7	4	0	4	3	7	3		
D	3	11	3	5	8	6	9	1		
E	3	9	4	5	9	5	9	0		*
F	11	17	5	9	14	9	14	0		*
G	9	17	2	9	11	12	14	3		
H	5	13	6	2	8	5	11	3		
J	7	13	3	4	7	8	11	4		
K	7	15	5	4	9	7	12	3		
L	13	19	2	8	10	11	13	3		
M	15	19	1	9	10	12	13	3		
N	13	17	3	8	11	11	14	3		
O	17	21	5	14	19	14	19	0		*
P	19	21	6	10	16	13	19	3		

Calculations for each activity

Forward Pass = Early Start (ES)
Backward Pass = Late Finish (LF)
Early Finish (EF) = ES + Duration
Late Start (LS) = LF – Duration
Total Float (TF) = LF – EF
or
LS – ES

Problem 3-6: Total Float

Given the data on Figure 3-14 and the formula TF = LS – ES or LF – EF, calculate total float for each activity.

Analysis

Figure 3-15 shows the solution for the total float.

Figure 3-16. Tabulation Solution of Data

Activity Description	I	J	DUR	ES	EF	LS	LF	TF	FF	Critical Path
A	1	3	5	0	5	0	5	0	0	*
B	1	5	2	0	2	3	5	3	0	
C	1	7	4	0	4	3	7	3	0	
D	3	11	3	5	8	6	9	1	1	
E	3	9	4	5	9	5	9	0	0	*
F	11	17	5	9	14	9	14	0	0	*
G	9	17	2	9	11	12	14	3	3	
H	5	13	6	2	8	5	11	3	0	
J	7	13	3	4	7	8	11	4	1	
K	7	15	5	4	9	7	12	3	0	
L	13	19	2	8	10	11	13	3	0	
M	15	19	1	9	10	12	13	3	0	
N	13	17	3	8	11	11	14	3	3	
O	17	21	5	14	19	14	19	0	0	*
P	19	21	6	10	16	13	19	3	3	

Calculations for each activity

Forward Pass = Early Start **(ES)**
Backward Pass = Late Finish **(LF)**
Early Finish **(EF)** = ES + Duration
Late Start (LS) = LF – Duration
Total Float **(TF)** = LF – EF
or
LS – ES
Free Float **(FF)** = ES (following act.) – EF (act. being calculated)

FREE FLOAT (DEFINITION & CALCULATION)

The other type of float found in a network is called Free Float. Free Float is defined as the spare time available to an activity when all activities in the chain are started as early as possible. Thus, an activity may be delayed to the extent of its Free Float. Free Float for a given activity is calculated as:

Free Float (FF) = ES (following activity) – EF (activity being calculated)

Problem 3-7: Free **Float**

Apply this definition to Figure 3-15 and calculate Free Float for each activity of the network.

Analysis

Examination of Figure 3-16 calculation reveals a general rule of Free Float, which is that Free Float occurs only when two or more activities have the same J Node.

CONCLUSION DRAWN FROM THE NETWORK ANALYSIS

It becomes obvious that in large networks with several thousand activities, it would be physically impossible to make all the calculations manually. As indicated earlier, computerization of the Critical Path Method of scheduling has solved a tremendous calculation problem. The result is a concise method of planning, scheduling and controlling major projects. However, the case of computer calculation and updating routines must not detract from the need for a cost effective scheduling program. Working at summary levels and only going into greater detail, when necessary, will usually produce the most effective program.

PRECEDENCE DIAGRAMS – TERMINOLOGY

Figure 3-17 lists terms and definitions of precedence.

The following are examples of simple precedence networks.

MAJOR PIPING MODIFICATION NETWORK

On first inspection, this logic may appear to be satisfactory with the sequence of events being as follows:

1) Install pipework
2) Hydrotest pipework
3) Install electrics and instrumentation
4) Loop check instruments

The first detail that becomes apparent on examination is that all constraints are type FS (finish to start), which means that no

Figure 3-17. Precedence Diagrams – Terminology

General

Activity	: An item of work with a clearly defined beginning and end. **e.g.,** INSTALL PUMP.
Duration	: Time required to complete an activity, **e.g.,** 5 days, 30 hours.
Event	: Indicates a specific point in the course of a project, and is shown as an activity with no duration, **e.g.,** FIRST OIL.
Constraint	: Defines the logical relationship between activities and events. This relationship is called a DUMMY in arrow networks and the subject shall be discussed fully in a subsequent section of the course.
Preceding Event **(PE)**	: Preceding activity identifier. A constraint showing the logical relationship between one activity and its previous activity.
Succeeding Event **(SE)**	: Succeeding activity identifier. A constraint showing the logical relationship between one activity and its following activity.

Constraint Types

Finish to Start **(FS)**	: This is the most frequently used type of constraint and indicates that the SUCCEEDING activity cannot start until the PRECEDING activity is totally complete.
Start to Start **(SS)**	: A constraint that indicates the SUCCEEDING activity can start immediately the PRECEDING activity has started.
Finish to Finish **(FF)**	: A constraint that stipulates the SUCCEEDING activity can only be completed once the PRECEDING activity is complete.
Start to Finish **(SF)**	: A constraint that is rarely used and indicates that the SUCCEEDING activity cannot finish until the **PRECEDING** has started.

activity can start before the preceding activity is complete. Therefore, (2) cannot start until (1) is complete. Likewise, **(3)** cannot start until (2) is complete, and also (4) cannot start until (2) is complete. (Refer to Figure 3-18).

In practice, this logic is not correct as the piping system would be divided into more than one hydrotest. This would allow hydrotesting to begin as soon as sufficient piping had been installed. The same situation would apply to loop checking of instruments. This could start once the necessary instruments and electrics has been installed.

This overlapping of activities is shown on a network by the use of SS (start to start) and FF (finish to finish) constraints as shown on the revised Figure 3-18.

REVISED NETWORK LOGIC

The revised sequences of activities as shown on Figure 3-19 are as follows:

1) Install pipework.
2) Start hydrotesting as soon as sufficient pipework is available. Pipework installation must be complete before hydrotesting can be completed. This is shown by the FF constraint.
3) Electrical installation can start when pipework installation is complete.
4) Installation of instruments can start once the hydrotesting is complete.
5) Loop checking begins as soon as sufficient instruments and electrics have been installed, but cannot be finished until after all the instruments and electrics have been installed.

The ability to further define this logic is also shown on these diagrams. This would be achieved by adding delays to the constraints as shown by the number in the parentheses. This is known as lead or lag time. Without the lead/lag times, the network indicates that hydrotesting can start immediately after the piping installation has started. This in not strictly true, as the pipework associated with any hydrotesting would have to be installed prior to the start of testing.

When a duration is added to a constraint, the start of the activity is delayed by this amount. For example, by adding a duration of 4 to the SS constraint between the INSTALL PIPEWORK and HYDROTEST activity, hydrotesting would not start until four days after the start of the piping activity.

This method of overlapping network activities is a powerful planning tool and is used extensively in all precedence networks.

Figure 3-18. Network Logic.

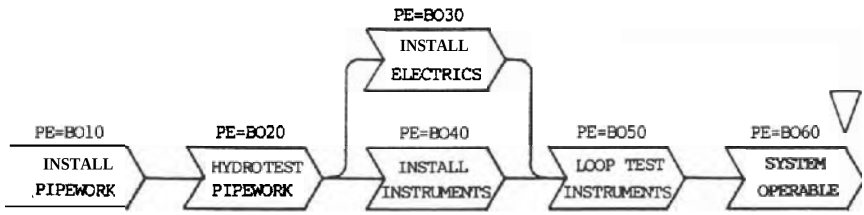
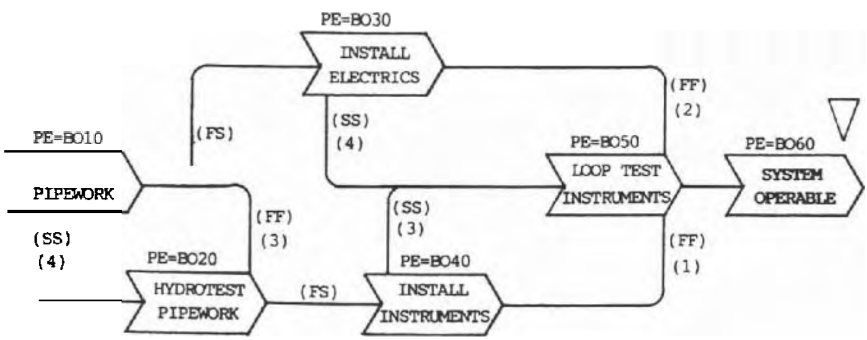


Figure 3-19. Amended Network Logic.



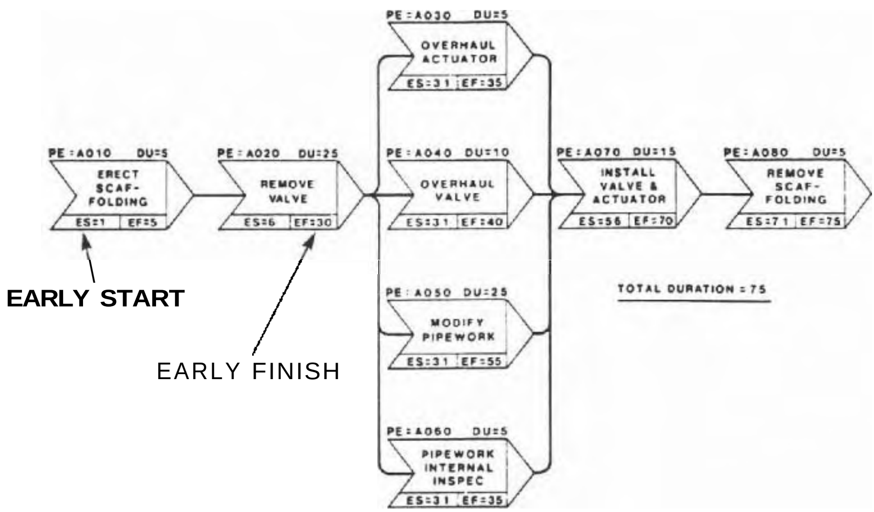
CRITICAL PATH EVALUATION

The critical path or the duration of a project is determined by calculating the longest logical path through the network. This path is determined by going through the following stages:

1) Calculating the forward pass.
2) Calculating the backward pass.
3) Calculating the activity float and determining the critical path of the project.

Each of the above stages will be examined in detail and the calculations applied to the network illustrated in Figure 3-20.

Figure 3-20. Forward Pass.



Forward Pass	:	Calculation of early start and early finish dates.
Early Start	:	Earliest time an activity can logically start.
Early Finish	:	Earliest time an activity can logically finish.
Target Start	:	Imposed start by planning engineer and means that the activity to which the date applies will not start BEFORE the time shown, but may start at a later date if the logic so dictates.

FORWARD PASS

a) **Terminology:**

FORWARD PASS – Calculation of early start and early finish dates.

EARLY START – Earliest time an activity can logically start.

EARLY FINISH – Earliest time an activity can logically finish.

TARGET START – Imposed start by planning engineering and means that the activity to which the date applies will not start **BEFORE** the time shown, but may start at a later date if the logic so dictates.

b) Time Analysis:

When drawing networks, time should always flow from left to right. It should also be remembered that when working in days, the day begins one minute past midnight and ends at midnight. Therefore, subsequent activities always start the day after completion of the preceding activity.

1. Activity A010 starts on day 1 and has a duration of 5 days. The EARLY START (ES) of this activity is 1. The EARLY FINISH (EF) is calculated as ES plus the duration, less 1, which results in an EF of 5.

2. Activity A020 cannot start until A010 is complete, therefore, A020 ES is day 6 with a resulting EF of day 30.

3. Activity A070 cannot start until all preceding activities are complete. Therefore, the ES of A070 is day 56, which is determined by the completion of Activity A050.

4. Activity A080 has an EF of day 75, which means that the project is going to take a minimum of 75 days to complete.

BACKWARD PASS

a) Terminology:

BACKWARD PASS – Calculates latest start and finish times for activities and constraints.

LATEST FINISH – The EARLIEST late start date of any succeeding constraint leading from the activity.

LATEST START – Latest finish less activity duration.

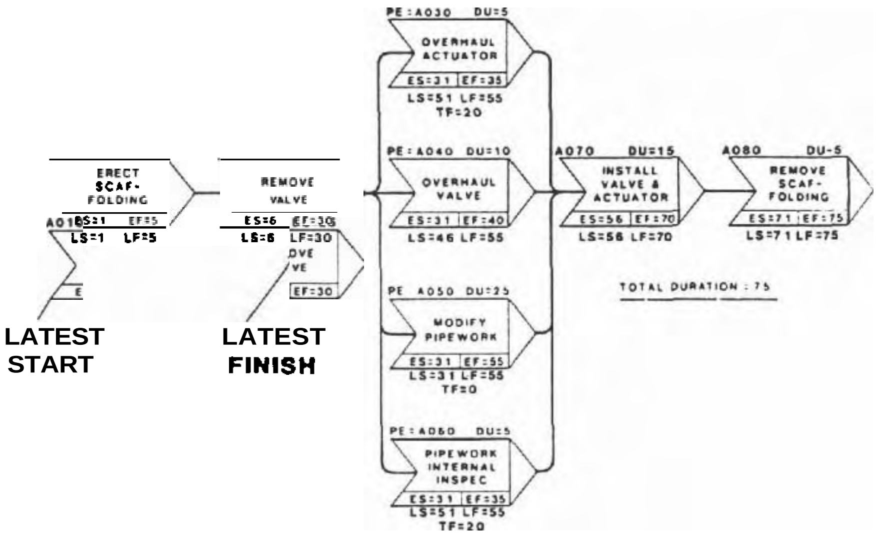
TARGET COMPETE – An imposed completion date – used to increase the criticality of an activity.

b) Time Analysis:

The backward pass calculation STARTS AT THE END AND WORKS TOWARD THE FRONT. The calculation process, therefore, starts from the final activity of the network. This should also be the last activity of the forward pass, and is the activity that determines the project duration.

In the illustrated example, Figure 3-21, A080 is the final activity.

Figure 3-21. Backward Pass.



Backward Pass	: Calculates latest start and finish times for activities and constraints.
Latest Finish	: The EARLIEST late start date of any succeeding constraint leading from that activity.
Latest Start	: Latest finish less activity duration.
Target Complete	: An imposed completion date—used to increase the criticality of an activity.

1. The EF of activity A080 is day 75, and as this is the final network activity, this is the LATEST FINISH DATE (LF). The LF date for activity A080 is entered as day 75.

2. The LATEST START DATE (LS) is calculated by deducting the activity duration from the LF. Activity A080 LS is therefore calculated as *75* less 5, plus 1, resulting in a LS of day 71.

3. The LF of activity A070 is subsequently calculated as day 70, due to the LS of A080 being day 71 and the use

of days as our unit of calculation. The LS of A070 is then calculated as day 56.

4. The LF of activities A030, A040, A050 and A060 is then day 55.

5. An examination of activity A020 shows that it has four constraints leading into it from the backward pass. The EARLIEST LS is than allocated as the LF date of activity A020. The earliest LS is the constraint leading from activity A050 with a LS of day 31. The LF of activity A020 is therefore day 30 with a LS of day 6.

FLOAT CALCULATIONS AND THE CRITICAL PATH

a) Float Terminology:

TOTAL FLOAT – The amount an activity can be delayed without impacting the end date or intermediate target date of a project.

FLOAT CALC – Total float = Late start less Early start.

CRITICAL PATH – The path through a project with zero float. Any activity delayed on this path will automatically impact the project end date.

b) Network Float Calculations:

Figure 3-22 illustrates the following results:

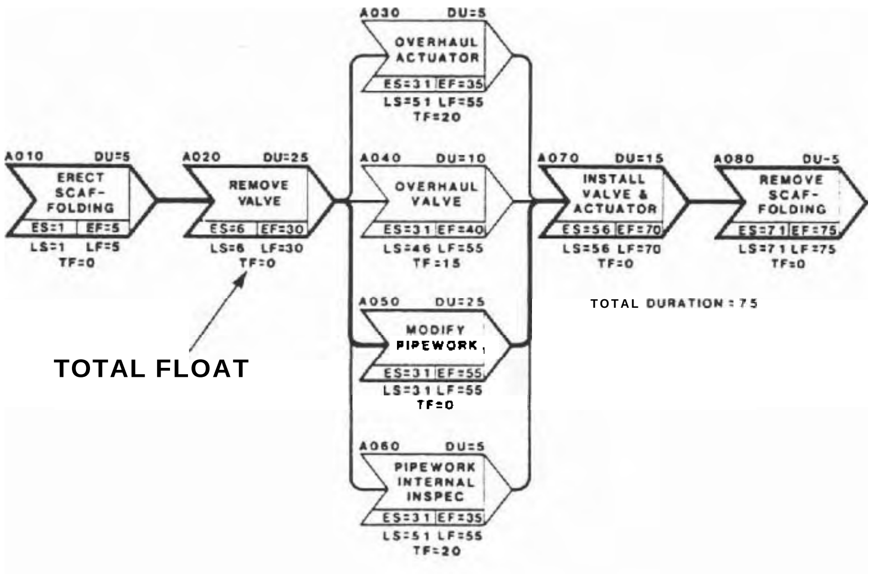
Activity A030 has 20 days float, A040 15 days float, and A060 20 days float. This means that these activities can be delayed by the float duration without impacting the project end date of 75 days. The critical path runs through activities A010, A020, A050, A070 and A080. Should any of these activities be delayed, the project end date will be extended. The critical path is normally shown by either a thicker line, or in some other color.

RESOURCES

a) Terminology:

RESOURCE – Any element exerting a limitation on an activity.

Figure 3-22. Float and Critical Path.



Total Float	:	The amount an activity can be delayed without impacting the end date or intermediate target date of a project.
Float Calc	:	Total float = Late start less Early start.
Critical Path	:	The path through a project with zero float. Any activity delayed on this path will automatically impact the proeject end date.

RESOURCE SCHEDULE – Plan that is limited by available resources.

SCHEDULE DELAY – The amount an activity is delayed through resource limitations.

RESOURCE PROFILE – The quantity of resources available for scheduling.

ACTIVITY PROFILE – The number of resources required to complete an activity.

CALENDAR – Details activity resource rest periods and holidays.

b) Unscheduled Resources Requirements:

As shown on the "unscheduled barchart," Figure 3-23, the following manpower is required:

1. Two scaffolders from day 1 until day 5.
2. Two pipefitters from day 6 until day 30.
3. Five pipefitters from day 31 until day 35.
4. Three pipefitters from day 36 until day 40.
5. Two pipefitters from day 41 until day 70.
6. Two scaffolders from day 71 until day 75.

c) Scheduled Resource Requirements:

As shown in the revised barchart, Figure 3-24, the earlier peak of five pipefitters has now been reduced to three by taking up some of the float. The project end date of 75 days is still being achieved, with a lower number of men. This technique is called RESOURCE LEVELLING.

SUMMARY OF PRECEDENCE NETWORK DEVELOPMENT

The following is a recap of the sequence of events in developing a project schedule:

1) Develop list of activities of WBS
2) Determine network logic
3) Determine activity durations
4) Allocate activity resources
5) Network time analysis
6) Verify network logic and critical path
7) Resource level schedule

SCHEDULE DEVELOPMENT AND EVALUATION

a) General:

Whenever possible, the development or evaluation of a schedule should be carried out with alternative methods. This will provide a checking procedure which can increase the quality of the schedule workup and provide a schedule with a higher degree of probability.

Figure 3-23. Unscheduled Barchart.

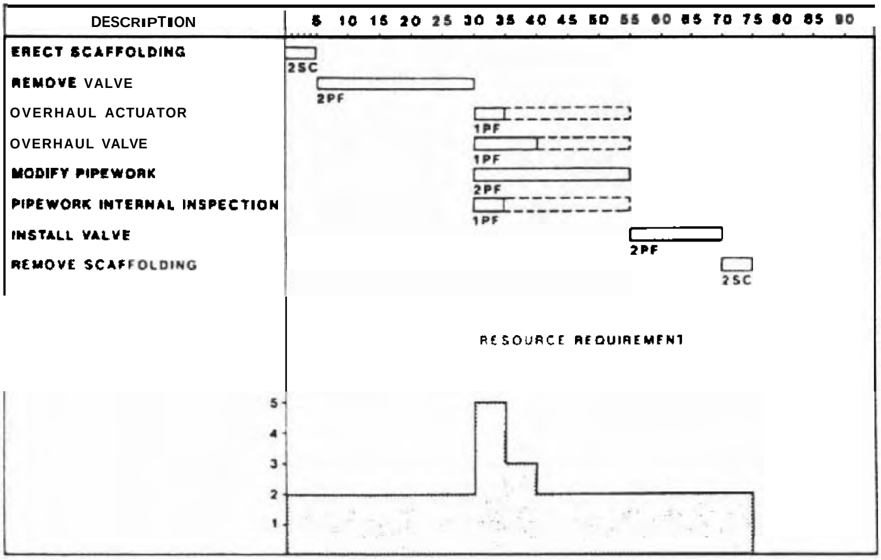
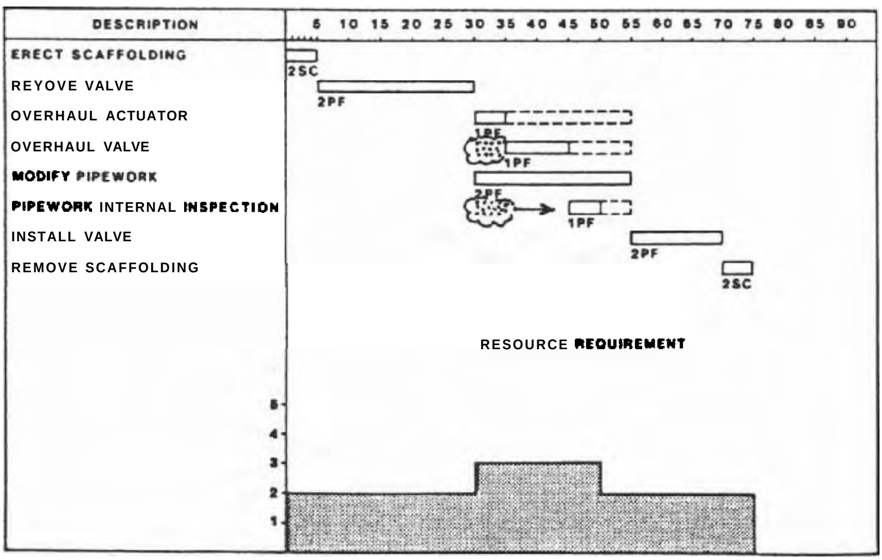


Figure 3-24. Scheduled Barchart.



Schedules should be developed on a *tight, but achievable* basis. An *80%* probability is a good basis for a schedule. Too optimistic and too pessimistic schedules are not recommended as they will provide a poor base for control and performance. The following are three methods for developing and evaluating schedules.

b) Personal Judgment:

This is the most common method and, very often, the **only** method used. The experience and capability of the schedule engineer are vital for a quality schedule. When the type of project or major project conditions are outside the experience of the schedule engineer, a poor schedule can be the result. Thus, an alternative checking method is necessary.

c) Historical Data Base:

An historical scheduling data base can be a very effective tool for developing or checking schedules. Standard schedules, by size and type of plant, would be available. Standard overall progress curves for material commitment, engineering and construction would quickly and easily provide manpower histograms and an excellent check of the progress curves of any project. Peak rates of progress would be known. Ideal sequences of activities, dependent relationships and lengths of durations would be available. Probable critical paths would be identified.

All of the above could provide an outstanding method for checking personal judgment and opinion. However, it should always be remembered that any project can lie outside the history of past projects and also the historical data base must be constantly updated so as to properly reflect current experience.

d) Construction Duration – **Trapezoidal/Labor** Density Method:

This method can improve a schedule evaluation by substituting quantity analysis for personal judgment. The method uses battery limit area, manhours, and labor density data to calculate overall construction duration.

Construction duration is calculated using a trapezoidal approximation of time for manpower build-up, peak and rundown over the construction period, and then evaluated using the estimated construction manhours in conjunction with the craft labor density.

The success of this evaluation method depends on the quality of judgment and experience used to assess the density level. Manpower build-up and rundown can be verified with an historical data base, if available. This method, when properly carried out, will generally provide the best result of the three scheduling methods. The procedure is covered in further detail.

DETERMINATION OF DURATION

a) Logical Critical Path:

On most projects, there are two types of critical paths. The first, and most generally recognized form, is a logical sequence of activities which, when the durations are added up, will give the longest time or "path" on the project. The critical path method (CPM) was developed to provide analysis of logical sequences of work so as to determine the longest chain or critical path of a schedule. **A** CPM schedule is usually referred to as a network.

b) Manning and Peak **Labor:**

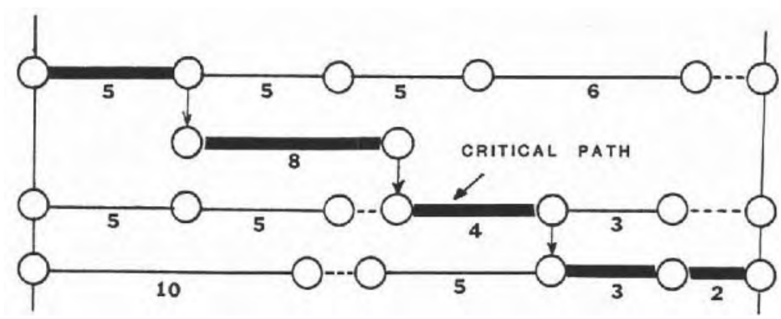
The second type of critical path is the dependency of construction manpower. Very often, the overall construction duration of a very tight project schedule is determined by the ability to place a maximum number of men on the work. Historical manpower density data can clearly show appropriate or possible manpower levels. The data will also show impossible manpower levels.

c) Working Hours:

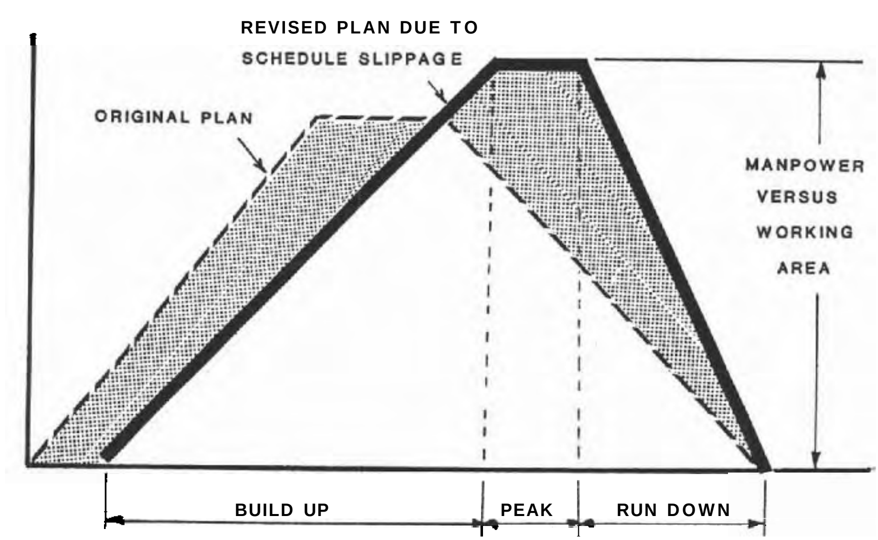
When an "impossible" level of manpower is required for the construction schedule, then the only alternative is to increase the number of hours work through an extended workweek or additional work shifts. Both of these alternatives may add increased costs. Refer to Cost Estimating, Chapter 6, and Keeping a Project on Time and Within Budget, Chapter 7 for information on extended workweek/overtime productivity losses. Figure 3-25 illustrates the effect of manpower requirements based on schedule.

Figure 3-25. Determination of Duration.

CRITICAL PATH - LOGICAL SEQUENCE OF ACTIVITIES



CONSTRUCTION BULK PROGRESS



PRACTICAL SCHEDULING – BASIC SCOPE APPRECIATION

The use of historical data, typical relationships, statistical correlations and practical "rules of thumb" can greatly add to the effectiveness of a project scheduling program. Such information can provide guidance in:

- developing/evaluating schedules
- assessing manpower requirements
- determining appropriate productivity levels
- improving cost/schedule assumptions
- carrying out trend analysis
- establishing the cost of the project
- evaluating the status and performance of the work
- recognize the scope of work at all times

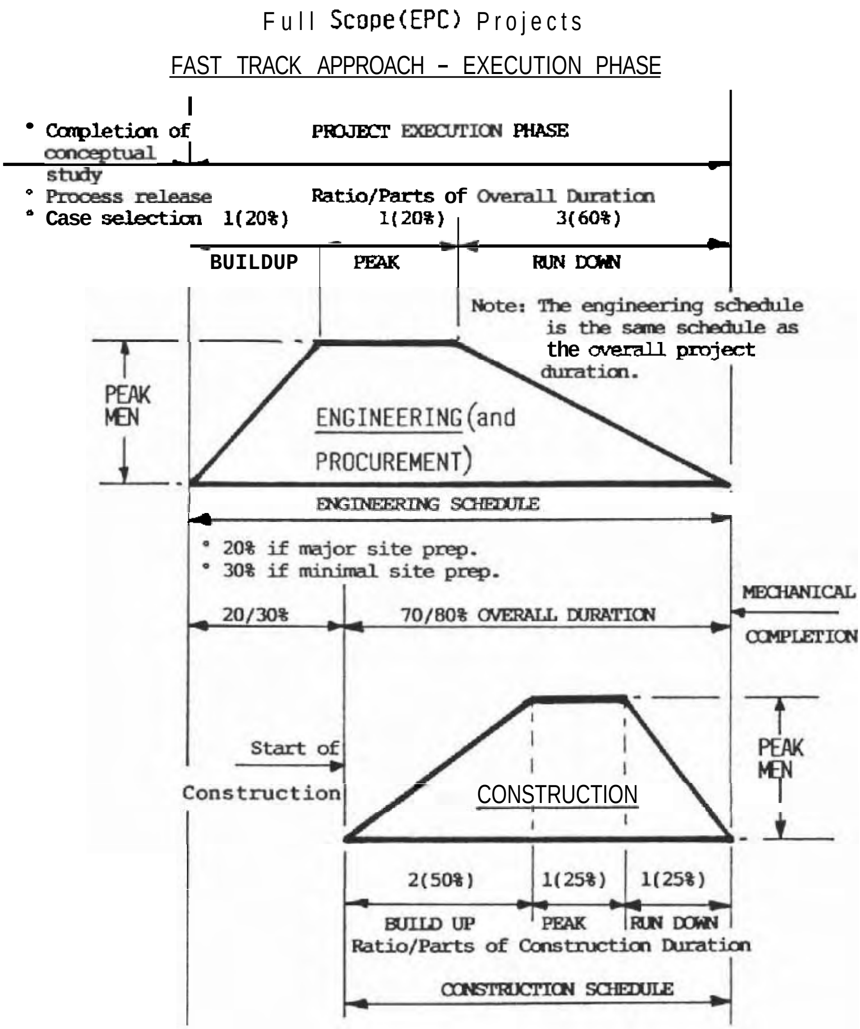
It is this last item that really highlights the key to effective project scheduling; *SCOPE RECOGNITION.* This equates to the ability to properly establish the scope in the first place, through a good estimate and, thereafter, to constantly recognize the true scope of the work as the project develops and is executed. The "testing" and measuring of actual performance against past experience can be a valuable source of verifying status, determining trends and making predictions. Naturally, the application of historical data to a specific project must always be carefully assessed.

The following figures represent historical and typical schedule "rules of thumb" that can assist in the establishment and development of schedules during the execution phase of a project. This information is especially useful at the front end of a project when engineering is at a low percentage of completion, resulting in a preliminary and overall schedule.

"FAST TRACK" SCHEDULING RELATIONSHIP

Figure 3-26 illustrates the scheduling relationship of engineering and construction for a project on a fast track program, with the "full scope" of engineering, procurement and construction (EPC). Such a project is often referred to as an EPC Project. The schedule relationship/duration only covers the execution phase. This phase

Figure 3-26. Typical Overall Scheduling Relationship



The above schedule ratio/parts are "typical", but based on historical experience (see historical charts for specific numbers). Each project schedule should be carefully evaluated for it's specific application to the standard, historical data.

is sometimes referred to as the Phase 2, where the earlier Phase 1 covers the conceptual design studies of process/utility alternatives and case selection.

It should also be noted that the "schedules" are illustrated as "trapezoids." This concept is extremely important as it shows that all "complex work" is executed with:

- a build-up
- a peak period
- arundown

This concept, ***this fact,*** then forms the basis of quality scheduling and manpower assessment. It is only "simple" work, where the task is performed by a single crew or squad that has no build-up or rundown.

As indicated on Figure 3-26 the ratio breakdowns of the build-up, peak and rundown, have been rounded off to whole numbers as the historical numbers are slightly different. But, at this overall level of scheduling, such minor numerical differences are of little consequence. Based on the author's altered historical data base of several projects, there is only a slight difference with the "idealized" trapezoids. For example, the engineering build-up, shown as 20%, is 22%, and the construction build-up, shown as 50%, is 57%.

CONSTRUCTION DURATION – TRAPEZOIDAL TECHNIQUE

Figure 3-27 shows the trapezoidal technique for the construction phase. The calculation procedure shows two formulas.

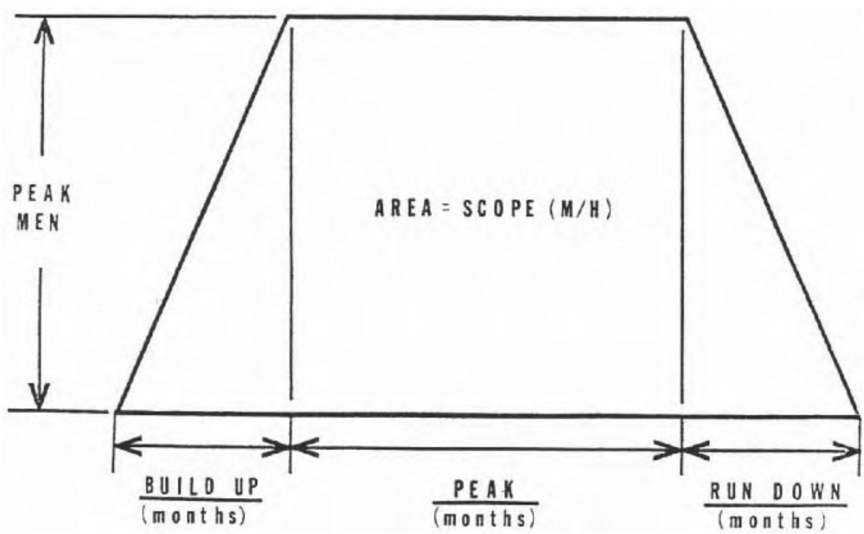
Formula 1 is used to determine the peak duration, shown as X, on the basis that the following information is known, or assumed:

- scope, in manhours
- effective monthly hours, per man
- build-up, usually developed from standard or actual schedules
- rundown, half of build-up
- peak men, as per Formula 2

Formula 2 covers the calculation of peak men, if the battery limits area (plot plan) is known. By evaluating a labor density level (usually in the range of 150-300 sq. ft./man), the peak number of men can then be determined.

This schedule/manpower evaluation technique is a very powerful program for developing or checking an overall construction duration. The key assumption requiring good judgment is the assessment of the labor density level. If this assessment is good, then the resulting scheduling evaluation is of a high quality.

Figure 3-27. Construction Duration (Trapezoidal Technique)



CALCULATION **PROCEDURE.**

(1) $$\frac{\text{Scope in manhours}}{\text{Effective Monthly Manhours}} = \left[\frac{\text{Buildup}}{2} \cdot \text{Peak men}\right] + \left[X \cdot \text{Peak men}\right] + \left[\frac{\text{Rundown}}{2} \cdot \text{Peak men}\right]$$

(2) $$\text{Peak manpower} = \frac{\text{Battery limits area}}{\text{Peak Density Level}}$$

SOLVE FOR PEAK DURATION:

It is emphasized that the Peak Manpower/Density Level application can only be used on single process units or complete process areas/buildings. The calculation process does not always work for individual categories of work.

WORKED EXAMPLE: TRAPEZOIDAL/DENSITY METHOD

Figure 3-28 illustrates a worked example of the trapezoidal density method for a Refinery FCC unit. As noted in the figure, a selected density level of 250 sq. ft./man, was too optimistic for such a complex unit as an FCC plant. The first step in the calculation process is to properly assess the manhour scope. As shown, allowances have been made for indirect labor working in the same area as direct labor and also, for an estimating allowance. An allowance for better subcontract productivity has been made.

Assessing the density/level is extremely important.

A 12% absenteeism allowance has been made.

The build-up duration was determined from a standard schedule that showed the peak labor period would be reached at 30% of the piping duration. This activity was preceded by foundation and equipment installation work (three months and two months, respectively). The total piping duration was fifteen months.

For the subcontract labor case, the manhours are reduced to reflect a better productivity than with the direct hire case (possibly a 10% improvement).

SCHEDULING SYSTEMS (COST INTEGRATION)

When developing or evaluating the effectiveness of a planning and scheduling program, the following are generally the major considerations:

1) Size of planning and scheduling program (level of detail)
2) Manual or computer program (CPM method), or combination
3) If a CPM program:
    a) What type of network (precedence or arrow diagram)
    b) Number of activities
4) Degree of integration of cost control system with scheduling

Figure 3-28. Worked Example Using Trapezoidal/Density Method.

EXAMPLE

Refinery FCC unit:

- Plot area = 320 ft × 200 ft = 64.000 ft^2
- Scope (direct hire) = 445.000 man-hours
- Allowance lor indirect labor in area + 10% = 44,500 man-hours
- Estimating allowance + 15% = 66,700

556,200 total scope for evaluation

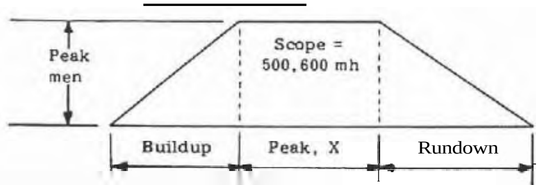
Consider two cases: Case 1, direct-hire labor, and case 2, subcontract labor.

ASSUMPTIONS:

- Due to "criticality", use Density of 250 (but 300 more probable)
  Allow 12% absenteeism for "effective manhours"
  "Buildup" duration from standard schedule (fdns+eqpt+piping buildup)

Case 2: Subconlract Labor. The project strategy, based on experience, is that local subcontractors are more productive than prime contractors (direct hire).

Scope = 556.200 man-hours for direct hire
less 10%productivity adjustment for local subcontractor labor
\- 55.600
= 500,600 man-hours



1. Labor availability: No restraint, no adjustment to manpower level.
2. Peak density level: U.S. large project. subcontract labor (from curves) = 250 ft^2/man.
3. Peak manpower = $\frac{64{,}000\ ft^2}{250\ ft^2/man}$ = 256 men.
4. Effective man-hours per man-month = 40 × 88% × $4\frac{1}{3}$ = 153 h.
5. Buildup (by judgment) = 3 + 2 + 5 = 10 months.
6. Rundown (by judgment) = 6 months.

Solve far peak, X_2:

$$\frac{500{,}600}{153} = \left(\frac{10}{2} \times 256\right) + \left(X_2 \times 256\right) + \left(\frac{6}{2} \times 256\right)$$

X_2 = 1.8 (say 5 months)

Therefore

Total construction duration (subcontract labor) = 10 + 5 + 6 = 21 months

This confirms that a subcontract operation. even though more productive. Will generally take longer than one on a direct-hire basis.

For CPM/computer programs, there are two basic approaches. Large or small networks. Each approach has significant advantages and disadvantages.

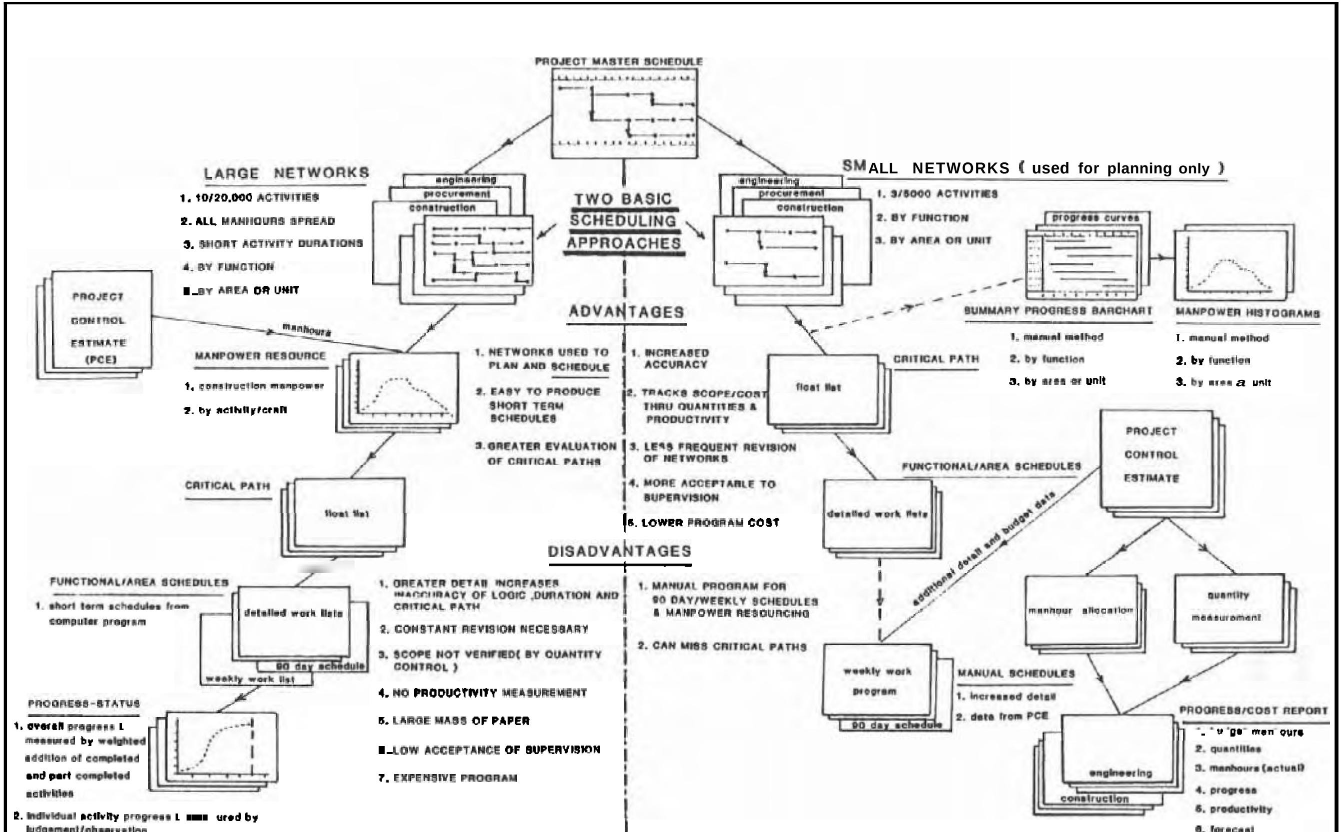
Figure 3-29 outlines the essentials of the large and small network approach and lists major advantages and disadvantages of each approach.

It is the author's judgment that even for mega size projects, the small networks (3,000/5,000 activities) approach will provide a more efficient and cost effective program. There is the mistaken concept that greater level of detail provides more accuracy and increases quality of schedules, as follows: At a great level of detail (10,000/20,000 activities), there can be many options for the critical path logic and durations of short-term activities can vary greatly. Also, activity logical dependency can significantly increase, resulting in a requirement for many restraints or dummies, further complicating the network.

The jobsite working environment is extremely volatile, so that constant adjustment and revision of the networks may be required. The larger the size of the network, the greater is the potential for change. ***The "small network" approach is, therefore, strongly recommended.*** On large projects, the small network is mainly used to plan the project. Lower level/short-term schedules and manpower resourcing can be developed manually. Progress is evaluated through work quantity measurement and budget unit assessment. Scope is constantly assessed with quantity takeoffs of construction issue drawings. Expended manhours are collated and a comparison with the budgeted manhours (quantities multiplied by budget work units) results in productivity measurement. The lack of scope verification and productivity assessment is a significant deficiency of a large activity network program.

Finally, greater integration with the cost control program is achieved through the scope/quantity control program. If the quantities can be accurately determined, then the labor cost is a matter of productivity and wage rate. The complete integration of cost and scheduling at a detailed "code of accounts" level is rarely cost effec-

Figure 3-29. Scheduling Systems - Cost Integration



TYPICAL PROJECT MASTER SCHEDULE

This basic schedule is generally the master plan for the project. Schedulers should ensure that this is a quality document and that the activities represent the critical and subcritical paths.

Figure 3-30 illustrates a recommended format. It should be noted that this is not the typical format currently in industry **use.** In fact, it is quite revolutionary. Most companies use a barchart that displays milestone activities against a calendar timeframe for engineering, procurement and construction. Logical relationships and critical restraints are not shown. As such, the critical path and critical activities cannot be determined. This is the major drawback of the barchart as an effective overall scheduling method.

Figure 3-30, on the other hand, shows logic sequences and restraints against a calendar timeframe. To accomplish this, the "overlaps" of individual activity durations have been cut off so that the relationship to the next activity is a direct and clear one.

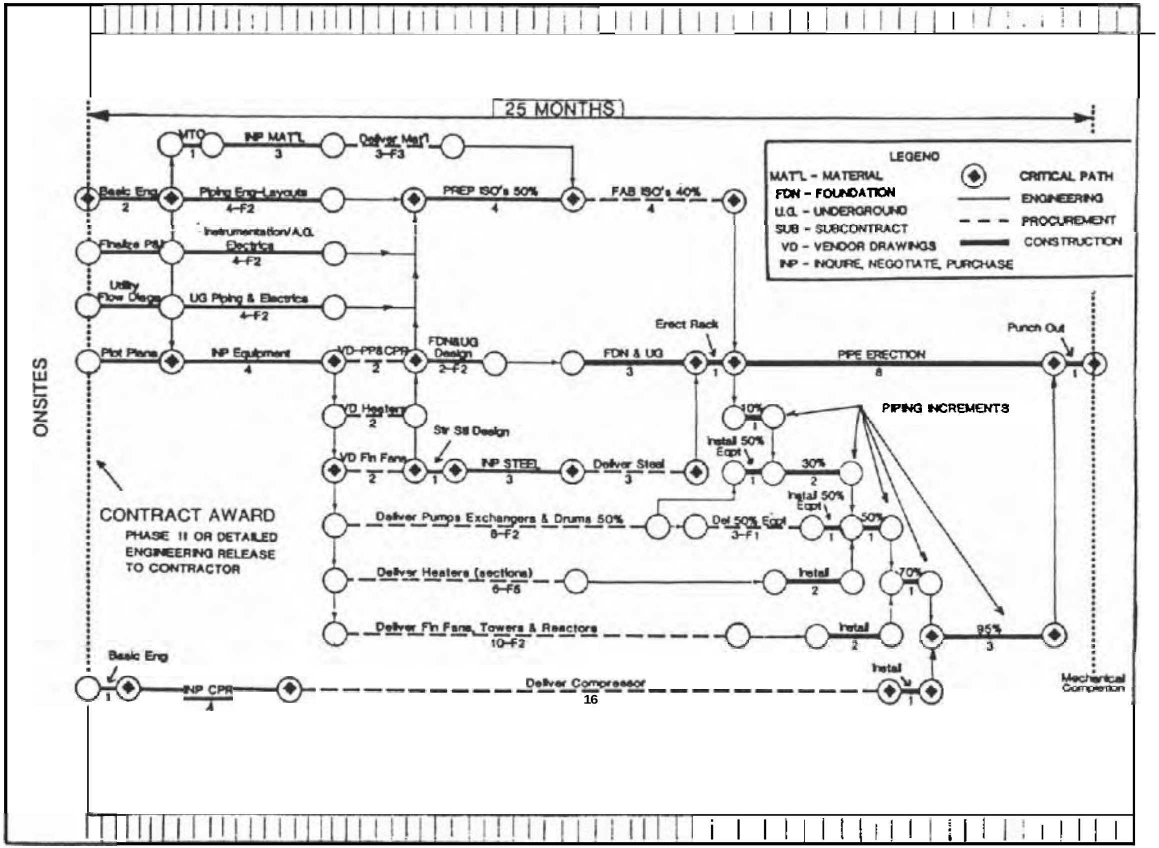
This technique requires considerable experience and significant historical data to develop the relationships of partial activities to partial activities. This requirement, then, is both the strength and weakness of this new technique. The lack of skills and historical data are the main reasons why this technique is not widely used.

SUMMARY SCHEDULE

On large, multi-unit projects, the level of detail of the illustrated Project Master Schedule for each unit would be too great for executive management. In addition, the critical path, composite project master schedule may not display the overall schedules of individual process units and major offsite facilities as most of these units would not be on the critical path.

A summary schedule, then, could be developed to show each individual unit and/or area and the associated critical paths.

Figure 3-30. Typical Project Master Schedule – Small Project – USA



4
Computer Methods for Scheduling

CONTENTS

[1]A revolution is taking place in project management. As recently as a few years ago, computerized project management was still in the domain of the mainframe. But now there are very powerful, yet relatively inexpensive project management software programs that run on the microcomputer. At latest count there are more than a hundred of these programs, and most are available for less than $1,000.

The availability of these programs has moved full-scale computerized project management out of the domain of the mainframe and into the hands of the project manager. This represents a major shift in management and control. The microcomputer and project management software give the project manager direct access to powerful project management tools, which means accurate and timely status reports, rapid recalculation of project schedules and powerful resource and cost-tracking capabilities.

In this chapter are included the results[2] of a software survey mailed to 150 companies. The fifty-five companies that responded include most industry levels. The products are listed according to price range.

With the software field in constant change, please contact the companies you are interested in for latest prices and options available. For Directory of Software Buyers' Guide, please refer to Table 4-1.

The project management software market is booming. Future Computing Inc. estimates it will grow by 77% in 1986. This would make project management software the second fastest growing software application, second only to communications. Actual sales of project management software programs are predicted by Future Computing to almost double this year for a total of $85 million.

In comparing the features of the various programs there are many ways to assess a program's capabilities. Generally, the program's value might be based upon how well it helps you manage the three phases of a project—planning, schduling and control.

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[1] **Reprinted from *Industrial Engineering Magazine,* January 1986.**
[2] **Reprinted from *Industrial Engineering Magazine,* January 1987. Copyright Institute of Industrial Engineers, 25 Technology Park/Atlanta, Norcross, Georgia 30092.**

Most of the less expensive programs are able to handle only the scheduling aspect of project management. The real difference between the low-end, inexpensive programs and full-powered project management programs is how well they perform in these five areas:

- Project planning.
- Resource management.
- Tracking actual versus planned progress.
- Producing key reports.
- Ease of use/power and sophistication.

By looking at the capabilities of a program in each of these five areas, you can quickly determine if the program will meet your project management requirements.

The first step in finding the right program, however, is to take a long, hard look at just what your requirements are. The more clearly you have in mind what your needs are, the easier it will be to find the right software. The points that follow highlight several features you might want to consider.

CREATING THE PROJECT PLAN

The programs now available vary widely in the way they let you create your project plan. Some make planning the project easier, while others present serious limitations in how you can define the project elements.

Entering the project plan – The way you enter the project plan into the program and the ease of changing the plan may have a direct effect on how much use you get out of the program.

When entering the project plan, you must define all the project activities. Most of the programs have you build your plan by listing the project activities down the left side of a Gantt or timeline chart. You then fill in a form for each activity to identify its duration, required resources and any activities that must precede it.

A few programs let you create your project as a network first, actually drawing the boxes for each activity and the connecting Lines that show their sequence.

You may prefer one method of creating the project plan over the other. But what is important is the ease with which you can create the plan and make changes in it. Some programs make it downright difficult to add or delete activities once the plan is created. And as any experienced project manager knows, projects rarely go exactly as planned. So the first consideration is to make sure the program makes it easy to create the plan and change it.

Full precedence capability – A second important feature to check for is how well the program can represent the relationships among the activities that make up the project. When you enter the activities into the program, you also specify their sequence and precedence; that is, how the activities depend upon each other and which must be done before others can begin.

At a minimum the program must be able to contain all the project activities, and calculate and show the project's critical path, which is the sequence of activities that must be done on time if the project is to be completed on schedule.

Beyond showing the critical path, a program can be judged by how well it depicts the precedence relationships among the activities. Many of the less expensive programs permit only a finish to start precedence relationship between activities. A finish to start relationship means a subsequent activity can start only after a previous activity is finished.

Finish to start is a common relationship among activities, but you may also frequently have activities that depend on each other, but overlap to some degree. With these activities the finish to start relationship does not accurately apply. So if you have a program that allows only for finish to start relationships you must decide either not to show the relationship as it should be or to artificially break down the activity into subactivities so they fit into the finish to start mode.

The ability to handle full precedence relationships is a key difference between programs. Determining the precedence relationships a program is capable of showing is an important first test of any software you consider. After all, you do not want to have to force your project to meet the software program requirements. You want the software to meet your requirements.

Limits on number of activities – Many of the less expensive programs have a maximum number of activities that can be entered into a project. This maximum may be well below your needs. If your projects have more than a hundred activities, you should keep this in mind when shopping for a program.

WBS capability – Equally important to some managers is the ability to identify activities in a work breakdown structure (WBS). A WBS as it applies to software programs is the capability of assigning ID codes to each task in the project, from the highest level main tasks all the way down to the lowest level subtasks.

WBS codes can be used to cross reference the tasks to be performed with the account codes of the organizations or individuals who are to do them. By assigning WBS codes to each task you can produce cost reports that are sorted based upon either the task group or the organizational group. This can allow for improved accounting and cost control.

Of those programs that do let you create a WBS, few have the capability of showing the WBS graphically in the normal heirarchical tree structure.

RESOURCE MANAGEMENT

After breaking the project down into tasks and their relationships, you will want to identify available resources and allocate them to the project tasks. Surprisingly, there are several programs that do not allow for realistic resource identification and allocation, even though the ability to assign resources to a project is essential to effective project management.

Programs that allow for the assignment of resources usually make it a two-step process: (1) you first specify all project resources and their associated costs; (2) you then allocate them to the various tasks.

Assigning resources – A key thing to look for in a program is the degree of discrimination allowed in identifying the assigning resources. The software programs vary widely with regard to resource management, and it is well worth a close look to see if the program can meet your specific needs.

The number and type of resources you can assign to a task is the first consideration. Some programs let you identify and assign only one or a few resources per task.

More powerful programs let you assign codes to each resource so you can further break down each type of resource; for example, E1 = level 1 engineers; E2 = level 2 engineers; etc. The program can then produce reports that are sorted based upon any given resource type or subtype. For example, you could print out a histogram, or resource allocation chart, for all level 1 engineers.

Assign partial resources – The ability to assign partial resources to an activity is another valuable feature of some programs. You may be able to assign a percentage of a resource to a task, which is a common need in projects. If the program does not allow partial assignment of resources to a task, you will have to artificially break down the task so it matches the resources allocated to it. But if you have to do this, the program is forcing you to meet its requirements instead of meeting your requirements.

Many programs let you distinguish between conventional resources, such as labor and equipment, and expendable resources, such as cash. When a program lets you make this distinction, you can usually allocate the cash as an expendable resource and then produce cash-flow reports.

Resource leveling – Resource leveling is the process of smoothing out the use of resources over time so you can meet whatever constraints you have on resource availability. Some of the better programs let you specify limits to resources, and the program will then automatically calculate the best use of the resources over time within the given limits.

Many times a project or certain activities in a project are resource-driven; that is, the availability and use of resources are of overriding importance. Using a program that does resource leveling can save a lot of time and effort when you are trying to juggle schedules to optimize the use of resources.

Assigning costs – When you define a resource, in most programs you specify its cost per unit of time. Then, when the resource is assigned to project tasks, the total costs are calculated and kept track of by the program. Usually a program will let you assign only one rate for any given resource. To have multiple rates for a resource you would need to identify it as a different resource for each rate.

Another valuable feature of some programs is the ability to assign a cost to an activity and specify that the cost accrue at the beginning or end of the activity. Many programs do not give you this choice when assigning costs, and automatically prorate the cost over the duration of the activity. But this is often not the way costs actually accrue.

TRACKING PROGRESS

After defining the project activities and determining their relationships, you will want to schedule their start and finish dates and identify any other scheduling constraints individual activities may have. **A** distinguishing feature of some better programs is that you can assign specific start to finish dates to individual activities.

Another important feature is that some programs require that you first specify a project start date before the program will schedule the project. But, of course, you may have a project for which all you know is the deadline, the required finish date. Fortunately, some programs let you schedule the project by entering the finish date first. The program will then calculate backwards from the finish date to obtain the appropriate calendar dates for each project activity.

***Schedule display* –** How the schedule is displayed can also be important. For example, can the schedule be presented in various units, such as months, days and hours? And if you have a very long project, can the schedule be summarized so the entire project can be graphically represented on a single page?

Showing the scheduled progress of a project is what separates many low-end programs from their more powerful competitors. Many low-end programs require you to change the planned schedule in order to show actual progress. This leaves no baseline plan against which you can compare actual progress.

Far better are those programs that display, usually on a Gantt chart, actual and planned progress. You enter the actual progress or percentage of completion for each activity. And the result, a graphic comparison between actual and planned progress, can be a valuable tool for managing the project.

REPORTS

Graphic reports of the project plan and project status are some of the most valuable tools a program can provide. **A** software program can make updating project reports quick and easy. And to the benefit of all, it is becoming the norm that programs provide graphic and plotting reporting capabilities.

The various programs offer a full range of reporting capabilities, but there are certain reports you will want your program to produce:

- *Network Diagram (PERT chart)* – The network diagram should show all project activities and their precedence relationships.

- *Gantt (or bar) chart* – This favorite shows each project activity as a horizontal bar extending along the project timeline. The Gantt chart should also show milestones (key dates) and, preferably, planned activity progress versus actual progress.

- *Network schedule* – This report may go by various names, but it is a tabular listing of all project activities with their earliest and latest start and finish dates. It also shows how much float, or slack time, each activity has.

- *Resource reports* – At a minimum, you will want a tabular listing of all resources and their assignment to activities. Resource histograms, vertical bar charts showing assignment of resources over time, are also valuable. Some histograms also show load limits; that is, the maximum allowable assignment of a resource.

- *Cost reports – A* detailed breakdown of assigned project costs is a minimum requirement. Very useful are cumulative cost reports which depict cash flow requirements. More powerful programs will calculate and graph out earned–value as the project progresses. An earned value graph compares project completion with costs expended. These reports will also show the estimated cost to complete the project.

EASE OF USE VERSUS POWER AND SOPHISTICATION

In software there often is a tradeoff between the program's ease of use and its power and sophistication. Many project management programs are extremely easy to learn and easy to use, but are too simplistic to manage real-life projects. They might be appropriate for creating the schedule for a small project (less than 50 activities), but are inadequate for handling the size, budget and resources of a larger project (more than 100 activities).

On the other hand, several of the more powerful programs—and some of these have been downloaded from mainframes to micros—are so difficult to learn and to use that they are often not used at all.

Somewhere in between these extremes you must reach a compromize between your project management requirements and the requirement that the program be easy enough to learn that it will actually be used.

There are, fortunately, a few programs that are both extremely easy to use and very powerful. Viewpoint, Time Line, PMS II and PertMaster, to name just a few, offer full project management power, but not at the expense of ease of use.

Ease of use and the quality of the program's training may be one of your most important considerations. This will be true if the people who will be using the software are not themselves experienced project managers or familiar with project management techniques. In that case, you will want the program to have a good training session or online tutorial and very clear documentation.

Also, the ease with which the user interacts with the program, enters project data and processes reports will be of importance. If the program is not used, it is not useful. So good training and user friendliness may turn out to be the key to whether or not the program is a useful tool.

Training – Because few of the programs offer any training on project management itself, you may want to consider training your users first on basic project management techniques. This way you can base the selection of a program more on how the program will actually be used and what it can do than on how well it can get someone started in project management.

Finding **the** Right **Program**

The program features mentioned above provide useful criteria for comparing programs and judging their capabilities. There are, of course, many factors that might be important in deciding which program is the best one for you.

The most important thing is to take a hard look at your project management requirements and determine the minimum capabilities a program must have if it is to meet your needs.

When you have a good idea of what the program will need to do in order to be a useful tool in managing your projects, think about what you want the program to help you with most. Do your projects tend to be of a certain sort and have special requirements? For example, is account management and cost control always a primary consideration? If so, you want a program that will let you put in enough detailed cost information that you will have full cost tracking capability.

On the other hand, after a close look at the nature of your projects, you may realize they are primarily resource-oriented. For example, if most of your projects involve, say, R&D, in which successful management of the project is less a matter of completing tasks than it is a matter of using resources efficiently, you should look first at those programs that provide full resource management.

The power and capacity of a program might be your driving consideration. If you are the master scheduler for a large project that is made up of many other projects, you will want to look at those programs that allow unlimited tasks and speed in processing, keeping in mind as well the hardware requirements.

Along this same line, some projects, especially federal government projects, have very specific reporting requirements. Even though federal projects amount in dollar volume to a large piece of the project management pie, only a few project management programs actually meet federal reporting requirements specifications. So if your projects have to meet these requirements, you know which programs you need to look at first.

Or, again, if less experienced staff will be the primary users of the program, good training and documentation and ease of use can be a major consideration.

And finally, you will want to consider the program cost and how to justify its purchase. Programs vary widely in cost. But it is not possible to judge the value and capabilities of the program on the basis of its price tag. There are some minicomputer programs that cost thousands of dollars that cannot do what some microcomputer programs, which cost only hundreds of dollars, can do.

The best method for justifying a program's cost is to determine what your project management requirements are and to judge the value of the program on the extent to which it gives you the tools you need to better manage your projects. After a close look at your requirements you may decide that $1,000 for a program is a small price to pay for the power and sophistication it can deliver. At the same time it would be hard to justify paying a few hundred dollars for a program that lacked the capability to truly help in managing your projects.

Making the effort to find the right program can yield significant dividends to the serious project manager. And with so many programs now offering full project management capability at a microcomputer price, you won't have to look too far before you find the right one for you.

Project Management Software Buyers' Guide.

$0-$100.00	PROGRAM FEATURES														GRAPHICS					USER SERVICES			
COMPANY NAME *Program name*	Computes critical path	Creates network diagram	Generates network schedule	Work breakdown structure	Specify scheduling constraints	Labor costs breakout	Capital/Equipment costs breakout	Assign/Report planned costs	Assign/Report actual costs	Windows	Relational database	Query to MIS database	Custom report generator	Business graphics generator	Project network	Project calendar	Gantt chart	Resource histograms	Resource S-curves	User hotline	Tutorial disk(s)	User newsletter	Organized user group
Applied MicroSystems Inc. *Protracs*				•						•			•			•	•			•	•		
Campbell Services Inc. *The Reminder System*																•				•			
Cinnamon Microsystems *Engineering Mgt. Series*						•	•	•	•	•			•	•				•	•	•			
Data Consulting Group *Data*Easy Project Scheduler*			•														•			•			
Davis & Associates Inc. *PC/MIS Project Cost/Mgt. Information System*				•		•	•	•	•												•		
Educol Inc. *PMS*	•	•	•	•		•														•		•	
H & S Software *Schedule-Pro*	•		•					•								•	•			•	•		
Westminster Software *In Control!*	•	•	•		•			•							•	•	•	•	•	•	•		

$101.00-$250.00

COMPANY NAME / *Program name*	PROGRAM FEATURES														GRAPHICS					USER SERVICES			
	Computes critical path	Creates network diagram	Generates network schedule	Work breakdown structure	Specify scheduling constraints	Labor costs breakout	Capital/Equipment costs breakout	Assign/Report planned costs	Assign/Report actual costs	Windows	Relational database	Query to MIS database	Custom report generator	Business graphics generator	Project network	Project calendar	Gantt chart	Resource histograms	Resource S-curves	User hotline	Tutorial disk(s)	User newsletter	Organized user group
Applitech Software Inc. *Project Planner*	•	•	•												•	•	•			•			
Breakthrough Software Corp. *Time Line Graphics*															•	•	•	•		•	•	•	•
Earth Data Corp. *Micro Gantt 22*	•	•	•	•		•	•	•	•		•		•		•	•	•			•	•	•	
Elite Software Development Inc. *Critical Path Method Program*	•		•					•					•			•	•		•		•	•	
IIE *Project Management Group*	•	•	•	•	•															•		•	•

Project Management Microcomputer Software

PROGRAM CAPABILITIES Tasks/Activities per project; Milestones per project; Resource tracking- number per project: number per task; Partial resource allocation available; Network format; Time base.	COMPUTER SYSTEM REQUIREMENTS Make of computer-RAM; Graphics card; Color monitor; Disk drives; Operating system. Program language; Is program source code available?	OTHER INFORMATION List price; Date introduced; Copy protected; Units sold to date.	Reader Service Number
400; NA; —; 1; —; —; Days; Weeks.	IBM PC/XT/AT or compatible-256K; 1 or 2 disk drives or hard disk; PC-DOS (2.0 or later). Assembly; no.	$59.95; 1984; no; —.	141
—; —; —; —; —; —; Variable.	IBM PC/XT/AT or compatible-256K; 2 disk drives or hard disk; MS/PC-DOS (2.0 or later). C, Basic, no.	$99.00; 1984; no; —.	142
200; 24; 200; 200; Yes; —; Variable.	IBM PC/XT/AT or compatible 640K; 1 or 2 disk drives or hard disk; MS/PC-DOS (2.X or 3.X); CGA/EGA; yes. Lotus; yes.	$79.95; 1985; no; —.	143
Unlimited; 1; 1; 1; —; —; Days.	IBM PC/XT/AT or compatible-64-128K; 1 disk drive or hard disk; MS/PC-DOS (2.0 or later). Basic/Assembly; yes.	$78.00; 1984; no; NA.	144
44; 44; 999' 999; —; —; Variable.	IBM PC/XT/AT or compatible-256K; 2 disk drives or hard disk; PC-DOS (2.0 or later). —; —.	$69.00; 1984; no; —.	145
Unlimited; Unlimited; Unlimited; 6; Yes; Activity-on-node; Days.	IBM PC/XT/AT or compatible-256K; 2 disk drives or hard disk; MS/PC-DOS (3.2 or later). MS Basic; no.	$95.00; 1985; yes; 20.	146
500; 500; 5; 5; Yes; Activity-on-arrow; Hour, Days, Weeks.	IBM PC/XT/AT or compatible-256K; Apple IIe/IIc/III-64K; 2 disk drives or hard disk; MS/PC-DOS (1.1 or later). Compiled Basic, yes.	$69.95; 1981; no; 1,000+.	147
75; 75; 29; 10; —; Activity-on-arrow, Activity-on-node; Variable.	IBM PC/XT/AT or compatible-128K; 2 disk drives or hard disk; PC-DOS 2.0 or later. Basic; no.	$69.50; 1986; no; 600.	148

Project Management Microcomputer Software

PROGRAM CAPABILITIES	COMPUTER SYSTEM REQUIREMENTS	OTHER INFORMATION	
Tasks/Activities per project; Milestones per project; Resource tracking- number per project; number per task; Partial resource allocation available; Network formal; Time base.	**Make of computer-RAM; Graphics card; Color monitor; Disk drives; Operating system. Program language; Is program source code available?**	**List price; Date introduced; Copy protected; Units sold to date.**	**Reader Service Number**
150 (128K); —; —; —; —; Activity-on-node; Variable.	Apple IIe/IIc/II+-64/128K; 2 disk drives; Apple II DOS. Apple Pascal; no.	$195.00; 1982; yes; 1,000.	149
—; —; —; —; —; —; —.	IBM PC/XT/AT or compatible-256K, IBM 3270 PC/AT; Hewlett Packard 7475A/7470A/7550A/7580B/7585B/7586B/7586R, HI695/DMP51/DMP52, RLDXY880; PC-DOS (2.X or 3.X). Modula-2; —.	$195.00; 1986; no; 1000.	150
Unlimited; Unlimited; Unlimited; —; Yes; Activity-on-arrow, Activity-on-node; Variable.	IBM PC/XT/AT or compatible-256K; One disk drive; MS-DOS. C; File layouts are.	$195.00 & $395.00; —; no; thousands.	151
600; —; —; —; —; Activity-on-node; Days.	IBM PC/XT/AT or compatible-256K, HP 150-256K; 2 disk drive or hard disk; MS/PC-DOS (2.0 or later). —; —.	$249.00; 1982; no; 2050.	152
500; —; 200; 1; Yes; Activity-on-node; Days.	IBM PC/XT/AT or compatible-48K, Apple II/II+/IIe/II-48K; 2 disk drive; PC-DOS, Apple Dos (1.3), TRS DOS (1.3). Basic; yes.	$175.00 ($140 IIE members); 1982; no; 500+.	153

. . . Continued on next page

$101.00-$250.00

	PROGRAM FEATURES														GRAPHICS					USER SERVICES			
COMPANY NAME *Program name*	Computes critical path	Creates network diagram	Generates network schedule	Work breakdown structure	Specify scheduling constraints	Labor costs breakout	Capital/Equipment costs breakout	Assign/Report planned costs	Assign/Report actual costs	Windows	Relational database	Query to MIS database	Custom report generator	Business graphics generator	Project network	Project calendar	Gantt chart	Resource histograms	Resource S-curves	User hotline	Tutorial disk(s)	User newsletter	Organized user group
Patton & Patton *FLOW CHARTING IIt*		•												•						•	•		
Progressive Peripherals & Software *Logistix*	•				•	•	•	•	•	•		•	•	•		•	•	•		•	•		
SoftCorp Inc. *Advanced Pro-Path 6*	•			•		•	•	•					•			•	•			•		•	

$251.00-$500.00

COMPANY NAME / *Program name*	PROGRAM FEATURES														GRAPHICS					USER SERVICES			
	Computes critical path	Creates network diagram	Generates network schedule	Work breakdown structure	Specify scheduling constraints	Labor costs breakout	Capital/Equipment costs breakout	Assign/Report planned costs	Assign/Report actual costs	Windows	Relational database	Query to MIS database	Custom report generator	Business graphics generator	Project network	Project calendar	Gantt chart	Resource histograms	Resource S-curves	User hotline	Tutorial disk(s)	User newsletter	Organized user group
Applitech Software Inc. *Project Planner*	●	●	●		●			●	●				●		●	●	●	●		●			
Breakthrough Software Corp. *Time Line*	●	●	●	●	●	●	●	●	●	●	●			●	●	●	●	●		●	●	●	●
Computer Associates *Superproject Plus*	●	●	●	●	●	●		●	●				●		●	●	●			●	●	●	
Decision Support Software Inc. *Expert Choice*																				●	●		
Earth Data Corp. *Micro Gantt*	●	●	●	●		●	●	●	●		●		●		●	●	●			●	●	●	
CP/M-80 Systems	●	●	●	●		●	●	●	●		●		●		●	●	●			●	●	●	
MC2 Engineering Software *Critical Path Project Management*																				●	●		
Micro Planning Software *Micro Planner*	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Micro Planner	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Project Management Microcomputer Software

PROGRAM CAPABILITIES Tasks/Activities per project; Milestones per project; Resource tracking- number per project; number per task; Partial resource allocation available; Network formal; Time base.	COMPUTER SYSTEM REQUIREMENTS Make of computer-RAM; Graphics card; Color monitor; Disk drives; Operating system. Program language; Is program source code available?	OTHER INFORMATION List price; Date Introduced; Copy protected; Units sold to date.	Reader Service Number
—; —; —; —; —; —; —.	IBM PC/XT/AT or compatible-256K; Graphics card; 1 disk drive or hard disk; MS/PC-DOS (2.0 or later). Assembler; no.	$229.00; 1984; no; 10,000.	154
1000+; Unlimited; 0; 0; 0; Activity-on-arrow; Variable.	IBM PC/XT/AT or compatible-384K, HP 150-512K, Commodore Amiga-512K, Atari-512K; Graphics card; Color monitor; 1 or 2 disk drives or hard disk; MS/PC-DOS (2.0 or later), Commodore Amiga, Atari. C; no.	$249.95; 1986; no; NA.	155
250; —; 60; 5; Yes; Activity-on-arrow; Variable.	IBM PC/XT/AT or compatible-160K; 1 disk drive; MS-DOS (2.0 or later). Basic; no.	$199.00; 1984; no; NA.	156

Project Management Microcomputer Software

PROGRAM CAPABILITIES: Tasks/Activities per project; Milestones per project; Resource tracking- number per project; number per task; Partial resource allocation available; Network formal; Time base.	COMPUTER SYSTEM REQUIREMENTS: Make of computer-RAM; Graphics card; Color monitor; Disk drives; Operating system. Program language; Is program source code available?	OTHER INFORMATION: List price; Date Introduced; Copy protected; Units sold to date.	Reader Service Number
250+; —; 100; 20; —; Activity-on-node; Variable.	IBM PC/XT/AT or compatible-256K; Graphics card; 2 disk drive or hard disk; MS/PC-DOS (2.0 or later). Turbo Pascal; no.	$300.00; 1986; no; —.	157
Unlimited; Unlimited; Unlimited; 12; Yes; Activity-on-node; Variable.	IBM PC/XT/AT or compatible-256K, IBM 3270 PC/AT; Color monitor; 2 disk drives or hard disk; PC-DOS (2.X or 3.X). Modula-2; no.	$495.00; 1984; no; 40,000.	158
Unlimited; Optional; Unlimited; Unlimited; Yes; Finish-to-finish; Hours, Days.	IBM PC/XT/AT or compatible-320K; 2 disk drives or hard disk; MS/PC-DOS (2.0 or later). Third Party C; no.	$495.00; 1986; no; —.	159
	IBM PC/XT/AT or compatible-320K; Graphics card; 2 disk drives or hard disk; PC-DOS (2.1 or later). Basic; no.	$495.00; 1983; yes; 2000	160
Unlimited; Unlimited; Unlimited; —; Yes; Activity-on-arrow, Activity-on-node; Variable.	IBM PC/XT/AT or compatible; One disk drive; MS/PC-DOS. Micro Gantt takes MPERT & Micro DOD.	$395.00; —; no; thousands.	161
Unlimited; Unlimited; Unlimited; —; Yes; Activity-on-arrow, Activity-on-node; Variable.	CP/M-80 64K; Compiled Basic.	$295.00; —; no; thousands.	162
1500; —; 0; —; —; —; Hours, Days, Weeks.	IBM PC/XT/AT or compatible-128K, HP 150-128K; TRS II, 16-64K; 1 disk drive, MS/PC-DOS. MBasic; yes.	$295.00; 1981; no; 225.	163
1400; 1400; 26; 20; Yes; Activity-on-arrow, Description-on-node; Days, Weeks.	Macintosh-512K; 2 disk drives; Apple Finder. Pascal; —.	$495.00; 1986; yes; 7000.	164
500; 500; 26; 20; Yes; Activity-on-arrow; Description-on-node; Days, Weeks.	Macintosh-128K; 2 disk drives; Apple Finder; Pascal; —.	$395.00; 1985; yes; 3000.	165

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$251.00-$500.00

COMPANY NAME / *Program name*	PROGRAM FEATURES: Computes critical path	Creates network diagram	Generates network schedule	Work breakdown structure	Specify scheduling constraints	Labor costs breakout	Capital/Equipment costs breakout	Assign/Report planned costs	Assign/Report actual costs	Windows	Relational database	Query to MIS database	Custom report generator	Business graphics generator	GRAPHICS: Project network	Project calendar	Gantt chart	Resource histograms	Resource S-curves	USER SERVICES: User hotline	Tutorial disk(s)	User newsletter	Organized user group
Pinnell Engineering Inc. *PMS80*	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•	•	•	•	•	•	
Project Software Inc. *Project Cost Model (PCM)*	•	•	•	•	•	•	•	•	•				•			•		•	•	•	•		
Project Software & Development *QWIKNET*	•	•	•	•	•	•	•	•	•	•						•	•	•	•		•	•	•
Scitor Corp.																							
Project Scheduler Network	•	•	•	•		•	•	•	•				•	•		•	•	•	•		•		
Project Scheduler 5000	•					•	•	•										•			•		
Westminster Software																							
Keeping Tabs				•	•			•	•												•		
Pertmaster Project Mgt. System	•	•	•	•	•			•	•							•	•	•	•	•	•	•	

$501.00-$1,000.00

COMPANY NAME / *Program name*	PROGRAM FEATURES														GRAPHICS					USER SERVICES			
	Computes critical path	Creates network diagram	Generates network schedule	Work breakdown structure	Specify scheduling constraints	Labor costs breakout	Capital/Equipment costs breakout	Assign/Report planned costs	Assign/Report actual costs	Windows	Relational database	Query to MIS database	Custom report generator	Business graphics generator	Project network	Project calendar	Gantt chart	Resource histograms	Resource S-curves	User hotline	Tutorial disk(s)	User newsletter	Organized user group
AGS Management Systems Inc. *PAC MICRO Project Mgt. System*	●	●	●	●	●	●	●	●	●				●	●			●	●	●	●		●	●
Computerline Inc. *PLANTRAC-CM*				●		●	●	●	●		●	●	●	●					●	●	●	●	●
Monitor Software *Task Monitor*	●	●	●		●	●	●	●	●				●	●	●	●	●		●	●			●
National Information Systems Inc. *VUE*	●	●	●	●	●	●	●	●	●				●	●	●	●	●	●		●			
SofTrak Systems Inc. *MicroTrak w/PlotTrak*	●	●	●	●	●	●	●	●							●		●			●	●	●	
Westminster Software *Pertmaster*	●		●		●										●	●	●	●	●	●	●		

Project Management Microcomputer Software

PROGRAM CAPABILITIES *Tasks Activities per project;* Milestones per project; Resource tracking- number per project; number per task: Partial resource allocation available; network format; Time base.	COMPUTER SYSTEM REQUIREMENTS *Make of computer-RAM;* Graphics card; *Color monitor;* Disk drives; Operating system. Program language; Is program source code available?	OTHER INFORMATION List price; Date Introduced; Copy protected; Units sold to date.	Reader Service Number
32K; 1000; 32K; 88; —; Activity-on-arrow, Activity-on-node; Days.	IBM PC/XT/AT or compatible-512K; Graphics card; Color monitor; 2 disk drives, hard disk; TI Professional-512K; Color monitor; 2 disk drives, hard disk; MS/PC-DOS (2.1 or later), UNIX (5.0). Xenix. Fortran 77; no.	$495.00-$6700.00; 1979; NO; 500.	166
3000; 3000; 300; Unlimited; Yes; Activity-on-node; Variable.	IBM XT/AT or compatible-512K; 1 disk drive or hard disk; PC-DOS. Fortran; no.	$500.00; 1983; no; 215.	167
500; User defined; 200; 12; No; Activity-on-node; Days, Weeks.	IBM PC/XT/AT or compatible-512K; One disk drive, hard disk; MS/PC-DOS (2.0 or later). C; no.	$395.00-$895.00; 1984; yes; 3000.	168
2000; 2000; 96; 999; Yes; Activity-on-node; Days, Weeks, Months.	IBM PC/XT/AT or compatible-320K, HP 150-320K, Wang PC-320K, TI Pro-320K; Graphics card; 2 disk drives or hard disk; MS/PC-DOS (2.0 or later). Pascal; no.	$500.00; 1985; no: —.	169
Memory; Memory; 96; —; Yes; —; Days; Weeks, Months.	IBM PC/XT/AT or compatible-256K; HP 150-256K; Wang PC-256K, TI Pro-256K, DEC Rainbow-256K; Graphics card; 2 disk drives or hard disk; MS/PC-DOS (2.0 or later). Pascal; no.	1395.W: 1984; yes; —.	170
—; —; —; —; —; —.	IBM PC/XT/AT or compatible-256K, HP 150-256K, Zenith 150-256K, TI PC-256K; 2 disk drives or hard disk; MS/PC-DOS (2.0 or later). —; —.	$295.00; —; no; —.	171
2500; 2500; 29; 10; —; Activity-on-arrow, Activity-on-node; Variable.	IBM PC/XT/AT or compatible-320K, HP 150-320K; 2 disk drives or hard disk; MS/PC-DOS (2.0 or later). Basic, C, Turbo Pascal; no.	$1,495.00-1,695.00; 1980; no; —.	172

Project Management Microcomputer Software

PROGRAM CAPABILITIES	COMPUTER SYSTEM REQUIREMENTS	OTHER INFORMATION	
Tasks/Activities per project; Milestones per project; Resource tracking- number per project; number per task; Partial resource allocation available; Network format; Time base.	Make of computer-RAM; Graphics card; Color monitor; Disk drives; Operating system. Program language; Is program source code available?	List price; Date Introduced; Copy protected; Units sold to date.	Reader Service Number
400; 400; 999; 1; —; —; —.	IBM PC/XT/AT or compatible-192K; MS/PC-DOS. Compiled Basic; no.	$990.00; 1984; —; 1500+	173
—; —; —; —; —; —; —.	IBM PC/XT/AT or compatible-256K, Wang PC, Tandy-256K; 1 disk drive or hard drive; MS/PC-DOS (2.0 or later), UNIX. Basic; no.	$996.00; 1986; no; 10+.	174
Unlimited; Unlimited; Unlimited; Unlimited; Yes; Activity-on-node; Variable.	IBM PC/XT/AT or compatible-512K, Wang PC-512K, 2 disk drives; MS/PC-DOS. Pascal; no.	$695.00; 1984; yes; 2000.	175
3000.99; 100; *20;* Yea: Activity-on-Arrow, Activity-on-node; Variable.	IBM PC/XT/AT, AT & T, DEC, Fortune, Gould, Honeywell, HP, Intel. NCR, Plexus, Pyramid, Spew. Sun 3, Zilog, Concurrent Computer Corp., Convergent Tech.; MS-DOS, UNIX. Fortran 77; —.	$995.99-$49995.00; 1980; —; 250.	176
5000; 5000; Unlimited; Unlimited; No; Activity-on-node; Days, Weeks, Months.	IBM PC/XT/AT or compatible-256K, Wang PC, Zenith Z100, Altos, Sun, Tandy, Plexus-256K; 2 disk drives; MS/PC-DOS (2.0 or later), UNIX, VAX VMS. C; no.	$595.00-$895.00; 1983; no; 10,000+.	177
1500-2500; 1500-2500; 29; 10; —; Activity-on-arrow; Activity-on-node; Variable.	IBM PC/XT/AT or compatible-256K, HP 150-256K, Wang-256K, DEC Rainbow 100-256K; MS/PC-DOS (2.0 or later). Basic; no.	$695.00-$895.00; 1980; no; 15,000.	178

$1,001.00-$2,500.00

COMPANY NAME / *Program name*	PROGRAM FEATURES														GRAPHICS					USER SERVICES			
	Computes critical path	Creates network diagram	Generates network schedule	Work breakdown structure	Specify scheduling constraints	Labor costs breakout	Capital/Equipment costs breakout	Assign/Report planned costs	Assign/Report actual costs	Windows	Relational database	Query to MIS database	Custom report generator	Business graphics generator	Project network	Project calendar	Gantt chart	Resource histograms	Resource S-curves	User hotline	Tutorial disk(s)	User newsletter	Organized user group
Advanced Technology Inc. *PHOENIX-PMS*	•	•	•	•		•		•	•					•	•		•	•		•	•	•	
Applied Business Technology Corp. *Project Workbench*	•	•	•	•	•	•		•	•	•			•		•		•			•	•	•	•
Computer Aided Management *View Point*	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•
Computer Cognition *Acuity*	•	•	•	•	•	•	•	•	•				•							•	•	•	
Datamatics *Chronomatics TC-1*				•	•	•			•	•			•							•	•	•	
MicroPlanning Software																							
Micro Planner IBM & Compatibles	•	•	•	•	•	•	•	•	•			•	•	•		•		•	•	•	•	•	•
Micro Planner IBM & Compatibles Version 2000	•	•	•	•	•	•	•	•	•			•	•	•		•		•	•	•	•	•	•
Micro Planner IBM & Compatibles Version 500	•	•	•	•	•	•	•	•	•			•	•	•		•		•	•	•	•	•	•
Nichols & Company Inc. *N1100 Project Planning System*	•	•	•	•	•	•	•	•	•	•			•	•		•	•	•	•	•			
North America MICA Inc. *PMS-II Project Management*	•	•	•	•	•	•	•	•	•			•	•	•	•	•	•			•	•	•	•
Primavera Systems Inc. *Primavera Project Planner*	•	•	•	•	•	•	•	•	•	•			•	•		•	•	•	•	•	•	•	•
Professional Applications Corp. *Pert+*	•	•	•	•	•	•	•	•	•					•		•	•			•	•	•	
Systonetics Inc. *VIS10N Micro*	•	•	•	•	•			•	•	•	•		•			•	•	•	•		•	•	

$2,501.00-$5,000.00

COMPANY NAME *Program name*	PROGRAM FEATURES														GRAPHICS					USER SERVICES			
	Computes critical path	Creates network diagram	Generates network schedule	Work breakdown structure	Specify scheduling constraints	Labor costs breakout	Capital/Equipment costs breakout	Assign/Report planned costs	Assign/Report actual costs	Windows	Relational database	Query to MIS database	Custom report generator	Business graphics generator	Project network	Project calendar	Gantt chart	Resource histograms	Resource S-curves	User hotline	Tutorial disk(s)	User newsletter	Organized user group
Computer Cognition *Acuity*	•	•	•	•	•	•	•	•	•				•							•	•	•	
Computerline Inc. *PLANTRAC*	•	•	•		•					•			•	•	•	•	•	•		•	•	•	•
Dekker Ltd. *TRAKKER PLUS*	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•

Project Management Microcomputer Software

PROGRAM CAPABILITIES	COMPUTER SYSTEM REQUIREMENTS	OTHER INFORMATION	
Tasks/Activities per project; Milestones per project; Resource tracking- number per project; number per task; Partial resource allocation available; Network formal; Time base.	Make of computer-RAM; Graphics card; Color monitor; Disk drives; Operating system. Program language; Is program source code available?	List price; Date introduced; Copy protected; Units sold to date.	Reader Service Number
10K; 10K; 10K; 4; Yes; Activity-on-node; Days.	DEC Professional, DEC MicroVAX, DEC VAX; VAX/UMS. Fortran; no.	$1795.00 & up; 1985; no; 300.	179
Unlimited; Unlimited; 200; 6; Yes; Activity-on-node; Hours, Days.	IBM PC/XT/AT or compatible-512K; 2 disk drives or hard disk; MS/PC-DOS (2.0 or later). Assembly & Cobol; no.	$1150.00; 1983; yes; 10000.	180
Unlimited; Unlimited; Unlimited; Unlimited; Yes; PDM (precedence diagram method); Days.	IBM PC/XT/AT or compatible-512K; Graphic card; Color monitor; Hard disk; MS/PC-DOS. C; no.	$1995.00; 1985; no; 1000+.	181
3000; 99; 100; 20; Yes; Activity-on-arrow; Activity-on-node; Variable.	IBM XT/AT or compatible-512K; Hard disk; MS-DOS. Fortran; no.	$1800.00-$3600.00; 1982; no; 100.	182
999; Unlimited; —; —; —; —; —.	IBM XT or compatible-256K, IBM AT-512K; Hard disk; MS/PC-DOS (2.1). Cobol; no.	$2195.00; 1985; no; 23.	183
4000; 4000; 35; 20; Yes; Activity-on-arrow; Variable.	IBM PC/XT/AT or compatible-256K; 1 or 2 disk drives or hard disk; MS/PC-DOS. Pascal; —.	$1995.00; 1981; yes; 15,000.	184
2000; 2000; 35; 20; Yes; Activity-on-arrow; Variable.	IBM PC/XT/AT or compatible-256K; 1 or 2 disk drives or hard disk; MS/PC-DOS. Pascal; —.	$1995.00; 1981; yes; 15,000.	185
500; 500; 35; 26; Yes; Activity-on-arrow; Variable.	IBM PC/XT/AT or compatible-256K; 1 or 2 disk drives or hard disk; MS/PC-DOS. Pascal; —.	$1995.00; 1981; yes; 15,000.	186
1000; 999; 100; 1; No; Activity-on-arrow; Hours, Days.	IBM PC/XT/AT or compatible, HP 150, Wang PC, NCR, DEC Rainbow-128K; Color monitor w/IBM; 2 disk drives or hard disk; MS-DOS. Basic; —.	$1800.00; 1985; yes; 250.	187
Unlimited; Unlimited; 32K; 32K; —; Activity-on-arrow; Hours, Days, Weeks.	IBM PC/XT/AT or compatible, HP 150, DEC Rainbow, TI Professional, Wang PC-512K; Hard disk; MS/PC-DOS (2.0 or later). CB 86; no.	$1295.00; 1980; no; 2000+.	188
10K; 10K; 96; 6; —; Activity-on-arrow; Days, Weeks.	IBM PC/XT/AT or compatible, Wang-512K, Burroughs B20-768K; 1 disk drive or hard disk; MS/PC-DOS (2.0 or later), VMS (4.4). Fortran & Assembler; no.	$2500.00; 1983; no; 3000.	189
5000; 5000; Unlimited; Unlimited; Yes; Activity-on-arrow; Variable.	IBM PC/ST/AT or compatible, HP 150, Wang VS, Wang 2200 Mini, Televideo Mini, Novell Network-256K; Color monitor; 1 disk drive or hard disk; MS/PC-DOS. Basic; yes.	$395.00; 1981; yes; 100+.	190
Unlimited; —; Unlimited; Unlimited; Yes; Activity-on-node; Days.	IBM PC/XT/AT or compatible-512K; Graphics card; Color monitor; Hard disk; MS/PC-DOS (2.0 or later). C; no.	$2500.00; 1985; no; 250.	191

Project Management Microcomputer Software

PROGRAM CAPABILITIES Tasks/Activities per project; Milestones per project; Resource tracking- number per project; number per task; Partial resource allocation available; Network format; Time base.	COMPUTER SYSTEM REQUIREMENTS Make of computer-RAM; Graphics card; Color monitor; Disk drives; Operating system. Program language; Is program source code available?	OTHER INFORMATION List price; Date Introduced; Copy protected; Units sold to date.	Reader Service Number
3000; 99; 100; 20; Yes; Activity-on-node, Activity-on-arrow; Variable.	AT&T, CT, DEC, GOULD, NCR, HP, PYRAMID, HONEYWELL, SUN, SPERRY, ZILOG, INTEL, FORTUNE-512K; Hard disk; UNIX. Fortran, no.	$4200.00-$6500.00; 1982; no; 100.	192
250K; —; —; —; —; Activity-on-arrow, Activity-on-node, Bar chart; Variable.	IBM XT/AT or compatible, HP 150, Wang PC, Tandy-256K; 1 disk drive or hard disk; MS-DOS (2.0 or later), UNIX, Xenix. Basic; no.	$3000.00; 1980; no; 1500+.	193
Unlimited; Unlimited; Unlimited; Unlimited; Yes; Activity-on-arrow, Activity-on-node, Gantt; Variable.	IBM PC/XT/AT or compatible-640K; Graphic card; Color monitor: 1 dirk drive and hard disk: MS-DOS (2.1 or later). C; no.	$2995.00; 1985; no; 1200.	194

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$2,501.00-$5,000.00

COMPANY NAME / *Program name*	PROGRAM FEATURES														GRAPHICS					USER SERVICES			
	Computes critical path	Creates network diagram	Generates network schedule	Work breakdown structure	Specify scheduling constraints	Labor costs breakout	Capital/Equipment costs breakout	Assign/Report planned costs	Assign/Report actual costs	Windows	Relational database	Query to MIS database	Custom report generator	Business graphics generator	Project network	Project calendar	Gantt chart	Resource histograms	Resource S-curves	User hotline	Tutorial disk(s)	User newsletter	Organized user group
Global Computer Systems Inc. *Accounting for Engineers & Architects* *Manufacturing Management System +*						• •		• •	•	•										• •			
K & H Project Systems Inc. *Prestige PC*	•	•	•	•	•			•	•	•	•	•	•	•	•	•	•	•	•	•		•	•
Patton Consultants Inc. *COMMS*			•	•	•	•	•	•	•	•	•	•	•							•			
Primavera Systems Inc. *Finest Hour*	•	•	•	•	•	•	•	•	•	•			•	•		•	•	•	•	•	•	•	•
Strategic Software Planning Corp. *PROMIS*	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•
Welcom Software Technology *Open Plan*	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

Over $5,000.00

COMPANY NAME / *Program name*	Computes critical path	Creates network diagram	Generates network schedule	Work breakdown structure	Specify scheduling constraints	Labor costs breakdown	Capital/Equipment costs breakdown	Assign/Report planned costs	Assign/Report actual costs	Windows	Relational database	Query to MIS database	Custom report generator	Business graphics generator	Project network	Project calendar	Gantt chart	Resource histograms	Resource S-curves	User hotline	Tutorial disk(s)	User newsletter	Organized user group
	PROGRAM FEATURES														GRAPHICS					USER SERVICES			
ADP Network Services *APECS/8000*	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•			•
PMS Administrator	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•			
ASK Computer Systems *MANMAN/PROJECTS*				•		•		•	•							•	•					•	•
A-Systems Corp. *Contractor III/CPS*	•	•	•			•	•	•	•											•		•	
Dynamic Solutions Inc. *PERT6*	•	•	•	•	•	•	•	•	•				•			•	•	•	•	•			
Planning Control International *EASYTRAK*	•	•	•	•	•	•	•	•	•		•	•	•		•	•	•	•	•	•	•	•	•
Shirley Software Systems *MISTER*	•	•	•	•	•	•		•	•	•			•		•		•			•			
Systems Control Inc. *Multinet*	•	•	•		•			•	•				•		•	•	•	•		•			

Project Management Microcomputer Software

PROGRAM CAPABILITIES: Tasks/Activities per project; Milestones per project; Resource tracking- number per project; number per task; Partial resource allocation available; Network formal; Time base.	COMPUTER SYSTEM REQUIREMENTS: Make of computer-RAM; Graphics card; Color monitor; Disk drives; Operating system. Program language; Is program source code available?	OTHER INFORMATION: List price; Date Introduced; Copy protected; Units sold to date.	Reader Service Number
9999; 9999; —; —; —; —; Variable.	IBM XT/AT-512K or Wang PC-512K; Hard disk; MS-DOS. Basic; yes.	$4500.00; 1983; either; NA.	195
9999; 9999; —; —; —; —; Variable.	IBM XT/AT-512K or Wang PC-512K; Hard disk; MS-DOS. Basic; yes.	$5000.00; 1985; either; NA.	196
2000; Unlimited; Unlimited; Unlimited; Yes; Activity-on-node; Variable.	IBM XT/AT or compatible-512K; Graphics card; Color monitor; Hard disk; MS-DOS (2.0 or later). Fortran; no.	$5000.00; 1986; yes; new.	197
Unlimited; Unlimited; Unlimited; Unlimited; —; Activity-on-arrow, Activity-on-node; Variable.	IBM PC/XT/AT or compatible-640K; Hard disk; MS/PC-DOS. —; —.	$4950.00-$12,900.00; 1980; YES; 30.	198
10K; 10K; 96; 6; Yes; Activity-on-node; Activity-on-arrow; Hours, Days, Weeks.	IBM XT/AT or compatible-512K; 1 disk drive and hard disk; MS/PC-DOS (2.0 or later). Fortran and Assembler; no.	$5000.00; 1985; no; 250.	199
Unlimited; Unlimited; Unlimited; Unlimited; Yes; Activity-on-node; Days.	IBM PC/XT/AT or compatible, HP Vectra, Wang PC, VAX w/ emulation board-512K; Hard disk; MS/PC-DOS (2.0 or later). Pascal; no.	$2995.00; 1984; yes; 2000.	200
10K; 10K; 500; 250; Yes; Activity-on-arrow, Activity-on-node; Variable.	IBM XT/AT or compatible-256K; MS/PC-DOS (2.0 or later). Fortran 77, dBase; yes.	$4200.00; 1984; no; 700.	201

Project Management Microcomputer Software

PROGRAM CAPABILITIES: Tasks/Activities per project; Milestones per project; Resource tracking- number per project; number per task; Partial resource allocation available; Network formal; Time base.	COMPUTER SYSTEM REQUIREMENTS: Make of computer-RAM; Graphics card; Color monitor; Disk drives; Operating system. Program language; Is program source code available?	OTHER INFORMATION: List price; Date Introduced; Copy protected; Units sold to date.	Reader Service Number
32K; Unlimited; 256; 64; Yes; Activity-on-arrow; Activity-on-node; Variable.	MICRO VAX II; Hard disk; UNIX, ULTRIX, UTS. C and Fortran 77; —.	$27,000.00; 1984; yes; 50.	202
32K; 32K; 256; 64; No; Activity-on-arrow, Activity-on-node; Variable.	MicroVAX II-2000K, AT & T 3B2-2000K; Color monitor; Hard disk; Unix. C/Fortran; no.	$46,000.00; 1984; yes; 30+.	203
Unlimited; NA; NA; NA; NA: NA; Hours.	HP 3000, DEC VAX; VAX UMS, HP MPE. Fortran 77; yes.	$13,500.00-$25,000.00; 1985; yes; 55.	204
32K; 99; —; —; —; —; —.	IBM PC/XT/AT or compatible-128K, Autos, Televideo; 1 disk drive and hard disk; MS/PC-DOS (2.0 or later). Basic and Assembly; yes.	$8000.00-$12,000.00; 1978; no; 1000.	205
32K; 32K; —; 7; —; Activity-on-arrow, Activity-on-node; Variable.	IBM XT; VAX/VMS, Alpha Micro-AMOS/L. Fortran, no.	$39,000.00; 1972; no; —.	206
Unlimited; Unlimited; Unlimited; Unlimited; —; Activity-on-arrow, Activity-on-node, ETM; Variable.	IBM XT/AT or compatible-128K; Graphics card; Color monitor; Hard disk; EASYTRAK Coprocessor. —; no.	Over $5000.00; 1983; yes; —.	207
Model dependent; Activity-on-arrow, Activity-on-node; Hours, Days, Weeks.	DEC VAX, PRIME; VMS, PRIMOS. Fortran; —.	$4000.00-$42,000.00; 1969; yes; NA.	208
—; —; —; —; —; Activity-on-node; Variable.	IBM XT/AT; PC-DOS. Cobol; yes.	$25,000.00; 1986; yes; —.	209

5
Managing Cogeneration Projects

CONTENTS

The project manager is faced with unique challenges when dealing with a cogeneration project. This chapter outlines the engineering, construction, and contractual considerations which must be taken into account.

Cogeneration is defined as the simultaneous production of electricity and usable thermal energy from a single primary fuel source such as natural gas. Due to the fact that cogeneration is more efficient than electricity generated by a utility company it is gaining in popularity. A recent survey illustrating the success of cogeneration projects installed is detailed in Figure 5-1.

Another factor influencing the growth of cogeneration is that the Public Utility Regulatory Act (PURPA) mandated utility purchase power obligations, fair standby rates supplemental service and guaranteed interconnection with the utility grid. There are many types of cogeneration plants utilizing combustion turbines or reciprocating engines or steam turbines. Refer to Table 5-1 for a summary of cogeneration basics.

There are several options for installing cogeneration at the user site. Third-party financing offers no investment from the user and guarantees electric rates below the local utility rates. Details of managing cogeneration projects are described in this chapter.

Cogeneration Project Management starts with a successful feasibility study.[1] This phase is followed by the preliminary engineering effort, which identifies basic plant configuration and cogeneration cycles, and results in sizing of major equipment. The effort continues through all of the engineering and permitting processes. When the project enters the construction phase, the major effort in the Project Management is then directed to construction management and supervision.

At the completion of construction, the Project Manager's attention is directed to the critical start-up and testing phase.

The Project Manager's responsibility is finished only after the operator training is complete and when the operating and maintenance procedures are in place.

Through the entire project management one of the major responsibilities is budgeting. The Project Manager is responsible for keeping the project on time and on budget.

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[1] **Cogeneration Project Management by J.W. Egan, presented at 9th World Energy Engineering Congress, Association of Energy Engineers, Atlanta, GA 30340.**

Figure 5-1. Survey of The Cogeneration Systems Installed.

Survey Findings

- Overall cogeneration system performance:
  42.8% Excellent ***28.6%*** Good ***25%*** Satisfactory ***3.6%*** Poor
- Overall cogeneration savings are:
  27.6% Better than estimated ***37.9%*** Met estimated calculations
  34.5% Less than estimated
- Overall total cogeneration system cost:
  16.7% More than 10% over budget ***70%*** Within budget
  13.3% Under budget
- Would you recommend a second cogeneration system if the same need arose?
  93.1% Yes ***6.9%*** No
- How long from initial feasibility study to construction start-up?
  19.3% Less than one year ***9.7%*** 3-4 years
  41.9% 1-2 years ***0*** 4-5 years
  19.4% 2-3 years ***9.7%*** Over 5 years
- What was the attitude of your state's energy regulator towards your project?
  37.9% Helpful ***41.4%*** Neutral ***20.7%*** Not helpful
- What was the attitude of your electric utility towards your project?
  29.6% Helpful ***37%*** Neutral ***33.4%*** Not helpful
- What was the attitude of your gas utility towards your project?
  68.2% Helpful ***27.3%*** Neutral ***4.5%*** Not helpful
- Type of system installed:
  3.1% Stirling cycles
  3.1% Brayton cycles
  9.4% Extraction steam turbine
  12.5% Back pressure steam turbine
  18.8% Gas turbine
  9.4% Combined cycles (steam turbine & gas turbine)
  37.5% Diesel and gas engines
  6.2% Other
- For organizations planning to install a cogeneration facility in the next 12 months specify application:
  23.7% Commercial ***34.2%*** Institutional ***42.1%*** Industrial

The survey is based on responses from members of the Cogeneration Institute.

Reprinted with permission: Cogeneration Institute of the Association of Energy Engineers, 4025 Pleasantdale Road, Suite 420, Atlanta, Georgia 30340 (404) 447-5083.

Table 5-1. Cogeneration Basics

Definition of Cogeneration	Cogeneration is the sequential production of electricity and usable thermal energy from a single primary fuel source such as natural gas, oil, coal, garbage, wood or agricultural waste.
Cogeneration Efficiency	Cogeneration is more efficient that electricity generated by a traditional electric power plant. The cogeneration facility is located near a user of heat (unlike a central power plant). The heat released from the exhaust gases or cooling water of the cogeneration unit is used to satisfy thermal load requirements. The overall efficiency of cogeneration systems may be 80% in converting fuel to useful energy compared to the delivered efficiencies of 30-35% of electricity-only plants.
Impact of Public Utility Regulatory Policies Act (PURPA) of 1978	PURPA mandated utility purchase power obligations, fair standby and supplemental service and guaranteed inter-connection with the utility grid. Prior to PURPA, cogen-eration facilities had to be oversized to insure 100% self sufficiency.
Type of Cogeneration Systems	There are three main types of cogeneration systems: ● Combustion Turbines systems include a combustion turbine which drives a generator to produce electri-city. Hot exhaust gases from turbines can be used with a waste heat boiler which produces steam or hot water. Combustion turbines provide a higher thermal-to-mechanicalenergy ratio than reciprocating engines. Total efficiency of 90% is possible with a generating mechanical efficiency of 12% to 30%. These units can be used in conjunction with absorption cooling. ● Reciprocating Engines include an engine which drives a generator to produce electricity and hot water or steam (produced from the hot exhaust gases and engine cooling system. Used primarily in smaller applications. ● Steam Turbines are used primarily for large applications and use coal, solid fuels and biomass as the fuel source. The steam turbine is ideal for industries such as steel or paper that require large quantities of high pressure steam. Steam turbines produce the most heat per kilowatt of power.
Financing & Ownership	There are several options available for installing a cogen-eration facility at the user's site. Third-party ownership requires no investment from the user and guarantees

(Table 5-1 continued)

	electric rates below the local utility. The user may decide to finance the facility and take total ownership and risk as well as lower cost of electricity.

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In the engineering discipline, as well as others, the major problem in project management is communication. Communication is extremely important and without good communications a project is doomed to failure. There are several communication techniques which can be used on cogeneration projects whether these projects are small or large. A typical method used is the "Project Meeting." Meetings must be scheduled as necessary, during the very preliminary stages of the feasibility study and through the preliminary engineering, engineering design, construction, and startup phases. These meetings must be well organized, there must be an agenda for every meeting and prompt and detailed minutes must be prepared immediately after every meeting and distributed to all concerned parties.

ENGINEERING PHASE

Feasibility Study

A successful feasibility study will consider all of the major engineering elements in a congenration project. These elements include thermal use, electrical use, sizing of basic plant configuration, cogeneration cycles, regulatory considerations, project cost and project economics. Many successful congeneration feasibility studies employ sophisticated computer programs and usually include a verbal presentation to the prospective owners of the facility to summarize the results of the feasibility study.

Preliminary Engineering

Once the feasibility study has been completed and a decision has been made to fund the project, the preliminary engineering phase can then begin. In this preliminary engineering phase the following efforts are undertaken.

Conceptual Design – This effort involves the mass flow and heat balance diagrams and the process and instrumental drawings, (P&ID).

Once the P. and I.D.'s are complete and the project heat balance is determined, the major equipment on the project can be properly sized.

Prepurchased Specifications – After the equipment has been sized, specifications for prepurchased equipment can be prepared.

Request for Quotations – After the specifications are complete the engineer can advertise for quotations from major equipment vendors.

Award of Bids for Major Equipment – After the bids for the major equipment have been received and analyzed, then the awards can be made for the major cogeneration equipment.

Environmental Permitting

The next major engineering activity in the project management of a cogeneration facility is the Environmental Permitting.

This phase includes obtaining all of the permits required for the construction and operation of the facility.

These permits include the following:

- Air Quality Permits
- Environmental Permits
- Federal Energy Regulatory Commission (FERC) Permits
- Building Permits

During this phase of the work the engineer will assist the owner in obtaining required permits from the various regulatory agencies. The most crucial permit required is usually the air quality permit. Obtaining this permit can be a very complicated process depending on the particular requirements affecting the specific plant design. Federal Environmental Protection Agency (EPA), State EPA agencies, and the local *air* quality permitting districts are involved in this permitting strategy. This permitting involves federal and state laws, regulations and almost always requires a certain defined Best Available Control Technology (BACT) for the control of emissions. Since this is a very crucial phase in the project affecting design, the regulatory phase should be started very early in the project, since the time required can be a critical item.

Utility Interface

A critical element in the project management of the cogeneration facility is the proper interface with the local utility.

The Utility Interface will include the following items:

- Power Sales Agreements
- Utility protection considerations
- Electrical Utility Upgrades
- Gas, fuel supply to the plant

Power Sales Agreements – Depending upon the particular utility involved and whether the cogeneration plant owner's strategy is to sell electrical energy and or capacity to the utility or at a minimum to interconnect with the utility, there are certain agreements that must be negotiated with the utility. The timing of these agreements also can be critical since the utility must be notified early on in the project, regarding the particular characteristics and location of the proposed cogeneration facility.

Utility Protection Considerations – The electrical utility companies are very concerned with the integrity of their electrical generating and distribution systems and have very specific requirements for cogeneration facilities if they are to interconnect with the utility's electrical distribution system. These requirements include the protection for both sides of the system, that is, the utility and the cogeneration, or generating, sides of the plant. When the cogeneration facility is above a certain size, most utilities require specific metering arrangements for gross and net generation and also require telemetering of the generating production of the cogeneration plant to a central utility control center.

Electrical Utility Upgrades – Another major concern is the possibility of utility upgrades to accept the power from the cogeneration facility. These upgrades are often required because of the location of the cogeneration plant and these upgrades require significant time and cost. The planning and construction of these electrical upgrades are often critical and therefore require attention by the project manager early in the process.

Gas, Fuel Supply to Plant – On the fuel side, if the cogeneration plant is to purchase gas fuel from the utility, often the fuel pressure required is higher than the utility has available in the local area. This will require either gas fuel compression at the site or arrangements for the utility to run a separate high-pressure gas service to the facility. This also requires time for the utility to plan and engineer such upgrades. There may also be a significant cost involved.

Detailed Engineering Design

The next significant phase of the project development is the detail engineering design. This engineering design will include the following design elements:

- Mechanical
- Electrical
- Structural
- Civil
- Architectural
- Instrumentation and Control

The final product of this detailed engineering design effort is the production of a complete project manual. This project manual will consist of the following components: all bidding documents; general conditions; all technical specifications; all plans of the various disciplines required to constitute a complete set of plans and specifications.

This project manual will be used to obtain construction estimates or bids for the construction effort and the installation of the cogeneration equipment.

Design Review – When the detail design is complete the next crucial element is a design review. This design review should incorporate a review of the plans and specifications by qualified engineers in various disciplines. This design review would include the following elements:

- Coordination
- Review for omissions or duplications
- Constructability review
- Replaceability review
- Maintenance and operating review
- Budget review

CONSTRUCTION PHASE

Bid Phase

Under this phase of the work the engineer will organize and execute the following construction efforts:

- Invitation of bids
- Receipt of bids
- Review of bid proposal
- Award of bids

Construction Contracts

The construction contracts can be awarded through a prime contractor who will be responsible for all subcontractors or the engineer and owner can elect to award separate contracts for major divisions of the work, or the project can be constructed under a construction management contract. Whatever procedure is used for the construction contracts the engineer must be involved in the construction monitoring effort.

Construction Monitoring

This monitoring of the construction effort will include the following activities:

- Scheduling
- Coordination
- Budget Control.

Scheduling – The construction scheduling activities and format, which will vary with the size and complexity of the project, is critical and must be designed and maintained by the project manager.

Coordination – The coordination of a cogeneration project can be very complex. This activity will require major attention by the project manager.

Budget Control – The maintenance of the budget goals will be a constant activity of the project manager. During the construction phase this effort will be a crucial concern.

STARTUP AND TESTING PHASE

General

The startup and testing phase of the cogeneration project depending on the size and complexity can be a very involved procedure. The elements involved in this procedure will include the following:

- The designation of testing requirements.
- Supervision of independent testing laboratories when used to perform equipment testing and certification.
- Supervision of electrical calibration by independent electrical service companies.
- Final approvals of the testing procedures and final acceptance.

The testing and acceptance procedures can involve significant time and planning and the employment of standard American Society of Mechanical Engineers (ASME) testing procedures for the mechanical elements of the construction of the cogeneration facility and the monitoring and testing of the electrical relay protection systems which are required both for the protection of the cogeneration plant and utility electrical distribution systems.

Controls

The final testing and commissioning of the instrumentation and control systems is very crucial to the final checkout of the cogeneration facility. This must be witnessed by the project manager or delegated to a commissioning specialist. Once the testing of the various components of the system is complete and all of the test reports are available, the project manager must review these testing reports and decide to accept or reject the various components of the system. Once the components are accepted and the final project demonstration is complete the project manager can then generate a certificate of final acceptance. When this certificate is produced, the contractors can be paid the final payments and/or retentions and the project can enter into the training and operating phase.

Training

Training of Operating and Maintenance Personnel – At this point the operating and maintenance personnel should receive the final training to operate and maintain the plant. Ideally, the senior operators and supervisors should be brought on board early in the construction phase, so that they are able to witness testing of the various components usually in the manufacturers' facilities and to witness the installation of the major equipment and begin to become familiar with this equipment. The regular classroom training of the senior operators can then begin during the startup phases of the work.

Operation and Maintenance Manuals – The project manager must decide if the overall project manuals are to be assembled by a subcontractor or whether this is to be performed by the general contractor, or by the project manager's staff. However, a total operating and maintenance manual must be assembled for the entire plant systems.

Operating and Maintenance Procedures – The project manager has the responsibility to develop operating and maintenance procedures for the plant. This plant should then be staffed with qualified, well trained professional operators and maintenance people who understand the procedures implemented by the project manager.

The plant is then ready for the shake down phase of the operation. This shake down phase could consist of several weeks to several months to get through the initial problems that present themselves in any complicated plant operation. It will be necessary for the project manager to remain available during this period to shepherd the project into a smooth operating phase.

CHECKLIST FOR MAJOR CONTRACTS FOR COGENERATION AND SMALL POWER PRODUCTION[2]

This checklist addresses the requirements that these contracts must meet for a successful, nonrecourse or project financing of a cogeneration project (where the lenders or leasing company look solely to the revenues of the project for the return of their capital). Due to this form of financing, the contracts must minimize the various risks and adverse consequences that might occur. These same considerations are applicable to projects financed on more conventional bases because if the risks are minimized, the likelihood of the project achieving its projected results and returns are enhanced.

[2] Major Contracts for Cogeneration & Small Power Production by J.W. Pestle & E J. Schneidewind, presented at 9th World Energy Engineering Congress.

"Maintaining The Spread"
The Interrelationship of The Fuel and
Power Sales Contract

I. Project makes money on the spread between the cost of fuel and the price of energy sold.

A. The key is to protect the spread against

1. Electric/thermal revenue decline without corresponding fuel price decreases, and
2. Fuel price increases without corresponding electric/thermal rate increases.
3. Declines due to poor heat rate/capacity factor (see below).

II. Maintaining the spread is helped by factors such as:

A. A floor on energy rates, either

1. Absolute; or
2. Carried (if rate drops below floor, utility pays floor rate and shortfalls are later repaid to the utility with interest).

B. Consistent underlying economics (so as to prevent divergences):

1. For example, the electric rate is based on coal prices and the cogeneration plant is coal-fired.
2. The electric rate is based on gas prices and the cogeneration plant is gas-fired.

C. Financially strong fuel vendors

1. Who for this reason can absorb decreases in fuel prices below their cost of production, at least for a period of time.

D. Diversity in and actual alternate sources of supply

1. Spreads risk.
2. Project should have an express contractual right to go to alternate suppliers if existing suppliers cannot meet specified price and terms.

E. Use of true wastes or by-products where the use of the substance as fuel is a no cost (or cost reduction) item to the fuel supplier, rather than a revenue item

1. Wood
2. Bagasse
3. Municipal solid waste
4. Waste coal
5. Etc.

F. Energy rate based on less volatile solid fuels

III. Specific mechanisms

A. Simple indexing—fuel price varies with electric price:

1. Either based on total electric price rate change (energy and capacity), or
2. Based on energy portion only.

B. Subordination of fuel payment to loan/lease payment and reserves:

1. Totally.
2. Up to X% (similar to retainage).

C. Suspense/tracking account:

1. Deferral of a portion of fuel payments, with or without interest, so as to maintain the spread in the event of revenue shortfall/decrease in energy rates below a specified level.

D. Profit and loss sharing with fuel vendor:

1. Equity interest.
2. Contractual.

IV. Fuel Purchase requirements: Must track actual plant operations

A. No or low minimum purchase requirements.

B. Purchase requirements are *only* those *actually* needed for actual operation.

1. Purchases decrease and increase as plant actually operates no matter what the cause is:
   a. Mechanical failure.
   b. Operator error.
   c. Negligence by owner.
   d. Intentional actions by owner (e.g., intentional shutdown of plant for financial reasons).

C. Purchase obligation ceases if plant stops operation.

V. Term of Fuel Supply contract

A. In comparison with

1. Power sales contract and
2. Term of primary financing

B. Absolute term of fuel contract

1. 5, 10, 15 years or beyond and
2. Market price projections for that term

"Getting the Btu's"
The Fuel Purchase Contract

I. Fuel specification described in detail

A. Btu content
B. Moisture
C. Ash
D. Sulfur
E. Other
F. Remedies for noncompliance

1. Reject fuel.
2. Fuel supplier replaces with complying fuel.
3. Automatic fuel price adjustment to keep project economics constant.

II. Price

A. Price adjusted automatically to maintain project net revenues constant if there is a deviation from the fuel specification.

1. The project is buying useful btu's. The price should be on a per MMbtu basis (e.g., btu/lb).
2. Table or formula for other major variable factors, such as moisture content.
3. Specified remedies for deviation from environmental requirements (e.g., compliance coal fails to EPA specification).

B. The price should be a delivered price (seller of fuel to absorb any transportation price changes, up or down).

C. Price mechanisms have to correspond with power sales contract, as described above.

III. Other provisions

A. Measurement of fuel to conform to specifications

1. Who does the measurement.
2. Sampling method
3. Specific standards for measurement (ASTM or equivalent)

B. Delivery means carefully specified

1. Type of railcar (rotary coupler or bottom dump)
2. Truck delivery standard specified (to meet dumper specification), if applicable

C. Extensive default and remedy provisions favorable to cogenerator

D. Agreement to provide financial institutions with all data needed on seller of fuel that is necessary for a project financing

E. Term of contract to be short initial term with renewals at cogenerator's option. Allows cogenerator to switch if fuel delivery is unsatisfactory/market price should drop

F. Delivery schedule provisions:

1. "Look-ahead" notification of likely requirements for next several months.
2. Obligation on fuel supplier to maintain a specified minimum inventory of fuel at the cogeneration plant.

"Selling The Power"
The Power Sales Contract

I. Power Sales Contract Goals:

A. ***High*** rates are only ***part*** of the goal.

B. Rates *must* be financeable—predictable with ***downside*** risks ***minimized.***

1. Downward fluctuations minimized/prevented.
2. Risks of nonpayment removed.
3. Risks of rate change minimized/removed.
4. In summary—goal is a contract with complete assurance that the stated rate will be paid for all hours of operation for the life of the contract.

C. Typical type of solution for financeable projects.

1. Negotiated rate where upward fluctuations are traded to utility in return for removal of downward fluctuations. Results in a firm, fixed rate, often at a discount from projected rates.
   (a) A high but fluctuating rate is thus discounted to a lower fixed rate.
   (b) Avoided costs escalating (but not decreasing) at a percentage of full avoided cost escalation.
   (c) Other.
2. Resulting rate is ratepayer neutral or favorable.

D. Specific rate design matters.

1. Seasonal rates vs. flat rate year round.
2. Time of day rates (on-peak, intermediate peak, off-peak).
3. Utility fees for administering PURPA contracts.
4. Contract adders for pollution decrease.

E. Methodology: The contract should specifically spell out the precise methodology used to compute the rates so as to prevent future disputes/aid financeability.

F. Rate Security: Assurance that the contract as written will stay in effect for the life of the contract.

1. "Contract or rate"—Can the contract be revisited/reopened by the parties or by the Public Service Commission?
   (a) Can PSC reopen contract even if the contract does not allow same/parties do not want it? If so, what are the standards?
   (b) If allowed in the contract, under what circumstances and what are the standards?
2. Contract enforceable *even if* PURPA or state regulations changed/repealed (not a PURPA contract).
3. Pass through—utilities ability to pass through costs to the ratepayer.
   (a) Express approval on this in advance very desirable
   (b) PSC approval of contract in advance as just, reasonable, in the public interest and complying with PURPA.

(c) Can contract be reopened/unrecovered costs charged back to the project if the utility cannot pass through costs?

4. General language of force majeure clauses should not allow the contract to be opened under the preceding or other analogous circumstances.
5. Loss of QF status.

   (a) Does the utility still have to purchase?
   (b) If so, for how long (during any appeals; while the project has QF status restored)?
   (c) Is so, on what terms?
   (d) Agreement to have contact approved as wholesale contact by FERC.

G. Curtailment: Minimize situations/hold project harmless in the event of utility inability/lack of requirement to purchase (transmission line de-energized or overloaded, system emergency, testing interconnect equipment, light loading).

1. Cap on number of hours per year when need not purchased.
2. Some/all of the rate (e.g., capacity payment) is paid during times of curtailment.

II. Interconnection: Interconnection requirements can be a major hurdle. Must be expressly dealt with in the power sales contract or related contracts.

A. What is required for interconnection?

1. Dual feeds to the utility's transmission system?
2. What is the point of connection to the utility's existing system—and thus length of needed transmission lines?
3. Islanding issues (project and some customers cut-off from rest of utility grid):

   (a) Does project continue to operate?
   (b) Surge protection.
   (c) Frequency maintenance.
   (d) Voltage limits.
   (e) Load following ability.
   (f) Does this make the project a utility?
   (g) How is billing handled?

4. Telemetry/telecommunications requirements: Is direct, secure, redundant telemetry and phone connection with utility dispatcher required?
5. Amount and types of other protective and safety equipment.

B. Provision and cost of interconnection equipment:

1. If provided by a private contractor, how to assure that the utility's standards for the interconnection equipment have been met?
2. If the utility supplies the interconnection equipment:
   (a) Will its price meet the lowest competitive private bid?
   (b) Will it commit to a fixed price, schedule and adequate delay damages for its provision of the interconnection equipment?
   (c) Who resolves the above issues if the utility and project can't?

C. Is the project required only to pay for interconnection costs incurred at the time the installation is placed on line, or repair, replacement or *additional* interconnection costs in later years as well? If future costs are included are there any dollar limits on them?

D. Will transmission bottlenecks require payments by the project to removed the transmission bottleneck?

III. Indemnities/Non-Interference Clauses:

A. Scope—where circumstances on the utility's sytem harm the project and vice versa.

B. Equivalence—are they truly a two-way street? Should they be?

C. Are the risks imposed on the project insurable (important for financing)?

D. Non-interference and indemnity can be quite important if there is a risk that islanding or the project tripping off line can lead to surges harming other customers, or if interferences on the company's system reduce the power factor, and thus the output, of the project.

IV. Station Power:

A. Will it be produced by the project or bought at retail?

B. How is this affected by the utility's retail demand ratchets and standby rates?

V. PSC Approval/Ratepayer Pass Through:

A. Is the power sales contract contingent on Public Service Commission approval? Even if not, does the contract (and will the utility) allow advance Public Service Commission approval?

1. Advance approval minimizes the risks of later rejection/alteration of the contract by the Commission as imprudent or violating PURPA.
2. Approval aids financing, especially with a weak utility.
3. Utilities may oppose such approval as infringing on their management prerogatives or moving the Public Service Commission out of its reviewing role.
4. But approval may give the commission ***more*** ability to reopen the contract (against the cogenerator's wishes) later.

B. Must/can/will advance rulings be obtained from the State Commission on the ability of the utility to pass through all costs to its ratepayers?

1. Similar issues to number A above.
2. If obtained this minimizes one of the biggest risks for the utility and the project—that part way through the contract the utility cannot pass through its costs. This may result in the utility trying to alter the contract.

VI. Other Issues:

A. No or minimal limits on project's ability to assign the contract are usually necessary for financing.

B. Billing and prompt (20-30 days) payment terms very helpful—reduce working capital needs.

C. Contract term must be significantly longer than term of expected financing.

D. Default provisions must provide adequate notice and ability to cure.

E. Does the utility require an option to purchase at the end of the contract?
   1. Price.
   2. Terms.
F. Dispatchability.
   1. Does the utility desire/require this?
   2. Can the project accommodate this?
G. Coordination of maintenance and planned outages between the utility and project.
H. Provision by the utility for emergency purchases from the project if project not already operating at full capacity.
   1. Required by utility?
   2. Provision for dumping excess thermal energy.
   3. Effect on qualified facility status.
   4. Rate (X% over fuel costs).
   5. Telemetry/telephone notification.
I. Utility arrange/assist in wheeling power if project located in another utility's service territory.

"Building It to Work"
The Design-Build Contract

I. Two Main Concepts:
   A. Construction Phase: Strong contract provisions/assurances on the cost and schedule for completing the project.
      1. Developer has only a limited amount of funds, and no more, with which to complete the plant and bring it on line.
   B. Operation Phase: Strong contract provisions/assurances that the project will operate as planned—producing X kWh of electricity for sale per year while burning no more than Y amount of fuel.
      1. Heat Rate: That if provided X tons of coal/Y mcf of gas/etc., the plant will produce at least a certain number of kWh of electricity.

2. The number of kWh of electricity actually generated per year is the product of rated output x capacity factor x 8,760. Requires assurances that:
   (a) That the plant will have the rated output planned (e.g., at least a 25 MW plant), and
   (b) That it will meet or exceed a specified capacity factor (e.g., 85%).

C. Implementing these concepts involves a combination of
   1. Contractual performance standards and responsibilities on vendor and
   2. Remedies, bonuses and penalties.

II. True Turn-Key Contract Approach

A. The vendor delivers a fully operable plant meeting the specified scope of work by a certain date for a certain amount of dollars.

B. Place total responsibility for bringing the project to completion on the vendor.
   1. The contract is all inclusive on items which must be done to bring the plant to completion.
   2. Few, if any, provisions in the contract for price increases or schedule changes.
   3. Extremely limited force majeure clause (e.g., strikes do not excuse performance).
   4. Construction contract is keyed to a general scope of work document ("A plant which will produce 25 MW with an 85% availability factor when provided with fuel meeting a certain specification") and not to a detailed design. The scope of work requires building a plant to a performance specification with general quality standards as opposed to a detailed design specification.
   5. Responsibilities of the developer and owner minimized.

C. The results should be similar to the developer/owner buying an existing plant: Most or all of the risks of the construction phase (cost increases, schedule delays, not meeting specifications) are placed on the vendor.

D. Typical problem areas in allocating responsibilities/risks include:

1. Sub-surface/hidden conditions.
2. Obtaining and complying with permits.
3. Subsequent law changes.
4. Strikes (vendor or sub-supplier).
5. Utility interfaces.

III. Performance Test

A. Goals

1. To show compliance with contract standards; trigger penalties/remedies of non-compliance; lead to closeout of contract.
2. To provide substantial assurance to the owner/lender/lessor that the plant will perform as intended for a long time.

B. To achieve these goals, have the performance test resemble reality.

1. Long duration.
   (a) 30-90 days
   (b) Two 30-day tests, six months apart.
2. Performed under actual operating conditions.
   (a) Operators who will actually run the plant.
   (b) No more than actual number of operators specified in operating manuals (no additional help).
   (c) No special equipment.
   (d) In accordance with all operation manuals, vendor instructions, warranty requirements and the like.
3. Comply with all environmental and other laws.
4. Vendor to perform the test when it believes shakedown is sufficiently complete.
5. Plant performance during test determines whether the contract is met, applicable bonuses and penalties.

C. Typically measure many plant parameters during the performance test, especially those relating to

1. Output level.
2. Fuel used.
3. Heat rate.
4. Emissions.

D. Detailed specifications on the performance test must be included in the contract covering such matters as:

1. Design conditions for the plant.
2. Method of correcting from actual test conditions to design conditions.
3. Condition of the plant at start and stop of test (inventories at various portions of the process).
4. How the plant will operate with respect to intermittent factors (cycling equipment and the like)

E. Instrumentation and measurement

1. What is measured?
2. By what instruments?
3. To what standards (ASTM #X, etc.)
4. With what precision?
5. With what adjustments?
6. Record-keeping requirements.

F. Type of Reports/Data/Computations to be supplied to Owner/Lender/Lessor by Vendor.

G. General formulas to be used in computing key variables carefully spelled out.

IV. Remedies/Bonuses/Penalties

A. Goal. Penalty (and perhaps bonus) arrangement that holds project's over-all economics constant against the major project risks of delays and failure to perform as intended.

1. Reality. It may not be possible to obtain complete contractual protection on all points from the vendor.

2. The owner, interested third parties and/or financing institutions will likely have to take some of the residual risks in return for cash payments or expected future payments/rate of return.

B. Schedule: Goal is a fixed completion date with delay damages equal to cost to owner of any delays after a specified date, such as:

1. Interest on construction loan
2. O & M costs (operators and equipment being paid for even though the plant is not generating revenues)

3. Loss of tax benefits due to delays.

C. Failure to Meet Performance Test Standards.
   1. First and most important remedy is obligation of vendor to promptly fix plant to meet standards.
      (a) Best for all parties and especially for owner/lender/lessor as the monetary damages described below may not be sufficient to totally compensate all parties for failure to meet specifications.
      (b) Dollar and time limits on vendor's reponsibility to reperform and correct problems are usually a major issue.
   2. The secondary remedy is dollar penalties/liquidated damages for failure of the project to meet the performance tests standards.
      (a) "Buy-down" of the plant so that the cost per kilowatt (cost/kW) is held constant if the rated output is not met for any reason, e.g.,
         (i) Inability to produce output at contract level (20MW rather than 25MW plant)
         (ii) Environmental constraints.
      (b) Similar "buy-downs" if heat rate is higher than provided for/capacity factor is not met
         (i) The reality is that the discounted present value of the lost income stream due to either of these factors is very large and there is a likely inability to get liquidated damages approximating this disaccounted present value.
         (ii) Reinforces the need for a conservative design and extensive first obligation on the vendor to make the plant work.

D. Bonuses for project exceeding specifications.
   1. Desired by vendor but risky for the owner due to the vendor's ability to "skew" matters to achieve some bonus whereas the actual plant may not be deserving of same.
   2. **A** likely intermediate position is a partial bonus determined based in part on the performance test and part on the actual operating characteristics over time.

V. Many other factors to be covered in the contract

A. Detailed warranty provisions.
1. Scope
2. Duration (several years on major equipment)
3. Wrap around by main vendor

B. Limitations on liability

C. Owner's rights
1. Review and comment.
2. Receive data
3. Participate in meeting/negotiations
4. Observe inspections.

D. Coordination and priority among design contract documents.

E. Clear specification of external interfaces to be met
1. Raw water qualities
2. Air discharge
3. Water discharge.
4. Electric utility interface.
5. Gas utility interface.

"Interfaces and Consistency"
Making Sure The Contracts Meet And Match

I. Financing/Legal Perspective

A. The project is a "paper project" where the contract package represents the project. **All** the contracts must fit together perfectly and be consistent with no over-laps and no gaps on all matters materials to the project.
1. If the contract package, scopes of work, assumptions, interfaces and the like in the various documents are not all consistent or do not match, there is a significant risk that the project will not be completed or operated as planned.

B. Solution: Structure the project from the start for consistency, no overlaps, no gaps; and at the appropriate time (neither too early nor too late) the developer, lawyer and engineer must carefully review the entire document package for consistency and gaps.

II. Typical Issues.

A. Fuel Contract and Design Build Contract: Consistency between the two on

1. Fuel specification
2. Delivery method
3. Schedule for deliveries.

B. Power Sales Contract and Design Build Contract.

1. Usually complicated issues as to who does what on connecting plant to utility grid.
   (a) Standards
   (b) Timing
   (c) Respective roles of the parties on review/comment; approval; construction and cost responsibility.
   (d) Typically applicable to
      (i) Meters
      (ii) Line to utility grid
      (iii) Transformers
      (iv) Relays
      (v) Disconnects and the like
2. Typical example: Is the project output metered on the high side or low side of the output transformer? If on the high side, have the transformer losses been included in the performance standards for the plant?
3. Power Delivery Characteristics
   (a) Wave forms
   (b) Frequency Limits
   (c) Nominal voltage and ability to increase/decrease same within utility's scheduled limits for same.
   (d) Reactive supply and ability to make power factor leading/lagging within utility's scheduled limits.

C. Design-Build Contract and Its Attachments.

1. Reluctance on the part of lawyers to examine the scope of work, general technical requirements, performance, test documents, design documents and the like. Similar reluctance by technical experts to examine legal documents.
2. Each must examine the other's documents in detail. Typically find actual/potential inconsistencies or am-

biguities which should be resolved at the time, ***not*** later via a conflict/priority of document provision.

D. Correspondence of Design Build Contract With External Environment.
   1. Raw water characteristics.
   2. Air permit requirements.
   3. Water permit requirements.
   4. Easements and rights-of-way.

6
Cost Estimating: Conceptual and Detailed

CONTENTS

GENERAL

a) Quality of Estimate

This chapter on estimating of engineering/procurement/construction (EPC) is roughly divided into conceptual and detailed estimating. The general range in the quality of these two phases of estimating is about 40% to 10%, respectively. The measure of the quality of an estimate is usually categorized by the amount of contingency that is contained in the estimate. For example, a 10% estimate would have a 10% contingency. Due to the high development cost and the time necessary to produce a 10% quality estimate, most companies approve the funding and full execution of EPC type projects at the ±20% estimate quality. It is possible, in the "specialist equipment" areas and building industry, to produce 10% quality estimates from preliminary design information.

The accuracy of estimates varies considerably and is largely dependent on the quality of the estimating program and experience of the estimator. Quality also can be controlled to a substantial extent, by increasing or decreasing estimating manpower and time. The relationship is not linear. Appropriate, modest investments of time and resources will, usually, provide capital cost estimates of acceptable reliability. Further improvement becomes increasingly expensive, with only modest improvements in accuracy, resulting from substantial expenditures of time and resources. A point is soon reached where estimate quality is almost completely controlled by problems of forecasting economic conditions, local project conditions and quality of project performance. No significant improvement in estimate quality can be made thereafter, except by incorporation of actual design and cost information as it develops.

b) **Purpose(s)** of Estimates

Owner and constructor estimates are prepared at various stages of project development. They have two major purposes:

1. To establish cost levels for economic evaluation and financial investment.
2. To provide a base for cost control as the project develops.

This second purpose of "project control" is often ignored by "professional" estimators as they perceive their only purpose is to develop a quality estimate. In such cases, the resulting estimate may be of a high quality for investment purposes, but of a low quality from a project execution/control point of view. As most conceptual estimating bases are structured on a system basis, rather than on an area basis, it requires considerable effort at an early estimating stage, to develop an estimate on an "area" basis that, in turn, maximizes the "controlability aspect."

Even though a contractor's first early estimate can be of a lesser quality than an owner's estimate, it is recommended that a contractor provide an estimate early, after a contract award. This very quickly establishes a base for contractor cost control and should provide the contractor with a sense of commitment and responsibility for the financial basis of the project.

Due to the lack of time, it is probably that this early conceptual estimate would be a capacity-cost or curve-type estimate for direct costs with indirects on a percentage basis. Even though lacking time, the contractor should be encouraged to put as much quality (definition) into the estimate as possible, as this estimate may become the control base for the project.

The "appropriation" estimate, prepared by the owner, is on the same basis as the contractor's estimate, but statistically broken down into further detail so as to provide a checking basis of the contractor's first estimate.

The following could be the further breakdown:

- Itemized equipment list: material cost and labor manhours
- Bulk materials: material costs and labor manhours by category
- Offsite systems: material costs and labor manhours
- Home office costs and engineering manhours
- Field indirects: material costs, labor and staff manhours
- Owner costs: capital and expenses
- Estimating allowance: risk analysis

The statistical development of manhours provides information for overall scheduling and manpower resource evaluations.

c) Typical Estimating Systems

The most popular estimating systems that are available on the open market are:

1. Richardsons (buildings and process plants)
2. **R.S.** Means (mostly buildings)
3. Dodge (mostly buildings)
4. Page and Nation (process plants)
5. Icams (process plants)

Most of these systems or standards are published on a periodic basis, some of them annually, and it is therefore possible to update a company's estimating program at a very low cost. It is also quite common for large companies to develop their own estimating programs, and then it becomes necessary for these companies to provide an annual development program to maintain the quality of the historical data base.

d) Typical Estimating Categories

The following estimating methods or systems are the ones most commonly used:

1. Proration, Budget, Rough Order or Magnitude, etc.
2. Cost Capacity Curves
3. Equipment Ratio (curves)

The above methods are generally in the "Conceptual" category.

4. Quantity/Unit Cost

This last method is generally referred to as a detailed cost estimate.

PRORATION ESTIMATES

This method takes the cost of a similar, previously built facility, and "prorates" the cost for the new facility, based on changes for project conditions, capacity, escalation, productivity, design differences, and time. This method is based on some historical data and a lot of statistical relationships and assumptions. It is, therefore, not very accurate and is generally around ±40%.

COST CAPACITY CURVES (OVERALL)

An historical data base is developed for similar plants where the total cost is related to capacity. This method is usually more accurate, generally around ±30%, but does depend on the quality of the data base.

This method is also used, at a lower level of detail, for individual pieces of equipment and/or process/utility systems.

The above two conceptual estimating systems are generally used to give a quick and ***early indication*** of required investment level. The resulting evaluations are only used for "budget" purposes and investment possibilities. The information is not sufficiently accurate to make firm investment decisions. Sometimes investment decisions are made on this preliminary information, where economic viability is not the first priority. Projects to meet environmental standards, "stay in business" criteria, or R&D programs would fall into this category. Another purpose of these "early" estimating programs is to provide technical and economic information on investment and resource requirements to advance the technical basis and estimating quality to a higher level. Thus, many projects are funded on a partial or phased approach.

EQUIPMENT RATIO (CURVES)

This method calculates the costs of "bulk" materials, such as concrete, electrical, structural, piping, etc., as a percentage of the major equipment cost. Ratio methods can be used only with an appropriate data base. The accuracy of this method is generally ±20%. This quality of estimate is usually the minimum requirement for a "full investment" decision of an EPC project.

This "appropriation" estimate for an EPC project should be produced after completion of conceptual design and process selection and would be an update of the conceptual estimate prepared during feasibility studies.

The following would be the design/scope basis:

- Overall process flow diagrams
- Heat and material balances
- On-site and off-site facilities and layouts (power, steam, air, electricity, water)

- Preliminary plot plans/building layouts
- Equipment list – by size and category
- Preliminary execution plan/organization/resources/schedule
- Completed survey of appropriate estimating data

This would be an equipment and bulk ratio estimate for direct labor and material costs. Indirect costs would be factored from direct costs. A further statistical breakdown would be made to develop engineering and construction manhours for scheduling and resource evaluation.

QUANTITY/UNIT COST ESTIMATES

This method is the most accurate, generally ±10%, but it can be costly and time-consuming, as detailed takeoffs must be made of all labor and material units in the system. This method requires that engineering be sufficiently advanced so that accurate material quantity takeoffs can be produced. It also requires detailed historical data for applying unit manhour rates and monetary costs to the estimated quantities.

This last, general category is usually referred to as a detailed cost estimate.

This estimate can be developed only when the process design has essentially been completed. It will also require a significant amount of detailed engineering to be completed so that bulk material takeoffs can be developed for civil work, mechanical, piping, electrical, etc.

The following would be typical for an EPC project:

a) Approved process descriptions - feedstock and product slate
b) Licensor engineering (schedule A package)
c) Approved flow sheets
d) Heat and material balances
e) Approved process piping and instrumentation diagrams (PIDs) (process and utilities)
f) Approved plot plans
g) General specifications
h) Equipment specifications and data sheets
i) Completed site-soil survey and report
j) Site development and grading drawings
k) Underground piping and electrical layouts

l) Concrete foundation layouts
m) Above-ground piping layouts
n) One-line electrical drawings
o) Milestone schedule
p) Detailed project-owner conditions and requirements
q) Project-owner conditions and requirements
r) Environmental and governmental requirements
s) Equipment quotations - transportation costs
t) Bulk material takeoffs
u) Labor cost-productivity data
v) Layouts for construction temporary facilities
w) Organization charts (project, engineering, and construction)
x) Personnel schedules and manpower histograms
y) Construction equipment schedules

A detailed estimate would be quantity based with separate unit costs for material, labor, and manhours. Construction would be based on an area breakdown rather than on the "system" basis of a conceptual estimate. This estimate could be an updated, trended version of the first conceptual estimate and subsequent updates or a completely separate exercise. In most cases, it would be a separate exercise, as the format and work breakdown structure would be different and more detailed than that of a conceptual estimate. In particular, the construction estimate would be on an area basis with takeoffs by work units and manhour unit rates.

Apart from "trend" updates, this estimate breakdown could be sufficient to control costs to completion of the project. This estimate could be developed about 6-8 months after contract award, on an EPC reimbursable type project, as this amount of time would be required to provide an adequate completion of detailed engineering.

The most significant element of a high quality estimate is the maximizing of quantities and minimizing of factors and statistical relationships.

"FUDGING THE DETAILED ESTIMATE

Many companies have a policy that requires a detailed 10% estimate before the project appropriation will be approved. These same organizations, typically manufacturing companies, also require that the project be started "yesterday." Manufacturing and plant management are able to "insist" on these conflicting objectives. These two objectives are incompatible. In most cases, the practical resolution of this management inconsistency is for the estimate to be *"fudged."* This is to say, the estimate shows a 10% contingency, "below the line," with a similar amount of money "buried above the line" in individual categories where the risk is deemed to be the greatest. Whereas this "process" meets the company financial approval policy, it, nevertheless, provides a poor basis to execute and manage the project. From a project management viewpoint, it is poor practice. It is also quite common for such companies to execute projects on a "crisis management" basis. In most cases, this type of approach will increase the capital costs of their projects. However, this may increase the economic return as the product can reach the marketplace at an earlier time.

DESIGN CONSTRAINT ON ESTIMATING QUALITY

Figure 6-1, entitled "Overall Breakdown of Engineering, Procurement, and Construction," shows the quality of estimating in relation to its completion of the EPC progress curves. This information is based on historical experience and it shows that for a 10% quality estimate, the percentage completion for an EPC project should be the following:

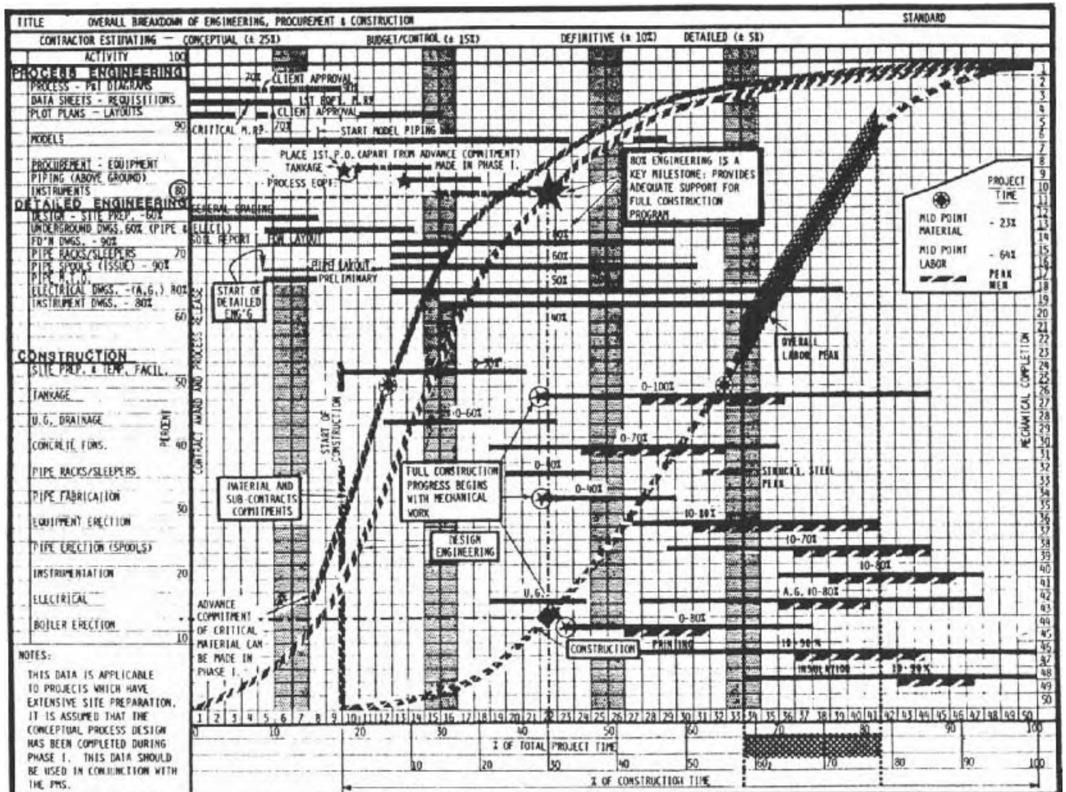
- Engineering - 85%
- Procurement - 90%
- Construction - 20%

With an outstanding historical data base and high quality personnel, it is possible to provide a 10% estimate with lower percent completions of EPC.

PROJECT MANAGEMENT ESTIMATING RESPONSIBILITY

As many companies have a formal estimating section, the relationship between the estimator and project manager should be clearly defined and properly understood by all parties.

Figure 6-1. Overall Breakdown of Engineering, Procurement and Construction.



The project manager should "direct" the estimate(s) development, approve the estimate(s) prior to issue, and ensure the estimate(s) properly reflects:

a) Project objectives and their priorities
b) Design scope and design specifications
c) Maximizing of quantities and minimizing of factors (numbers of drawings and construction work units)
d) Correct evaluation of design and labor productivities
e) Current project and site conditions (access, congestion, etc.)
f) Proposed execution plan/contract strategy
g) Schedule requirements (economic versus acceleration)
h) Adequate contingency evaluation

As can be seen from the above "definition," the project manager is actively involved in the development of the estimate and is responsible for the final product.

DEVELOPING OR CHECKING AN ESTIMATE

a) **Scope Review**

To ensure that the scope definition is of the required quality, the estimator/project manager should make a detailed review of all basic design documents, their revision numbers, and dates of issue:

1) Check that all major equipment is included and is listed by equipment number.
2) Review all items shown on plot plans, flow sheets, PIDs, and equipment lists to ensure their inclusion in the estimate.
3) Equipment and system capacities, flow rates, temperatures, and pressures should be checked for deviation.
4) Check that owner costs are to be included, or shown separately.
5) Evaluate deviations in the scope, design, or estimating basis from those assumed in the earlier estimate and include these on a "puts and takes" list.
6) Specialist engineers assigned to the project should review and verify the design scope.

b) Project Conditions Review

Prior to developing the line-by-line details of the estimate, an overall evaluation should consider the following.

1) Project location considerations, i.e., site characteristics (high winds, weather, soil conditions) and local affiliate-governmental practices or regulations.
2) Schedule, i.e., start of engineering, start of construction, mechanical completion, and milestone dates.
3) Labor basis, e.g., subcontract or direct hire.
4) Economic outlook.
5) Contracting mode and execution plan.
6) Estimate is compatible with contract conditions.

c) Reviewing Significant Overall Relationships

A comparison should be made of significant relationships including:

1) Engineering manhours per piece of equipment.
2) Construction manhours per piece of equipment.
3) Ratio of direct field manhours to engineering manhours.
4) Contractor's home office and engineering cost as a percent of total cost.
5) Contractor's fee as a percent of total cost.
6) Indirect construction costs as a percent of direct labor cost.
7) Percent breakdown of engineering manhours by prime account.
8) Percent breakdown of construction manhours by prime account.
9) All-in engineering manhour rate.
10) All-in field manhour rate.
11) Escalation allowances for material and labor.
12) Productivity factors for engineering and construction.
13) Currency exchange rates (for overseas purchases).

d) Major Equipment and Material

The cost of major equipment can be established by actual quotations or from historical data. The method depends on the type of equipment involved and its relative cost. For example, quotations should be obtained for large compressors, but small mixers may be estimated from catalogues or estimating manuals.

1) Developmental (or growth) allowances for "Fast Track" projects: Estimates based on vendor quotes, catalogue prices, or initial inquiries should include an allowance for future increases in scope. Costs can rise as much as 15% from an original purchase price as a result of design changes. Verify that the estimate has included an appropriate design allowance (typically 5-10%) for future changes. Based on the general specifications and detailed equipment specifications and data sheets, evaluate as follows.
2) Vessels (towers, reactors, drums): Check unit costs; adjust for size, material, shop versus field fabrication, operating temperature-pressure, metallurgy, number of manholes and platforms, internals required, and the need for insulation-stiffening rings and lifting lugs.
3) Heat exchangers: Check the cost per square foot of useful transfer surface.
4) Heaters and furnaces: Check the cost per British thermal unit of heat absorbed. Evaluate the degree of prefabrication prior to field erection.
5) Boilers and superheaters: Check the cost per pound of steam generated.
6) Pumps: Check the cost per horsepower. Pumps of similar capacity can vary greatly in price depending on type and materials of construction. It is important to know all special service requirements and design characteristics.
7) Storage Tanks: Check the cost per barrel capacity and the cost per pound of fabricated weight. Ensure that tank foundations are adequate for duty and soil conditions.
8) Evaluate project-schedule conditions which could influence prices, e.g.:
   i. Market conditions
   ii. Purchasing preference/plant compatibility/maintenance costs
   iii. Schedule acceleration (premium costs)
   iv. Escalation/currency exchange rates
   v. Freight, duties, taxes
   vi. Size of order/quantity discount

   Use a "cheapest source" program for guidance on the source for a worldwide purchasing program.

e) Bulk Materials: Quantities and Costs Evaluation

1) Concrete:
   i. Spot-check design quantities for large equipment foundations
   ii. Average cost per cubic yard installed (with rebar, formwork, excavation, and backfill)
   iii. Quantity of rebar, formwork, excavation, and backfill per cubic yard of concrete.
2) Roads and paving: Cost per square foot installed—overall areas from plant layout.
3) Underground piping and sewers:
   i. Total linear feet from drawing layout
   ii. Location and number of manholes
   iii. Cost per linear foot of installed piping, including excavation, backfill, manholes and sumps.

   On large projects, underground quantities are often underestimated.
4) Miscellaneous concrete work: Ensure sufficient requirements for cooling tower basins, API separators, pipe sleepers, culverts, and particularly road and electrical crossings.
5) Fireproofing:
   i. Check the cost per area of surface fireproofed.
   ii. Ensure adequate allowance for cutouts and rework.
6) Buildings, structures: Review individual costs for the substructure, heating, ventilation, air conditioning, plumbing, and lighting as a function of the floor area and total cost. Look at all-in square-foot costs of building.
7) Site preparation:
   i. Review grading and site preparation; check costs per cubic yard.
   ii. Check soil conditions, i.e., type, frost depth, de-watering, sheet piling, and draining requirements.
   iii. Consider possible underground obstructions.

   On large grass roots projects, earth-moving quantities are often underestimated.
8) Piling:
   i. Check the all-in cost per linear foot (including mobilization and demobilization) and the type of piles (e.g., precast, in situ, or timber) and the cutting of pile caps.

ii. Check who does the layout work (the prime contractor or a subcontractor?).

9) Fencing and railroads (usually subcontracted):
   i. Total linear feet.
   ii. All-in subcontract installed costs.

10) Piping estimating methods: Following are four methods of preparing a piping estimate. The specific method would depend on detail and accuracy of the estimate.
   i. "Estimating by Length Method." This method is based on historical data and assumes an average number of fittings and flanges for a "standard" piping configuration. Costs would be on a unit length basis by pipe size and schedule. Fabrication would be separated from field installation. It is necessary to add only the cost of valves, pipe supports, testing, etc. to arrive at a total direct cost for the piping system. Care should be taken to check allowances for unusual complexity of piping arrangements (especially on-site units or revamps).
   ii. "Estimating by Weight Method." In this method, piping materials are assumed to have a value approximately proportional to their weight. Pipe is assigned a cost per pound for material and a number of manhours per ton for fabrication and erection. Adjustments should be made for unusual materials and labor productivity for the plant location.
   iii. "Estimating by Ratio Method." This method calculates piping as a percentage of the major equipment cost. Ratio methods can be used only with an appropriate data base. This is not a very accurate method and is usually applied to conceptual estimates.
   iv. "Estimating by Unit Cost Method." This method is more accurate but is costly and time-consuming as detailed takeoffs must be made of all labor and material units in the system. This method requires that engineering be well advanced before accurate takeoffs can be produced. It also requires detailed historical data.
   v. "Piping Estimate Review." Examine the method and extent of takeoff by sampling line takeoffs, and com-

pare actual quantities and costs with estimate. Review the basis of fabrication, impact of special materials, etc. Also check the following:

A. Total linear feet and total weight as a function of plant capacity and plant area.
B. Overall cost of pipe, fittings, valves, and flanges to total cost of piping material.
C. Separately, compute the cost per ton for material, prefabrication, and erection of both small- and large-bore piping.
D. Cost per foot of pipe tracing (steam or electrical).

11) Electrical: In estimating electrical work, a schedule of the number and size of motor drives is a basic requirement. Motor control center and power distribution items usually constitute a major part of the electrical work. Since their prices can vary considerably, budget prices should be obtained from potential suppliers. The cost of power cable should be estimated in reasonable detail. A plot plan layout is useful in assessing quantities, while material unit prices may be estimated from historical data. Minor, miscellaneous services, such as emergency lighting, fire alarms, intercoms, power outlets, and telephone systems, can be assessed approximately or represented as an allowance. Plant lighting may be estimated on an area or unit length basis. A gross estimate of electrical work based on horsepower can be inaccurate. The estimate should take into consideration local electrical codes and area classification. Climatic conditions may require a different type of cable and hardware, and therefore could affect cost.

i. Electrical estimate review. Review the motor list against the equipment list and the single-line diagram. Also check the following:

A. Overall cost of the power supply related to the total horsepower or thousands of kilowatts.
B. Cost of the power supply per motor related to the size of the motor.
C. Lighting cost per square foot, per linear foot, etc.
D. Cost of grounding related to the area covered.

12) Instrumentation estimating methods: The following are those generally used:

i. Factor estimating. With an adequate data base, instrumentation can be factored relative to the installed major equipment cost. Additional points for consideration are the following:
   A. Local electrical and environmental codes.
   B. Degree of computer control.
   C. Does the plant need clean, dry air? If so, an instrument air compression system may be required.

ii. Estimating by instrument loops. Instrument costs are estimated at a cost per loop. This can be done by using previous return data to establish costs for typical loops based on instrument type and materials of construction and multiplying these by the number of estimated loops in the system. Loop configurations should be developed by the instrument engineer.

iii. Total installed cost per unit. In this method, instruments are priced from a preliminary list by means of quotes, catalogue prices, or past data. Auxiliary material and installation costs (e.g., tubing, wiring, racks, supports, testing, etc.) are assessed for each instrument based on past experience and judgment.

iv. Detailed estimating. This is the most accurate approach and requires a detailed instrument list. This can be priced from past data or quotes. Labor manhours for each instrument are added. Instrument tubing and wiring should be established by detailed takeoff. Auxiliary material and labor cost can be taken as a percentage of the total instrument cost.

v. Instrument estimate review. Examine process and instrumentation diagrams for numbers-complexity of instrumentation. Check for conflicts between owner and contractor specifications. Also review the following:
   A. Interface between scope of work for additions to existing plants.
   B. Electronic-pneumatic requirements.
   C. Total number of instruments related to the number of pieces of major equipment.
   D. Ratio of the cost of instrument piping and instrument wiring to the basic instrument cost.

E. Average cost of piping and wiring per instrument.

13) Insulation: Review requirements for heat conservation, winterizing, cold insulation, and personnel protection for equipment and piping. Analyze the cost of pipe insulation as a factor of the total installed piping value.

14) Painting: Not normally large enough to justify a detailed estimate. Review any prorated method and values allowed.

f) Direct Construction Labor

1) Equipment installation (manhours): A check of manhours requirement for equipment installation may be made as follows:
   - i. Manhours per material cost.
   - ii. Manhours per weight and type of equipment.
   - iii. Manhours per piece and type of equipment.

2) Bulk materials installation (manhours): The following would be major items to check:
   - i. Manhours per cubic yard for excavation (machine, hand, or weighted average).
   - ii. Manhours per cubic yard for foundation concrete (including forming, pouring, reinforcing steel, and embedments). Review dewatering, sheet piping, and shoring requirements for a civil program.
   - iii. Manhours per ton of structural steel (for field fabrication and erection).
   - iv. Manhours per ton or per foot of piping by size and pipe schedule.
   - v. Manhours per valve and specialty item.
   - vi. Manhours per instrument installed (including cable, termination and testing).

3) Productivity (manhours): Depending on the quality of the estimating base, the preceding manhours would normally then have to be factored for time and the location of the project. A geographic productivity system is essential for a quality estimating program. General items (handling, scaffolding, testing, rework, etc.) would be on a manhour percentage basis for a detailed estimate and included in manhour rates for a conceptual estimate.

4) Labor costs: Review current labor agreements and conditions, productivity factors, manpower availability, site conditions,

and project conditions. Review total manhours as well as the craft manhour distribution:

i. Subcontract versus direct hire; what is covered in the all-in subcontract wage rate, especially field indirects?
ii. Average wage rate.
iii. Inclusion of appropriate fringe benefits, taxes, and insurances.
iv. Allowances for premium pay on overtime and shift work.

g) Construction Indirect Costs

Where possible, ensure that estimates have dimensional sketches showing layouts of temporary facilities which can then be quantified for estimating.

1) Temporary facilities: Review estimates for the following:
   i. Temporary utility lines and utilities consumed during construction.
   ii. Temporary roads and parking and laydown areas.
   iii. Fencing and security.
   iv. Temporary buildings, furnishings and equipment.
   v. Personnel transportation and equipment-receiving facilities.
   vi. Erection-operation of construction camp, if required.

   Most of these items would be estimated on a cost per foot and square foot basis.
2) Construction tools and equipment: Discuss and check the methods used by the construction group in establishing equipment requirements. Check the following:
   i. List and scheduled duration of all major equipment.
   ii. Small tools (normally estimated as cost per labor manhour or percent of direct-labor costs).
   iii. Availability of equipment; start and termination of rental period.
   iv. Equipment maintenance, major and minor.
   v. Equipment purchased; equipment rented and source.
   vi. Review of cranage and heavy lift requirements.
   vii. Construction equipment cost per direct-hire manhour.
3) Construction staff: Examine the site organization chart and assignment durations of personnel; also review the following:

i. Relocation costs, travel and living allowances, fringe benefits and burdens, and overseas allowances.
ii. Total staff manhours related to total labor manhours.
iii. Supervision cost related to the construction labor cost.
iv. Average monthly rate for the technical staff.

4) Field office expenses: Review the estimates of field office supplies, reproduction, telephone, telex, office equipment, and consumables. These items are usually estimated as cost per labor manhour or as a percent of direct field costs.

h) **Home** Office Costs

1) Percentage of project costs: This method requires considerable analysis of previousprojects, but can provide a reasonable estimate of H.O. costs for a conceptual estimate. Normally, H.O. costs would be expressed as a percentage of the following bases:
   i. Total "constructed cost" (i.e., material + labor + subcontracts + field indirects). **A** typical range would be 10-15%.
   ii. Direct material and labor (subcontractor or direct hire). A typical range would be 18-22%.
2) Engineering manhours based on pieces of major equipment: A typical range would be 1000-1500 manhours/piece of equipment. Factors may be applied to reflect size, complexity, prototype, and revamp work. These manhours will cover all engineering and design manhours. Manhours for services such as planning and scheduling, estimating, cost control, and procurement are derived as percentages of engineering hours.
3) Manhours per drawing (or work item): This method requires major completion of the process design so that a detailed drawing list can be developed. It is necessary that PIDs, plot plans, and equipment lists be available from which a total number of drawings can then be estimated.
4) Reviewing home office estimate: Review the basis of establishing manhours with the engineering group. Analyze the following:
   i. Manhours per major piece of equipment.
   ii. Manhours per drawing using the estimated total number of drawings.

iii. Percentage relationship of discipline manhours for abnormalities.
iv. Average all-in rate for total home office technical personnel.
v. Benefits, burdens, and overhead rates.
vi. Fee basis on reimbursable and cost-plus contracts.
vii. General specifications for conflict or "gold plating."
viii. Service group estimates by organization chart, manning schedule, and statistical relationship.
ix. New technology contingency for prototype design.

i) Contingency

The contingency or estimating allowance is usually a function of the following:

1) Design definition (process unit, off sites, revamps).
2) Estimating methods (data base and level of detail).
3) Time frame and schedule probability.
4) New technology and prototype engineering.
5) Remoteness of job site; infrastructure requirements.
6) Engineering physical progress (percentage complete).
7) Material commitment.
8) Construction physical progress (percentage complete).

Determining overall estimate reliability is made more difficult by the fact that some segments of a project may be completely defined at the time of estimate, and others only sketchily defined; some may be estimated by reliable methods and others necessarily are estimated by methods which produce less accurate results, and so forth.

To cope with this, it is necessary to separately quantify the degree of reliability of the sub-estimate for each of the major independently estimated segments or units of an estimate as a whole. This can be done with the aid of guidelines for classifying degree of definition and quality of methods/data used. These, in turn, establish appropriate estimating allowances and accuracy ranges for each of the segments.

When a project has been approved and work begun, changes begin to take place in facility definition, estimating methods, knowledge of project conditions, and forecast time-span. This entails successive re-appraisals of contingency. It should produce a continuing reduction of estimating allowances.

Estimating Allowances and Accuracy Ranges

Estimating allowances or contingency is defined as the amount which statistical experience indicates must be added to the initial, quantifiable estimate, in order that the total estimate has an equal chance of falling above or below the actual cost. This allowance is required to cover oversights and unknowns, which on average, always results in final project costs that are higher than initial quantifiable estimates. If required, estimating allowances may be modified to produce greater or lesser overrun probabilities.

For any individual project in a series of projects, the estimated cost including estimating allowance, will fall under or over the actual cost of the project. **A** well-developed estimating system, when applied to a series of projects, produces a pattern of under and overruns which approach "normal" or bell-curve distribution. Overestimate and underestimate amounts are determined by so many unrelated happenings that the results resemble those obtained by chance. Major systematic errors are eliminated in the development of an estimating system, and analysis of departures from normal distribution is one of the tools available for estimating system improvement.

The error distribution of estimates produced by a given organization at a given period in its development will have a wider or narrower spread, or range, depending on factors previously listed. **A** quantitative measure of this spread is "accuracy range." This is defined as the percentage range, relative to actual project costs, within which eight tenths of the estimates of a given quality will fall. Theoretically, one tenth of such estimates will be outside the range on the high side. One tenth will be outside the range on the low side. When appropriate estimating allowances have been applied, half the estimates will be over actual cost and half under, so that average deviation will be close to zero.

In practice, most companies experience an average deviation which varies 10-20% from the zero level. This means that for an 80% probability, the estimating program has a built-in bias. In general, this is mostly a plus (overrun) bias in the range of 10-15%. In simplistic terms, this means that the estimating program has a +10-15% "accuracy range," which means that more projects

(10-15% more) will overrun than underrun, even with the inclusion of an appropriate contingency.

It is important therefore, that a constant analysis be carried out of the actual costs versus the estimate, so that such biases can be detected and corrected.

These elements of contingency and accuracy are often determined by a computer risk analysis program.

j) Escalation

Escalation is usually included as a separate line item or is built into the estimate details. Either method is acceptable—assuming that escalation rates and cost centroids have been developed properly. Escalation rates for material and labor costs should be separately identified. The "cost centroid" technique and application of escalation rates is illustrated with the technique found in the data section.

k) Currency Exchange Conversion

As currency conversion rates can fluctuate widely over the life of a project, it is recommended that one use the rate established at the time of appropriation and track deviations thereafter as a one-line item. Corporate and affiliate financial groups should be consulted when establishing currency conversion rates for the estimate.

CONSTRUCTION LABOR PRODUCI'MTY

a) General

Good assessments of labor productivity are essential for a quality cost estimate. Cost control and planning and scheduling can be ineffective without an adequate evaluation of labor manhours.

Figure 6-2 shows major elements that can affect labor productivity. The recommended "condition productivity ranges" and associated curves have been developed from many projects built in the 1950's-1970's. However, on a specific project, any one or even several conditions can have an abnormal effect on productivity. It is assumed that the company estimating data

Figure 6-2.

PROJECT CONDITION ANALYSIS - CONSTRUCTION PRODUCTIVITY

PRODUCTIVITY FACTORS ARE MULTIPLIERS

THIS ANALYSIS ASSUMES THE ESTIMATING DATA BASE IS BASED ON GRASS ROOTS WORK , UNION LABOR	JOB No
PROJECT	DATE
	LOCATION
SIZE(HOURS)	FIELD START / WORK WEEK
PEAK LABOR	FIELD DURATION

1. AREA LOCATION FACTOR (FROM DATA BASE) ________
   - THIS FACTOR GENERALLY RECOGNIZES LABOR SKILLS OF AREA
   - PREVIOUS PROJECTS IN SAME AREA — PRODUCTIVITY
     - a) ________
     - b) ________
     - c) ________
     - d) ________
2. AREA WORK LOAD & PEAK LABOR (SEE CHART) ________
   NOTE OTHER PROJECTS IN AREA
3. JOB SIZE (SEE CHART) ________
   IT HAS BEEN ASSUMED THAT THE ESTIMATING DATA BASE REFLECTS A PROJECT SIZE OF ONE MILLION HOURS
4. SITE CONDITIONS
   - a) ABNORMAL WEATHER (precipitation/temperature) 1.0 - 1.20 ________
   - b) SITE ACCESSIBILITY 1.0 - 1.06 ________
   - c) GROUND . HEIGHT. HAZARD CONDITIONS 1.0 - 1.10 ________
   - d) MAJOR REVAMP 1.3 - 1.7 ________
5. LABOR CONDITIONS
   - a) WORK WEEK (SEE CHART) ________
   - b) UNION PRACTISES (work rules . craft restrictions etc.) 1.0 - 1.10 ________
   - c) WORKER ATTITUDE (union labor) 1.0 - 1.10 ________
   - d) OPEN SHOP 0.80 - 1.0 ________
6. FIELD MANAGEMENT (ANTICIPATED) 0.95 - 1.05 ________
7. CONSTRUCTION BASIS (DIRECT HIRE TO SUBCONTRACT) 1.0 - 0.90 ________
8. PLANNING & SCHEDULING & CONTROL 0.95 - 1.05 ________
9. OTHER
   - a) ANTICIPATED ENGINEERING DRAWING DELAYS 1.0 - 1.05 ________
   - b) ANTICIPATED MATERIAL DELIVERY DELAYS 1.0 - 1.05 ________
   - c) ________
   - d) ________
   - e) ________

ESTIMATED PROJECT PRODUCTIVITY	

base is at 1.0. Higher numbers are poorer productivity and lower numbers are better productivity.

The productivity analysis starts from a general, area factor. Additional allowances, based on the recommended ranges are then made for the listed conditions. Judgment and experience are necessary for determining these additional allowances. If there is no previous experience of the area, this procedure can still be very effective as the "condition productivity adjustments" are often of a greater magnitude than area productivity differences.

Refer to Figure 6-3 for productivity adjustments for:

- Area workload and peak construction labor
- Job size
- Extended work week

The data and analysis is generally based on construction of new facilities at an existing plant, with minor hot work restrictions and an average labor performance. Guidance for major revamps is given in the historical data section.

b) Area **Workload/Peak** Construction Labor

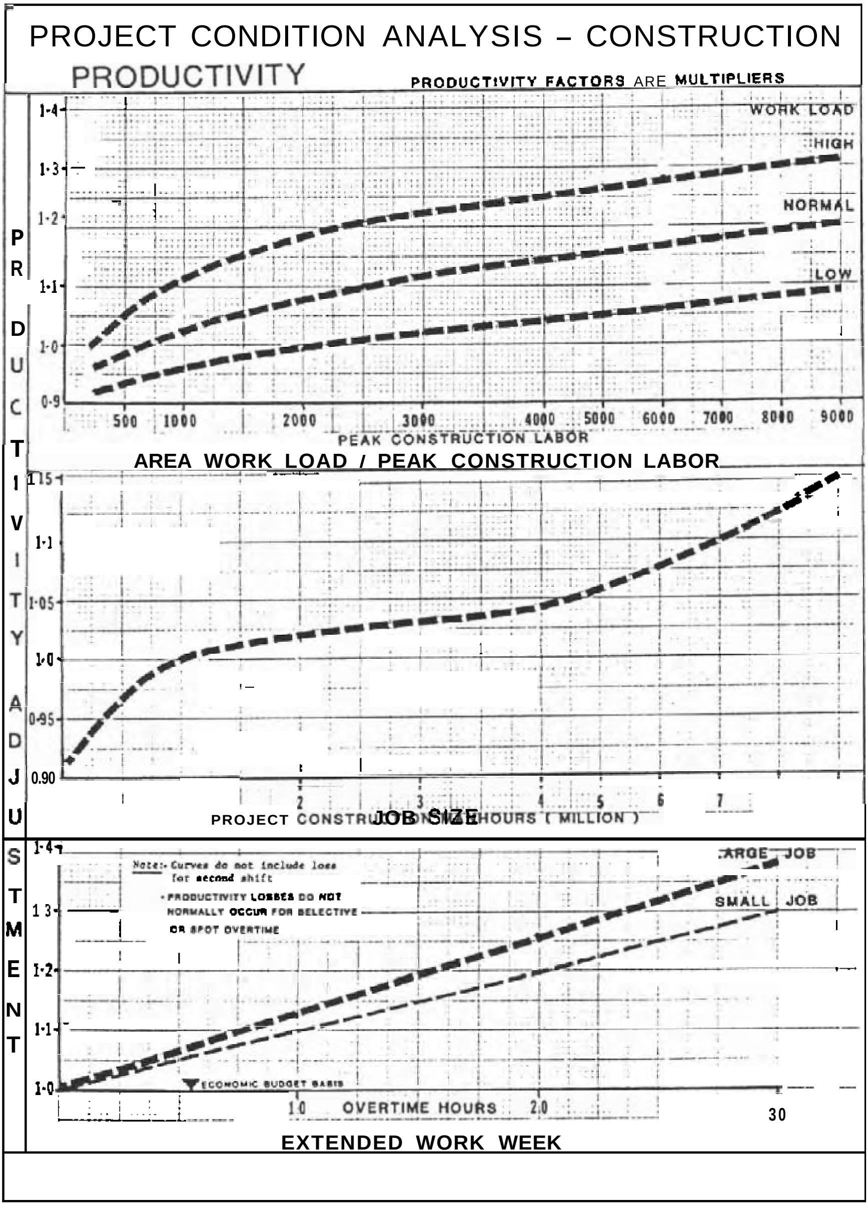
As area workload and peak labor increases, productivity will generally reduce in a normal economic environment. It is assumed that the estimating data base, at a productivity of 1.0 (on the curves), is based at "normal" area workload, with a peak manpower level of 750.

If area workload is low, then manpower peak can rise to 2000 before a productivity loss adjustment needs to be made. Conversely, if area workload is low and project size and schedule requires a manpower peak of 1000, then a productivity improvement (0.96) is determined from the curves.

c) Job **Size**

In addition to manning levels, job size (in manhours) has a significant effect on productivity. This curve shows the estimating data base reflects a project size of one million manhours (direct work only). Thereafter, as job size increases, productivity decreases.

Figure 6-3.



PROJECT CONDITION ANALYSIS – CONSTRUCTION
PRODUCTIVITY
PRODUCTIVITY FACTORS ARE MULTIPLIERS
PRODUCTIVITY ADJUSTMENT
WORK LOAD
HIGH
NORMAL
LOW
1·4
1·3
1·2
1·1
1·0
0·9
500
1000
2000
3000
4000
5000
6000
7000
8000
9000
PEAK CONSTRUCTION LABOR
AREA WORK LOAD / PEAK CONSTRUCTION LABOR
1·15
1·1
1·05
1·0
0·95
0.90
1
2
3
4
5
6
7
PROJECT CONSTRUCTION MANHOURS (MILLION)
JOB SIZE
LARGE JOB
SMALL JOB
Note:- Curves do not include loss for second shift
- PRODUCTIVITY LOSSES DO NOT NORMALLY OCCUR FOR SELECTIVE OR SPOT OVERTIME
ECONOMIC BUDGET BASIS
10
20
30
OVERTIME HOURS
EXTENDED WORK WEEK

d) Extended Work Week

Two curves are shown for small and large jobs. The productivity loss adjustment applies to total manhours and not merely to the additional overtime hours.

Refer to Figure 6-23, "Productivity Loss for Extended Workweek," for a more detailed explanation of this condition. ***Note:*** During periods of major low employment, such as recessions and depressions, it is possible that labor productivity will not follow these curves, as the fear of unemployment can be an over-riding consideration.

PRE-ESTIMATING SURVEY

Figure 6-4 shows the major items to be developed and/or considered prior to developing the estimate.

ESTIMATING CHECK LIST

a) General

In conjunction with the Pre-Estimating Survey, a comprehensive check list can be a significant aid in insuring that all appropriate details have been covered. The following is not a complete list, but it will significantly assist with the following major considerations:

1) Planning The Estimate
2) Cover All Items
3) Serve As **A** Base For Your Data Base
4) Particularly, Cover The Three P's–Political-Procurement-Process Design

b) Political Considerations

These considerations can be broken down as follows:

1) Local, political and social environment
2) Regulatory, permitting requirements
3) Business environment
4) Tax structure; expense vs. capital costs allocation
5) Overseas – nationalistic/logistics/infrastructure

Figure 6-4.

PRE-ESTIMATING SURVEY

GEOGRAPHICAL AREA	OVERTIME	RECREATION FAC.
CLIMATE	PRE-FABRICATED ASSEMBLIES	SCHOOL
SITE ACCESS	SPECIFICATIONS	PERMANENT COMMUNITY
SOIL CONDITIONS	LOCAL CODES	SCHEDULE
EARTHQUAKE FACTORS	PROCUREMENT	INFLATION
SITE ELEVATION	ORIGIN OF MATERIALS & EQUIPMENT	ESCALATION
OFFSHORE PLATFORMS		CURRENCIES
ENVIRONMENT	EXPORT PACKING	FINANCING
ATTITUDE OF COMMUNITY	CONSTRUCTION FACILITIES	OVERSEAS PREMIUM
POLITICAL CLIMATE	TEMPORARY FACILITIES	COST OF LIVING
GENERAL BUSINESS CLIMATE	HOUSING	COST OF TRAVELING
PRIME CONTRACTOR	LOGISTICS	TAXES
JOINT VENTURE	COMMUNICATIONS	INSURANCE
UNIONIZED LABOR	WAREHOUSING	LEGAL ASSISTANCE
QUALIFIED LABOR POOL	GUARD SERVICE	GOVERNMENT AGENCIES
RECRUITING AND TRAINING	SITE FABRICATION FAC.	LETTERS OF CREDIT AND BONDS
LABOR PRODUCTIVITY	CONSTRUCTION EQUIPMENT	
LABOR CONTRACTS	MEDICAL FACILITIES	LANGUAGE PROBLEMS
LABOR COST	FOOD & CATERING	LOCAL CULTURES
	SANITARY FACILITIES	

RETRO-FIT / REVAMP

- Hazards-Work Limitations
  - **Men**
  - **Equipment**
- Security-Clearance-Permits
- Health Factors
  Contractor Training
- Standby Allowance

c) Procurement Program Considerations

A careful review of the procurement program is essential, as the equipment/material costs can be more than 50% of the total cost. The following are typical considerations:

1) Quality Vendors List/Information/Experience of Suppliers
2) Domestic Vs. Worldwide Purchasing Plan
3) Import Duties, Taxes, Delivery Charges (company exception)
4) Currency Considerations and Exchange Rates
5) Vendor Servicemen Requirements
6) Plant Compatibility of Existing Vs. New
7) Ease of Maintenance/Operating Costs
8) Spare Parts Requirements
9) Inspection and Expediting Requirements
10) "Critical" Purchasing Plan (Schedule Priority)

d) Detailed Checklist for Estimating

1) ***Climate***
- Arctic
- Humidity
- Temperate
- Temperature
- Prevailing Winds
- Winterization
- Storms
- Winters
- Snow Accumulation
- Rain
- Lost Days Due to Weather
- Shelters Required
- Special Method of Construction Necessary
- Indoor/Outdoor Equipment

2) ***Earthquate Factors***

3) ***Access***
- Distance
- Roads/Water/Air/Railroads
- Conditions of Roads
- Clearance of Roads (Tunnels)
- Capacity of Roads & Bridges
- Ice Conditions

4) *Offshore Facilities*

- Water Depth
- Wind Forces
- Wave Forces
- Sea Floor Conditioning
- Soil Conditions

5) *The Environment*

- The Attitude of the Community
- Present & Future Zoning
- Other Industry in the Area
- Environmental Restrictions
- Environmental Impact Study
- Required Permits – Local - State - Federal - Others
- Legal Counseling
- Delays in Obtaining Permits & Associated Costs in Terms of Escalation
- Requirements for Pollution Control for Noise, Air, Water, Disposal of Waste, and Their Cost
- Consideration for Alternate Site

6) *The Political Aspect*

- What is the political climate of the proposed site and the prospect for future stability?
- Is the governing authority encouraging investment; is it favorable to business; what is the tax structure?
- For an overseas project, to what degree are governments involved?
- For an overseas project, what are the terms of payment and are delayed payments probable?

7) *Procurement*

- What is the source of information about vendors
- Where are the vendors located
- How will equipment and material be transported
- Are there a minimum of three bidders available
- What is vendor reliability and experience
- What will be the origin of material and equipment
- For overseas, what are the import restrictions
- What is the import duty
- Is equipment available on reasonable delivery schedules

- What will be the terms and conditions
- Any discounts for large purchases
- Will purchase orders be firm, cost plus, or with specified escalation
- What are the warranties
- What service can a supplier provide during construction and operation, and at what cost
- Provisions for inspection and expediting
- Export packing requirements
- Spare parts and their costs
- In what currency will the purchases be made
- What is the exchange rate
- What will be the payment schedule
- Marshalling yards requirements
- Loading and unloading requirements
- Lightering
- Demurrage costs
- Higher costs due to congested harbors
- Will trading companies be used

8) ***The Process***
- What is the plant capacity
- What are the products
- What are the by-products
- Flow sheets available
- Utility flow sheets
- The plant layout
- Plant location
- Material specs – exotic - standard
- Mechanical specs: Pressures - temperatures - flows - corrosion

9) ***The Process***
- Local code requirements
- State code requirements
- National code requirements
- Client/engineer's specifications
- Architectural requirements
- Metric/English measurements
- Pollution control

STATISTICAL/HISTORICAL DATA

This section includes the following references which should be helpful in developing a cost estimate.

*a) Typical Prime Contractor Cost Breakdown (large project) – Figure 6-5.
*b) Cost Basis - Engineering/Construction Relationship – Figure 6-6.
*c) Construction Complexity and Labor Density – Figure 6-7.
*d) Typical Project Cost Breakdown (large versus small project) – Figure 6-8.
e) Engineering Costs – Figure 6-9.
f) Nelson-Farrar Cost Index – Figure 6-10.
*g) Cost - Size Scaling (economy of scale) – Figure 6-11.
h) Cost Capacity Curve - Alkylation Unit – Figure 6-12.
i) Estimating Shutdowns/Turnarounds and Retro-fits – Figure 6-13.
j) Engineering/Home Office Estimating – Figure 6-14.
*k) Home Office Manhour Breakdown – Figure 6-15.
l) Typical Data Points - Engineering – Figure 6-16.
m) Construction Estimate Basis – Figure 6-17.
n) Construction Overhead Costs – Figure 6-18.
o) Home Office Expense Breakdown – Figure 6-19.
p) Subcontract Estimating – Figure 6-20.
q) Typical Data Points - Construction – Figure 6-21.
r) Typical Data Points - Construction – Figure 6-22.
*s) Productivity Loss for Extended Workweek – Figure 6-23.
t) Escalation Calculation Technique – Figure 6-24.

***The figures asterisked are described below:**

TYPICAL PRIME CONTRACTOR COST BREAKDOWN

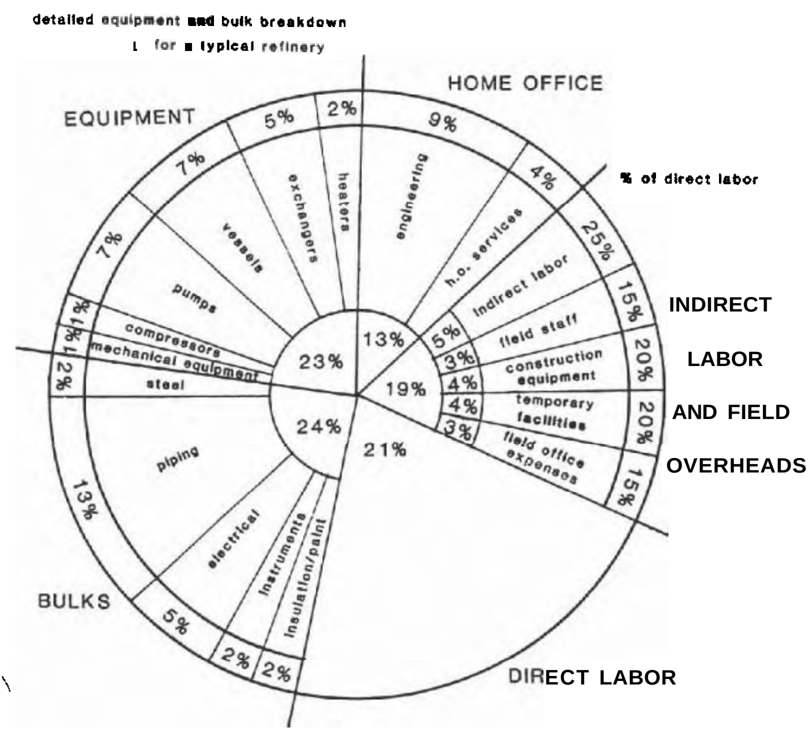
Figure 6-5 illustrates the overall breakdown of project cost, based on historical data for projects built in the United States on a prime contract basis during the period 1955-1975.

Application

When only an overall cost is known, this breakdown can be useful in providing overall data for a quick evaluation of engineering and construction costs and manhours. This can enable cost claim and schedule evaluations to be made.

Figure 6-5.

TYPICAL PRIME CONTRACTOR COST BREAKDOWN
(EPC PROJECT)
(excludes owner's costs)



Example:
Assume that a project has an estimated overall cost of $100 million.

1. From Figure 6-5, home office costs are roughly 13% or $13 million. By a further assumption that the contractor home office all-in cost is $30/hr., we can derive a total number of home office manhours:

   $$\text{No. of manhours} = \frac{13{,}000{,}000}{30} = 433{,}000$$

   Thus, a gross schedule and manpower evaluation can now be made.

2. From the chart, direct field labor costs are roughly 21% or $21 million. By a further assumption that the direct field labor payroll cost is $10/hr.:

   $$\text{No. of manhours} = \frac{21{,}000{,}000}{10} = 2{,}100{,}000$$

   Applying known and historical relationships, allow gross evaluations for engineering and construction durations to be made. These, in turn, can be used to prepare manpower histograms and progress curves.

Note: For larger projects, the percent of home office and field overheads will probably increase.

COST BASIC – ENGINEERING/CONSTRUCTION RELATIONSHIP

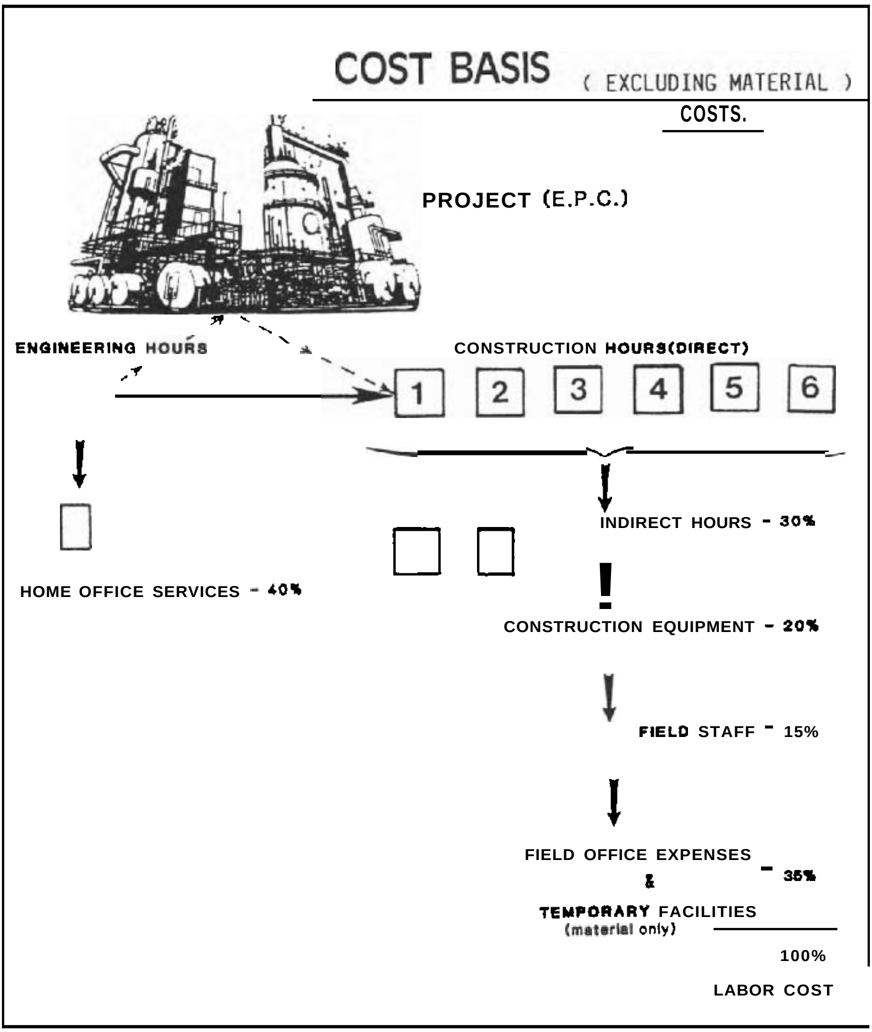
Figure 6-6 shows the construction indirect and direct costs in the "true" trapezoidal configuration. The "trapezoidal reality" is extremely important for the development of construction claims. As the majority of construction claims are time/scheduled related, the understanding of the trapezoidal reality is vital. In fact, quality assessments of claims cannot be made without this application.

A typical breakdown of the major indirect costs is also shown. Individual companies might allocate their indirect costs slightly differently, but there is a high degree of conformity to this direct/indirect allocation within the process industry. Again, it is emphasized that the stated information only applies to a "full EPC" project.

A further emphasis of this exhibit is on the engineering/construction manhour relationship. This is shown as the ratio of 1:6. In other words, one engineering manhour "automatically" generates six (6) direct construction manhours. This is a very useful "rule of thumb" and, of course, the ratio does vary a little as the design/construction complexity varies.

This relationship highlights the need for design engineers to *fully* realize that as they are designing, they are also "generating" the construction manhours. Full realization of this fact should lead the

Figure 6-6. Engineering-Construction Relationship.



designers to more carefully consider the question of "Constructability." This is the design process of working to construction installation considerations, as well as working to standard design specifications. Constructability considerations can result in significant savings in construction labor. Such considerations are essential in the following types of construction:

- heavy lifts
- prefabrication and pre-assembly
- rnodularization
- offshore hookup work
- site problems of limited access
- lack of resources at the jobsite location

The relationship between home office support services (project management, project control, procurement, computer, clerical, etc.) and engineering is also shown at 40%. This relationship is in manhours.

CONSTRUCTION COMPLEXITY AND LABOR DENSITY

Figure 6-7 illustrates a typical relationship between construction complexity and labor density. Judgement is required in assessing the appropriate density level for the specific project.

Complexity (manhours/sq. ft.)

Complexity is "automatically" generated by the design specifications. This statistic is based on the number of direct construction manhours (within the plot) divided by the plot area (battery limits). As noted, this assumes that there is no "pre-investment" in the design basis. Pre-investment is a fairly common practice and is carried out when forward company planning has determined that the plant will need to be expanded within a few years. At the moment, the planned (design) capacity is sufficient. The design pre-investment, therefore, usually includes extra area in the plot for future installation of equipment. This "extra" area, open at the moment, would give "false" complexity manhours and density levels. This data can be used to quickly provide a reasonable manhour estimate when only the plot/building area is known. However, good judgment is required in selecting the appropriate manhour/sq. ft. rate.

Figure 6-7.

CONSTRUCTION COMPLEXITY AND LABOR DENSITY

- Only applicable to "complete" Process Units (small or large)
- Assumes an economic design - no "Preinvestment"
- Based on "average" US labor productivity (Calif./Union)

COMPLEXITY (direct manhours/sq.ft.)

	Manhours/sq.ft.
SIMPLE UNIT	4/5
AVERAGE UNIT	6/7
COMPLEX UNIT	8/10

LABOR DENSITY (sq.ft./man)

Tied to above Complexity Data.

	Sq.ft./man
SIMPLE UNIT (4/5 mh./sq.ft.)	150/180
AVERAGE UNIT (6/7 mh./sq.ft.)	180/250
COMPLEX UNIT (8/10 mh./sq.ft.)	250/300

Density data Is based on a Prime EPC Contractor/reimbursable contract. For fixed or unit price contracts, density numbers should be increased by about 50sq.ft./man. This reflects the need for lower numbers of men to achieve higher productivity to meet "hard money" financial requirements.

Density (sq. ft./man)

This statistic is based on the "economic" total number of craftsmen working at peak (supervision is not included). The data is based on historical experience and is tied to the complexity of the area. The more complex, the lower number of men who can work in the area. In practical terms, this means that greater complexity has more equipment (more manhours) per sq. ft., thus taking up space for the men to work in. As with the complexity data, good judgment is essential in selecting the appropriate density level.

TYPICAL PROJECT COST BREAKDOWN

Figure 6-8 compares the breakdowns (%) of overall costs and construction manhours for large, grass-roots projects against small, revamp projects. The data for the large, grass-roots breakdown is based on historical experience, whereas the small, revamp breakdown is typical only. As there are wide variations in the EPC makeup of small projects, the "typical breakdown" should be examined very carefully for its application to a specific project.

As with the previous exhibit, these breakdowns/relationships can be helpful in evaluating manhours, schedules and manpower requirements.

HOME OFFICE MANHOUR BREAKDOWN

Figure 6-15 is a typical breakdown of total home office manhours for a 'full scope" project. It is based on historical data for small-to-medium sized projects engineered on a reimbursable basis and executed during the period 1955-1975.

Application

This information can be used to check an estimate or a contractor proposal of home office manhours. It can be used for early evaluations of home office manpower and schedules when only total costs or manhours are available.

Example:

1. For a typical project, we can assess the percent piping manhours. This is derived by summing the hours required for piping engineering activities (plant design, 16.4%; piping engineering, 2.1%; bill of materials, 2.1%; and model, 0.4%; giving a total of 21%).
2. As a percent of engineering only, piping becomes 21%/0.67 = 32%. As overall engineering and piping design are often on the critical path, individual evaluations are frequently required. Where information is lacking, use the following:
   - Engineering manhours as a percent of total home office: 65%
   - Piping manhours as a percent of engineering: 35%

Figure 6-8.

TYPICAL PROJECT COST BREAKDOWN

(CONTRACTOR – TOTAL SCOPE PROJECT)

GRASS ROOTS-LARGE %	ITEM	SMALL REVAMP %
10	ENGINEERING (D&D)	20
3	HOME OFFICE (SUPPORT)	5
47	MATERIAL (DIRECT)	40
21	CONSTRUCTION DIRECT	17
19	CONSTRUCTION INDIRECT	18
100%		100%

DIRECT CONSTRUCTION LABOR HOURS

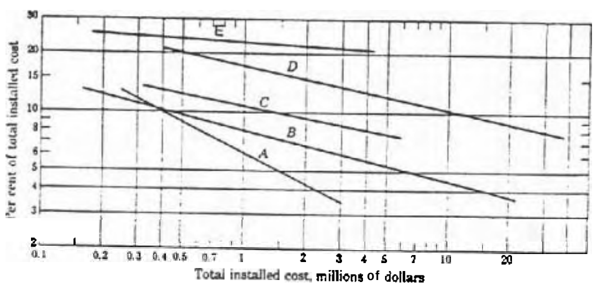
10	SITE PREPARATION	1
12	FOUNDATIONS/UNDERGROUNDS	8
7	STRUCTURAL STEEL/BUILDINGS	5
10	EQUIPMENT	12
35	PIPING	48(INCL.FAB)
11	ELECTRICAL	10
6	INSTRUMENTS	8
4	PAINTING	3
4	INSULATION	3
1	HVAC/FIREPROOFING	2
100%		100%

Figure 6-9.

ENGINEERING COSTS.

ENGINEERING COSTS APPROXIMATELY 10% PROJECT COST (EPC),

VARY WITH SIZE AND TYPE JOB



Engineering costs as average percent of total installed costs. A, office buildings and laboratories; *B*, power plants, cement plants, kilns, and water systems; C, battery-limits chemical process plants; *D*, complex chemical and grass-roots chemical plants and pilot plants.

E – small revamp/retrofit projects

Figure 6-10.

NELSON-FARRAR COST INDEX

Refinery construction (1946 basis)

(Explained on p. 145 of the issue of Dec. 30, 1985)

	1962	1973	1984	1985	1986	July, 1986	June, 1987	July. 1987
Pumps, compressors, elc	222.5	346.9	950.5	969.9	982.6	984.8	995.4	998.4
Electrical machinery	189.5	220.2	486.5	497.0	504.6	505.8	508.5	512.0
Internal-comb. engines	183 4	238.3	663.1	666.7	676.9	680.3	689.3	689.9
Instruments	214.8	338.0	696.8	713.7	733.3	732.3	739.5	757.4
Heat exchangers	183.6	313.7	530.9	520.0	524.7	518.0	562.8	577.1
Misc. equip. average	198.8	291.4	665.6	673.4	684.4	684.2	699.1	707.6
Materials cornponenl	205.9	292 3	735.3	739.6	730.0	729.6	746.1	744.4
Labor component	258.8	585.2	1,278.1	1,297.6	1330.0	1,344.9	1,365.4	1,371.0
Nelson Refinery (Inflation) Index	237.6	468.0	1,061.0	1,074.4	1,089.9	1,098.8	1,115.6	1,120.3

Refinery operating (1956 basis)

(Explained on p. 145 of the issue of Dec. 30. 1985)

	1962	1973	1984	1985	1986	July, 1986	June, 1987	July, 1987
Fuel cost	100.9	186.8	968.3	878.9	548.8	454.2	583.8	599.8
Labor cast	93.9	102.9	308.0	293.4	259.4	251.0	245.7	250.6
Wages	123.9	221.2	629.9	642.3	651.8	647.4	651.5	678.5
Productivity	131.8	214.9	204.5	219.7	253.8	257.9	265.1	270.7
Invest., maint.. etc.	121.7	193.0	436.6	445.8	460.0	463.6	470.7	472.7
Chemical costs	96.7	117.3	233.4	222.9	206.7	204.3	197.7	196.4
Nelson operating indexes Refinery	103.7	125.7	417.4	406.8	369.0	358.6	370.8	374.9
Process units'	103.6	168.0	584.2	551.7	430.8	396.5	442.8	450.6

'Add separate index(es) for chemicals, if any are used See current Quarterly Costimating, first issue, months of January, April, July. and October.

These indexes are published in the first issue of each month They are compiled by Gerald L Farrar, Journal Contributing Editor

Indexes of selected individual items of equipment and materials are also published on the Costimating page in the first issue of the months of January. April, July, and October.

Figure 6-11.

COST – SIZE SCALING

(economy of scale)

COST – CAPACITY FACTORS

APPLICABLE TO SIMILAR PROJECTS OF DIFFERENT CAPACITIES

SIX-TENTHS FACTOR RULE: $C_2 = C_1\left(\frac{Q_2}{Q_1}\right)^X$

WHERE C_2 = DESIRED COST OF CAPACITY Q_2

C_1 = KNOWN COST OF CAPACITY Q_1

X = COST-CAPACITY FACTOR = 0.6 (AV.)

EXAMPLE: $C_2 = \$8{,}000{,}000 \left(\frac{200{,}000 \text{ TONS/YEAR}}{100{,}000 \text{ TONS/YEAR}}\right)^{0.6} = \$12{,}100{,}000$

Figure 6-12.

COST CAPACITY CURVE

	ECONOMIC DATA
COST DATA SHEET	REFINERY UNITS

BY KMG	DATE 1970	**Alkylation:** A catalytic process to upgrade light gaseous hydrocarbons (propylene, butylene, or amylene) into high-octane gasoline and aviation fuels, in the presence of sulfuric acid.
EXPONENT	0.60	
TIME BASE	MID 1970	

ALKYLATION

TOTAL CAPITAL INVESTMENT

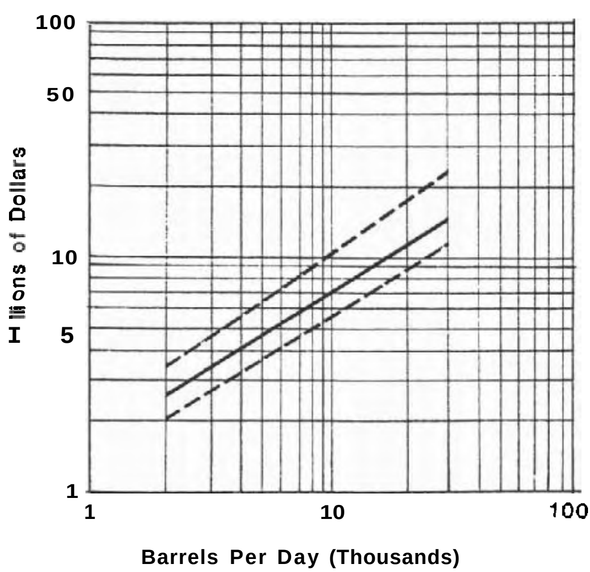


Figure 6-13.

PLANNING & SCHEDULING
ESTIMATING
SHUTDOWNS/TURNAROUNDS

RETRO-FITS

	PREPARATORY (6-12 MONTHS)	SHUTDOWN (1-4 WEEKS)
1. PRODUCTIVITY(GRASS ROOTS BASE)	+ 30%/50%	+ 70%/100%
2. LEVEL OF DETAIL	WEEKS/DAYS	HOURS

3. CONTROL

a) SCOPE BOOK
- PHYSICAL CONDITION OF SITE/PLANT (U.G. RUNS-OBSTRUCTIONS-ROUTING)
- INSPECTION/REPORT OF ALL EQUIPMENT TO BE REWORKED
- OPERATING INSPECTION REPORTS
- DESCRIBE DETAIL OF WORK
  - REPLACEMENT
  - ADDITION
  - REWORK/MODIFICATION

b) PLAN – ENGINEERING-PROCUREMENT-CONSTRUCTION

c) SCHEDULE – RESOURCES(LABOR-EQUIPMENT-STAFF)

d) ESTIMATE

4. SCHEDULE/PROGRESS
- PLANNING BOARD
- C.P.M. SCHEDULES

Figure 6-14.

ENGINEERING/HOME OFFICE ESTIMATING

1. STATISTICAL HISTORICAL
   a) overall project breakdown("pie-chart")
   b) home office breakdown

2. ENGINEERING HOURS PER EQUIPMENT ITEM
   a) approx. 1000 - 1500

3 ENGINEERING HOURS PER DISCIPLINE/ITEM
   a) pipelines/item/tons/c.y./ft.etc.

4 MANHOURS PER DRAWINGIDOCUMENT
   a) count by design groups

5 ADD ONS/EXTRA FUNCTIONS
   a) see typical estimate sheet(sub total c)

Figure 6-15.

HOME OFFICE MAN-HOUR BREAKDOWN

FOR FULL SCOPE EPC PROJECT

Description		% Man-hours
Design & Drafting	*Full-Scope (%)*	
Civil & structural	25.00	10.000
Vessels	7.50	3.000
Electrical	15.00	6.000
Plant design (piping)	41.00	18.400
Piping engineering	5.25	2.100
Bill of material	5.25	2.100
Model	1.00	0.400
	100.00	40.000
Administration—indirecl drafting		4.000
Engineering		
Instrument (engineering & drafting)		3.000
Mechanical (rotating machinery. plant utilities, metallurgy. etc.)		3.000
Mechanical (consultants)		0.200
Project management		7.500
Project engineering		6.000
Project (operating expenses. services administration)		0.200
Process design		3.000
Process technology services		0.100
Project services	67%	Engineering
Estimating & cost control		4.000
Proposals		–
Computer control		–
Computer systems		1.000
Initial operations—office		0.200
Technicnl information		0.200
Scheduling		2.000
Procurement		
Purchasing		5.000
Inspection and Expediting		5.000
General *office*		
Stenogrnphic		4.500
Accounting		7.000
Office services		2.000
Labor relations		0.100
Construction (office)		2.000
	Total	100.000

PRODUCTIVITY LOSS FOR EXTENDED WORKWEEK

There are occasions when a project is placed on extended overtime to shorten the schedule. In many cases, under normal economic conditions, productivity will be reduced and costs will increase. If this condition was not part of the original estimate, an assessment of the increased cost, as well as the schedule advantage, should be made. The schedule evaluation should recognize increased manhours in the duration calculation. It is also possible that absenteeism will increase, sometimes to an extent that there is no schedule advantage for the increased workweek.

Figure 6-23 presents data compiled from the sources indicated and plots labor efficiency against overtime hours worked, based on 5-, 6-, and 7-day workweeks. This data applies only to long-term extended workweeks. Occasional overtime can be very productive with no loss of efficiency. The exhibit shows a recommended range of productivity loss by project size (small-large).

Application

This figure can be useful in an overall evaluation of the impact of overtime hours on schedule and cost. It can establish an increase in total labor hours required for a loss in efficiency due to an extended workweek. However, judgment should be used on an individual location basis. Some areas, particularly less developed countries (LDCs), work 60-hour weeks which are as productive as 40-hour weeks.

Example:

Assume that a project has a total construction scope of 1 million manhours and is based on a 5-day, 40-hour workweek. If the same workweek were increased by 8 hours to 48 hours, look to the chart for 8 hours of overtime, and using the (NECA) 5-day (large project) curve, read across to an efficiency of 90%. This indicates that 10% more hours will be required to accomplish the same amount of work due to a loss in efficiency. Thus, we estimate that the total manhours will be 1 million x 1.10 = 1,100,000 manhours. Schedule and cost evaluations can now be made for an additional 100,000 manhours, but at an increased level of work. Obviously, there is a schedule advantage.

Note: These curves do not include efficiency losses for a second shift, which can be about 20%. However, shift work losses depend on the type of work, company organization and experience. In the Offshore Industry, where shipyards traditionally work on a shift basis, losses can be minimal, or zero.

Figure 6-16. Typical Data Points - Engineering.

The following are typical data points for evaluating estimating levels or monitoring project performance.

This data applies to large U.S. process plants. Adjustments should be made for overseas locations and for small projects.

Engineering	NOR.	U.S.
• Manhours per drawing (total drawings)	1701185	1501160
• Manhours per piece of equipment	115011400	100011200
• Manhours per piping isometric	15/20	8/10
• Manhours per P & I diagram	4501570	4001500
• Manhours per plot plan	2301350	200/300
• Manhours per material requisition	9/12	8110

Figure 6-17. Construction Estimate Basis

ITEM	ESTIMATE BASIS
1. Direct Field Labor	• Quantities updated by field take off • Productivity factor for time & location • Unit manhours per work operation • Handing & rework by factor
2. indirect Field Labor (non-productive & lost time)	• Factor on direct labor manhours
3. Field Staff	• Organization chart • Time frame schedule • Relocation & local living • Replacement &training
4. Temporary Facilities	• Dimensioned layouts • Quantity take off • Unit rates • Maintenance by factor
5. Construction Equipment	• Listing by category & number • Time frame schedule • Unit rates (rental vs. purchase) • Maintenance by factor
6. Small Tools & Consumables	• Factor on direct labor • Loss allowance
7. Field Office Expenses	• Factor on direct labor • Listing for office furniture/equipment
8. Escalation & Contingency	• By judgment &formula

Note: Direct material purchase by the field is usually covered by the material estimate.

Figure 6-18.

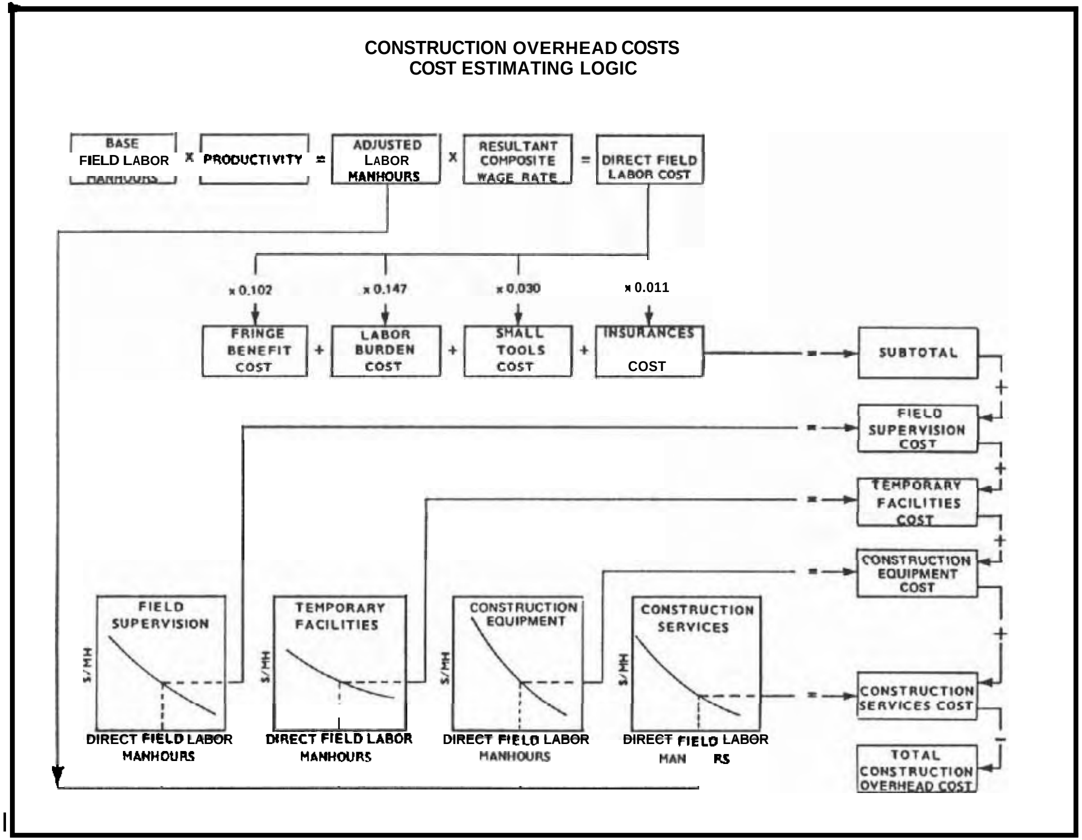

CONSTRUCTION OVERHEAD COSTS
COST ESTIMATING LOGIC
BASE FIELD LABOR MANHOURS
X
PRODUCTIVITY
=
ADJUSTED LABOR MANHOURS
X
RESULTANT COMPOSITE WAGE RATE
=
DIRECT FIELD LABOR COST
x 0.102
x 0.147
x 0.030
x 0.011
FRINGE BENEFIT COST
+
LABOR BURDEN COST
+
SMALL TOOLS COST
+
INSURANCES COST
=
SUBTOTAL
+
FIELD SUPERVISION COST
+
TEMPORARY FACILITIES COST
+
CONSTRUCTION EQUIPMENT COST
+
CONSTRUCTION SERVICES COST
TOTAL CONSTRUCTION OVERHEAD COST
FIELD SUPERVISION
TEMPORARY FACILITIES
CONSTRUCTION EQUIPMENT
CONSTRUCTION SERVICES
$/MH
DIRECT FIELD LABOR MANHOURS

Figure 6-19. HOME OFFICE EXPENSE BREAKDOWN

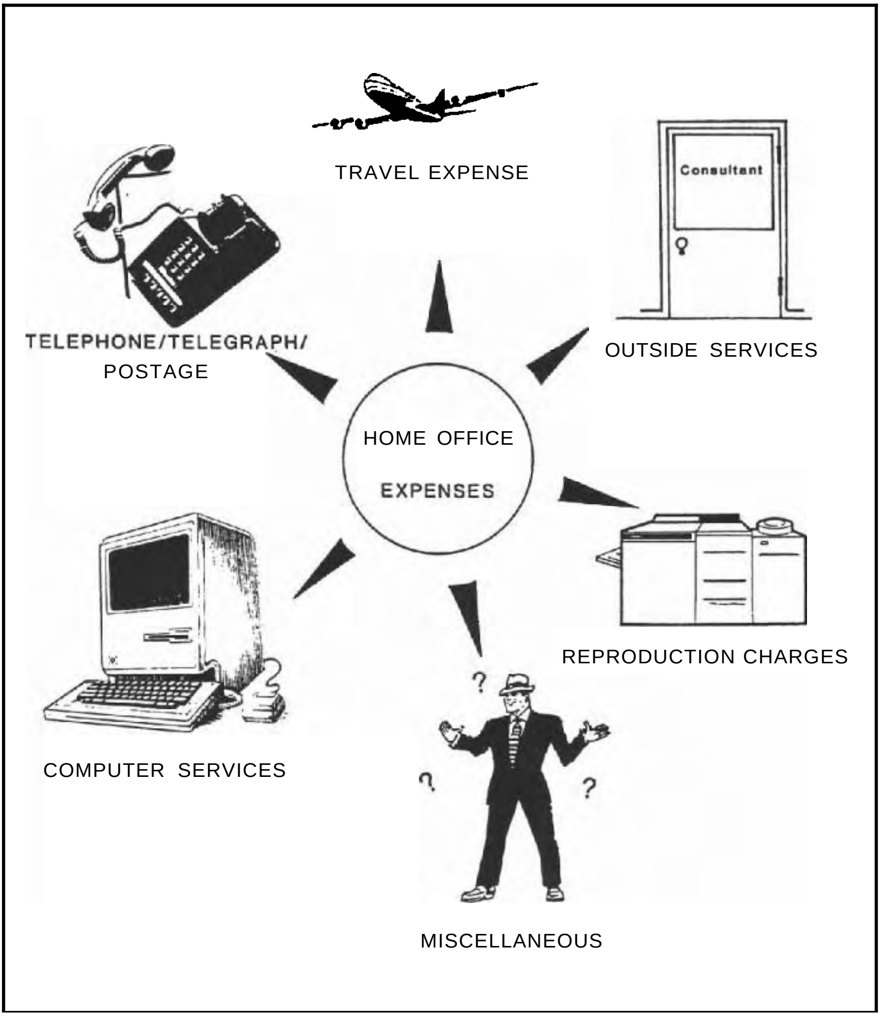


Figure 6-20.

SUBCONTRACT ESTIMATING

ALL-IN LABOR RATE

DETAILED ESTIMATE

AS FOLLOWS;

LABOR RATE -	(INCL. BENEFITS ALLOWANCES)	
CONSTRUCTION STAFF -	10120%	LABOR RATE
" EQUIPMENT -	10/40%	"
(EARTHMOVING HIGH COST - INSULATION LOW COST)		
FIELD COSTS -	30140%	"
OVERHEAD & PROFIT -	20%	"
ALL IN LABOR COST -	70/120%	"

JUDGEMENT IS REQUIRED TO ASSESS SPECIFIC PERCENTAGES FROM ABOVE RANGES. SIZE, WORK TYPE AND JOB CONDS. ARE SIGNIFICANT ELEMENTS.

Figure 6-21. Typical Data Points – Construction

The following are typical data points for evaluating estimating levels or monitoring project performance.

This data applies to large U.S. process plants. Adjustments should be made for overseas locations and for small plants.

Construction

The following rates do not include handling, scaffolding, testing, or rework.

Civil	U.S.	NOR.
• Site strip – **manhours** per square yard	0.2	0.3
• Machine excavation – **manhours** per cubic yard	0.5	0.7
• Hand excavation – **manhours** per cubic yard	2.0	2.6
• Underground C.S. pipe – **manhours** per foot (2"-10")	1.0	1.3
• Underground plastic pipe – **manhours** per foot (½"-10")	0.5	0.7
• Concrete foundations (incl. formwork, rebar, (etc.) – **manhours** per cubic yard	20/25	26/32

Structural Steel		
• Erect heavy steel (100 lbs per foot) – **manhours** per ton	12	16
• Erect light steel (20 lbs per foot) – **manhours** per ton	36	47
• Install platforms, ladders, etc. – **manhours** per ton	40	52

Figure 6-22. Typical Data Points – Construction

The following are typical data points for evaluating estimating levels or monitoring project performance.

This data applies to large U.S. process plants. Adjustments should be made for overseas locations and for small projects.

Construction

The following rates do not include handling, scaffolding, testing, or rework.

Equipment	U.S.	NOR.
• Install pumps (0-10HP) – rnanhours per each	20	26
• Install pumps (10-100HP) – manhours per each	45	58
• Install compressors (large) – manhours per ton	20	26
Install exchangers (S&T) – manhours per each	6	8
manhours per ton	0.7	0.9
• Install towers/vessels – manhours per ton	2	2.6
• Install vessel internals – manhours per ton	120	156

Piping (including pipe supports and testing)

• Prefabricate – all sizes – manhours per ton	801100	1051130
• Erect piping (0-2%") – manhours per foot	0.6/1.0	0.8/1.3
• Erect piping (3"-8") – manhours per foot	1.5	2
• Erect piping (10"-20") – manhours per foot	2.0	2.6
• Erect piping (3"-8") – manhours per ton	200	260
• Erect piping (10"-20") – manhours per ton	250	325

Figure 6-23. Productivity Loss for Extended Workweek.

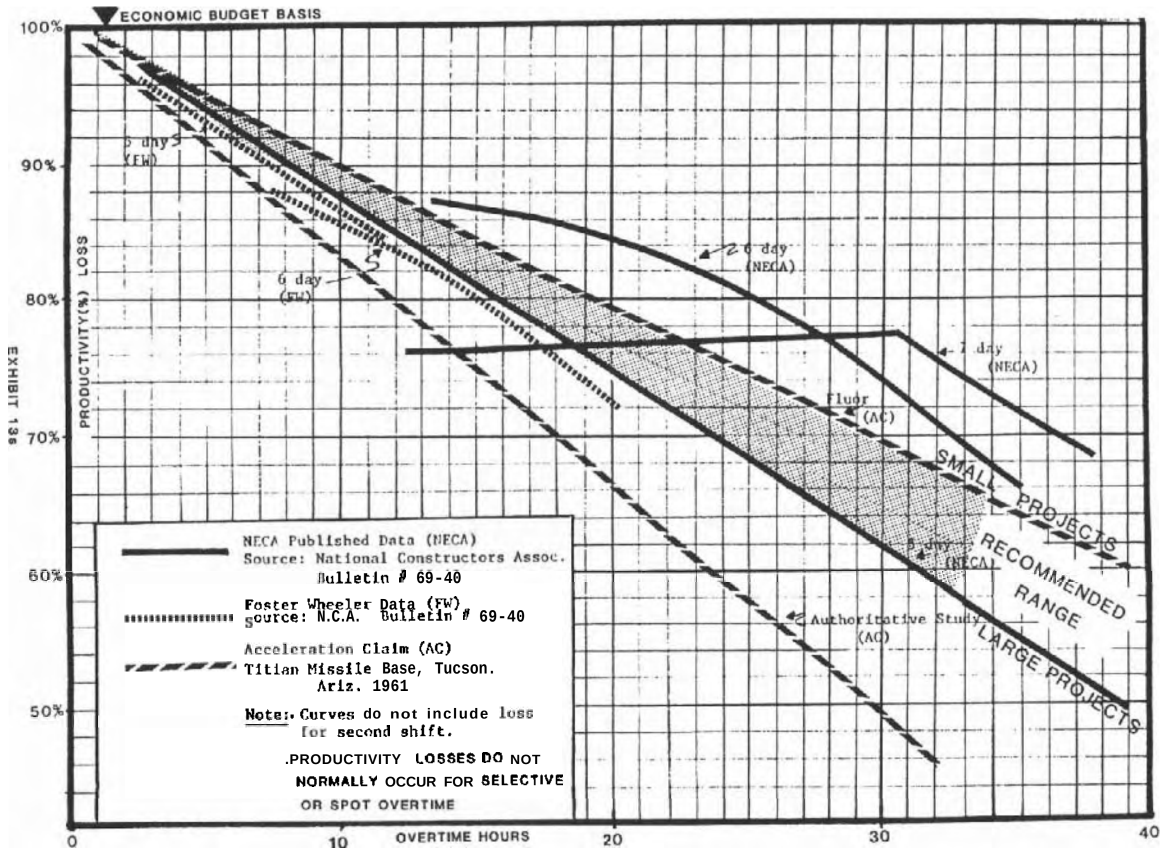
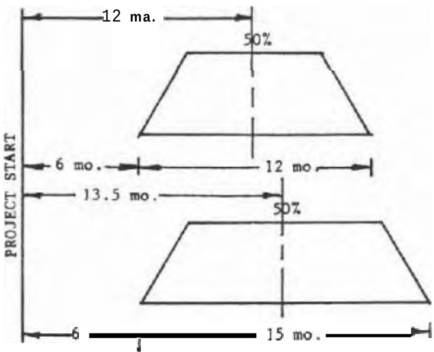


Figure 6-24.

ESCALATION CALCULATION TECHNIQUE
CONSTRUCTION LABOR

Escalation of "rate costs" far a new time period.



Originally, the costs for direct labor and field indirects were developed by estimating the monetary rate that would be appropriate at the point in time when 50% if the costs were expended. Assume all the construction costs are proportionally expended, as per the sketch. for this example.

With a three month schedule extension and the start of construction occuring at the previously planned date of six months, then the center of construction costs is now 13% months.

The general approach to Escalation, then, is to take 50% of the schedule slippage as the "escalation time period" and apply the appropriate escalation rate to the construction costs for chat time. A further adjustment may be appropriate as escalation may nor apply to some minor fired costs (such as mobilization) which could occur in the originally planned time period.

Escalation • Total Construction Costs x Escalation Rate x $\frac{3 \text{ mos.}}{2}$

Use same technique for Engineering Costs.

Keeping a Project On Time and Within Budget

(EFFECTIVE PROJECT CONTROL)

CONTENTS

GENERAL

a) Project Manager Responsibility

Without question, it is the project manager's responsibility to create an environment that will enable project control to be exercised. This means the project manager will seek counsel, accept sound advice, and stretch cost/schedule personnel to the extent of their capability.

On smaller projects, where the project manager is also the project control engineer, it is essential that the project manager develop project control skills and/or motivate the supporting/ service groups to provide the basic information that is needed for creative analysis and effective decision making.

b) Establishing Project/Cost Consciousness

Effective project control requires the timely evaluation of potential cost and schedule hazards and the presentation of recommended solutions to project management. This means that the cost/schedule specialist must be a skilled technician and also able to effectively communicate to management level. Sometimes, a skilled technician's performance is not adequate because he or she is a poor communicator. Technical expertise will rarely compensate for lack of communication skills. As in all staff functions, the ability to "sell" a service can be as important as the ability to perform the service. On larger projects, project teams are usually brought together from a variety of "melting pots," and the difficulty of establishing effective and appropriate communications at all levels should be underestimated. In this regard, the project manager is responsible for quickly establishing a positive working environment where the separate functions of design, procurement, construction, and project control are welded into a unified, cost-conscious group. Project managers who relegate the project control function to a reporting or accounting function are derelict in their duties.

c) Project Control Defined

Effective project control can be defined as the process that does the following:

1) Forecasts and evaluates potential hazards prior to occurrence so that preventive action can be taken;

2) Reviews trends or actual situations to analyze their impact and, if possible, proposes action to alleviate the situation;
3) Provides constant surveillance of project conditions to effectively and economically create a "no-surprise" condition, apart from "force majeure" situations.

d) Cost Effective Program

All project control programs must live up to their own principles and be *Cost Effective.* Many large and "sophisticated" A/Es and contractors over-control and over-report. There is always the tendency, and this is a feature of the petrochemical industry, to add additional levels of control, reporting and personnel as projects get larger or more complex. *'Wore" does not necessarily translate to "better."* Project managers must carefully review their company program, project needs and eliminate all "over-control" and "over-reporting."

BUSINESS OR TECHNICAL DECISIONS

There are three important steps to effective project control of any project:

a) Business Decision-Making

The first important step is to ensure that the decisionmakers make decisions on the basis of sound business practice. In most cases, the real decisionmakers are the project manager, the engineering manager(s), the procurement/contracts manager, and the construction manager. When these decisionsmakers are not motivated by the business ethic, then cost overruns and schedule delays are common.

b) Business Analysis/Information

The second important step is that all information necessary for making good decisions be available at the right time and in the right place. All too often, the necessary information for analysis of options and alternatives is just not available or has not been developed. Much of this "information" is found in a firm technical scope of work, a quality estimate and a good schedule.

When these items are not available, then decision-making may be flawed or ineffective. The early stage of a project is often the time when many significant business decisions have to be made and, therefore, "quality information" is vital at that time. This early stage is also the time when "firm" information may not be available, as technical options are being considered, execution plans and contract strategies being developed. Creative analysis and experienced judgment is, therefore, essential to "bridge" this gap that is sometimes referred to as "The Blackout Period." "The Blackout Period" is described in more detail in this chapter. It is also extremely important that personnel having the responsibility for technical scope, estimating and schedule development be good communicators as well as technical experts.

c) Communication Channels

It is the project manager's responsibility to actively promote "project consciousness" with all involved departments and key personnel, to ensure that the project team and/or service groups work to the "agreed" project objectives and execution plan, and also to properly coordinate and liaise with the client to establish a good interface for all decision-making/approval requirements. Limits of authority, lines of communication, degrees of responsibility and approval requirements must be clearly established in the Project Coordination Procedure. Personnel motivation and leadership skills are essential in developing "project consciousness" and effective communication channels.

PROJECT CONTROL PROGRAM/ SERVICES

a) Who Is Responsible?

On intermediate/large projects, the project manager may utilize the services of departmental specialist(s) to provide project control services. On small projects, it is anticipated that the project manager will carry out some or all of the project control work. In either case, it is the responsibility of the project manager to ensure that the project is supported with appropriate cost/scheduling methods. The following techniques are recommended for different size projects.

b) Intermediate/Large Project Techniques

The following are "essential" requirements:

1. Quality project control estimate (+/– 10-15%)
2. Good scheduling program
3. Project control specification for major contracts
4. Timely cost accounting/reporting (five days after cut-off)
5. Effective trending system
6. Accurate cost and schedule forecasts
7. Engineering progress/productivity
8. Equipment bid evaluation
9. Construction progress/productivity
10. Contingency control and rundown
11. Cash flow evaluation/control
12. Vendor drawing control
13. Subcontract cost control and forecast

c. Small Project Techniques

The following are "essential" requirements:

1. Quality project control estimate (+/– 10-15%)
2. Key cost items control/report
3. A summary schedule/date list
4. Timely cost accounting/reporting (five days after cut-off)
5. Effective trending system
6. Trend curve(s) (overall)

d) Potential Techniques (Supplementary)

The following techniques are additional to the previous listing and should be considered on a unique or supplementary basis.

Reimbursable projects would require greater owner control than fixed-price projects.

1. Manhour rate curves (engineering and construction)
2. Material commitment curve
3. Engineering and construction trend curves (manhours and/or monetary)
4. Rundown control system (engineering and construction)
5. Engineering change log (supports trending)
6. Field staff control
7. Work unit tracking curves (engineering and construction)
8. Subcontract performance/report

e) Estimating

A comprehensive estimating program is covered in Chapter 6. The emphasis in this chapter is on the use of the estimate as a scope definition and control base. To this end, the project manager should "direct" the estimate(s) development, approve the estimate(s) prior to issue and ensure the estimate(s) properly reflect:

1. Project objectives and their relative priorities
2. Design scope and design specifications
3. Maximizing of quantities and minimizing of factors (numbers of drawings and construction work units)
4. Correct evaluation of design and labor productivities
5. Project and site conditions (access/congestion, etc.)
6. Proposed execution plan/contract strategy
7. Schedule requirements (economic versus acceleration)
8. Adequate contingency evaluation.

The detail and work breakdown structure of the estimate should be developed so as to provide, as much as is possible, a clearly identifiable financial base for controlling project costs and providing the information necessary for good business decisions.

f) Feasibility Studies/R&D Projects Techniques

By their very nature, feasibility/engineering studies and R&D projects have no fixed design or quantity basis. Such projects are best managed with an effective CostTime-Resource (CTR) program.

GOOD SCHEDULING PROGRAM

a) Technical Considerations

Major considerations for developing a quality and cost effective program are as follows:

1. Levels of detail
2. Manual or computer schedules
3. CPM or barchart formats
4. The need for early planning and scheduling
5. Identification of critical path(s)
6. Evaluation of required resources

7. Development of progress/productivity measurement method
8. Develop an 80% probable schedule

The detailed methods of scheduling are outlined in the scheduling manual and also illustrated with the list of exhibits.

b) Schedule **Development/Operations**

Too often, schedules, especially logic networks, appear to be a mass of arrows, lines, squares and circles. At first sight, project, engineering and construction managers throw up their hands in horror and resort to barcharts which they have maintained for just such a situation. Schedule engineers need to be reminded, regularly and forcibly, that "their" schedule is not the end product. The successful completion of the project is the end product. The best schedules keep the following in mind:

1. Their fundamental purpose is to communicate
2. Technical excellence will not compensate for non-communicative schedules
3. They cannot work in a vacuum but must make themselves part of the daily give-and-take of the project
4. They must avoid poor layouts and poor formats
5. The activities they establish must be quantifiable
6. Simplicity is essential
7. Their schedule formats must be organized for updating and showing progress.

Last, they will find that when the preceding are observed, their schedules will have credibility and will receive the serious consideration and usage they deserve.

PROJECT CONTROL SPECIFICATION FOR MAJOR CONTRACTS

This specification should expressly state the necessary techniques and methods for controlling costs and schedules, and the contractor would be required to give assurances that its program would meet this criteria. The reporting requirements to the owner would be clearly outlined.

Should the contractor take exception to this approach and not wish to work at the level of detail outlined in the specification, the contractor must specifically state, in writing, its objection to providing any information, procedure or report.

The specified requirements/criteria will vary according to the type of contract.

TIMELY COST ACCOUNTING/REPORTING

a) Typical Program

An accounting procedure is an integral part of cost control, as it specifies levels of approval, billing and payment procedures, banking arrangements, accounts numbering systems, and all functions necessary for financial reporting of the project.

The key function for cost control is the collection and timely reporting of commitments and expenditures. This information is necessary to track the status and progress of cost objectives and also provide a base for developing cost predictions.

An accurate and up-to-date report of commitments and expenditures is essential. Delayed payments or lost invoices can cause poor cost predictions. Many control techniques are based on unit costs and they can be greatly distorted if the cost to date is inaccurately reported or if the information is reported late. For smaller projects, an accurate accounting/cost report should be available no more than five days after the cut off period. For large projects, no more than ten days after the cut off period would be essential.

b) Project Accounting Group

An effective organizational arrangement is to establish a "project cost accounting group" within the general accounting department. This group would concentrate solely on the accounting for capital projects and report directly to project management. This arrangement almost always improves the effectiveness of the cost accounting function. It is sometimes difficult to establish this organization as accounting managers are "afraid" they will "lose" authority and, therefore, resist this approach.

EFFECTIVE TRENDING SYSTEM

a) The "Blackout Period"

A difficult time for cost control is during the transition from the feasibility estimate to the detailed estimate. This is often called the "blackout period," and the time interval on large projects can be longer than four to six months. During this period, many engineering decisions are made, without full recognition of the cost impact. Also during this period, it is absolutely vital that the design/estimating and cost control effort be totally integrated and coordinated, so that up-to-date information is available for good decision-making.

b) **Owner** Versus Contractor Trending System

On larger reimbursable projects, it may be necessary for an owner to maintain an independent trending program. Compared with a small owner project task force, a contractor's operations and organization tend to be cumbersome, inflexible, and slow to respond. In many cases, an owner trending program will be more current, accurate, and responsive to changing circumstances.

c) Typical Trending Situations

On reimbursable projects, major engineering decisions are usually initiated by owner engineers or approved by them. This generally occurs during the process design phase, and cost engineers should ensure that communication channels with all engineers constantly provide an accurate assessment of the developing design.

General design specifications and equipment specifications should be monitored for conflict and "gold plating." Where quantity takeoffs exist, they should be monitored for change.

All project changes, engineering specifications, scope, procurement, subcontract, etc., should be recorded as they occur or are considered.

Changes to the project execution plan should be included. These changes could be contractual, environmental, regulatory, or schedule oriented. Potential and approved trends should be reported, and appropriate cost estimates should be included.

Approved trends are those which have been formally authorized by the project manager. Potential trends would cover items verbally approved and items which the cost engineer, through discussions with task force personnel, believes are likely to occur. Potential changes should be shown separately from approved trends.

d) The Weekly Trend Meeting

Of the many meetings held during the execution of a project, it is the weekly Trend Meeting that is probably the most important. This meeting is ***not*** a ***decision-making*** meeting; it is an information gathering/sharing meeting. The project manager "chairs" the meeting with the project cost engineer acting as the secretary and attending are the key technical/services specialists. All current and potential influences, changes, extras and trends are reviewed and discussed. The key objectives of the meeting are the common sharing, gathering, communicating and coordinating of ***all*** project influences that are developing at that time. If there are no significant problems or influences, then the meeting will be of a short duration. Even if this is the case, the meeting should still be held so as to maintain the "discipline" of trending.

ACCURATE COST AND SCHEDULE FORECASTS

The "end products" of an effective project control program are accurate cost and schedule forecasts. The forecasts would generally consider:

a) Current trends of time and money
b) Scope deviations, changes and claims
c) Project conditions changes
d) Changes to the project execution plan
e) Rundown/usage of contingency
f) Failure to meet contract conditions
g) Engineering and construction progress/productivity
h) Subcontract performance
i) Equipment/material bid experience (under/over budget)
j) Actual versus planned commitment levels

ENGINEERING PROGRESS/PRODUCTIVITY

a) Engineering Progress and Productivity Report

Figure 7-1 shows a typical format of an engineering progress and productivity report. The following is a brief explanation of this report:

1) Column A, physical completion (engineering only): evaluation of physical completion of drawings and documents, by engineering discipline and/or department, where work in progress is evaluated as per the following guide.
2) Column 5, weighted factor: based on budgeted hours for each discipline or department. This weighting will not change for minor revisions to the budget.
3) Column 6, weighted percent complete: physical completion multiplied by weighted factor (col. 4 x col. 5); addition to the bottom line total will give engineering progress.
4) Column 7, earned manhours: allocation of budgeted hours based on physical completion (col. 3 x col. 4).
5) Column 8, manhours expended: actual manhours charged to the work.
6) Column 9, productivity: actual manhours divided by earned or budgeted hours (col. 8 divided by col. 7).
7) Columns 10, 11 and 12: can be used if drawing and document performance data are required. However, physical completion and productivity are adequately evaluated using columns 1 to 9.

b) Guide to Completion of Design and Drafting

The stages of completion given in the following tables are a guide to determining the percentage of a specification or drawing completed. Each specification and drawing must be carefully examined before determining its percentage of completion.

This guide covers only drawings and specifications. There are other items (such as coordination and supervision) within the engineering scope which are not easily quantified. These items should be treated as "below-the-line" items and given the same measure of completion as the quantified work.

Figure 7-1. Engineering Progress & Productivity Report.

ENGINEERING PROGRESS & PRODUCTIVITY REPORT												PERIOD			PROJECT		
1	2	3	4		5	6		7		8		9		10	11	12	
A/C	SECTION	BUDG. HRS.	%		WTD. FACTOR	WEIGHTED %		EARNED HOURS		ACTUAL HOURS		PRODUCTIVITY		NO. OF DWGS.	BUDGET HOURS PER DWG.	ACTUAL HRS. PER DWG.	
			INC.	CUM.		INC.	CUM.	INC.	CUM.	INC.	CUM.	INC.	CUM.			INC.	CUM.
	TOTAL																

Stages of Completion	Percent Complete
Specifications	
Complete draft	20
Write specification	70
Check specification	85
Issue for approval	85
Issue for construction	85
Issue revisions as required	95-100
Architectural Drawings	
Complete sketches and general arrangements (GAs)	15
Check specification	85
Issue for approval	85
Issue for construction	85
Issue revisions as required	95-100
Architectural Drawings	
Complete sketches and general arrangements (GAs)	15
Issue sketches and GAs for approval as required	25
Complete drawing	75
Check drawing	85
Issue for approval	90
Issue for construction	95
Issue revisions as required	95-100
Civil Drawings	
Complete preliminary site plan (building locations and site elevation)	10
Issue preliminary site plan for approval as required	25
Complete design calculations	30
Complete drawing	80
Issue for approval	85
Issue for construction	95
Issue revisions as required	95-100
Concrete and Foundation Drawings	
Complete design calculations	25
Complete drawing	60
Check drawing	85
Issue for approval	90
Issue for construction	95
Issue revisions as required	95-100
Steel and Superstructure Drawings	
Complete design calculations	25
Complete drawing	60
Check drawing	85
Issue for approval	90

Stages of Completion	Percent Complete
Issue for construction	95
Issue revisions as required	95-100
Electrical Drawings	
Complete design calculations	15
Complete drawing	75
Check drawing	85
Issue for approval	90
Issue for construction	95
Issue revisions as required	95-100
Instrumentation Drawings	
Complete design calculations	50
Complete drawing	70
Check drawing	85
Issue for approval	90
Issue for construction	95
Issue revisions as required	95-100
Mechanical General Arrangement Drawings	
Complete design calculations	15
Complete preliminary GA drawings	20
Issue preliminary GA drawings for approval	40
Complete drawing	65
Check drawing	75
Issue for approval	80
Issue for construction	95
Issue revisions as required	95-100
Mechanical and Piping Drawings	
Complete design calculations	10
Complete drawing	65
Check drawing	85
Issue for approval	90
Issue for construction	95
Issue revisions as required	95-100
Flow Sheet Drawings	
Complete design calculations	40
Complete drawing	60
Check drawing	70
Issue for approval	80
Issue for construction	95
Issue for revisions as required	95-100

c) Engineering Drawing Status Report

Figure 7-2 illustrates the typical format used for reporting the status of engineering drawings. This document provides source information for evaluating engineering progress. The individual drawing status will be evaluated by discipline squad leaders and spot-checked by the scheduling group/project manager. This report covers progress, the schedule, and manhours.

EQUIPMENT BID EVALUATION

Good evaluations and quality equipment/material bid tabulations are essential for effective project control. Engineers carrying out technical evaluations of vendor bids and who may be involved in vendor negotiations should be encouraged to review the estimate basis of equipment prior to any negotiation. Preference choices with accompanying cost premiums should be thoroughly investigated prior to submission for management approval. Compatibility with existing plant equipment, ease of maintenance and operating costs are appropriate requirements for equipment selection.

If there are no schedule restraints, commercial evaluations should follow the technical evaluation. This would ensure that purchasing personnel do not waste time with technically unacceptable bids.

If there are cost deviations involved in the technical review, these items should be brought to the cost engineer's/project manager's attention, If there are critical schedule requirements, the selection may not be to the lowest commercial bid.

CONSTRUCTION PROGRESS/PRODUCTIVITY

a) Construction Manhour Report

Figure 7-3 shows the typical format used for reporting manhours and earned budget value. Progress is measured by budget manhours. A manhour prediction is based on the productivity to date versus the manhours spent to date. Productivity is derived from actual manhours expended versus budget hours earned. Indirect manhours should be shown separately. Indirect manhours are not quantity based. It is recommended that an indirects budget or earned value be based on direct work progress and/or judgment of each major indirect manhour account.

Figure 7-2. Engineering/Drawing Status Report.

ENGINEERING/DRAWING STATUS REPORT

COMPLETION DATE	
SCHEDULE	
ACTUAL	

ACCT.	ACT./DRG. NO.	ACTIVITY	START DATE	COMPLETION DATES ORIG.	REV.	REV.	% COMPLETION 10	20	30	40	50	60	70	80	90	100	BUDGET HOURS	ACTUAL HOURS	REMARKS	FORECAST HOURS
		S																		
		A																		
		S																		
		A																		
		S																		
		A																		
		S																		
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ISSUED FOR:
A – APPROVAL
C – CONSTRUCTION
D – DESIGN
M – MICROFILM
P – PURCHASE
Q – QUOTATION

CONTRACT NO.
CUSTOMER
PLANT

SECTION
~AWING NO.
~. NO.
OLE
DEPT.

REPORT NO.
STATUS AS OF

TOTAL THIS SHEET
GRANDTOTAL
compiled by

Figure 7-3. Construction Manhour Report.

CONSTRUCTION MANHOUR REPORT

SUMMARY REPORT (PRIME ACCOUNT)

JOB NO:
REPORT NO:
UNIT:
PERIOD:

DESCRIPTION	CLASS	MANHOURS SPENT		BDGT. FOR WORK DONE		TOTAL BUDGET	% COMPL.	PRODUCTIVITY		TOTAL PREDICTED MANHOURS
		THIS WEEK	TO DATE	THIS WEEK	TO DATE			THIS WEEK	TO DATE	
EARTHWORK										
FOUNDATIONS										
HEATERS										
SUBTOTAL DIRECT										
TEMPORARY FACILITIES										
TOOLS & EQUIPMENT										
UNALLOCABLE										
SUBTOTAL INDIRECT										

b) Construction Earned Budget Report

Figure 7-4 shows an earned budget report that collates quantities as the work is completed and also predicts total quantities based on a field takeoff made from construction issue drawings. The measured quantities are then converted into an earned value of budget hours, which are then entered on the manhour report, as previously illustrated. The "predicted quantities" section of this report is a very important item. Early detection of quantity changes can occur if the field takeoffs are completed as soon as the construction issue drawings are received. There is the tendency to not carry out "immediate" quantity takeoffs as the field personnel are heavily overloaded most of the time. This tendency should be resisted as the takeoff process can provide important scope deviation information.

Figure 7-4.

EARNED BUDGET REPORT

		ORIGINAL	PREDICTED		UNIT	QUANTITIES DONE		EARNED BUDGET		
ITEM	CLASS	QUANTITIES	QUANTITIES	UNIT	RATE	THIS WK.	TO DATE	THIS WK.	TO DATE	REMARKS
BY INDIV. WORK CATEGORY										

CONTINGENCY CONTROL AND RUNDOWN

a) A "Slush Fund"

Many project managers treat contingency as a "slush fund." This occurs when a project manager uses the contingency to balance the monthly trends. In such cases, it is quite common for the contingency to be "spent" well before the end of the project. Contingency is essentially for ***Unknowns.*** Unknowns only become known when commitments are made. It is at that time that the validity of the estimate becomes apparent.

b) Rundown Routine

The following method represents a typical rundown of contingency over the life of the project. The calculation process shows a rundown which is calculated on the basis of uncommitted and unspent costs and is computed as follows:

Major Cost Center	Cost Prediction Uncommitted (%)	Committed but Unspent (%)
a) Material and Equipment	10	5
b) Labor	20	15
c) Labor subcontracts	20	15
d) Material and labor subcontracts	15	10
e) Home office, engineering, and fee	10	5
f) Field indirects and temporaries	10	5
g) All other costs	10	5
h) Owner costs	10	5

This simple, but practical method covers risk on work yet to be committed and work committed but not yet paid for. Until the last and final invoice has been paid, there is still the risk that cost increases may occur. Construction labor and subcontracts are generally the most volatile items and therefore, carry the greatest contingency percentage. That is, the contingency would be about +/—10-15%. The maximum contingency that this method will develop is 13%. This would not be sufficient for a conceptual estimate. Alternatively, if the project only had a 10% contingency, then the above breakdown of percentages should be reduced.

c) **Start-Up/Commissioning**

A further consideration is the amount of contingency that is required at mechanical completion. This is to ensure that funds are available for late changes, commissioning accidents, start-up requirements, and final invoices/claims which were not anticipated. If funds have already been allowed in the estimate for this possibility, then this further "hold-back" would not be necessary.

CASH FLOW EVALUATION/CONTROL

a) **General/Objectives**

The major objective of cash advances and the bank handling procedure is to ensure that the project is funded by the responsible party, as per the contract. A cash flow forecast of a reimbursable-type contract is usually prepared for a one- to two-month period and then presented to the owner for cash advances on a biweekly or weekly basis. A good forecast should generate no more than a 5% excess requirement. This would be acceptable to most owners. Most forecasts are manually prepared and evaluate future expenditures for contract services, equipment and bulk materials, subcontracts and owner costs.

b) Documentation

As soon as practicable after the last day of each four-week period, contractor will prepare and submit to owner a complete statement of the amounts actually paid, including the proportionate amount of the contractor's copies of invoices, payrolls, bank statement and other documents to establish all costs as well as duly executed Waivers of Lien for each contractor and subcontractor.

c) Banking Arrangements

Any amount by which the advance payment to Contractor for such four-week period exceeds or is less than the amount of actual costs incurred for that four-week period shall be taken into account in ascertaining the advance payment for the next following four-week period.

Based on owner's prior agreement, contractor will arrange to utilize an agency interest-bearing account for advance payments and will transfer funds to an agency checking account as required to cover actual disbursements. Any interest received from such interest-bearing account, less any service costs, shall be paid or credited to owner.

VENDOR DRAWING CONTROL

A significant element of the engineering schedule is the timing of vendor drawings. For example, foundation design and piping design depend on vendor drawings for details of foundation bolts, bearing loads, nozzle orientation, pressure and capacity data.

An effective vendor drawing control system is essential for planning and scheduling engineering work. The bid tab evaluation should cover the issue of vendor drawings, and the successful vendor should be monitored thereafter to ensure compliance with promised or "need" dates. This is particularly necessary for critical vendor drawings.

A vendor material expediting program should also cover the supply and issue of vendor drawings. Schedule engineers should co-ordinate this effort with the expediting department. Figure 7-5 shows a typical format for control of critical vendor drawings. The same format can be identified separately. Vendor drawing control is usually the responsibility of the procurement department.

SUBCONTRACT COST CONTROL AND FORECAST

a) **Summary** Report

All subcontracts should be listed, in total, on the control form report shown in Figure 7-6. This form summarizes current cost and forecasted final value and identifies scope, claims and potential trends. The figures for each subcontract are independently developed.

b) Claims

Subcontractor claims will require careful attention. Claims, generally, will fall into the following categories:

1) Change in "original" quantities
2) Schedule delays – caused by the owner and/or the prime contractor
3) Drawing and material delays
4) Interference by others
5) Changes in site conditions or site regulations

Most subcontractors will greatly exaggerate adverse conditions and submit inflated claims. Consequently, it is essential

Figure 7-5. Control of Critical Vendor Drawings.

DATE		CRITICAL VENDOR DRAWING LIST				PROJECT		
P.O. NO	EQUIPMENT	VENDOR	VENDOR DRAWING	FOR APPROVAL			FINAL	
				REQ'D	REC'D	RET'D	REQ'D	REC'D

Figure 7-6. Subcontract Summary Report.

SUBCONTRACT SUMMARY REPORT	PROJECT JOB NO. REPORT NO. DATE

CONTRACT NO.	CONTRACTOR	WORK SCOPE	BUDGET	ORIGINAL CONTRACT VALUE	CHANGES & EXTRAS	CLAIMS	FORECAST	COMMD.	EXPEND.	

that daily logs, schedules, work programs, etc. be maintained for all major subcontracts. Contract value increases of over 10% can lead to a "legitimate claim for unit price increase for all the work.

c) Unit Price Quantities Variations

On unit price subcontracts developed with a minimum of engineering definition, factors of 20% respectively for quantity increases and claims should be added to the original contract price (labor only). Should an independent bid evaluation indicate a low bid, a further allowance should be made in anticipation of the subcontractor getting into financial difficulties or requiring additional monitoring/control.

d) **Low** Bids

A low bid can result through ignorance of the work and/or site conditions or through a subcontractor "buying the job." There can be occasions when subcontractors will attempt to break into a new area of work, or alternatively, attempt to keep out competitors. Such situations can result in low bids, which, in turn, can lead to serious schedule consequences for an entire project should a subcontractor subsequently get into financial difficulties.

Subcontractors in financial trouble will generally reduce their field effort to a minimum to contain their losses. This results in low manpower levels and a minimum of construction equipment and supervision, and often leads to schedule extension.

Each "low" bid should be very carefully evaluated on a case-by-case basis, and if the decision is made to accept the "low" bid, then that contract should be closely monitored as it is probable that the subcontractor will try every "trick" to increase the revenue.

KEY COST ITEMS **CONTROL/REPORT** (SMALL PROJECTS)

This is a technique used on smaller projects. This method concentrates on the high cost items, usually material and construction contracts, and evaluates the budget versus the commitments for these items on a continuous (monthly) basis. An initial review of the estimate should reveal the high cost items, and these items should be identified on this report. The listing of the key cost items should be developed in conjunction with other control and reporting items.

Ensure that the accounting/cost report can identify all commitments to the estimate item number. The budgeted amount should be shown on the report for each estimate item. This will then allow comparisons, evaluations, and forecasts to be made of the "Key Cost Items." The "Key Cost Items Report" should be issued monthly to show the cost situation of these items. The forecasts will probably be developed by the project manager.

A SUMMARY SCHEDULE/DATE LIST (SMALL PROJECTS)

A simple but effective scheduling program for small projects is the use of the "schedule list" method. This requires a listing of the major work items together with start and finish dates for each item. The start and finish dates should be developed on a planned basis, and as the project is executed, the actual dates should be entered on the schedule sheets. As this scheduling program is also to be the base for planning the departmental manpower, the engineering man days will be required to be shown on the sheets.

The development of the planned start/finish dates should be carried out with the "executing departments" in order to secure their commitment to the project execution program. This scheduling program can be reviewed and updated on a monthly, bi-monthly, or quarterly basis. This simple program is illustrated in Figure 7-7.

EFFECTIVE TRENDING SYSTEM (SMALL PROJECTS)

As it is not cost effective to apply a "full" trending program to small projects, the following ***monthly*** trend analysis/report is recommended. The purpose of this report is to identify the cost impact of the following:

a) Key cost items deviations (from the report)
b) Engineering changes

Figure 7-7. Summary Schedule - Small Projects.

LEGEND		
NOTE: THE EMPHASIS SHOULD BE PLACED ON THE THREE "C"s — COORDINATION, COMMUNICATION COMMITMENT	S.P.I. (CATEGORY 2-4 PROJECTS)	Rev. Date ____ No. ____ File No. ____ By ____ Date ____ Sheet No. ____

TITLE OVERALL PROJECT SCHEDULE

	MANDAYS	ACTIVITY #	ACTIVITY	START PLAN	START ACTUAL	FINISH PLAN	FINISH ACTUAL
1		1.	AFE AUTHORIZED				
2							
3		2.	ENGINEERING -- TOTAL				
4			a) PROJECT ENGINEERING (CHOC/BEV/DEV)				
5			b) PROCESS				
6			c) FACILITIES				
7			d) PACKAGING				
8			e) BUILDING				
9			f) ELECTRICAL / INSTRUMENTS				
10			g) MISC. (CONSULTANTS, ETC.)				
11							
12							
13		3.	PURCHASE KEY COST ITEMS				
14			a)				
15			b)				
16			c)				
17			d)				
18			e)				
19			f)				
20			g)				
21			h)				
22			i)				
23			j)				
24							
25		4.	DELIVERY KEY COST ITEMS				
26			a)				
27			b)				
28			c)				
29			d)				
30			e)				
31			f)				
32			g)				
33			h)				
34			i)				
35			j)				
36							
37							
38		5.	CONSTRUCTION -- TOTAL				
39			a) GENERAL/SITE WORK				
40			b) BUILDING				
41			c) MECHANICAL				
42			d) ELECTRICAL/INSTRUMENTS				
43			e) MISC. SPECIAL				
44							
45							
46							
47							
48			THIS SCHEDULE DEVELOPED BY				
49			P.C.s -- 30 PROJECTS				
50							
	1 2 3	4 5 6 7	8 9 10 11 12 13 14 15 16 17 18 19 20 21	22 23 24	25 26 27	28 29 30	31 32 33

c) Project conditions changes (schedule/site/estimating) factors, etc.
d) Scope changes.

TREND CURVE(S) (SMALL PROJECTS)

Figure 7-8 illustrates a series of typical trend curves. This figure shows curves that reflect cumulative committed costs against time for equipment/material, engineering, construction and in total. The total curve is weighted from the individual EPC curves, based on an historical breakdown of costs. As the "Key Cost Items Report" and "Trend Reports" are intended to identify individual and significant cost deviations, the purpose of trend curves is to show the major or total cost picture against time. Commitment curves (planned and actual) for phases of the work and for the total project can, with proper judgment, show the trend (overrun/underrun/or target) of costs at the reporting period. For this tool to be effective, particularly at the early stages of a project, the "planned" curve should reflect the anticipated rate of commitments (against time) for the project. As the weight of commitments increases, the "planned" curve becomes less important as the experience of commitments to date (actual trend curve) provides its own base for forecasting the total costs.

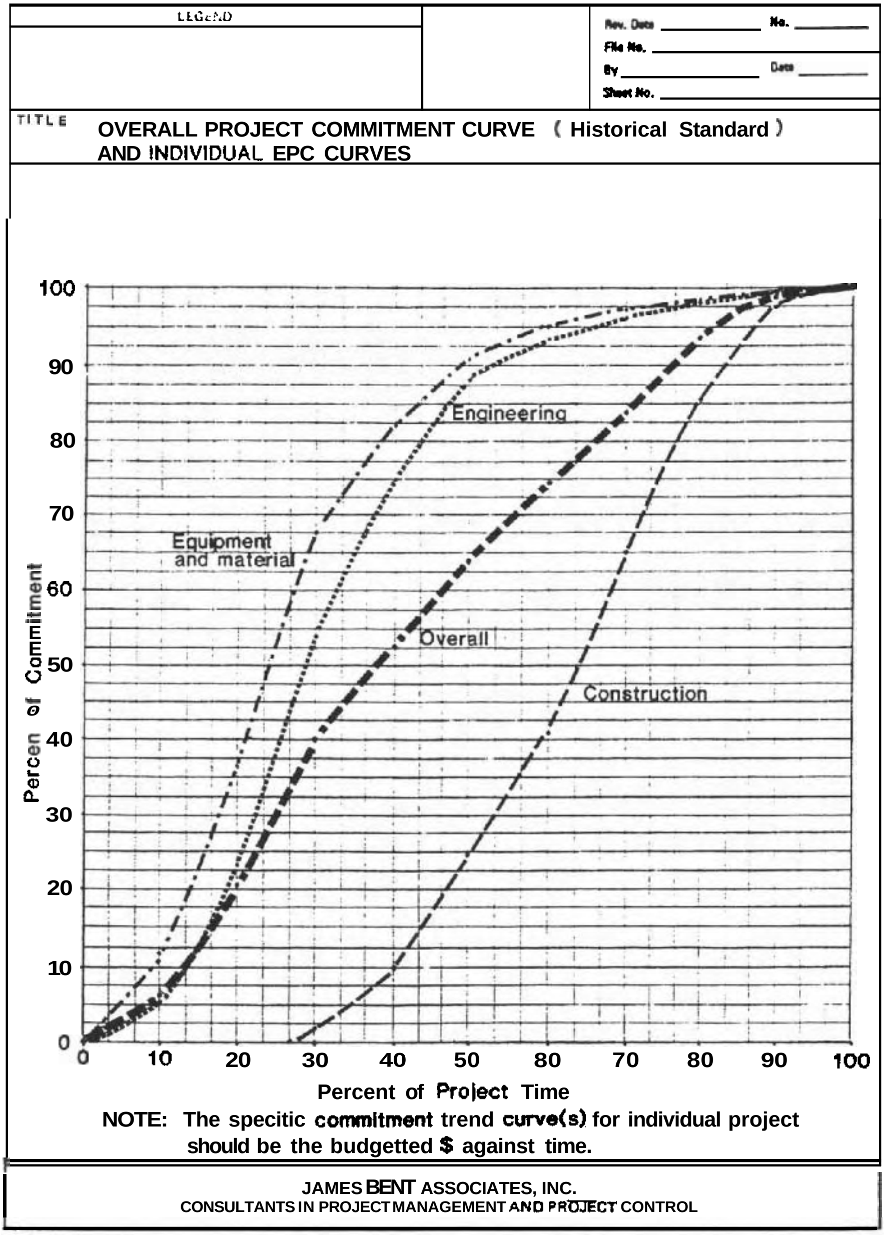
It is recommended that only the overall curve be used for small projects. A material commitment curve is not necessary as the significant material costs are covered by the "Key Cost Items Report." As project size increases, the engineering and construction trend curves can be considered. The following controls are supplementary and are used at the project manager's discretion.

MANHOUR RATE CURVES

a) **Home Office/Engineering *Curve***

Figure 7-9 illustrates cumulative planned and actual profiles of a home office manhour rate. This rate represents total home office costs divided by total manhours. Significant deviation of actual to planned can indicate a potential overrun. Rate overruns can occur because of a different mix of salary levels, unantici-

Figure 7-8. Trend Curves.



pated increases in salary levels, changes in benefits and burdens, overruns in service and expense budgets, premium costs for overtime, or the assignment of higher priced personnel than planned.

This example shows an estimated rate of $20 with tracking curves starting at $23-$26, dropping to $17-$18, and finishing at the estimated level. It reflects high-salaried personnel at the start of the project (department managers, project management, process engineers) followed by a lower-priced drafting operation with higher-salaried engineers returning at the end for punchlist work and plant start-up/commissioning.

The planned curve can be developed from historical experience and/or by evaluating rate curves for each major section, category, or engineering discipline and then adding them together on a weighted manhour basis.

b) Construction Labor **Curve**

Figure 7-10 shows cumulative planned and actual profiles of direct labor manhour rate. This rate represents total labor costs divided by total direct manhours. The monthly status can be tabulated as shown.

Significant deviation of actual versus planned values can indicate a potential overrun. Rate overruns can occur because of different craft mixes, union contract changes, governmental regulation changes, and premium costs for overtime and shift work.

In this example, the planned and actual curves track reasonably closely for the first six months. Abrupt changes in a cumulative profile do not generally occur when the job is well advanced as there is too much weight of past performance to allow instant or abrupt change.

A turndown can indicate release of higher paid crafts, escalation lower than anticipated, or failure by trade unions to achieve pay demands.

The following curve characteristics are typical of a process-type plant project:

- Low at first due to low skill civil workers (laborers)
- Increasing to peak due to highly paid equipment operators, millwrights, pipe fitters and electricians
- Then a slight turndown due to lower paid insulators and painters.

Figure 7-9. Overall Home Office Man-Hour Rate Curve.

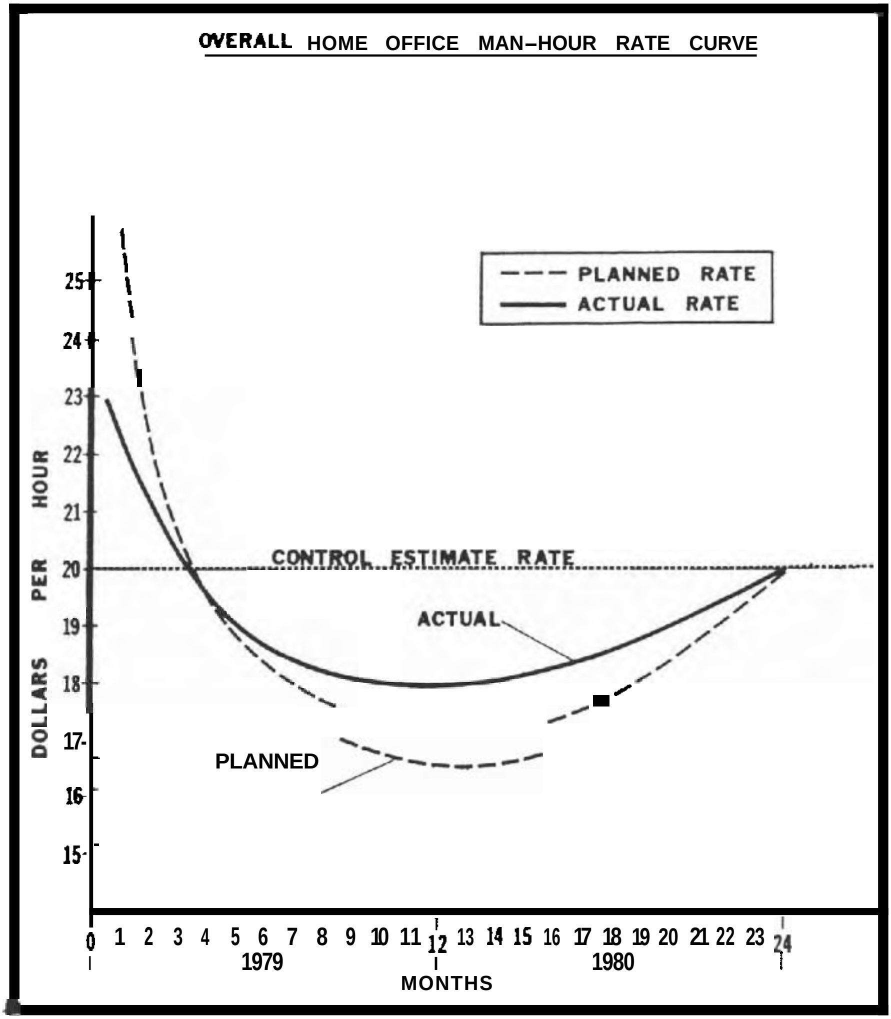
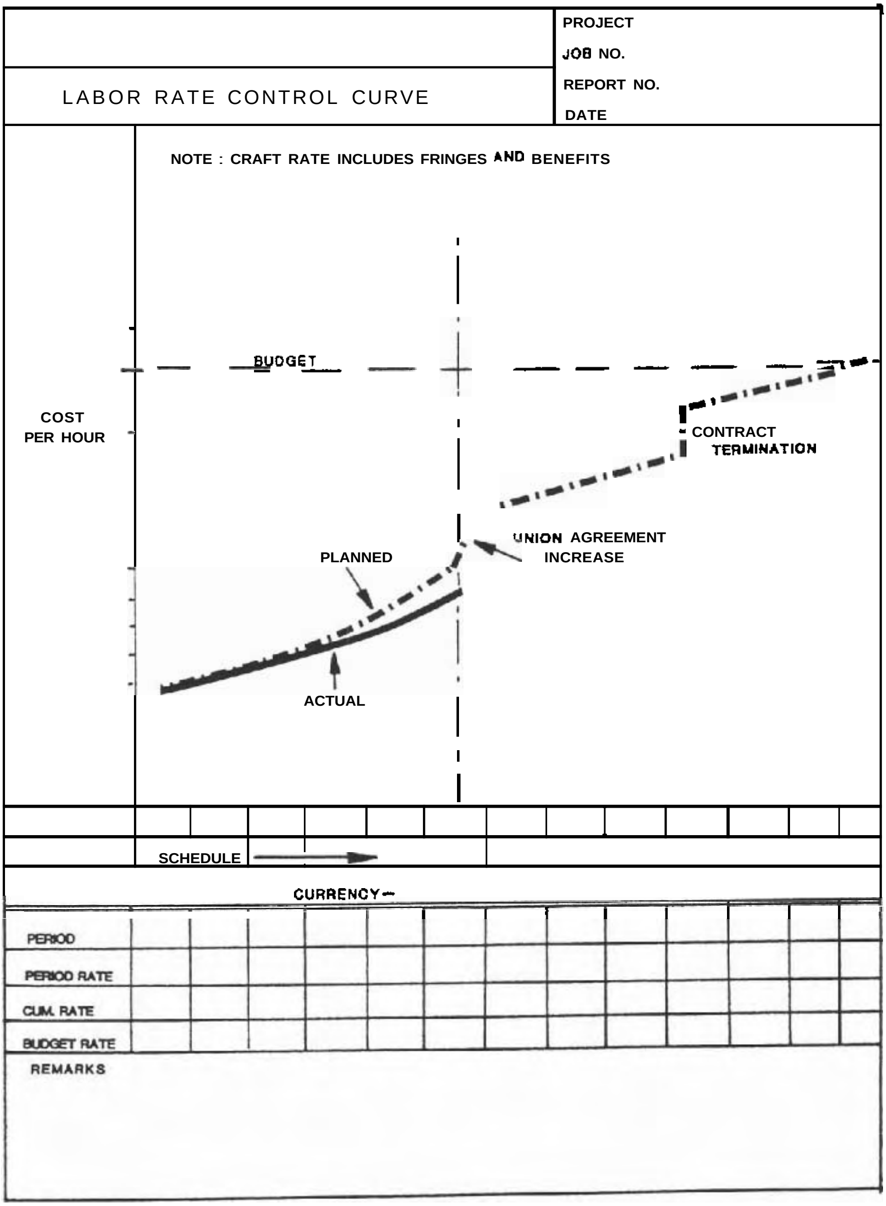


Figure 7-10. Construction Labor Curve.



MATERIAL COMMITMENT CURVE

Figure 7-11 illustrates a typical commitment curve for bulk materials and equipment. This curve tracks actual cumulative material commitments relative to a planned profile. This curve will only indicate a trend of total commitment. A significant trend at this stage is an underrun or overrun of actual commitments versus individual control estimate budgets.

The bulk material and equipment commitment curve can be used for two purposes:

a) As a graphical, overall forecasting tool
b) As a rough check on the procurement progress, assuming the planned curve reflects the current schedule. Significant deviations of actual versus planned values can provide a trend for cost deviation. It may be required that separate curves be drawn for equipment, bulk materials, and supply and erect subcontracts for the project control of large projects.

ENGINEERING AND CONSTRUCTION TREND CURVES

a) Purpose

The major purpose of trend curves is to track actual performance/experience against a planned or anticipated base. The effectiveness of this technique depends on the quality of the "measuring base," or plan. Any resulting trend deviation can then be analyzed and the "result" can then be forecasted or trended. Curves provide a much better analytical tool than does a tabulation or report of numbers. The following are typical examples of monetary and manhour expenditure curves.

b) **Home** Office Cost Expenditure Curve

Figure 7-12 shows planned and actual expenditure curves of home office costs. Planned curves are developed by judgment and historical experience and can be compiled from profiles of more detailed elements. It is possible on large projects that individual curves might be used to track non-manhour related expenses, such as computer, reproduction, communication and travel-relocation costs.

Figure 7-11. Material Commitment Curves.

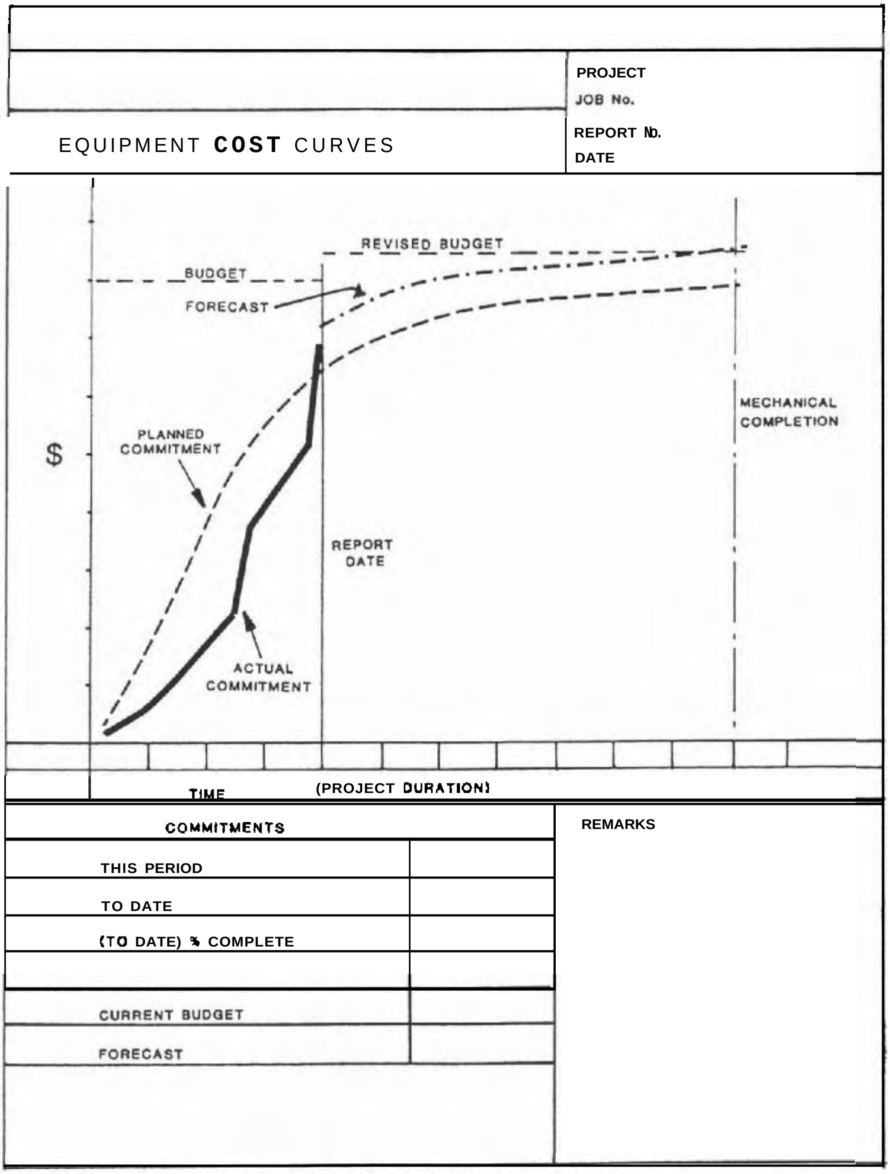
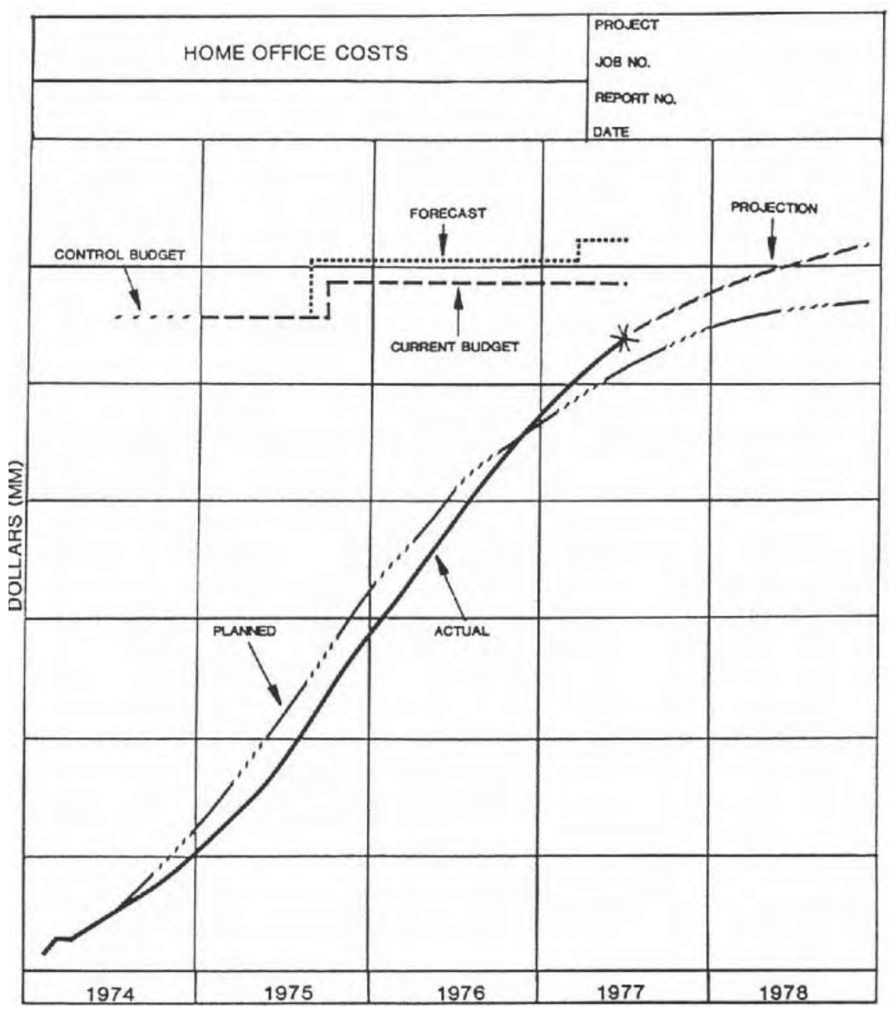


Figure 7-12. Home Office Cost Expenditure Curve.



This example shows the actual expenditure curve consistently underrunning the planned until the end of 1976 where it continues straight on instead of commencing to run down. **A** trend was discernible in mid-1976, and, in fact, a forecasted overrun had been made in the third quarter of 1975. **A** further overrun was made in the first quarter of 1977 due to failure of the curve to commence a rundown.

c) Engineering Manhour Control

Figure 7-13 shows typical examples of manhour tracking curves. It should be emphasized that this technique does not really control effort or measure performance, but indicates a trend and plots a possible outcome.

This example shows an overrun in process design (completed), shows an overrun in the civil plan as of the reporting period, and is on target with piping design, but with a different profile. The overall cumulative report is an overrun. Projecting forward at a rundown profile similar to the plan will give a forecasted overrun at completion.

Target curves of anticipated manhour expenditure could be developed for other significant engineering sections. A typical split might be as follows:

1) Process
2) Civil and structural design
3) Equipment and mechanical
4) Piping
5) Electrical
6) Instrumentation

Historical experience can assist in developing good expenditure curves. However, evaluation will depend on the skill and experience of the cost engineer. In practice, especially on large, complex projects, manhour overruns might be due to recycling of engineering, caused by design error or owner changes.

d) Indirect Labor Manhour Curves

As indirect labor budgets are often poorly estimated, tracking curves should be considered for major indirect categories. Figure 7-14 shows a typical indirect manhour tracking curve. Manhours and manhour costs could be tracked separately. A separate curve for average hourly rate could be drawn, or alternatively, the hourly rate can be entered on the manhour chart as per this exhibit. The monthly status is tabulated as shown, and forecasts are shown. Forecasted manhours multiplied by the anticipated hourly rate will give forecasted costs.

As is often the case, this example shows a significant manhour overrun. The overrun started in month 10 and further

Figure 7-13. Engineer Manhour Expenditure Curves.

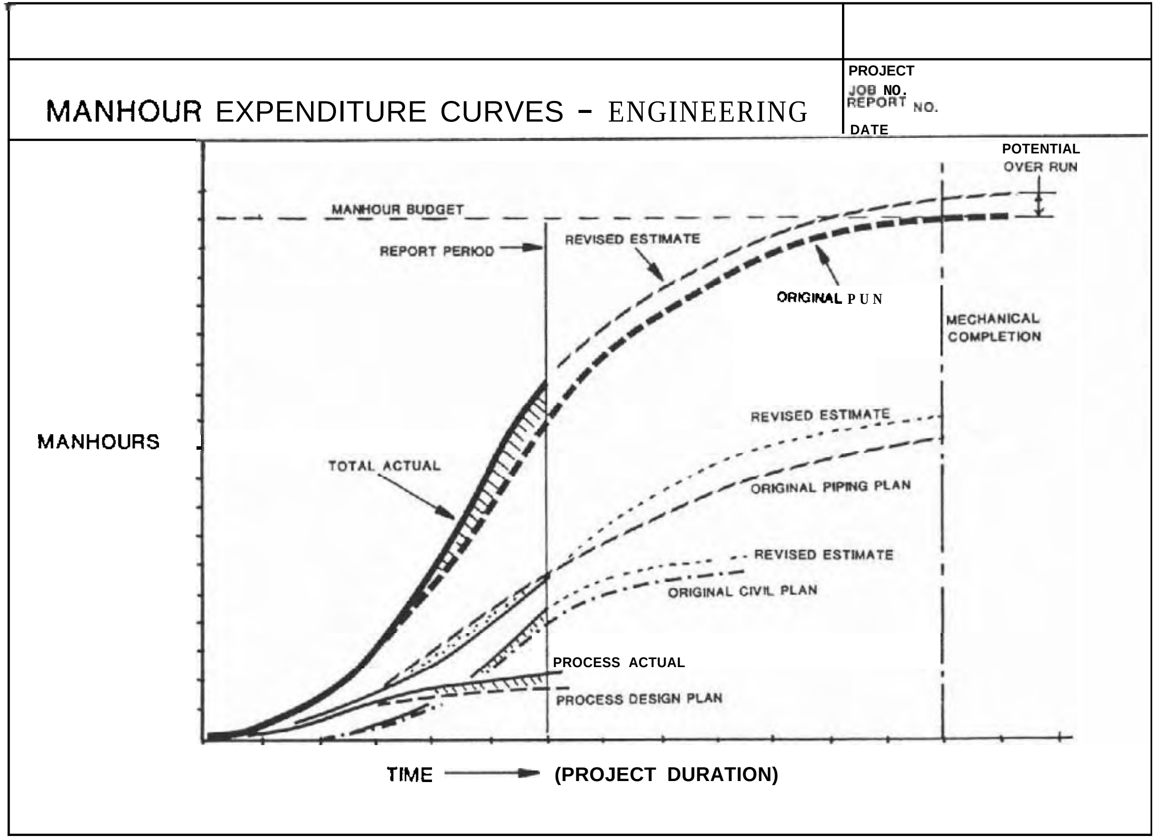
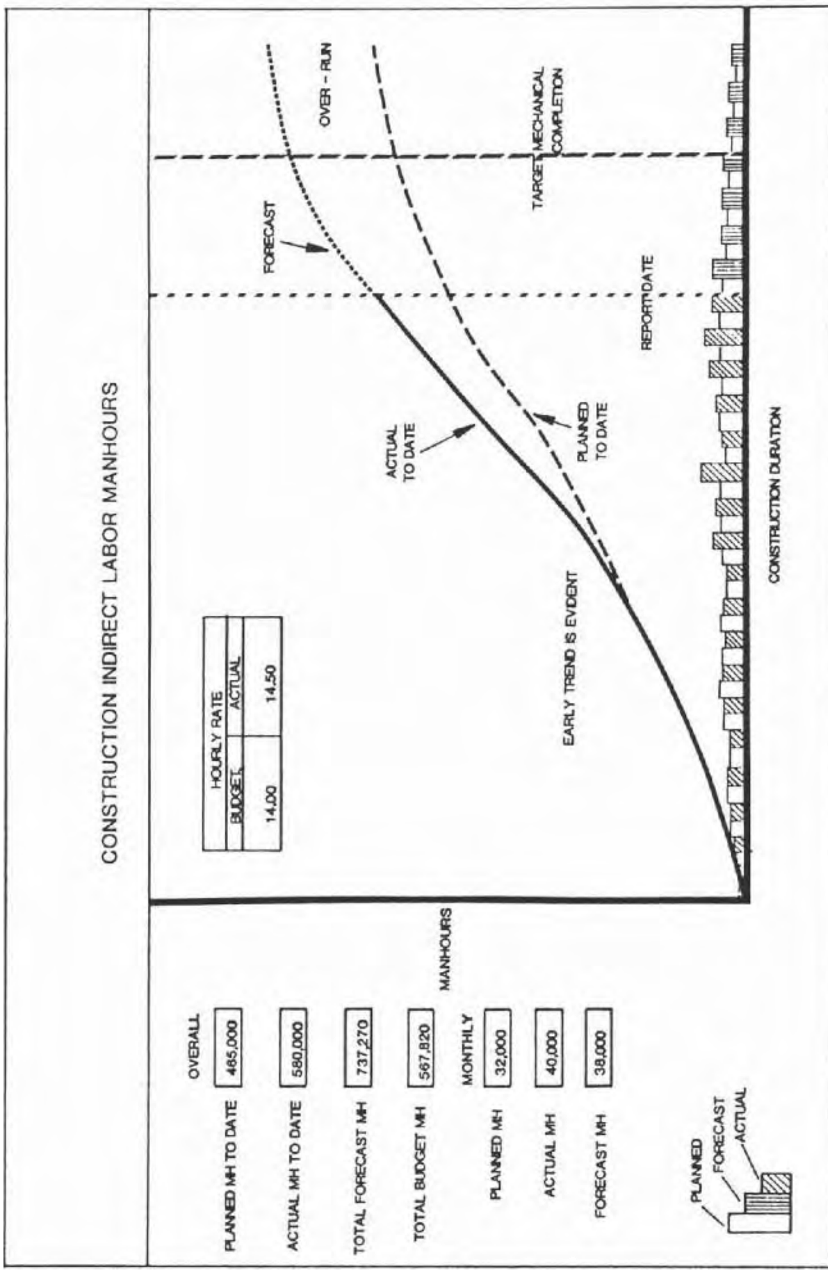


Figure 7-14. Construction Indirect Labor Manhours.



escalated in month 13. **A** significant overrun was evident at that time. The hourly rate is also shown to be overrunning.

Indirect labor covers hourly paid labor not directly involved in the construction of permanent facilities; indirect activities covers all non-productive and lost time and can include the following:

- Erection of temporary buildings, roads, etc.
- Erection and maintenance of temporary utility systems
- Site cleanup during and after construction
- Materials handling and preservation (warehouse operation)
- Scaffolding
- Equipment maintenance
- Lost time (weather, union allowances, training, etc.)
- Welder proficiency tests and other training programs
- Tea breaks, walking time, waiting time, etc.

This same technique can, of course, be used for direct labor manhours.

PROJECT RUNDOWN CONTROL

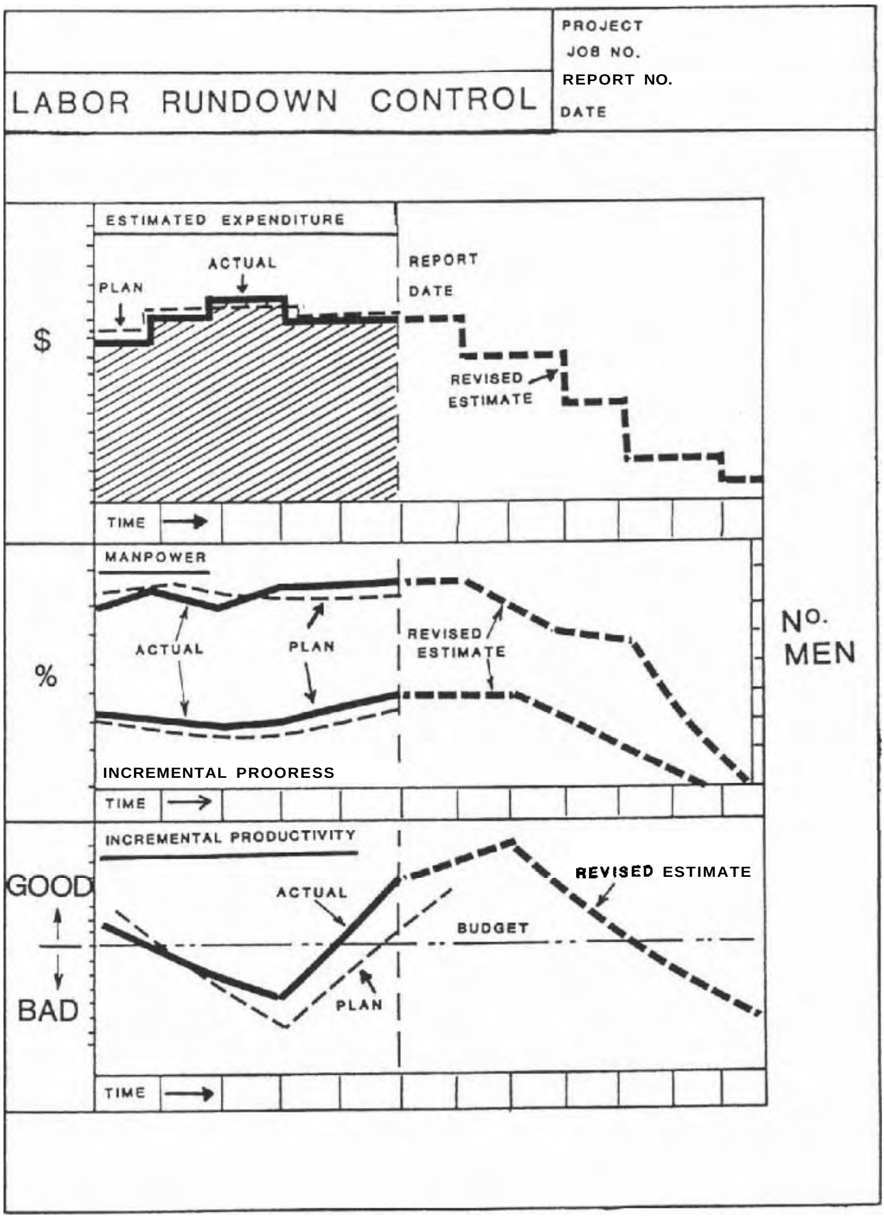
a) **Purpose**

As construction approaches mechanical completion, an efficient rundown can be difficult to achieve. Complicating efficient completion at this time are design changes, start-up, punchlists and rework.

On large projects, this situation can be especially serious and lead to increased costs. Moreover, the weight of accumulated performance now obscures incremental performance. Therefore, work can get completed in a haphazard and unplanned manner. It is difficult, as punchlists and completion lists are generated, to ascribe a factual scope of work to a multitude of different items, many having top priority for completion. A technique for reducing these problems is shown in Figure 7-15. This involves identification of the remaining scope, with work/punchlists and then individually controlling it to completion. This example shows a rundown for direct labor on a reimbursable project.

In addition to field labor, there are other costs to consider.

Figure 7-15. Labor Rundown Control.



b) Material

At this stage, field-purchased material usually reaches a peak due mainly to design changes and rework. It is suggested that an estimate of these expenditures be made. Planned dollar expenditure curves could be drawn for major categories and actual expenditures plotted.

c) Subcontracts

At this point, direct-hire forces could be replaced and the remaining work completed by subcontracts. Often these subcontracts are awarded on a time and material basis, making dollar expenditure curves the only way to retain proper control. There is also the need for closing out the regular construction subcontracts, many of which may require settlement of claims and extras. Resolution of these items requires time and attention, and the subcontract group should not be cut back too quickly at this time.

d) Design Changes and Start-Up Problems

A field change log could help identify the scope of this work, and designation of the initiator could assist in a proper allocation of costs.

On reimbursable-type contracts, the scope of work may not include commissioning activities. However, the contractor generally has responsibility for a plant meeting its design performance and so is often asked to assist with commissioning and start-up. Owners believe that design changes required for start-up are the contractor's responsibility as many of these design changes are required for safe plant operation. Thus, on large projects, it is vital that manpower, manhours and costs be tightly controlled through the rundown stage. This same "Rundown Control System" can also be effectively used to close out engineering.

ENGINEERING CHANGE LOG

An engineering change log would cover all changes from the original scope, including changes to specifications, requisitions, and drawings. All changes, including owner scope changes, should be numerically recorded and a report issued to design groups and the owner. Cost estimates should be made of these changes and included in the trend report.

Due to the broad base of a conceptual estimate, it is not always possible to identify all items as changes. When in doubt, enter the item, as subsequent evaluation will confirm or delete the item.

The major objective of the engineering change log is to track the developing design and costs against the design basis and cost of the conceptual estimate. The objective is not to highlight deficiencies in order to lay blame on the designer, estimator, or owner.

It is recommended that the engineering change log not be used as a device to turn all changes into owner change orders. Some changes can, of course, affect the contractor fee and profit margin.

FIELD STAFF CONTROL

In preparing a detailed control estimate, the construction department should provide a field staff organization chart showing all necessary job functions; in addition, this department should prepare a listing showing field staff positions, both permanent and local hire, and indicating planned arrival and release dates as well as estimated manhours or manmonths. Figure 7-16 shows a typical listing which could be a basic control document for allocation of field supervision. This document should be constantly updated.

The contract agreement will outline the basis of charging for the construction staff. On reimbursable projects, these charges are sometimes a source of contention between the owner and contractor due to differing interpretations of contract conditions. This account can be "controlled" on an overall basis with manhour expenditure and manhour rate curves.

WORK UNIT TRACKING CURVES

a) Method

Another approach to measuring productivity is recording actual manhours (incremental and cumulative) against physical units of completed work (e.g., lineal feet of piping, cubic yards of concrete, tons of steel, etc.). These rnanhours per unit are an absolute measure of productivity in contrast to the relative measure previously outlined. This technique can resolve a prob-

Figure 7-16. Field Supervision Listing & Schedule.

FIELD SUPERVISION LISTING & SCHEDULE	PROJECT JOB NO. REPORT NO. DATE

POSITION	NAME	SCHEDULE																		BUDGET $	FORECAST HOURS	HOURLY RATE	FORECAST $

lem of budget abnormalities and also enables cost engineers to readily compare performance in different geographical locations.

b) Piping Erection

Figure 7-17 shows typical tracking curves for above-ground pipe erection. Incremental and cumulative performance is monitored. This example shows a budgeted level of 5.4 manhours/unit and a current cumulative rate of 4.8—currently a good performance. Based on this performance and judgment of future conditions, a good forecast could be made. As above-ground piping is the major element of the piping account and piping usually represents 35% of a field budget, piping tracking curves are important control tools.

When required, work unit tracking curves should be prepared early in the engineering and/or construction phases. Significant deviations (e.g., +/– 10%) from the budget should be investigated.

Selection of individual work units for control will depend on need, the size of the project, the amount of money involved, and the ease of gathering data. This type of data is also very useful for historical purposes.

SUBCONTRACT PERFORMANCE/REPORT

a) Purpose of Performance Evaluation

Performance evaluation is a technique to measure a subcontractor's profitability. If a subcontractor is in financial difficulty due to poor performance, or due to "buying" the work with a low bid, this can lead to schedule and cost problems for the entire project. When this performance evaluation technique is properly used, it can provide early warning of potential problems.

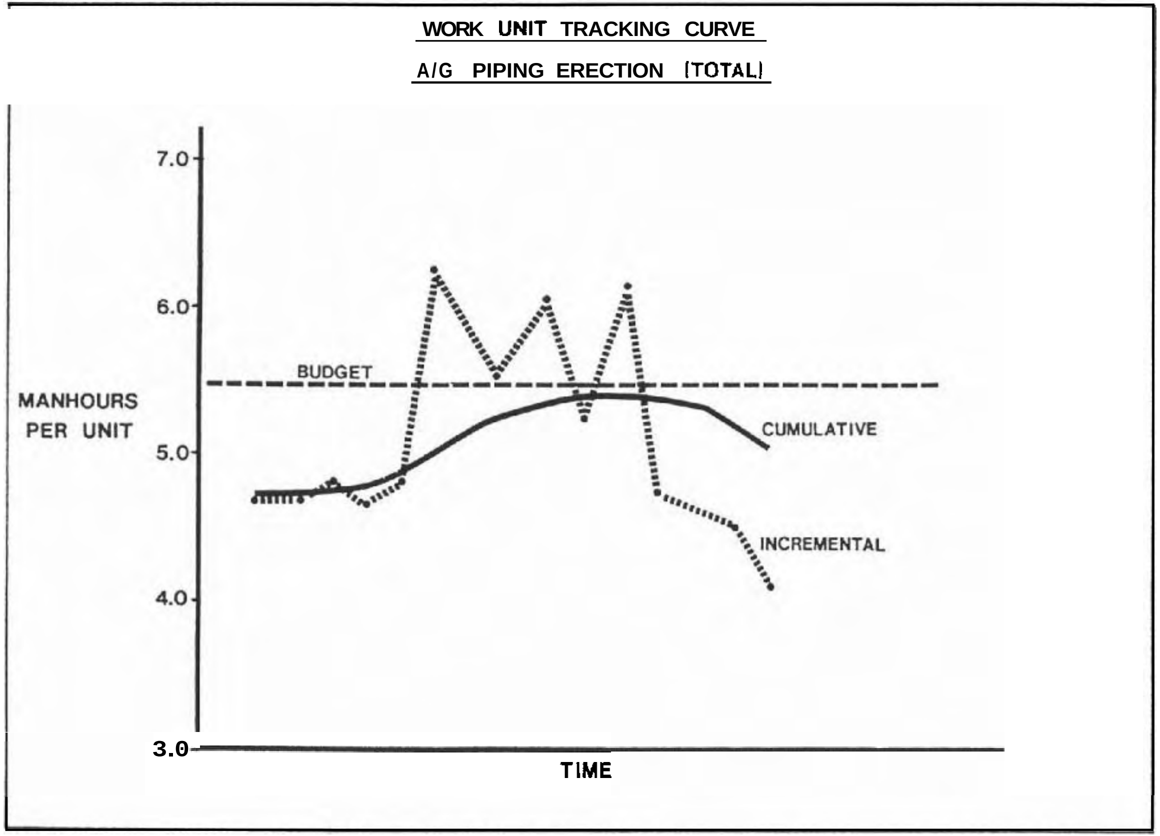
Early warning provides time to evaluate actions which might alleviate the subcontract situation or at least provide lead time for bringing in other subcontractors.

b) Performance Evaluation Method

1) Performance factor (labor) equals

$$\frac{\text{contract billings}}{\text{manhours expended}} \text{ equals dollars per manhour}$$

Figure 7-17. Tracking Curves for Above-Ground Erection.



2) Assess the subcontractor's operational cost by building up field costs, equipment costs, overhead, etc. onto the base labor cost: equals dollars per manhour
3) Ensure that billings truly represent work accomplished
4) Ensure that the manhour report is accurate
5) If the subcontract has a material supply, evaluate it for profit on material to add to the profit-loss of the labor element
6) Efficiency equals $\frac{\text{performance factor}}{\text{all-in cost}}$
7) If the cumulative efficiency is less than 1.0, the subcontractor is in a labor loss position. This can lead to schedule extensions and claims. This is a relatively simple procedure and requires up-to-date billings, an estimate of the subcontractor's all-in labor cost, actual manhours expended, and an assessment of profit on material supply.

c) Typical Report

Figure 7-18 illustrates a typical report. On large subcontract projects, this report can be an effective management technique and should be required.

COST-TIME-RESOURCE (CTR) PROGRAM

a) **Defining the** Program

A CTR program is the best method for managing projects that have little scope definition, such as:

1) R&D projects
2) Engineering/feasibility studies
3) Computer/software control projects
4) Subsea technology
5) Fabrication/modular construction (no experience)
6) Shutdowns and retro-fits

By "creative brain-storming" in a group session of technical experts, a potential list of work activities is developed. These activities are then grouped together in a series of logic diagrams and schedules. The cost, time and resources are then evaluated for each activity. **A** weekly cost/schedule report is produced,

Figure 7-18. Subcontract Performance Report.

SUBCONTRACT PERFORMANCE REPORT											PROJECT JOB NO. REPORT NO. DATE		
SUBCONTRACT			$ EARNED PER LABOR MAN HOUR (CUMULATIVE)										ESTD. RATE
P.O. NO.	WORK SCOPE	CONTRACTOR											

showing the status of the work. If there is "new" work, it cannot commence until a new CTR has been developed. A new CTR cannot be developed with APPROVAL of the project manager. This "NO WORK, NO CTR" rule is STRICTLY ENFORCED as it is the major method for managing the project. All CTR activities are weighted into a cumulative curve so that a total planned/actual performance is available. Close monitoring and resident personnel are essential for this program.

b) Contracting Arrangement

A fixed price can be agreed for the estimated CTR scope of work. **All** new CTRs are then treated as scope changes.

c) Example of CTR Program

Figure 7-19 illustrates the development of a small design task, a new steam let-down system.

Figure 7-19. Example of CTR Program.

EXAMPLE OF C.T.R. PROGRAM

(COST–TIHE–RESOURCE)

ENGINEERING TASK / ACTIVITY - $4350 / 4W / 3 MEN

(Steam "let down. System)

1 - PROCESS ENGINEER	50 HRS. @ $25		= 11250
1 - PIPING ENGINEER	100 HRS. @ $20		= $2000
1 - DRAFTSMAN	20 HRS. @ 115		= $ 300
COMPUTER TIME ■ REPORT			= $ 500
TRIP EXPENSES	3 DAYS @ $100		= $ 300
			$4350

- ALL HOURS AND COSTS CODED TO TASKIACTIVITY NUMBER
- EACH CTR/ACTIVITY SHOULD HAVE AN END PRODUCT OR A "DELIVERABLE"

Contract Planning Essentials

CONTENTS

GENERAL

It is essential that the administration and management of contracts results in reducing risks, maximizing cost savings, minimizing claims, and improving economic return. These results can only be achieved through effectively managing contract risks: developing tough but fair contract documents, engaging in aggressive negotiating practices, and employing outstanding communication skills.

The process of reaching a contract requires a specific sequence of steps. In taking these steps, the project manager must make a series of choices between priorities for project objectives, degrees of risk to be assumed by the contracting parties, control over project activities, and the cost of achieving selected goals. This process must first be fully understood by the project manager, then be tempered by experience, and finally be expanded into the ability to reach a contract through the exercise of negotiating and communicating skills.

WHAT IS A CONTRACT?

A contract is a mutual business agreement recognized by law under which one party undertakes to do work (or provide a service) for another party for a "consideration."

Owner contracting arrangements would cover:

- Contract Conditions
  Commercial Terms & Pricing Arrangements
- Scope of Work (Technical)
  Project Execution Plan

WHY HAVE A CONTRACT?

A written contract provides the document by which the risks, obligations, and relationships of all parties are clearly established, and ensures the performance of these elements in a disciplined manner. In the owner situation, the contract is the means by which the contractor can be controlled and ensures that the work and end product satisfy the owner's requirements.

PARTIES TO THE CONTRACT

Most projects are executed under a three-party contractual relationship:

- The owner, who establishes the form of contract and the general conditions.
- The engineer, who can have the following three roles:
  - Designer — carrying out the detailed engineering work, and purchasing equipment and material on the owner's behalf
  - Arbitrator — acting as the owner's agent in administering the contract and deciding, impartially, on certain rights of the parties under the contract
  - Project manager — handling design, procurement, and construction or construction management/services.
- The contractor

The normal contractual relationship among these three parties on a single project is for the owner to have one contract with the engineer for design, procurement, and other services, and a separate contract with the contractor for the construction work. No contractual relationship exists between the engineer and the contractor. This is usually referred to as a "divided or split responsibility" arrangement. In an alternative arrangement, called "single responsibility," a general contractor is awarded total responsibility for the engineering, procurement, and construction.

The projectmanager must carefully decide on a specific contracting arrangement, as outlined in the section below on Contract Strategy, and in Chapter 6, Planning.

CONTRACT RESPONSIBILITY

The project manager is essentially responsible for the contract strategy, which is developed as part of the project strategy. However, the proposed division of work, contracting arrangements, forms of contract, and bidders' lists should be developed in conjunction with the company's contracts department.

This combined responsibility of the project manager and the contracts department in the contracting process can lead to inefficiencies, delays, and disagreements and can negatively impact the project cost and schedule when there are organizational conflicts. Close coordination and effective communications must exist between all groups to ensure complete agreement and commitment to the proposed contracting program. This is particularly important in all submissions to contract committees and/or senior management.

The project manager must obtain agreement from the company's contracting department and insurance department before committing to contractual language regarding liability, indemnity, or insurance.

CONTRACT STRATEGY

As covered in the project strategy, the following would be major considerations when developing a contract strategy for the project:

- When and how will the work be divided up?
- How will the division of work affect client/project team/main contractor1 vendorlsubcontractor interfaces? (This division enables the project coor-

dination procedures to be properly prepared.)

- What type of contract should be used? Segment the project into discrete work packages to facilitate management, and subject the work packages to available resources. Consider the contract philosophy, the type of contract best suited to the project, contract interfaces, bid evaluation techniques. and bid documentation. This enables the contract strategy to be produced in liaison with the contracts department.
- What roles are licensors and consultants expected to play? This allows arrangements to be made for prequalifying suitable contractors, issuing invitations to bid, evaluating bids, and making award recommendations.

  Are there potential conflicts of interest with other owner projects in contractors' offices, in vendors' workshops, or within fabrication yards? Such conflicts can have an impact on the bidder's list.
- What is the availability of skilled labor? What is the industrial relations climate local to fabrication yards and local to the construction site? Lack of labor can delete a contracror from the bidder's list.

  What is the quality and availability of personnel to develop, evaluate, and administer the required type of contract/contract conditions?

CONTRACTING ARRANGEMENTS

Engineering and construction contracts can be drawn in a great variety of forms, depending on the contract strategy and the financial resources of the contractor. The most successful contracts have at least one element in common: thoughtful and thorough preparation before the contract is let.

Contractual arrangements in construction are becoming increasingly more involved, which leads to the potential for significant added costs. Project complexity, and the changing and increasingly costly legal and insurance environments, are major reasons for considering whether better contractual arrangements are possible. Contracts, of course, must be made early in the life of a project. To do this while simultaneously providing for the risks of uncertainties and gaining improved performance and innovation presents major challenges for owners and contractors alike.

FORMS OF CONTRACT

There are three principle types of contracts: reimbursable, measured (unit price), and lump sum. The following forms of contract are typical of these types:

- **Cost Reimbursable (Time & Material)**
- **Cost Reimbursable with Percentage Fee**
- **Cost Reimbursable with Fixed Fee**
- **Cost Reimbursable Plus Cost/Schedule Bonus—Penalties**
- **Measured Unit Price (Mostly Construction)**
- **Guaranteed Maximum Price**
- **Lump Sum/Fixed Price**

The objectives of cost, time, quality, risks, and liabilities must be analyzed and prioritized, since trade-offs will probably be necessary in deciding the type of contract to be used.

Reimbursable Cost Contracts. These require little design definition, but need to be constructed in a way that allows expenditures to be properly controlled. The major advantage of a reimbursable cost contract is time, since a contract can be established during the early stages of a project. This type of contract does present a disadvantage to an owner, however, since poor contractor performance can result in increased costs, and the final costs are the owner's responsibility. Additionally, the final/total investment level is not known until the work is well advanced.

Reimbursable cost contracts can contain lump sum elements. e.g. the contractor's overhead charges and profit, which is usually preferable to a percentage basis for calculating these costs. Reimbursements may be applied to salaries, wages, insurance and pension contributions, office rentals, communication cost. etc. Alternatively, reimbursement can be applied to all-inclusive hourly or daily rates for time spent by engineers on the basis that all office support costs are built into these rates. This form of contract is generally known as a fixed fee/reimbursable cost contract and can be used for both engineering and other office services as well as for construction work.

Such arrangements give the owner greater control over the contractor's engineering work, but the effect of reducing the lump sum content of the contractor's remuneration is to reduce its financial incentive to complete the work economically and speedily. It also reduces the ability to compare/evaluate competitive bids, since the comparison that can be made between contractor bids involves only a small percentage of the project cost. It is possible that the "best" contractor may not quote the lowest prices.

- Reauirements
  a. A competent and trustworthy contractor
  b. Close quality supervision and direction by the owner
  c. Detailed definition of work and payment terms covered by lump sums and by "all-inclusive" rates

- Advantaees
  a. Flexibility in dealing with changes (which is very important when the job is not well defined), particularly if new technology development is proceeding concurrently with the design
  b. An early start can be made
  c. Useful where site problems such as IR delays and disruptions may be encountered
  d. Owner can exercise control on all aspects of the work

- Disadvantages
  a. Final cost is unknown
  b. Difficulties in evaluating proposals—strict comparison of the amount tendered may not result in selection of the "best" contractor or in the lowest cost of the project
  c. Contractor has little incentive for early completion or cost economy
  d. Contractor can assign its "second division" personnel to the job and may make excessive use of agency personnel and/or use the job as a training vehicle for new personnel
  e. Owner carries most of the risks and faces the difficult decisions

Target Contracts (Cost and Schedule). Target contracts are intended to provide a strong financial incentive for the contractor to complete the work at minimum cost and time. In the usual arrangement, the contractor starts work on a reimbursable cost basis. When sufficient design is complete, the contractor produces a definitive estimate and project schedule for owner review, mutual negotiation, and agreement. After agreement is reached, these become targets. At the end of the job, the contractor's reimbursable costs are compared with the target and any savings or overrun is shared between the owner and the contractor on a pre-arranged basis. Similarly, the contractor qualifies for additional payment if it completes the work ahead of the agreed-upon schedule. The main appeal this form of contract has to the contractor is that it does not involve competitive bidding for the target cost and schedule provisions.

- Reauirements
  a. A competent and trustworthy contractor
  b. Quality supervision by owner (both technical and financial)

- Advantaees
  a. Flexibility in controlling the work
  b. Almost immediate start on the work, even without a scope definition
  c. Encourages economic and speedy completion (up to a point)

- Disadvantaees
  a. Final cost initially unknown
  b. No opportunity for competitive bidding for the "targets"
  c. Difficulty in agreeing on an effective target
  d. Variations are difficult and costly once the target has been established--contractors tend to inflate the cost of all variations so as to increase profit potential with "easy" targets
  e. If the contractor fails to achieve the targets, it may attempt to prove that this was due to interference by the owner, or to factors outside the contractor's control; hence, effective control and reporting is essential

Measured (Unit Price) Contracts. These require sufficient design definition or experience in order to estimate the unit/ quantities for the work. Contractors then bid fixed prices for each unit of work. The advantage is that the time and cost risk is shared: the owner will be responsible for the total quantities, and the contractors will have the risk of the fixed unit price. A quantity increase greater than 10% can lead to increases in the unit prices.

Reauirements
  a. An adequate breakdown and definition of the measured units of work
  b. A good quantity surveying/reporting system
  c. Adequate drawings and/or substantial experience for developing the Bill of Quantities
  d. Financial/payment terms that are properly tied to the measured work and partial completion of the work
  e. Owner-supplied drawings and materials must arrive on time
  f. Quantity-sensitivity analysis of unit prices to evaluate total bid price for potential quantity variations

- Advantaees
  a. Good design definition is not essential—"typical" drawings can be used for the bidding process
  b. Very suitable for competitive bidding and relatively easy contractor selection, subject to sensitivity evaluation
  c. Bidding is speedy and inexpensive and an early start is possible
  d. Flexibility—depending on the contract conditions, the scope and quantity of work can be varied

- Disadvantaees
  a. Final cost is not known at the outset since the Bills of Quantities have been estimated on incomplete engineering

b. Additional site staff are needed to measure, control, and report on the cost and status of the work

Lump Sum/Fixed Price Contracts. In this type of contract, the contractor is generally free to employ whatever methods and resources it chooses in order to complete the work. The contractor carries total responsibility for proper performance of the work although approval of design, drawings, and the placement of purchase orders and subcontracts can be monitored by the owner to ensure compliance with the specification. The work to be performed must be closely defined. Since the contractor will not carry out any work not contained in the specification without requiring additional payment, a fully developed specification is vitally important. The work has to be performed within a specified period of time, and status/progress can be monitored by the owner to ensure that completion meets the contractual requirements.

The lump sum/fixed price contract presents a low financial risk to the owner, and the required investment level can be established at an early date. This type of contract allows a higher return to the contractor for superior performance. A good design definition is essential, although this may be time-consuming. Further, the bidding time can be twice as long as that for a reimbursable contract bid. For contractors, the cost of bids and the high financial risk are factors in determining the lump sum approach.

- Reauirements
  a. Good definition and stable project conditions are essential
  b. Effective competition is essential
  c. Several months are needed for bidding and appraisal
  d. Minimal scope changes

Advantages
  a. Low financial risk to owner, maximum financial risk is on the contractor
  b. Cost (and project viability) is known before commitment is made
  c. Minimum owner supervision — mostly quality assurance and schedule monitoring
  d. Contractor will usually assign its best personnel to the work
  e. Maximum financial motivation of contractor — maximum incentive for the contractor to achieve early completion at superior performance levels
  f. Contractor has to solve its own problems — and quickly

g. Contractor selection (by competitive bidding) is fairly easy, apart from deliberate low price

- Disadvantaees
  a. Variations are difficult and costly—the contractor, having quoted keenly when bidding, will try to make as much as possible on extras
  b. An early start is not possible because of the time taken for bidding and for developing a good design basis
  c. The contractor will tend to choose the cheapest and quickest solutions, making technical monitoring and strict quality control by the owner essential; schedule monitoring is also advisable
  d. The contractor has a short-term interest in completing the job and may cause long-term damage to local IR relationships, e.g. by setting poor precedentslunion agreements
  e. Bidding is expensive for the contractor, so the bid invitation list will be short; technical appraisal of bids by the owner may require considerable effort
  f. Contractors will usually include allowances for contingencies in the bid price and they might be high. Bidding time can be twice that required for other types of contracts
  g. Bidding time can be twice that required for other types of contracts

Conditions of the Contract. While the same risks/liabilities can be established for most forms of contract, the price for those risks/liabilities can vary significantly, depending on contracting skills and the business environment/market place.

Typical Forms of Contract Used in the United Kingdom and the United States.

United Kinedom
  a. Institute of Civil Engineers—ICE—mainly for civil and construction-only contracts
  b. Federation Internationale des Ingenieurs-Conseils—FIDIC—primarily for offshore and overseas work
  c. Institute of Mechanical Engineers—IMech E—primarily for design and erection of mechanical plant

- United States
  a. American Institute of Architects (AIA) mainly for engineering work and project/construction management; the A/E usually functions as the owner's "agent" on a fee/reimbursable basis
  b. The Associated General Contractors of America (AGC) mainlv for construction work and construction management; the contractor usually functions as an "independent contractor" on a lump sum/fixed price basis
  c. The EJCDC forms of contract documents (issued jointly by the NSPE, ACEC. ASCE, and CSI and approved by the AGC), are often used by many engineering firms. In addition, it is becoming more prevalent

for an owner to develop a form of contract that is specifically customized to fit its particular needs. Similarly, an engineering/construction contractor may develop its own forms of contract for use on projects in which it acts as the construction/project manager for the owner. There are at least two basic options: (1) use one of the "standard" contracts and customize it to fit a particular project, or (2) use the "boiler plate" or "front-ends" developed by the engineer1 contractor for use on projects in which it is responsible for preparing the bidding documents and where the owner does not have its own.

SUMMARY

It is possible to devise a form of contract with appropriate terms and conditions to suit many different circumstances. Some basic considerations leading to the best choice are:

- Clear definition of each party's contractual responsibilities. Shared responsibilities are unsatisfactory, although they are unavoidable in some circumstances.

  The lump sum form of contract provides the best financial risk for the owner, gives the contractor the maximum incentive for early completion, and produces the greatest benefit of competitive bidding. Conversely, reimbursable contracts provide no such incentives. It is dangerous, however, to attempt to use a lump sum contract if the essential conditions are not satisfied—notably, a clear and complete definition of the scope of work.

  The owner must have the contractual right to exercise control adequate to ensure the success of the project, but the temptation to assume excessive control should be resisted.

- Control and responsibility go together—the greater the owner's control, the less responsibility is carried by the contractor.

One last point: the form of contract must be decided early in the project development and the choice must be made known to the engineers before they write the specifications. Obviously, the specification will be much more precise and comprehensive if it is to be used for a lump sum contract than would be required for a reimbursable contract.

9
Economic Decision Making

CONTENTS

LIFE CYCLE COSTING

When a project manager is evaluating capital equipment, the first question to be asked is: "What is the economic basis for equipment purchases?"

Some companies use a simple payback method of two years or less to justify equipment purchases. Others require a life cycle cost analysis with no fuel price inflation considered. Still other companies allow for a complete life cycle cost analysis, including the impact for the fuel price inflation and the energy tax credit.

USING THE PAYBACK PERIOD METHOD

The payback period is the time require to recover the capital investment out of the earnings or savings. This method ignores all savings beyond the payback years, thus penalizing projects that have long life potentials for those that offer high savings for a relatively short period.

The payback period criterion is used when funds are limited and it is important to know how fast dollars will come back. The payback period is simply computed as:

$$\text{Payback period} = \frac{\text{initial investment}}{\text{after tax savings}} \qquad (9\text{-}1)$$

The project manager who must justify energy equipment expenditures based on a payback period of one year or less has little chance for long-range success. Some companies have set higher payback periods for energy utilization methods. These longer payback periods are justified on the basis that:

- Fuel pricing will increase at a higher rate than the general inflation rate.
- The "risk analysis" 'for not implementing energy utilization measures may mean loss of production and losing a competitive

USING LIFE CYCLE COSTING

Life cycle costing is an analysis of the total cost of a system, device, building, machine, etc., over its anticipated useful life. The name is new but the subject has, in the past, gone by such names as "engineering economic analysis" or "total owning and operating cost summaries."

Life cycle costing has brought about a new emphasis on the comprehensive identification of all costs associated with a system. The most commonly included costs are initial in place cost, operating costs, maintenance costs, and interest on the investment. Two factors enter into appraising the life of the system; namely, the expected physical life and the period of obsolescence. The lesser factor is governing time period. The effect of interest can then be calculated by using one of several formulas which take into account the time value of money.

When comparing alternative solutions to a particular problem, the system showing the lowest life cycle cost will usually be the first choice (performance requirements are assessed as equal in value).

Life cycle costing is a tool in value engineering. Other items, such as installation time, pollution effects, aesthetic considerations, delivery time, and owner preferences will temper the rule of always choosing the system with the lowst life cycle cost. Good overall judgement is still required.

The life cycle cost analysis still contains judgement factors pertaining to interest rates, useful life, and inflation rates. Even with the judgement element, life cycle costing is the most important tool in value engineering, since the results are quantified in terms of dollars.

As the price for energy changes, and as governmental incentives are initiated, processes or alternatives which were not economically feasible will be considered.

THE TIME VALUE OF MONEY

Most energy saving proposals require the investment of capital to accomplish them. By investing today in energy conservation, yearly operating dollars over the life of the investment will be saved. A dollar in hand today is more valuable than one to be received at some time in the future. For this reason, a time value must be placed on all cash flows into and out of the company.

Money transactions are thought of as a cash flow to or from a company. Investment decisions also take into account alternate investment opportunities and the minimum return on the investment. In order to compute the rate of return on an investment, it is necessary to find the interest rate which equates payments outcoming and incoming, present and future. The method used to find the rate of return is referred to as discounted cash *flow.*

INVESTMENT DECISION-MAKING

To make investment decisions, the energy manager must follow one simple principle: Relate annual cash flows and lump sum deposits to the same time base. The six factors used for investment decision making simply convert cash from one time base to another; since each company has various financial objectives, these factors can be used to solve any investment problem.

Single Payment Compound Amount—SPCA

The SPCA factor is used to determine the future amount S that a present sum P will accumulate at i percent interest, in n years. If P (present worth) is known, and S (future worth) is to be determined, then Equation 9-2 is used.

$$S = P \times (SPCA)n_i \tag{9-2}$$

$$SPCA = (1 + i)^n \tag{9-3}$$

The SPCA can be computed by an interest formula, but usually its value is found by using the interest tables. Interest tables for interest rates of 10 to 50 percent are found at the conclusion of this chapter (Tables 9-1 through 9-8). In predicting future costs, there are many unknowns. For the accuracy of most calculations, interest rates are assumed to be compounded annually unless otherwise specified. Linear interpolation is commonly used to find values not listed in the interest tables.

Tables 9-9 through 9-12 can be used to determine the effect of fuel escalation on the life cycle cost analysis.

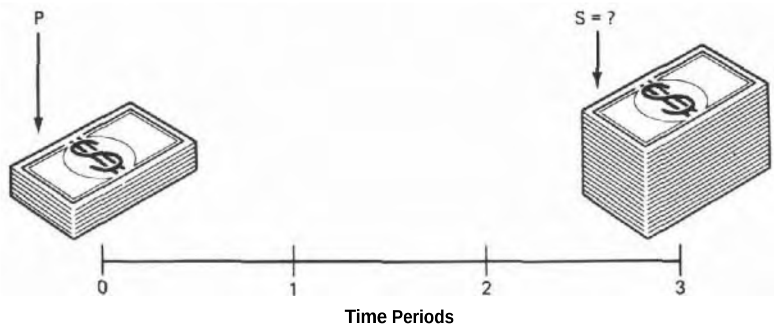


Figure 9-1. Single payment compound amount (SPCA).

Single Payment Present Worth—SPPW

The SPPW factor is used to determine the present worth, P, that a future amount, S, will be at interest of i-percent, in n years. If S is known, and P is to be determined, then Equation 9-4 is used.

$$P = S \times (SPPW)i_n \tag{9-4}$$

$$SPPW = \frac{1}{(1+i)^n} \tag{9-5}$$

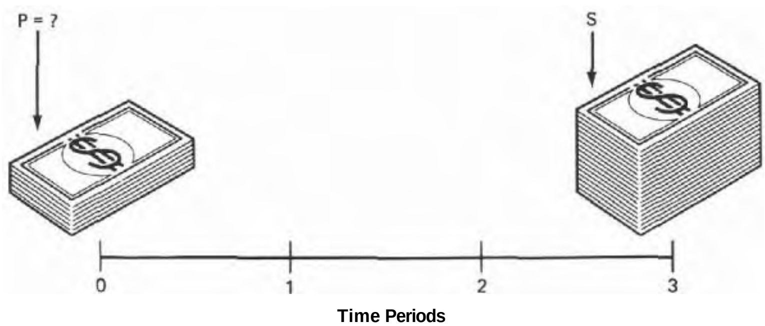


Figure 9-2. Single payment present worth (SPRW).

Table 9-1. 10% Interest Factors.

Period n	Single-payment compound-amount (SPCA) Future value of \$1 $(1+i)^n$	Single-payment present-worth (SPPW) Present value of \$1 $\frac{1}{(1+i)^n}$	Uniform-series compound-amount (USCA) Future value of uniform series of \$1 $\frac{(1+i)^n-1}{i}$	Sinking-fund payment (SFP) Uniform series whose future value is \$1 $\frac{i}{(1+i)^n-1}$	Capital recovery (CR) Uniform series with present value of \$1 $\frac{i(1+i)^n}{(1+i)^n-1}$	Uniform-series present-worth (USPW) Present value of uniform series of \$1 $\frac{(1+i)^n-1}{i(1+i)^n}$
1	1.100	0.9091	1.000	1.00000	1.10000	0.909
2	1.210	0.8264	2.100	0.47619	0.57619	1.736
3	1.331	0.7513	3.310	0.30211	0.40211	2.487
4	1.464	0.6830	4.641	0.21547	0.31547	3.170
5	1.611	0.6209	6.105	0.16380	0.26380	3.791
6	1.772	0.5645	7.716	0.12961	0.22961	4.355
7	1.949	0.5132	9.487	0.10541	0.20541	4.868
8	2.144	0.4665	11.436	0.08744	0.18744	5.335
9	2.358	0.4241	13.579	0.07364	0.17364	5.759
10	2.594	0.3855	15.937	0.06275	0.16275	6.144
11	2.853	0.3505	18.531	0.05396	0.15396	6.495
12	3.138	0.3186	21.384	0.04676	0.14676	6.814
13	3.452	0.2897	24.523	0.04078	0.14078	7.103
14	3.797	0.2633	27.975	0.03575	0.13575	7.367
15	4.177	0.2394	31.772	0.03147	0.13147	7.606
16	4.595	0.2176	35.950	0.02782	0.12782	7.824
17	5.054	0.1978	40.545	0.02466	0.12466	8.022
18	5.560	0.1799	45.599	0.02193	0.12193	8.201
19	6.116	0.1635	51.159	0.01955	0.11955	8.365
20	6.727	0.1486	57.275	0.01746	0.11746	8.514
21	7.400	0.1351	64.002	0.01562	0.11562	8.649
22	8.140	0.1228	71.403	0.01401	0.11401	8.772
23	8.954	0.1117	79.543	0.01257	0.11257	8.883
24	9.850	0.1015	88.497	0.01130	0.11130	8.985
25	10.835	0.0923	98.347	0.01017	0.11017	9.077
26	11.918	0.0839	109.182	0.00916	0.10916	9.161
27	13.110	0.0763	121.100	0.00826	0.10826	9.237
28	14.421	0.0693	134.210	0.00745	0.10745	9.307
29	15.863	0.0630	148.631	0.00673	0.10673	9.370
30	17.449	0.0573	164.494	0.00608	0.10608	9.427
35	28.102	0.0356	271.024	0.00369	0.10369	9.644
40	45.259	0.0221	442.593	0.00226	0.10226	9.779
45	72.890	0.0137	718.905	0.00139	0.10139	9.863
50	117.391	0.0085	1163.909	0.00086	0.10086	9.915
55	189.059	0.0053	1880.591	0.00053	0.10053	9.947
60	304.482	0.0033	3034.816	0.00033	0.10033	9.967
65	490.371	0.0020	4893.707	0.00020	0.10020	9.980
70	789.747	0.0013	7887.470	0.00013	0.10013	9.987
75	1271.895	0.0008	12708.954	0.00008	0.10008	9.992
80	2048.400	0.0005	20474.002	0.00005	0.10005	9.995
85	3298.969	0.0003	32979.690	0.00003	0.10003	9.997
90	5313.023	0.0002	53120.226	0.00002	0.10002	9.998
95	8556.676	0.0001	85556.760	0.00001	0.10001	9.999

Table 9-2. 12% Interest Factors.

Period n	Single-payment compound-amount (SPCA)	Single-payment present-worth (SPPW)	Uniform-series compound-amount (USCA)	Sinking-fund payment (SFP)	Capital recovery (CR)	Uniform-series present-north (USPW)
	Future value of \$1 $(1+i)^n$	Present value of \$1 $\frac{1}{(1+i)^n}$	Future value of uniform series of \$1 $\frac{(1+i)^n-1}{i}$	Uniform series whose future value is \$1 $\frac{i}{(1+i)^n-1}$	Uniform series with present value of \$1 $\frac{i(1+i)^n}{(1+i)^n-1}$	Present value of uniform series $\frac{(1+i)^n-1}{i(1+i)^n}$
1	1.120	0.8929	1.000	1.00000	1.12000	0.893
2	1.254	0.7972	2.120	0.47170	0.59170	1.690
3	1.405	0.7118	3.374	0.29635	0.41635	2.402
4	1.574	0.6355	4.779	0.20923	0.32923	3.037
5	1.762	0.5674	6.353	0.15741	0.27741	3.605
6	1.974	0.5086	8.115	0.12323	0.24323	4.111
7	2.211	0.4523	10.089	0.09912	0.21912	4.564
8	2.476	0.4039	12.300	0.08130	0.20130	4.968
9	2.773	0.3606	14.776	0.06768	0.18768	5.328
10	3.108	0.3220	17.549	0.05698	0.17698	5.650
11	3.479	0.2875	20.655	0.04842	0.16842	5.938
12	3.896	0.2567	24.133	0.04144	0.16144	8.194
13	4.363	0.2292	28.029	0.03568	0.15568	6.424
14	4.887	0.2046	32.393	0.03087	0.15087	6.628
15	5.474	0.1827	37.280	0.02682	0.14682	6.811
16	6.130	0.1631	42.753	0.02339	0.14339	6.974
17	6.866	0.1456	48.884	0.02046	0.14046	7.120
18	7.690	0.1300	55.750	0.01794	0.13704	7.250
19	8.613	0.1161	63.440	0.01576	0.13576	7.366
20	9.646	0.1037	72.052	0.01388	0.13388	7.469
21	10.804	0.0926	81.698	0.01224	0.13224	7.562
22	12.100	0.0826	92.503	0.01081	0.13081	7.645
23	13.552	0.0738	104.603	0.00956	0.12956	7.718
24	15.179	0.0659	118.155	0.00846	0.12846	7.784
25	17.000	0.0588	133.334	0.00750	0.12750	7.843
26	19.040	0.0525	150.334	0.00665	0.12665	7.864
27	21.325	0.0469	169.374	0.00590	0.12590	7.943
28	23.884	0.0419	190.698	0.00524	0.12524	7.984
28	26.750	0.0374	214.583	0.00466	0.12466	8.022
30	29.960	0.0334	241.333	0.00414	0.12414	8.055
35	52.800	0.0188	431.663	0.00232	0.12232	8.176
40	93.051	0.0107	767.091	0.00130	0.12130	8.244
45	163.988	0.0061	1358.230	0.00074	0.12074	8.283
50	288.002	0.0035	2400.018	0.00042	0.12042	8.304
55	509.321	0.0020	4236.005	0.00024	0.12024	8.317
60	897.587	0.0011	7471.641	0.00013	0.12013	8.324
65	1581.872	0.0006	13173.937	0.00008	0.12008	8.328
70	2787.800	0.0004	23223.332	0.00004	0.12004	8.330
75	4913.056	0.0002	40933.799	0.00002	0.12002	8.332
80	8858.483	0.0001	72145.892	0.00001	0.12001	8.332

Table 9-3. 15% Interest Factors.

Period n	Single-payment compound-amount (SPCA)	Single-payment present-worth (SPPW)	Uniform-series compound-amount (USCA)	Sinking-fund payment (SFP)	Capital recovery (CR)	Uniform-scrim present-worth (USPW)
	Future value of $1 $(1+i)^n$	Present value of $1 $\frac{1}{(1+i)^n}$	Future value of uniform series of $1 $\frac{(1+i)^n-1}{i}$	Uniform series whose future value is $1 $\frac{i}{(1+i)^n-1}$	series with present value of $1 $\frac{i(1+i)^n}{(1+i)^n-1}$	Present value of uniform series of $1 $\frac{(1+i)^n-1}{i(1+i)^n}$
1	1.150	0.8696	1.000	1.00000	1.15000	0.870
2	1.322	0.7561	2.150	0.46512	0.61512	1.626
3	1.521	0.6575	3.472	0.28798	0.43798	2.283
4	1.749	0.5718	4.983	0.20027	0.35027	2.855
5	2.011	0.48'2	6.742	0.14812	0.28832	3.352
6	2.313	0.4323	8.754	0.11424	0.28424	3.784
7	2.660	0.3758	11.067	0.09036	0.24036	4.160
8	3.059	0.3269	13.727	0.07285	0.22285	4.487
9	3.518	0.2843	16.786	0.05957	0.20857	4.772
10	4.046	0.2472	20.304	0.04925	0.18925	5.019
11	4.652	0.2149	24.349	0.04107	0.19107	5.234
12	5.350	0.1869	29.002	0.03448	0.18448	5.421
13	8.153	0.1625	34.352	0.02911	0.17811	5.583
14	7.076	0.1413	40.605	0.02469	0.17469	5.724
15	8.137	0.1229	47.580	0.02102	0.17102	5.847
16	9.358	0.1069	65.717	0.01795	0.16795	5.954
17	10.761	0.0928	65.075	0.01537	0.16537	6.047
18	12.375	0.0808	75.836	0.01319	0.16318	6.128
19	14.232	0.0703	88.212	0.01134	0.16134	6.198
20	16.367	0.0611	102.444	0.00876	0.15976	6.259
21	18.822	0.0531	118.810	0.00842	0.15842	6.312
22	21.645	0.0462	137.632	0.00727	0.15727	6.358
23	24.891	0.0402	159.276	0.00628	0.15628	6.398
24	28.625	0.0348	184.168	0.00543	0.15543	6.434
25	32.919	0.0304	212.783	0.00470	0.15470	6.464
26	37.867	0.0264	245.712	0.00407	0.15407	6.491
27	43.535	0.0230	283.569	0.00353	0.15353	6.514
28	50.066	0.0200	327.104	0.00306	0.15306	6.534
29	57.575	0.0174	377.170	0.00265	0.15265	6.551
30	66.212	0.0151	434.745	0.00230	0.15230	6.566
35	133.176	0.0075	881.170	0.00113	0.15113	6.617
40	267.864	0.0037	1779.OW	0.00056	0.15056	6.642
45	538.768	0.0018	3585.128	0.00028	0.15028	6.654
50	1083.657	0.0009	7217.716	0.00014	0.15014	6.661
55	2178.622	0.0005	14524.148	0.00007	0.15007	6.664
60	4381.998	0.0002	29219.992	0.00003	0.15003	6.665
65	8817.787	0.0001	58778.583	0.00002	0.15002	6.666

Table 9-4. 20% Interest Factors.

Period n	Single-payment compound-amount (SPCA)	Single-payment present-worth (SPPW)	Uniform-series compound-amount (USCA)	Sinking-fund payment (SFP)	Capital recovery (CR)	Uniform-series present-worth (USPW)
	Future value of $1 $(1+i)^n$	Present value of $1 $\frac{1}{(1+i)^n}$	Future value of uniform series of $1 $\frac{(1+i)^n-1}{i}$	Uniform aeries whose future value is $1 $\frac{i}{(1+i)^n-1}$	Uniform series with present value of $1 $\frac{i(1+i)^n}{(1+i)^n-1}$	Present value of uniform aeries of $1 $\frac{(1+i)^n-1}{i(1+i)^n}$
1	1.200	0.8333	1.000	1.00000	1.20000	0.833
2	1.440	0.8944	2.200	0.45455	0.65455	1.528
3	1.728	0.5787	3.640	0.27473	0.47473	2.106
4	2.074	0.4823	5.368	0.18629	0.38629	2.589
5	2.488	0.4019	7.442	0.13438	0.33438	2.991
6	2.986	0.3349	9.930	0.10071	0.30071	3.326
7	3.583	0.2791	12.916	0.07742	0.27742	3.605
8	4.300	0.2326	16.499	0.06061	0.26061	3.837
9	5.160	0.1938	20.799	0.04808	0.24808	4.031
10	6.192	0.1615	25.959	0.03852	0.23852	4.192
11	7.430	0.1346	32.150	0.03110	0.23110	4.327
12	8.916	0.1122	39.581	0.02526	0.22526	4.439
13	10.699	0.0935	48.497	0.02062	0.22062	4.533
14	12.839	0.0779	59.196	0.01689	0.21689	4.611
15	15.407	0.0649	72.035	0.01388	0.21388	4.675
18	18.488	0.0541	87.442	0.01144	0.21144	4.730
17	22.186	0.0451	105.931	0.00944	0.20944	4.775
18	26.623	0 0376	128.117	0.00781	0.20781	4.812
19	a1.948	0.0313	154.740	0.00646	0.20646	4.843
20	38.338	0.0261	186.688	0.00536	0.20536	4.870
21	46.005	0.0217	225.026	0.00444	0.20444	4.891
22	55.206	0.0181	271.031	0.00369	0.20369	4.909
23	66.247	0.0151	326.237	0.00307	0.20307	4.925
24	79.497	0.0126	392.484	0.00255	0.20255	4.937
25	95.396	0.0105	471.981	0.00212	0.20212	4.948
26	114.475	0.0087	587.377	0.00176	0.20176	4.956
27	137.371	0.0073	681.853	0.00147	0.20147	4.964
28	164.846	0.0061	819.223	0.00122	0.20122	4.970
29	197.814	0.0051	984.068	0.00102	0.20102	4.975
30	237.376	0.0042	1181.882	0.00085	0.20085	4.979
35	590.668	0.0017	2948.341	0.00034	0.20034	4.992
40	1469.772	0.0007	7343.858	0.00014	0.20014	4.997
45	3657.262	0.0003	18281.310	0.00005	0.20005	4.999
50	9100.438	0.0001	45497.191	0.00002	0.20002	4.999

Table 9-5. 25% Interest Factors.

Period n	Single-payment compound-amount (SPCA)	Single-payment present-worth (SPPW)	Uniform-series compound amount (USCA)	Sinking-fund payment (SFP)	Capital recovery (CR)	Uniform-series present-worth (USPW)
	Future value of \$1 $(1+i)^n$	Present value of \$1 $\frac{1}{(1+i)^n}$	Future value of uniform series of \$1 $\frac{(1+i)^n-1}{i}$	Uniform series whose future value is \$1 $\frac{i}{(1+i)^n-1}$	Uniform series with present value of \$1 $\frac{i(1+i)^n}{(1+i)^n-1}$	Present value of uniform series of \$1 $\frac{(1+i)^n-1}{i(1+i)^n}$
1	1.250	0.8000	1.000	1.00000	1.25000	0.800
2	1.562	0.6400	2.250	0.44444	0.69444	1.440
3	1.953	0.5120	3.812	0.26230	0.51230	1.952
4	2.441	0.4096	5.766	0.17344	0.42344	2.362
5	3.052	0.3277	8.207	0.12185	0.37185	2.689
6	3.815	0.2621	11.259	0.08882	0.33882	2.951
7	4.768	0.2097	15.073	0.06634	0.31634	3.161
8	5.960	0.1678	19.842	0.05040	0.30040	3.329
9	7.451	0.1342	25.802	0.03876	0.28876	3.463
10	9.313	0.1074	33.253	0.03007	0.28007	3.571
11	11.642	0.0859	42.566	0.02349	0.27349	3.656
12	14.552	0.0687	54.208	0.01845	0.26845	3.725
13	18.190	0.0550	68.760	0.01454	0.26454	3.780
14	22.737	0.0440	86.949	0.01150	0.26150	3.824
15	28.422	0.0352	109.687	0.00912	0.25912	3.859
16	35.527	0.0281	138.109	0.00724	0.25724	3.887
17	44.409	0.0225	173.636	0.00576	0.25576	3.910
18	55.511	0.0180	218.045	0.00459	0.25459	3.928
19	69.389	0.0144	273.556	0.00366	0.25366	3.942
20	86.736	0.0115	342.945	0.00292	0.25292	3.954
21	108.420	0.0092	429.681	0.00233	0.25233	3.963
22	135.525	0.0074	538.101	0.00186	0.25186	3.970
23	169.407	0.0059	673.626	0.00148	0.25148	3.976
24	211.758	0.0047	843.033	0.00119	0.25119	3.981
25	264.698	0.0038	1054.791	0.00095	0.25095	3.985
26	330.872	0.0030	1319.489	0.00076	0.25076	3.988
27	413.590	0.0024	1650.361	0.00061	0.25061	3.990
28	516.988	0.0019	2063.952	0.00048	0.25048	3.992
29	646.235	0.0015	2580.939	0.00039	0.25039	3.994
30	807.794	0.0012	3227.174	0.00031	0.25031	3.995
35	2465.190	0.0004	9856.761	0.00010	0.25010	3.998
40	7523.164	0.0001	30088.655	0.00003	0.25003	3.999

Table 9-6. 30% Interest Factors.

Period n	**Single-** payment **compound-** amount **(SPCA)**	Single- **payment** present- worth **(SPPW)**	**Uniform-series compound-** amount **(USCA)**	Sinking-fund payment **(SFP)**	**Capital recovery (CR)**	Uniform- **series present-** worth **(USPW)**
	Future value of $1 $(1+i)^n$	Present value $1 $\frac{1}{(1+i)^n}$	**Future** value of uniform **series of $1** $\frac{(1+i)^n-1}{i}$	**Uniform series** whose future value is $1 $\frac{i}{(1+i)^n-1}$	Uniform **series with** present **value** of **$1** $\frac{i(1+i)^n}{(1+i)^n-1}$	Present value of uniform series of **$1** $\frac{(1+i)^n-1}{i(1+i)^n}$
1	1.300	0.7692	1.000	1.00000	1.30000	0.769
2	1.690	0.5917	2.300	0.43478	0.73478	1.361
3	2.197	0.4552	3.990	0.25063	0.55063	1.816
4	2.856	0.3501	6.187	0.16163	0.46163	2.166
5	3.713	0.2693	9.043	0.11058	0.41058	2.436
6	4.827	0.2072	12.756	0.07839	0.37839	2.643
7	6.275	0.1594	17.583	0.05687	0.35687	2.802
8	8.157	0.1226	23.858	0.04192	0.34192	2.925
9	10.604	0.0943	32.015	0.03124	0.33124	3.019
10	13.786	0.0725	42.619	0.02346	0.32346	3.092
11	17.922	0.0558	56.405	0.01773	0.31773	3.147
12	23.298	0.0429	74.327	0.01345	0.31345	3.190
13	30.288	0.0330	97.625	0.01024	0.31024	3.223
14	39.374	0.0254	127.913	0.00782	0.30782	3.249
15	51.186	0.0195	167.286	0.00598	0.30598	3.268
16	66.542	0.0150	218.472	0.00458	0.30458	3.283
17	86.504	0.0116	285.014	0.00351	0.30351	3.295
18	112.455	0.0089	371.518	0.00269	0.30269	3.304
19	146.192	0.0068	483.973	0.00207	0.30207	3.311
20	190.050	0.0053	630.165	0.00159	0.30159	3.316
21	247.065	0.0040	820.215	0.00122	0.30122	3.320
22	321.184	0.0031	1067.280	0.00094	0.30094	3.323
23	417.539	0.0024	1388.464	0.00072	0.30072	3.325
24	542.801	0.0018	1806.003	0.00055	0.30055	3.327
25	705.641	0.0014	2348.803	0.00043	0.30043	3.329
26	917.333	0.0011	3054.444	0.00033	0.30033	3.330
27	1192.533	0.0008	3971.778	0.00025	0.30025	3.331
28	1550.293	0.0006	5164.311	0.00019	0.30019	3.331
29	2015.381	0.0005	6714.604	0.00015	0.30015	3.332
30	2619.996	0.0004	8729.985	0.00011	0.30011	3.332
35	9727.860	0.0001	32422.868	0.00003	0.30003	3.333

Table 9-7. 40% Interest Factors.

Period n	Single-payment compound-amount (SPCA)	Single-payment present-worth (SPPW)	Uniform-series compound-mount (USCA)	Sinking-fund payment (SFP)	Capital recovery (CR)	Uniform-series present-worth (USPW)
	Future value of $1 $(1+i)^n$	Present value of $1 $\frac{1}{(1+i)^n}$	Future value of uniform series of $1 $\frac{(1+i)^n-1}{i}$	Uniform series whose future value is $1 i	Uniform series with present value of $1 $i(1+i)^n$	Present value of uniform series of $1 $\frac{(1+i)^n-1}{i(1+i)^n}$
1	1.400	0.7143	1.000	1.00000	1.40000	0.714
2	1.960	0.5102	2.400	0.41667	0.81667	1.224
3	2.744	0.3044	4.360	0.22836	0.62936	1.589
4	3.842	0.2003	7.104	0.14077	0.54077	1.848
5	5.378	0.1859	10.846	0.08136	0.48136	2.035
6	7.530	0.1328	16.324	0.06128	0.46126	2.168
7	10.541	0.0949	23.83	0.04192	0.44182	2.263
8	14.758	0.0078	34.395	0.02807	0.42907	2.331
8	20.001	0.0484	48.153	0.02034	0.42034	2.379
10	28.925	0.0346	69.814	0.01432	0.41432	2.414
11	40.496	0.0247	98.739	0.01013	0.41013	2.438
12	56.694	0.0176	138.235	0.00718	0.40718	2.456
13	79.371	0.0126	195.828	0.00510	0.40510	2.469
14	111.120	0.0090	275.300	0.00363	0.40303	2.478
15	155.568	0.0064	386.420	0.00259	0.40259	2.484
16	217.785	0.0046	541.988	0.00185	0.40185	2.489
17	304.913	0.0033	758.784	0.00132	0.40132	2.492
18	426.879	0.0023	1064.697	0.00094	0.40094	2.494
19	587.630	0.0017	1481.576	0.00067	0.40067	2.486
20	836.683	0.0012	2088.206	0.00048	0.40048	2.487
21	1171.358	0.0009	2925.889	0.00034	0.40034	2.498
22	1838.898	0.0006	4087.245	0.00024	0.40024	2.498
23	2285.857	0.0004	5737.142	0.00017	0.40017	2.488
24	3214.200	0.0003	8032.988	0.00012	0.40012	2.498
25	4489.880	0.0002	11247.189	0.00009	0.40009	2.498
26	6289.831	0.0002	15747.079	0.00006	0.40006	2.500
27	8819.764	0.0001	22046.910	0.00005	0.40005	2.500

Table 9-8. 50% Interest Factors.

Period n	Single-payment compound-amount (SPCA)	Single-payment present-worth (SPPW)	Uniform-aeries compound-amount (USCA)	Sinking-fund psyment (SFP)	Capital recovery (CR)	Uniform-series present-worth (USPW)
	Future value of $1 $(1+i)^n$	Present value of $1 $\frac{1}{(1+i)^n}$	Future value of uniform series of $1 $\frac{(1+i)^n-1}{i}$	Uniform series whose future value is $1 $\frac{i}{(1+i)^n-1}$	Uniform series with present value of $1 $\frac{i(1+i)^n}{(1+i)^n-1}$	Present value of uniform series of $1 $\frac{(1+i)^n-1}{i(1+i)^n}$
I	1.500	0.6667	1.000	1.00000	1.50000	0.867
2	2.250	0.4444	2.500	0.40000	0.90000	1.111
3	3.375	0.2963	4.750	0.21053	0.71053	1.407
4	5.062	0.1975	8.125	0.12308	0.62308	1.605
5	7.594	0.1317	13.188	0.07583	0.57583	1.737
6	11.391	0.0878	20.781	0.04812	0.54812	1.824
7	17.086	0.0585	32.172	0.03108	0.53108	1.883
8	25.629	0.0390	49.258	0.02030	0.52030	1.922
9	38.443	0 0260	74.887	0.01335	0.51335	1.948
10	57.665	0.0173	113.330	0.00882	0.50882	1.965
11	86.498	0 0116	170.995	0.00585	0.50585	1.977
12	129.746	0.0077	257.493	0.003%	0 50388	1.985
13	194.620	0.0051	387.239	0.00258	0.50258	1.990
14	291.928	0 0034	581.859	0.00172	0.50172	1.993
15	437.894	0.0023	873.788	0.00114	0.50114	1.995
16	656.841	00015	1311.682	0.00076	0.50076	1.997
17	885.261	0.0010	1968.523	0.00051	0.50051	1.998
18	1477.892	0.0007	2953.784	0.00034	0.50034	1.999
19	2218.838	0.0005	4431.676	0.00023	0.50023	1.999
20	3325.257	0.0003	8648.513	0.00015	0.50015	1.999
21	4987.885	0.0002	9973,770	0.00010	0.50010	2.000
22	7481.828	0.0001	14961.655	0.00007	0.50007	2.000

Table 9-9. Five-Year Escalation Table.

Present Worth of a Series of Escalating Payments Compounded Annually
Discount-Escalation Factors for n = 5 Years

Discount Rate	Annual Escalation Rate 0.10	0.12	0.14	0.16	0.18	0.20
0.10	5.000000	5.279234	5.572605	5.880105	6.202627	6.540569
0.11	4.866862	5.136200	5.420152	5.717603	6.029313	6.355882
0.12	4.738562	5.000000	5.274242	5.561868	5.863289	6.179066
0.13	4.615647	4.869164	5.133876	5.412404	5.704137	6.009541
0.14	4.497670	4.742953	5.000000	5.269208	5.551563	5.847029
0.15	4.384494	4.622149	4.871228	5.131703	5.404955	5.691165
0.16	4.275647	4.505953	4.747390	5.000000	5.264441	5.541511
0.17	4.171042	4.394428	4.628438	4.873699	5.129353	5.397964
0.18	4.070432	4.287089	4.513947	4.751566	5.000000	5.259749
0.19	3.973684	4.183921	4.403996	4.634350	4.875619	5.126925
0.20	3.880510	4.084577	4.298207	4.521178	4.755725	5.000000
0.21	3.790801	3.989001	4.196400	4.413341	4.640260	4.877689
0.22	4.704368	3.896891	4.098287	4.308947	4.529298	4.759649
0.23	3.621094	3.808179	4.003835	4.208479	4.422339	4.645864
0.24	3.540773	3.722628	3.912807	4.111612	4.319417	4.536517
0.25	3.463301	3.640161	3.825008	4.018249	4.220158	4.431144
0.26	3.388553	3.560586	3.740376	3.928286	4.124553	4.329514
0.27	3.316408	3.483803	3.658706	3.841442	4.032275	4.231583
0.28	3.246718	3.409649	3.579870	3.757639	3.943295	4.137057
0.29	3.179393	3.338051	3.503722	3.676771	3.857370	4.045902
0.30	3.114338	3.268861	3.430201	3.598653	3.774459	3.957921
0.31	3.051452	3.201978	3.359143	3.523171	3.694328	3.872901
0.32	2.990618	3.137327	3.290436	3.450224	3.616936	3.790808
0.33	2.931764	3.074780	3.224015	3.379722	3.542100	3.711472
0.34	2.874812	3.014281	3.159770	3.311524	3.469775	3.634758

Table 9-10. Ten-Year Escalation Table.

Resent Worth of a Series of Escalating Payments Compounded Annually
Discount-Escalation Factors for n = 10 Years

Discount Rate	Annual Escalation Rate					
	0.10	0.12	0.14	0.16	0.18	0.20
0.10	10.000000	11.056250	12.234870	13.548650	15.013550	16.646080
0.11	9.518405	10.508020	11.613440	12.844310	14.215140	15.741560
0.12	9.068870	10.000000	11.036530	12.190470	13.474590	14.903510
0.13	8.650280	9.526666	10.498990	11.582430	12.786980	14.125780
0.14	8.259741	9.084209	10.000000	11.017130	12.147890	13.403480
0.15	7.895187	8.672058	9.534301	10.490510	11.552670	12.731900
0.16	7.554141	8.286779	9.099380	10.000000	10.998720	12.106600
0.17	7.234974	7.926784	8.693151	9.542653	10.481740	11.524400
0.18	6.935890	7.589595	8.312960	9.113885	10.000000	10.980620
0.19	6.655455	7.273785	7.957330	8.713262	9.549790	10.472990
0.20	6.392080	6.977461	7.624072	8.338518	9.128122	10.000000
0.21	6.144593	6.699373	7.311519	7.987156	8.733109	9.557141
0.22	5.911755	6.437922	7.017915	7.657542	8.363208	9.141752
0.23	5.692557	6.192047	6.742093	7.348193	8.015993	8.752133
0.24	5.485921	5.960481	6.482632	7.057347	7.690163	8.387045
0.25	5.290990	5.742294	6.238276	6.783767	7.383800	8.044173
0.26	5.106956	5.536463	6.008083	6.526298	7.095769	7.721807
0.27	4.933045	5.342146	5.790929	6.283557	6.824442	7.418647
0.28	4.768518	5.158489	5.585917	6.054608	6.568835	7.133100
0.29	4.612762	4.984826	5.392166	5.838531	6.327682	6.864109
0.30	4.465205	4.820429	5.209000	5.634354	6.100129	6.610435
0.31	4.325286	4.664669	5.035615	5.441257	5.885058	6.370867
0.32	4.192478	4.517015	4.871346	5.258512	5.681746	6.144601
0.33	4.066339	4.376884	4.715648	5.085461	5.489304	5.930659
0.34	3.946452	4.243845	4.567942	4.921409	5.307107	5.728189

Table 9-11. Fifteen-Year Escalation Table.

Resent Worth of a Series of Escalating Payments Compounded Annually Discount-Escalation Factors for n = 15 years						
Discount Rate	**Annual Escalation Rate**					
	0.10	**0.12**	**0.14**	**0.16**	**0.18**	**0.20**
0.10	15.000000	17.377880	20.199780	23.549540	27.529640	32.259620
0.11	13.964150	16.126230	18.690120	21.727370	25.328490	29.601330
0.12	13.026090	15.000000	17.332040	20.090360	23.355070	27.221890
0.13	12.177030	13.981710	16.105770	18.616160	21.581750	25.087260
0.14	11.406510	13.057790	15.000000	17.287320	19.985530	23.169060
0.15	10.706220	12.220570	13.998120	16.086500	18.545150	21.442230
0.16	10.068030	11.459170	13.088900	15.000000	17.244580	19.884420
0.17	9.485654	10.766180	12.262790	14.015480	16.066830	18.477610
0.18	8.953083	10.133630	11.510270	13.118840	15.000000	17.203010
0.19	8.465335	9.555676	10.824310	12.303300	14.030830	16.047480
0.20	8.017635	9.026333	10.197550	11.560150	13.148090	15.000000
0.21	7.606115	8.540965	9.623969	10.881130	12.343120	14.046400
0.22	7.227109	8.094845	9.097863	10.259820	11.608480	13.176250
0.23	6.877548	7.684317	8.614813	9.690559	10.936240	12.381480
0.24	6.554501	7.305762	8.170423	9.167798	10.320590	11.655310
0.25	6.255518	6.956243	7.760848	8.687104	9.755424	10.990130
0.26	5.978393	6.632936	7.382943	8.244519	9.236152	10.379760
0.27	5.721101	6.333429	7.033547	7.836080	8.757889	9.819020
0.28	5.481814	6.055485	6.710042	7.458700	8.316982	9.302823
0.29	5.258970	5.797236	6.410005	7.109541	7.909701	8.827153
0.30	5.051153	5.556882	6.131433	6.785917	7.533113	8.388091
0.31	4.857052	5.332839	5.872303	6.485500	7.184156	7.982019
0.32	4.675478	5.123753	5.630905	6.206250	6.860492	7.606122
0.33	4.505413	4.928297	5.405771	5.946343	6.559743	7.257569
0.34	4.345926	4.745399	5.195502	5.704048	6.280019	6.933897

Table 9-12. Twenty-Year Escalation Table.

Present Worth of a Series of Escalating Payments Compounded Annually
Discount-Escalation Factors for n = 20 Years

Discount Rate	Annual Escalation Rate 0.10	0.12	0.14	0.16	0.18	0.20
0.10	20.000000	24.295450	29.722090	36.592170	45.308970	56.383330
0.11	18.213210	22.002090	26.776150	32.799710	40.417480	50.067940
0.12	16.642370	20.000000	24.210030	29.505400	36.181240	44.614710
0.13	15.259850	18.243100	21.964990	26.634490	32.502270	39.891400
0.14	14.038630	16.694830	20.000000	24.127100	29.298170	35.789680
0.15	12.957040	15.329770	18.271200	21.929940	26.498510	32.218060
0.16	11.995640	14.121040	16.746150	20.000000	24.047720	29.098950
0.17	11.138940	13.048560	15.397670	18.300390	21.894660	26.369210
0.18	10.373120	12.093400	14.201180	16.795710	20.000000	23.970940
0.19	9.686791	11.240870	13.137510	15.463070	18.326720	21.860120
0.20	9.069737	10.477430	12.188860	14.279470	16.844020	20.000000
0.21	8.513605	9.792256	11.340570	13.224610	15.527270	18.353210
0.22	8.010912	9.175267	10.579620	12.282120	14.355520	16.890730
0.23	7.555427	8.618459	9.895583	11.438060	13.309280	15.589300
0.24	7.141531	8.114476	9.278916	10.679810	12.373300	14.429370
0.25	6.764528	7.657278	8.721467	9.997057	11.533310	13.392180
0.26	6.420316	7.241402	8.216490	9.380883	10.778020	12.462340
0.27	6.105252	6.862203	7.757722	8.823063	10.096710	11.626890
0.28	5.816151	6.515563	7.339966	8.316995	9.480940	10.874120
0.29	5.550301	6.198027	6.958601	7.856833	8.922847	10.194520
0.30	5.305312	5.906440	6.609778	7.437339	8.416060	9.579437
0.31	5.079039	5.638064	6.289875	7.054007	7.954518	9.021190
0.32	4.869585	5.390575	5.995840	6.702967	7.533406	8.513612
0.33	4.675331	5.161809	5.725066	6.380829	7.148198	8.050965
0.34	4.494838	4.949990	5.475180	6.084525	6.795200	7.628322

Uniform Series Compound Amount—USCA

The USCA factor is used to determine the amount S that an equal annual payment R will accumulate to in n years at i percent interest. If R (uniform annual payment) is known, and S (the future worth of these payments) is required, then Equation 9-6 is used.

$$S = R \times (\text{USCA})i_n \tag{9-6}$$

$$\text{USCA} = \frac{(1+i)^n - 1}{i} \tag{9-7}$$

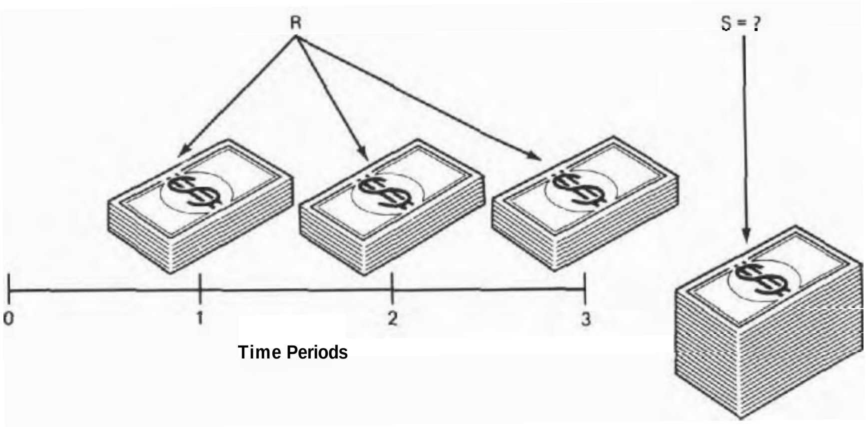


Figure 9-3. Uniform series compound amount (USCA).

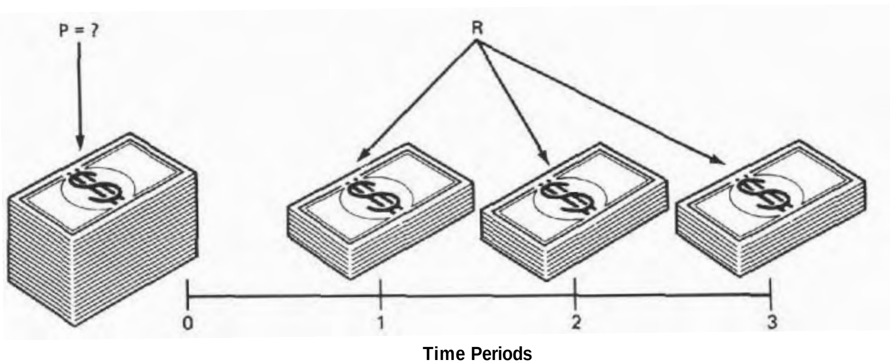


Figure 9-4. Uniform series present worth (USPW).

Uniform Series Present Worth—(USPW)

The **USPW** factor is used to determine the present amount P that can be paid by equal payments of R (uniform annual payment) at i percent interest, for n years. If R is known, and P is required, then Equation 9-8 is used.

$$P = R \times (\mathrm{USPW})i_n \tag{9-8}$$

$$\mathrm{USPW} = \frac{(1+i)^n - 1}{i(1+i)^n} \tag{9-9}$$

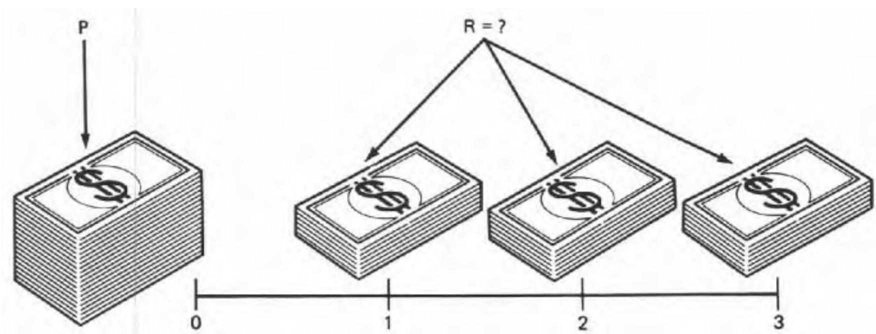


Figure 9-5. Capital recovery (CR).

Capital Recovery—CR

The CR factor is used to determine an annual payment R required to pay off a present amount P at i percent interest, for n years. If the present sum of money, P, spent today is known, and the uniform payment R needed to pay back P over a stated period of time is required, then Equation 9-10 is used.

$$R = P \times (\mathrm{CR})i_n \tag{9-10}$$

$$\mathrm{CR} = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{9-11}$$

Sinking Fund Payment—SFP

The SFP factor is used to determine the equal annual amount R that must be invested for n years at i percent interest in order to accumulate a specified future amount. If S (the future worth of a series of annual payments) is known, and R (value of those annual payments) is required, then Equation 9-12 is used.

$$R = S \times (\text{SFP})i_n \tag{9-12}$$

$$\text{SFP} = \frac{i}{(1+i)^n - 1} \tag{9-13}$$

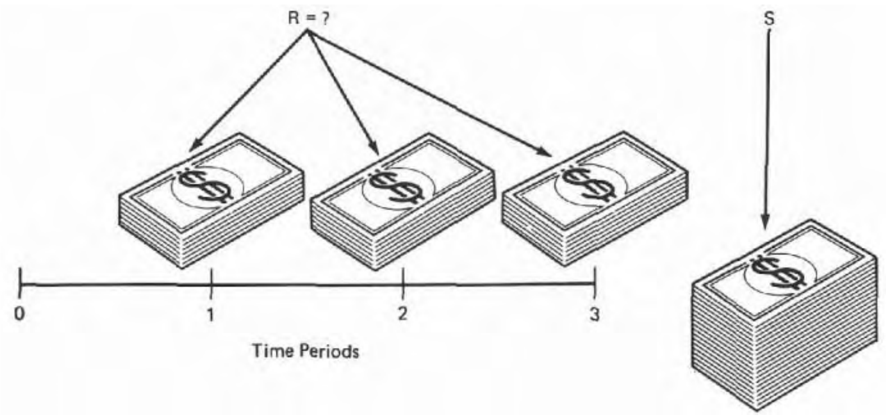


Figure 9-6. Sinking fund payment (SFP).

Gradient Present Worth—GPW

The **GPW** factor is used to determine the present amount P that can be paid by annual amounts R which escalate at e percent, at i percent interest, for n years. If R is known, and P is required, then Equation 9-14 is used. The **GPW** factor is a relatively new term which has gained in importance due to the impact of inflation.

$$P = R \times (\text{GPW})i_n \tag{9-14}$$

$$\text{GPW} = \frac{\dfrac{1+e}{1+i}\left[1 - \left(\dfrac{1+e}{1+i}\right)^n\right]}{1 - \dfrac{1+e}{1+i}} \tag{9-15}$$

The three most commonly used methods in life cycle costing are the annual cost, present worth and rate-of-return analysis.

In the present worth method a minimum rate of return (i) is stipulated. All future expenditures are converted to present values using the interest factors. The alternative with lowest effective first cost is the most desirable.

A similar procedure is implemented in the annual cost method. The difference is that the first cost is converted to an annual expenditure. The alternative with lowest effective annual cost is the most desirable.

In the rate-of-return method, a trial-and-error procedure is usually required. Interpolation from the interest tables can determine what rate of return (i) will give an interest factor which will make the overall cash flow balance. The rate-of-return analysis gives a good indication of the overall ranking of independent alternates.

The effect of escalation in fuel costs can influence greatly the final decision. When an annual cost grows at asteady rate it may be treated as a gradient and the gradient present worth factor can be used.

Special thanks are given to Rudolph R. Yanuck and Dr. Robert Brown for the use of their specially designed interest and escalation tables used in this text.

When life cycle costing is used to compare several alternatives the differences between costs are important. For example, if one alternate forces additional maintenance or an operating expense to occur, then these factors as well as energy costs need to be included. Remember, what was previously spent for the item to be replaced is irrelevant. The only factor to be considered is whether the new cost can be justified based on projected savings over its useful life.

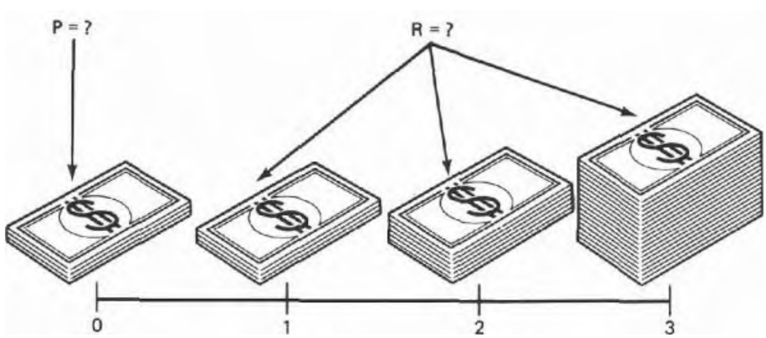


Figure 9-7. Gradient present worth (GPW).

THE JOB SIMULATION EXPERIENCE

Throughout the text you will experience job situations and problems. Each simulation experience is denoted by SIM. The answer will be given below the problem. Cover the answers, then you can "play the game."

Problem 9-1

An evaluation needs to be made to replace all 40-watt fluorescent lamps with a new lamp that saves 12 percent or **4.8** watts and gives the same output. The cost of each lamp is $2.80.

Assuming a rate of return before taxes of 25 percent is required, can the immediate replacement be justified? Hours of operation are **5800** and the lamp life is two years. Electricity costs 7.5¢/KWH.

ANSWER

$$R = P \times CR$$

$$R = 5800 \times 4.8 \times 0.070/1000 = \$1.94$$

$$CR = 1.94/2.84 = .69$$

From Table **9-5** a rate of return of 25 percent is obtained. When analyzing energy conservation measures, never look at what was previously spent or the life remaining. Just determine if the new expenditure will pay for itself.

Problem 9-2

An electrical study indicates electrical motor consumption is 4×10^6 **KWH** per year. **By** upgrading the motor spares with high efficiency motors a 10% savings can be realized. The additional cost for these motors is estimated at $80,000. Assuming an 8¢ per **KWH** energy charge and 20-year life, is the expenditure justified based on a minimum rate of return of 20% before taxes? Solve the problem using the present worth, annual cost, and rate-of-return methods.

ANSWER

Present Worth Method

	Alternate 1 ***Present Method***	***Alternate 2*** ***Use High Efficiency Motor Spares***
(1) First Cost *(P)*	—	$80,000
Annual Cost *(R)*	$4 \times 10^{12} \times .08$ = $320,000	$.9 \times \$320,000$ = $288,000

USPW (Table 9-4)	4.87	4.87
(2) R X USPW =	\$1,558.400	\$1,402,560
Present Worth	\$1,558,400	\$1,482,560
(1) + (2)		Choose Alternate with Lowest First Cost

Annual Cost Method

	Alternate 1	*Alternate 2*
(1) First Cost *(P)*	—	\$80.000
Annual Cost *(R)*	\$320,000	\$288,000
CR (Table 9-4)	.2	.2
(2) P X CR	—	\$16,000
Annual Cost	\$320,000	\$304,000
(1) + (2)		Choose Alternate with Lowest First Cost

Rate of Return Method

$$P = R(\text{USPW}) = (\$320{,}000 - \$288{,}000) \times \text{USPW}$$

$$\text{USPW} = \frac{80{,}000}{32{,}000} = 2.5$$

What value of i will make USPW = 2.5? i = 40% (Table 7, App. I).

Problem 9-3

Show the effect of 10 percent escalation on the rate of return analysis given the

Energy equipment investment	= \$20,000
After tax savings	= \$ 2600
Equipment life (n)	= 15 years

ANSWER

Without escalation:

$$CR = \frac{R}{P} = \frac{2600}{20{,}000} = 0.13$$

From Table 9-1, the rate of return is 10 percent,
With 10 percent escalation assumed:

$$GPW = \frac{P}{G} = \frac{20{,}000}{2600} = 7.69$$

From Table 9-10, the rate of return is 15.6%.

Thus we see that taking into account a modest escalation rate can dramatically affect the justification of the project.

MAKING DECISIONS FOR ALTERNATE INVESTMENTS

There are several methods for determining which energy conservation alternative is the most economical. Probably the most familiar and trusted method is the annual cost method.[35]

When evaluating replacement of processes or equipment ***do not*** consider what was previously spent. The decision will be based on whether the new process or equipment proves to save substantially enough in operating costs to justify the expenditure.

Equation 9-16 is used to convert the lump sum investment P into the annual cost. In the case where the asset has a value after the end of its useful life, the annual cost becomes:

$$AC = (P - L)\,CR + iL \qquad (9\text{-}16)$$

where

AC is the annual cost

L is the net sum of money that can be realized for a piece of equipment, over and above its removal cost, when it is returned at the end of the service life. L is referred to as the salvage value.

As a practical point, the salvage value is usually small and can be neglected, considering the accuracy of future costs. The annual cost technique can be implemented by using the following format:

	Alternate 1	Alternate 2
1. First cost (P)		
2. Estimated life (n)		
3. Estimated salvage value at end of life (L)		
4. Annual disbursements, including energy costs & maintenance (E)		
5. Minimum acceptable return before taxes (i)		
6. CR n, i		
7. $(P - L)$CR		
8. Li		
9. AC = $(P - L)$CR + Li + E		

Choose alternate with lowest AC

The alternative with the lowest annual cost is the desired choice.

Problem 9-4

A new water line must be constructed from an existing pumping station to a reservoir. Estimates of construction and pumping costs for each pipe size have been made.

Pipe Size	Estimated Construction Costs	Cost/Hour for Pumping
8"	$ **80,000**	**$4.00**
10"	**$100,000**	**$3.00**
12"	**$160,000**	**$1.50**

The annual cost is based on a 16-year life and a desired return on investment before taxes of **10** percent. Which is the most economical pipe size for pumping **4000 hours/year?**

ANSWER

	8" Pipe	10" Pipe	12" Pipe
P	\$80,000	\$100,000	\$160,000
n	16	16	16
L	—	—	—
E	16,000	12,000	6000
i	10%	10%	10%
$CR = 0.127$	—	—	—
$(P - L)CR$	10,160	12,700	20,320
Li	—	—	—
AC	\$26,160	\$24,700 *(Choice)*	\$26,320

DEPRECIATION AND TAXES

Depreciation

Depreciation affects the "accounting procedure" for determining profits and losses and the income tax of a company. In other words, for tax purposes the expenditure for an asset such as a pump or motor cannot be fully expensed in its first year. The original investment must be charged off for tax purposes over the useful life of the asset. A company usually wishes to expense an item as quickly as possible.

The Internal Revenue Service allows several methods for determining the annual depreciation rate. Tax considerations based on the tax reform act of 1986 are described in Chapter 8.

Straight-Line Depreciation. The simplest method is referred to as a straight-line depreciation and is defined as:

$$D = \frac{P - L}{n} \tag{9-17}$$

where

- D is the annual depreciation rate
- L is the value of equipment at the end of its usefullife, commonly referred to as salvage value
- n is the life of the equipment, which is determined by Internal Revenue Service guidelines
- P is the initial expenditure.

Sum-of-Years Digits. Another method is referred to as the sum-of-years digits. In this method the depreciation rate is determined by finding the sum of digits using the following formula,

$$N = n\frac{(n+1)}{2} \tag{9-18}$$

where n is the life of equipment.

Each year's depreciation rate is determined as follows.

First year $$D = \frac{n}{N}(P - L) \tag{9-19}$$

Second year $$D = \frac{n-1}{N}(P - L) \tag{9-20}$$

n year $$D = \frac{1}{N}(P - L) \tag{9-21}$$

Declining-Balance Depreciation. The declining-balance method allows for larger depreciation charges in the early years which is sometimes referred to as fast write-off.

The rate is calculated by taking a constant percentage of the declining undepreciated balance. The most common method used to calculate the declining balance is to predetermine the depreciation rate. Under certain circumstances a rate equal to 200 percent of the straight-line depreciation rate may be used. Under other circumstances the rate is limited to $1\frac{1}{2}$ or $\frac{1}{4}$ times as great as straight-line depreciation. In this method the salvage value or undepreciated book value is established once the depreciation rate is preestablished.

To calculate the undepreciated book value, Equation 2-22 used.

$$D = 1 - \left(\frac{L}{P}\right)^{1/N} \tag{9-22}$$

where

D is the annual depreciation rate
L is the salvage value
P is the **first** cost.

Tax Considerations

Tax-deductible expenses such as maintenance, energy, operating costs, insurance, and property taxes reduce the income subject to taxes.

For the after tax life cycle cost analysis and payback analysis the actual incurred and annual savings is given as follows.

$$AS = (1 - I)E + ID \tag{9-23}$$

where

- ***AS*** is the yearly annual after tax savings (excluding effect of tax credit)
- ***E*** is the yearly annual energy savings (difference between original expenses and expenses after modification)
- ***D*** is the annual depreciation rate
- ***I*** is the income tax bracket.

Equation 9-23 takes into account that the yearly annual energy savings is partially offset by additional taxes which must be paid due to reduced operating expenses. On the other hand, the depreciation allowance reduces taxes directly.

After-Tax Analysis

To compute a rate of return which accounts for taxes, depreciation, escalation, and tax credits, a cash-flow analysis is usually required. This method analyzes all transactions including first and operating costs. To determine the after-tax rate of return a trial and error or computer analysis is required.

All money is converted to the present assuming an interest rate. The summation of all present dollars should equal zero when the correct interest rate is selected, as illustrated in Fig. 9-8.

This analysis can be made assuming a fuel escalation rate by using the gradient present worth interest of the present worth factor.

Year	1 Investment	2 Tax Credit	3 After Tax Savings (AS)	4 Single Payment Present Worth Factor	$(2+3) \times 4$ Present Worth
0	$-P$				$-P$
1		$+TC$	AS	$SPPW_1$	$+P_1$
2			AS	$SPPW_2$	P_2
3			AS	$SPPW_3$	P_3
4			AS	$SPPW_4$	P_4
Total					ΣP

$$AS = (1 - I)E + ID$$

Trial and Error Solution:
Correct i when $\Sigma P = 0$

Figure 9-8. Cash flow rate of return analysis.

COMPUTER ANALYSIS

The Alliance to Save Energy, 1925 K Street, NW, Suite 206, Washington, DC 20006, has recently introduced an investment analysis software package, ENVEST, which costs only $55.00 and includes a 170-page user manual and 30 days of telephone support. The program can be run on an IBM PC, PCXT, PCAT with 256K ram. The program enables the user to:

- Generate spreadsheets and graphs showing the yearly cash flows from any energy-related investment.
- Compute payback, internal rate of return, and other important investment measures.
- Experiment with differing energy price projections.
- Perform sensitivity analysis on key assumptions.
- Compare alternative financing options, including loans, leases, and shared savings.
- Store data on over 100 energy efficiency investments.

The user is able to determine the impact of different energy price projections on the investment merits.

Another relatively low-cost software program package which can be used for operating cost analysis is available from Carrier, E20-11. The complete software package also includes operating cost analysis, commercial load estimating, residential load estimating, duct design, equipment selection, heat pump comparison program, piping data and rooftop packaged and chiller equipment selections. These programs are licensed for one year at $985 with a nominal maintenance fee for each additional year. The programs are capable of running on the Tandy 1200, 2000, Radio Shack 3, 4 and 4P computers and on the IBM PC, XT and AT series of microcomputers. A recent addition to the E20 package at no additional cost is the Hourly Analysis Program. This program includes weather data for 284 U.S. cities, 40 Canadian cities and 50 international cities.

10
Case Studies and Examples

CONTENTS

Problem 10-1

CPM PLANNING AND SCHEDULING

The following examples, illustrate the techniques for developing Precedence and Arrow Diagram CPM schedules.

a) Warehouse Building Conversion
This example shows a Precedence Diagram approach to the conversion of a building from warehousing to manufacturing. The worked case history, Figure 10-1, shows a typical Work Breakdown Structure (WBS), that includes the estimated number of men, duration and labor cost. The completed logic diagram is shown in Figure 10-2.

b) Small Plant Construction Program
The plot plan for a small plant is shown on Figure 10-3 with 6 major pieces of equipment, plus all services to be installed. **A** WBS and "scheduled assumptions" are shown in Figure 10-4a paragraphs 5 and 6. An "economic" construction schedule is required and the case solution of 16 weeks project duration is shown in Figure 10-4b.

c) Small Plant **Shutdown/Turnaround (S/T)**
This case covers the same project as (item 1b) except that, this time, the work is required to be completed as soon as possible, via a S/T. Figure 10-4a, paragraph 7, outlines the schedule assumptions and the WBS is shown in Figure 10-5. This WBS is more detailed than that shown in case 1b., as an S/T usually requires greater detail in the planning and scheduling program. The case solution is shown in Figure 10-6. This shows that the 16 weeks economic program of case 1b. can be compressed into 3 weeks, with a 7-day, 24-hour-day S/T.

Problem 10-2

COST ESTIMATING

The following examples show the development of a conceptual and detailed estimate.

a) Conceptual Estimate - Small Plant Addition
This estimating example is for the same project as shown in the schedule, cases 10-1b., and 10-1c. Figure 10-3 shows the plot

plan. **A** conceptual estimate is developed on a statistical basis, by judgment and an historical data base. Figure 10-8 shows the statistical development to the total project cost, starting from a "known" base of 3613 direct manhours for equipment and piping installation. Through experience, judgment and historical data, the statistical breakdown for this project, shown in Figure 10-7, is developed. The total cost and engineering manhours are then "factored" as shown in Figure 10-8.

b) Detailed Estimate - Instrument Contract
The required instrumentation is shown in Figure 10-9. A detailed quantity takeoff and estimate is then developed and this is in Figure 10-10. The estimating data comes from Richardson's Estimating manuals. Figure 10-11 shows the development of allowances for indirect costs, sales tax, contingency, contractor's profit and bond. The final estimated cost is then the contractor's Bid price.

Problem **10-3**

PROJECT ORGANIZATION OF TIME AND BUDGET

Two cases/examples of project organization/execution are illustrated. The first example covers contract strategy and the second case shows the "creative analysis" of a unit price contract for equipment foundations.

a) Project Management Problem - Contract Strategy
Experience and case histories have clearly indicated that many projects slip schedule and over-run cost because of an early, poor contract strategy. This case outlines the typical conflict of schedule priority versus minimum risk. These objectives are mostly conflicting objectives and a very careful analysis of contracting options is required to resolve this dilemma.

Problem **10-3A**

You are an owner or client, with limited/little project experience. A feasibility study/estimate of an **E.P.C.** project has been completed. The project is required as soon as possible.

Of the many types of contracts, ***which arrangement would you recommend, and why?***

What are the disadvantages?

Analysis

Figure 10-12 illustrates a typical contract strategy.

b) Unit Price Contract Analysis

"Creative analysis" is essential for effective project execution. Figure 10-13 illustrates a typical contract cost/schedule report. The progress figures have been removed, so that the example can become a case study for evaluation. The analysis indicated in Figure 10-14 shows that the reported progress figures were impossible and, therefore, the estimated quantities for rebar and concrete were incorrect. Judgment on the percent (%) complete numbers then allows a cost evaluation to be completed. This evaluation shows a cost overrun of the original contract value. The final analysis in Figure 10-15 considers the contractual implications of a contract "claim" and the final prediction of cost, for the contract.

Figure 10-1. Work Breakdown Structure.

Project: WAREHOUSE CONVERSION TO MANUFACTURING

"ESTIMATED" Nº MEN	ACTIVITY CODE	ACTIVITY DESCRIPTION	DURATION (DAYS)	"ESTIMATED" COST (LABOR $)
2L/2R	d	Remove Furniture/Equipment	5	1900/2000
--	B	Divert Traffic From Site	1	---
6L	C	Disassemble Pallet racks	7	7980
3L/2E	D	Rip Out Receiving conveyors	4	2280/1600
4R	E	Send Conveyors To Salvage Co.	2	1600
2E	F	Rip our Lighting - New Flwr Area	2	800
3E		Install New Lighting - New Floor Area	3	1800
3C	H	Build Knee Wall - New Floor Area	3	2025
--	I	--	--	--
4-E	J	Construct Pew Floor Conduit/Panels	7	5600
4-C	K	Install Floor Pedestals & Tiles	7	6300
3E	L	Install Grounding to Pedestals	2	1200
6L	M	Erect New Pallet Racks (Phase 1)	5	5700
2Pp	N	Install Sprinklers (Phase I)	2	840
6L	O	Erect Pallet Racks (Phase II)	11	12540
4R	P	Bring Excess Racks To Storage	2	1600
3L	Q	Rip Our existing Partition	3	1700
3C	R	Install new partition	8	5400
3C	S	Install New Cribbing (Above partitions)	10	6750
2Pt	T	Paint New Partitions	5	1800
2Pt	U	Paint Knee Wall 6 Rails	2	720
3E	V	Complete Lighting Rip Out	3	1800
3E	W	Install Remainder of New Lighting	5	3000
3R/6L	X	Install Zimmair Lifts	5	3000/5700
3Pp	Y	Pipe Compressed Air To Site	2	1260
4Pp	Z	Construct compressed air Drops/Connections	4	3360
2E	AA	Construct Electrical Feeders. Panels. Transf.	6	2400
4L	BB	Clean Up Job Site	2	1520
2E	CC'	Conduct Electrical Safety Inspection	1	400

E = Electrician; C = carpenter; L = Laborer; Pp = Plumber; R = Rigger; Pt = Painter;

NOTE: The estimated numbers of men and cost, per activity, do not. necessarily. reflect me actual men/costs that were required on the project.

Figure 10-2. CPM Solution.

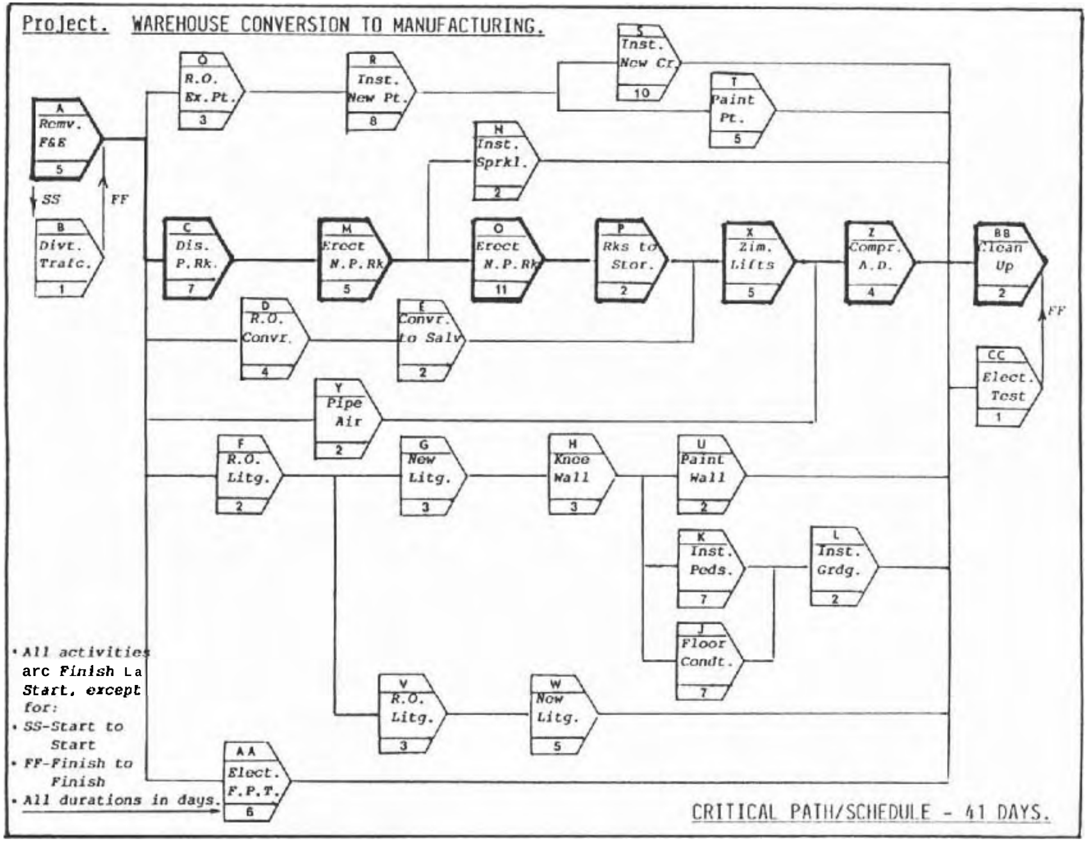


Figure 10-3. Plot Plan.

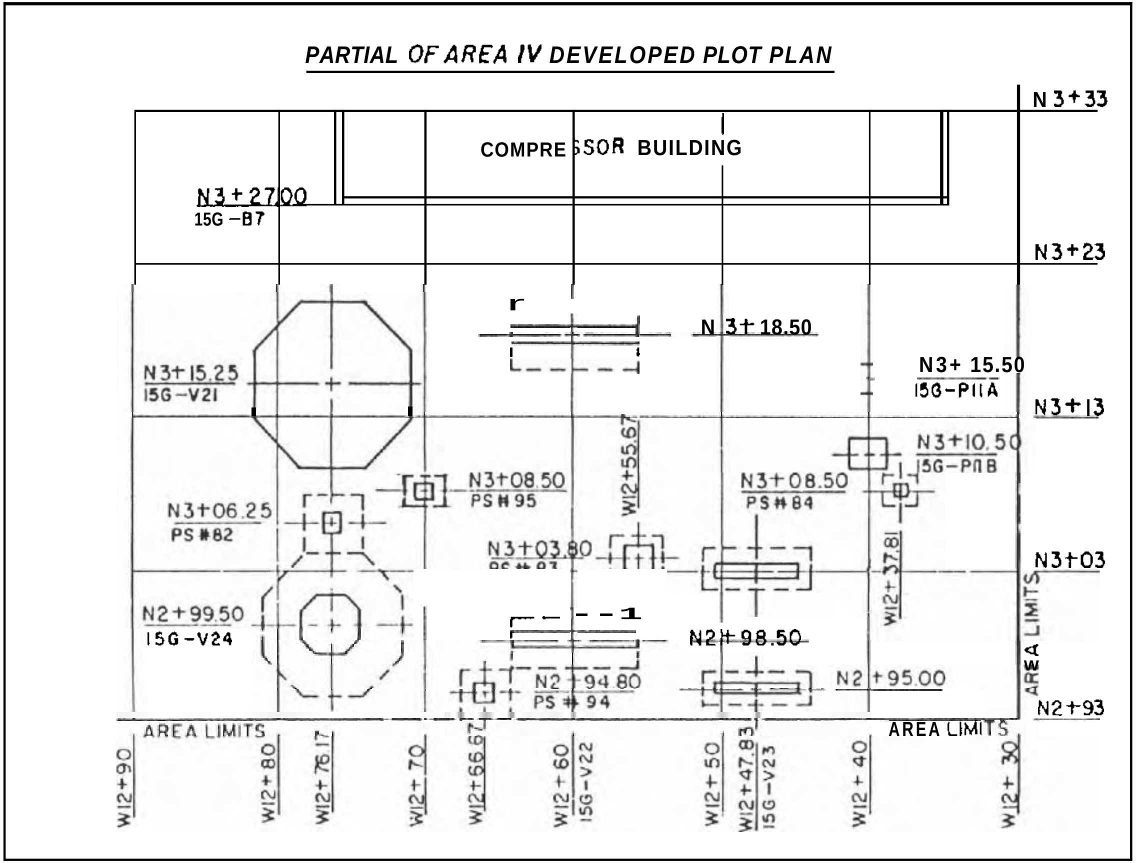


Figure 10-4a. Work/Breakdown Structure and Schedule Assumptions.

SUB AREA IV

5. "LATE START" ECONOMIC CONSTRUCTION SCHEDULE

Use following WBS (activity list) to develop schedule.

MANHOURS			
(30)	a)	Pumps foundations	P.FDNS
	b)	Cure pump Eoundations	CURE
	c)	Install pumps	PUMPS
(96)	d)	Vessels foundations	V.FDNS
	e)	Cure vessels foundations	CURE
	f)	Install vessels	VESSELS
	g)	Install pipe support .	P.S.
110001	h)	Install piping to vessels and pumps	PIPE
	i)	Install vessels/pumps electrical and instruments	E&I
(120)	j)	Tower foundations	FDNS
	k)	Cure tower foundations	CURE
	l)	Install towers	TOWERS
	m)	Install scaffolding	SCAFF.
(2000)	n)	Install piping to towers .	PIPE
	o)	Install towers electrical and instruments	E&I

6. "LATE START" SCHEDULE ASSUMPTIONS

a) 40 hour work week. discounted to 37 for absenteeism.
b) Strict observance of concrete curing spec of 25 days (3.5 weeks).
c) Use "simple" calculation techniques for durations.
d) Piping to vessels/pumps (item h) cannot start until towers piping (item n) is completed.
el Develop activity durations in weeks.

7. SHUTDOWN CRITICAL PATH

Assume construction work is carried out on a shutdown basis.

a) 7 day working with 2 10 hour shifts.
b) No discount of 10 hour days for absenteeism due to "overmanning."
c) Enter all (21) listed activities on attached blank network.
d) Assess individual crew sizes.
e) Based on activity manhours/crew sizes, estimate and calculate durations (days).
f) Determine overall schedule.

Figure 10-4b. "Economic Construction Schedule - Sub Area Plot IV.

NOTE: ALL ACTIVITIES ARE 'SIMPLE' TASKS – USE 'SIMPLE' CALCULATION TECHNIQUE

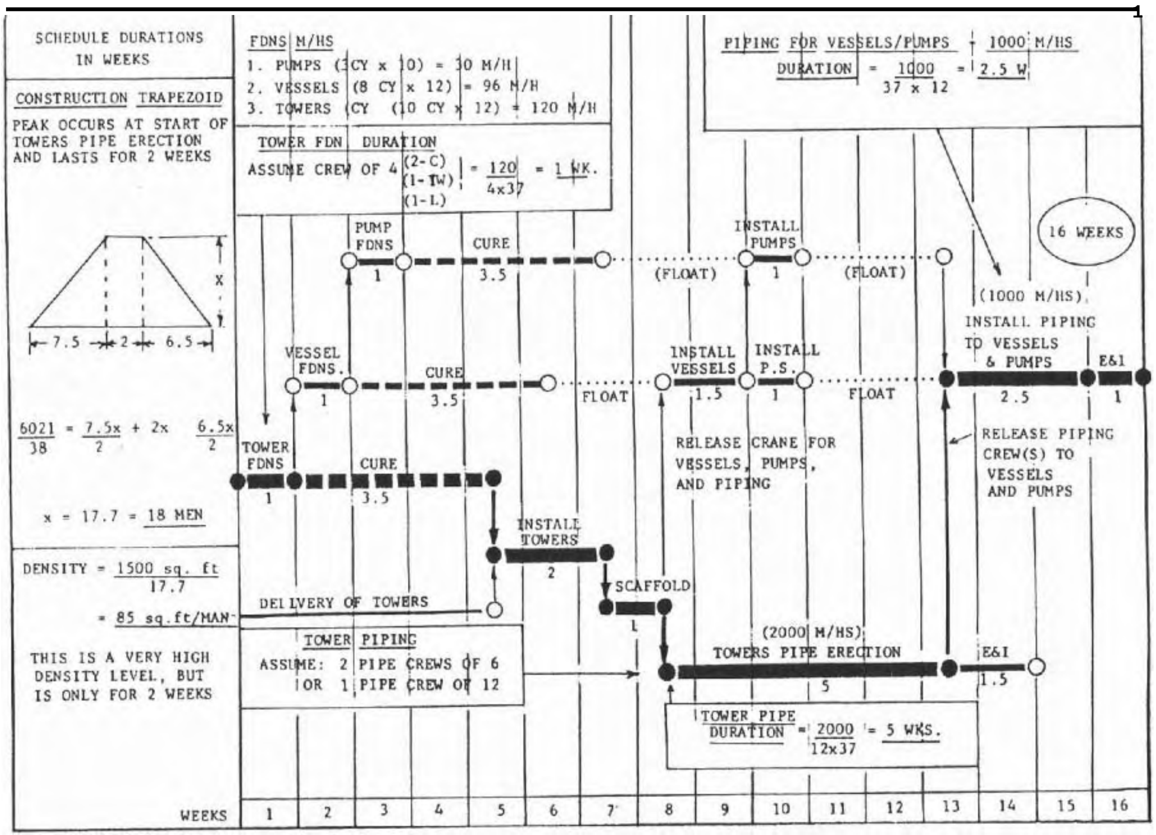


Figure 10-5. Work Breakdown Structure.

SUB AREA IV

SHUTDOWN CRITICAL PATH SCHEDULE

MANHOURS		LIST OF ACTIVITIES	
--	1.	'Install blinds/blocks and "gas-free'' unit .	BR/GF
(55)	2.	Initial align and grout pumps	IA/PP
(400)	3.	Install electrical/instrumentation for vessels/pumps	E&I/V-P
(45)	4.	Install pipe supports (incl. grouting) . .	P.S.
(250)	5.	Construct foundations (pipe supports and equipment)	FDNS
(2000)	6.	Install piping for towers (incl. hydro-test)	TWR/PIPE
(75)	7.	Vessel platforms, ladders and supports . .	V/P-L-S
(250)	8.	Scaffold towers	SCAFF/T
--	9.	Lag/lead start for vessels/pumps E&I . . .	L.S.
(38)	10.	Final align pumps	FA/P
(70)	11.	Set towers	SET/T
(10001	12.	Install piping for vessels and pumps . . .	V-P/PIPE
--	13.	Stress relieve pump piping	S-R/PIPE
(250)	14.	Install towers platforms, ladders and supports	T/P-L-S
(45)	15.	Install vessels internals	V/I
(100)	16.	Install pump piping	PP/PIPE
(70)	17.	Remove packing/braces from towers and check trays	TR/C.O.
(10)	18.	Set pumps.	SET/P
(680)	19.	Install electrical/instrumentation for towers	E&I/T
(15)	20.	Set vessels	SET/V
--	21.	Lag/lead start for towers E&I	L.S.

5353	SUBTOTAL
668	FOR EARTHWORK, INSULATION, PAINTING AND UNDERGROUNDS
6021	TOTAL DIRECT MANHOURS

NOTE: USE "HIGH & EARLY. CONCRETE FOR FOUNDATION8

Figure 10-6. Shutdown Critical Path Schedule - Sub Area IV -Workshop Solution

DURATION CALCULATIONS

1. FOUNDATIONS (1 CREW)
$= \frac{250}{25H \times 5 \times 10}$
= 3 DAYS

2. VESSELS/PUMPS PIPING (1 CREW)
$= \frac{1000}{25H \times 6 \times 10} =$
= 8 DAYS

3. TOWERS PIPING (2 CREWS)
$= \frac{2000}{25H \times 2 \times 6 \times 10} =$
= 8 DAYS

1.	FOUNDATION CREW	5
2.	PUMPS CREW	2
3.	VESSELS CREW	3
4.	TOWERS CREW	2x5
5.	V/P. PIPING CREW	6
6.	TOWERS PIPING CREW	- 2x6

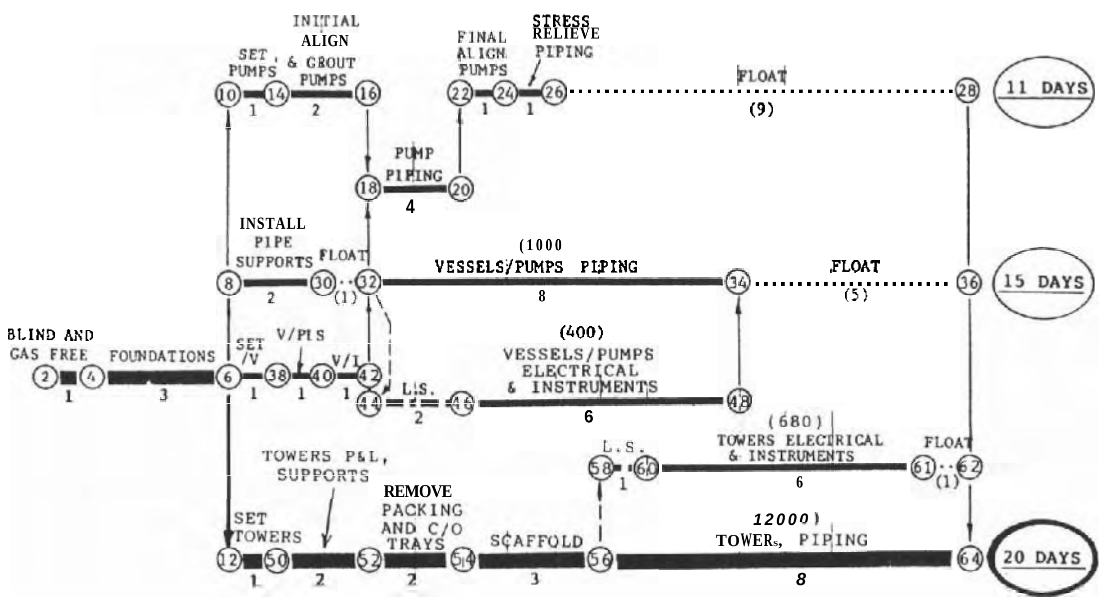


Figure 10-7. Typical Project Cost Breakdown

(Contractor - Total Scope Project).

GRASS ROOTS-LARGE %	ITEM	SMALL REVAMP %
10	ENGINEERING (D&D)	20
3	HOME OFFICE (SUPPORT)	5
47	MATERIAL (DIRECT)	40
21	CONSTRUCTION DIRECT	17
17	CONSTRUCTION INDIRECT	18
100%		100%

DIRECT CONSTRUCTION LABOR HOURS

GRASS ROOTS-LARGE %	ITEM	SMALL REVAMP %
10	SITE PREPARATION	1
12	FOUNDATIONS/UNDERGROUNDS	8
7	STRUCTURAL STEEL/BUILDINGS	5
10	EQUIPMENT	12
35	PIPING	48(INCL.FAB)
11	ELECTRICAL	10
6	INSTRUMENTS	8
4	PAINTING	3
4	INSULATION	3
1	HVAC/FIREPROOFING	2
100%		100%

Figure 10-8. Conceptual Estimate - Workshop Solution.

SMALL ONSHORE PLRNT ADDITION

1. SCOPE/BASIC DATA
   - Addition of 6 Major Pieces of Equipment plus Services
   - Plot Plan/Flow Sheet Drawings Provided
   - Only Piping/Equipment Installation Manhours Given
   - Factor Complete Cost From piping/Equipment Manhours
   - Data Provided - "Typical Project Cost Breakdown"
     - "Engineering Costs/Curves"

2. APPROACH

   Develop a "standard" percentage breakdown far construction labor hours and overall costs for SMALL REVAMPS, on the attached 'Typical Project Cost Breakdown". The attached "Engineering Costs/Curves" show that compared to a large project, the engineering costs for a small project, as a percent of total cost, DOUBLES. Then factor up from the known direct labor hours to:
   - a) TOTAL CONSTRUCTION LABOR MANHOURS
   - b) TOTAL CONSTRUCTION COST
   - c) TOTAL PROJECT COST

3. CONSTRUCTION M/H. ESTIMATE (Hours "factored" by 1.6 for operating plant)

			M/H	
a)	2 Pumps	= 2(32 M/H per pump x 1.61 =	103	assume = 12%
b)	2 vessels	= 2(3 M/H per ton x 10T) =	60	
c)	2 Towers	= 2(3 M/H per ton x 75T) =	450	
d)	Piping (Fab 6 Erect)	= 1500ft. x 2 M/H per ft. =	3000	assume = 48%

SUB TOTAL 3613 DMH (DIRECT M/H)

e) Based on assumption of equipment 6 piping at 60% of construction M/Hs;

$$\text{TOTAL DIRECT HOURS} = \frac{3613}{60\%} = 6021 \text{ DM/Hs.}$$

4. CONSTRUCT■ON M/H COST

   Assume labor rate of $22 per hour;

   Therefore, DM/H Cost = 6021 x $22 = $132,000

5. TOTAL PROJECT COST

   Assume direct labor = 17% of total project cost;

   $$\text{Therefore, Total Project Cost} = \frac{\$132,000}{.17} = \$776.000.$$

6. ENGINEERING - What would be the engineering manhours, @ $45 per hour ?

   $$\text{Engineering Manhours} = \frac{\$776,000 \times 20\%}{\$45} = 3450$$

Figure 10-9. Portion of a Typical Fluids Processing Plant Flow Sheet.

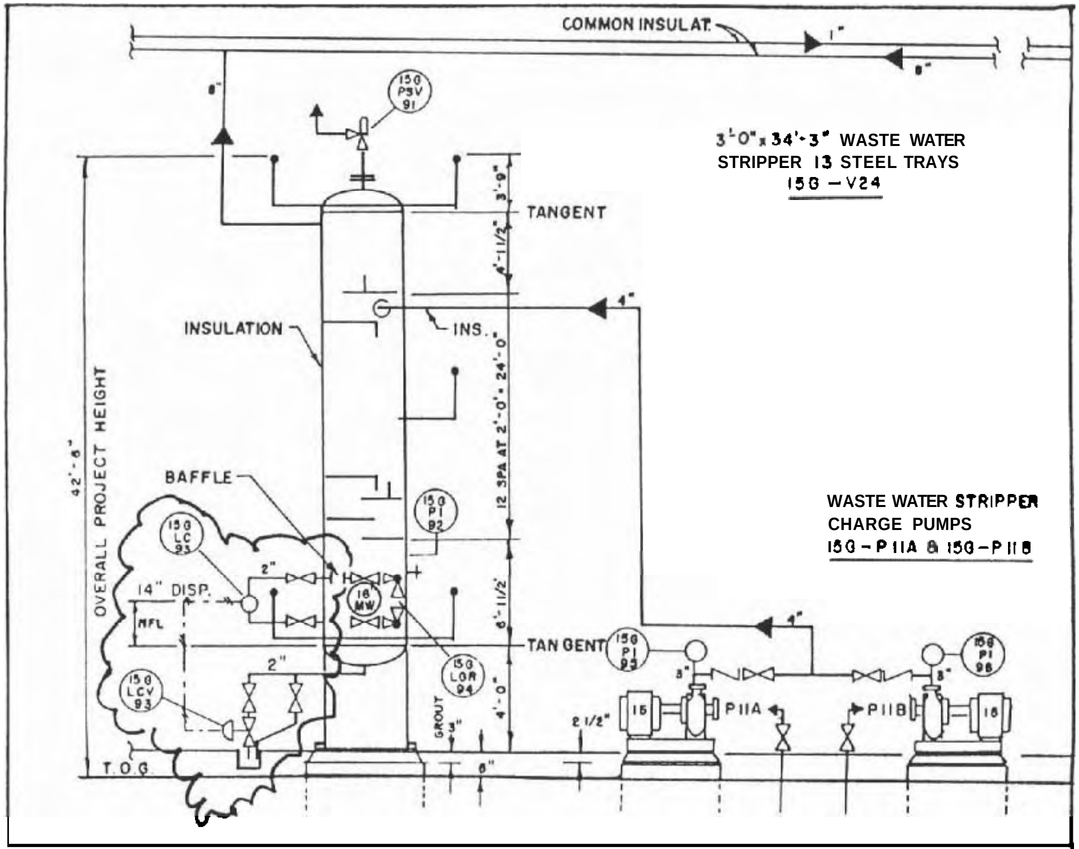


Figure 10-10. Detailed Quantity Takeoff.

PROJECT Process Plant — INSTRUMENT CONTRACT WORKSHOP
ACCOUNT Typical Instrumentation - Fluids Processing Plant
15-50 Thru 15-61
Level Control Loop

ESTIMATE NO
SHEET NO
PREPARED BY JAB DATE Jun 8·
CHECKED BY DATE

DESCRIPTION	QUANTITY	MATERIALS		LABOR				SUB-CONTRACT		TOTAL
		UNIT PRICE	AMOUNT	UNIT M H	TOTAL M H	RATE	AMOUNT	UNIT PRICE	AMOUNT	
Level Control "Loop" On Waste										
Water Stripper 15 G-V 24:										
Account 15-50										
Pg.2 15G-LCV-93 Control Valve,										
2" - 600# Screwed, Cast Steel										
With Factory Mounted Pneumatic										
Diaphragm Actuator On Design										
"EC" Body With S.S. Trim	1 Ea	$1330	$1330	(2.8)	(2.8)	20·50	$57	-	-	$1387
(Positioner And Airset Not Req'd.)										
Account 15-57										
Pg.3 15G-LC-93 Level Controller,										
Pneumatic, Side Mounted, External										
Displacement Type, Fabricated Steel										
Cage, S.S. Trim. Upper and Lower										
Side Connected. 2" - 300# Flanged										
14" Displacer Length, Factory Mtd.										
Controller w/Airset Filter Regulator	1 Ea	1585	1585	(3.5)	(3.5)	20.50	72	-	-	1657
Add for Upper & Lower Side Conn.	1 Ea	110	110	-	-	-	-	-	-	110
Total Account 15-57	-	-	1695	-	(3.5)	-	72	-	-	1767
Account 15-66										
Pg.9 Instrument Air Supply, From										
Valve On Instr. Air Header To										
15-LC-93 (Less Filter-Regulator)	1 Ea	$68.10	$68	(11.5)	(11.5)	20.50	$236	-	-	$304
Pg.10 Air Signal Conn., Between										
15G-LC-93 And 15G-LCV-93,										
Copper Tubing, Bare.	1 Ea	21.70	22	(4)	(4)	20.50	82	-	-	104
Pg.11 Add Tubing Supports										
Aluminum Channel 1" Wide	50 LF	0.66	33	(0.04)	(2)	20.50	41	-	-	74
Al. Horiz. 90° El. 1" "	2 Ea	4.60	9	(0.10)	(0.2)	20.50	4	-	-	13
" Vert. 90° El. 1" "	2 Ea	3.30	7	(0.10)	(0.2)	20.50	4	-	-	11
" Conn. Plate Ass'y. 1" "	10 Ea	1.65	18	(0.05)	(0.5)	20.50	11	-	-	29
" O.H. Hanger 1" "	6 Ea	5.45	34	(0.06)	(0.4)	20.50	9	-	-	43
S.S. Push Clamps 1" "	6 Ea	0.43	3	(0.01)	(0.1)	20.50	2	-	-	5
Total Account 15-66	1 Lot	-	$194	-	(18.9)	-	$389	-	-	$583
Account 15-67, Page 2										
2" 300# Flg'd Piping Ass'y For 15G-LC-93	1 Ea	75.44	$75	(3)	(3)	20.50	$ 62	-	-	$137
CARRY TOTALS FORWARD										

Figure 10-11. Development of Estimate.

PROJECT: INSTRUMENT LEVEL CONTROL LOOP

WORKSHOP SOLUTION

ACCOUNT:

MAIN ACCOUNT & SUMMARY

ESTIMATE NO.
SHEET NO.
PREPARED BY J.A.B. DATE Jun. 84
CHECKED BY J.A.B. DATE

DESCRIPTION	QUANTITY	MATERIALS UNIT PRICE	MATERIALS $ AMOUNT	LABOR UNIT M H	LABOR TOTAL M H	LABOR RATE	LABOR $ AMOUNT	SUB-CONTRACT UNIT PRICE	SUB-CONTRACT AMOUNT	$ TOTAL
B/FWD										
A.C. 15-50 CONTROL VALVE	1	-	1330	-	2.8	20.50	57	-	-	1387
15-57 LEVEL CONTROLLER	1	-	1695	-	3.5	20.50	72	-	-	1767
15-66 INSTR. PIPING	30 FT.	--	194	--	18.9	20.50	389	--	--	583
15-67 PIPING ASSEMBLY	1	-	75	-	3.0	20.50	62	-	-	137
TOTAL DIRECT COSTS		-	(3294)	-	(28.2)		(580)	-	-	(3874)
INDIRECT COSTS	TOTAL M/Hs	--	--	--	(28.2)	13.33	376	--	--	376
(See Section 1-0 Page 5-3story)										(4240)
ADMINISTER SUBCONTRACTS	10 %	SUBCONTRACTS --		--	--	--	--	10 %	--	---
SALES TAX ON MATERIALS	5 %	MATERIAL (3294)		--	--	--	--	--	--	165
									SUB TOTAL	4405
CONTINGENCY	5 %	ABOVE SUB TOTAL		--	--	--	--	--	--	220
									SUB TOTAL	4625
PROFIT FOR CONTRACTOR(S)	10 %	ABOVE SUB TOTAL		--	--	--	--	--	--	463
									SUB TOTAL	5088
PERFORMANCE & COMPLETION BOND	1 %	ABOVE SUB TOTAL		--	--	--	--	--	--	51
						TOTAL CONSTRUCTION BID PRICE				$5139
IF INSTALLATION TAKES PLACE IN OPERATING PLANT, ADJUST AS FOLLOWS:-										
1. DIRECT LABOR	+ 50%				580	0.5	290			290
2. INDIRECTS	+ 30%				376	0.3	113			113
					SUB TOTAL		403			
3. CONT'GY + PROFIT + BOND	+ 16%	ABOVE SUB TOTAL				0.16				65
					TOTAL CONSTRUCTION BID PRICE					$5607

Figure 10-12. Contract Strategy.

2. PROJECT MANAGEMENT SOLUTION - CONTRACT STRATEGY

Client has limited/little experience

Project (E.P.C.) required as soon as possible

1. HIRE CONSULTANT PROJECT MANAGEMENT (reimbursable)
   a) Develop contracting program
   b) Project/Contract Management

COMPETITIVE CONTRACTING

2. ENGINEERING/PROCUREMENT
   a) Fixed Fee/Reimbursable, plus
   b) Schedule Incentive/Milestone Program
   c) Develop L.S./Unit Price Construction Packages

3. CONSTRUCTION
   a) Combination of Unit Price/L.S. Contracts
   b) Schedule Incentive/Milestone Program

MEETS SCHEDULE OBJECTIVE

4. DISADVANTAGES
   a) Some risk with consultant project management costs
   b) Cost risk with Engineering/Procurement
   c) Overall lack of control by owner/client

Figure 10-13. Unit Price Contract -Analysis.

EQUIPMENT FOUNDATIONS

(CURRENT REPORT OF PROGRESS)

NOTE: - ALL FOUNDATIONS ARE TO SAME SPECs.

	ITEM	ESTIMATED Qs.	Qs. INSTALLED TO DATE
1.	FORMWORK (sq.m.)	3500 ✓	2275 ✓
2.	REINFORCING RODS (kg.) (Prefabricated)	60,000 ?	45,600 ✓
3.	CONCRETE (cu.m.)	1400 ?	1220 ✓

- IF Qs. TO DATE. AND ESTIMATED FORMWORK Qs. ARE CORRECT. WILL YOU SIGN THIS REPORT ?
- WHAT IS YOUR COST ASSESSMENT OF THIS CONTRACT ?

ASSUME :

1. THE WORK IS WELL PLANNED AND EXECUTED
2. UNIT PRICES

UNIT PRICES	LABOR ($)	MATERIALS ($)
FORMWORK (sq.m.)	233	0
REBAR (kg.)	3	17¢
CONCRETE (cu.m.)	53	54

Figure 10-14. Unit Price Fd'n. Contract - Solution.

ANALYSIS

		ESTIMRTED Qs.	TODATE Qs.	% COMPLETE
1.	FORMWORK	3500 ✓	2275 ✓	65% ✓
2.	REBAR	~~60,800~~ 76,000	45,600 ✓	~~76%~~ 60%
3.	CONCRETE	~~1400~~ 2218	1220 ✓	~~87%~~ 55%

° CANNOT BE

° MUST BE LAG IN % COMPLETE

COST FORECAST

1.	FORMWORK	° 3.500 (sq.m.)	@ $233		=	$ 815.500
2.	REBRR	° 76,000 (kg.)	@ $3 + 17e		=	240.920
3.	CONCRETE	° 2,218 (cu.m.)	@ $53 + 54		=	237,326
				TOTAL		$1,293,746

ORIGINAL CONTRACT VALUE

1.	FORMWORK	° 3,500 (sq.m.)	@ $233	=	$ 815.500
2.	REBAR	° 60.000 (kg.)	@ 53.17	=	190.200
3	CONCRETE	° 1.400 (cu.m.)	@ 5107	=	149,800
					$1,155,500

CONTINUED ON FIGURE 1015

Figure 10-15. Solution.

UNIT PRICE FOUNDATION CONTRACT

4. POTENTIAL CLAIM

When the scope of work increases by over 10%. a "compensable delay" and/or an increase in the unit cost of the work, may result.
In some countries. the legal system provides for a re-negotiation of the price for scope increases over 10% and in most countries, it is "industry practise" - if not a legal requirement.

INCREASE IN CONTRACT VALUE

$1,293,746 - $1,155,500 = $138,243 = +12%

As the increase is over 10%. allow 10% of the increase for a potential claim.

= $14,000

Therefore. Final Prediction = 61.308.000

11
Personal Performance, Company Culture, and Project Leadership For the 1990's

GENERAL

Much has been written on the factors affecting the efficient execution of engineering/procurement/construction projects. All major studies have come to the same following conclusion.
The following are the two major factors for success.

- Adequate/high personal skills
- Quality project management methods/techniques

IMPACT OF PERSONAL PERFORMANCE

Some companies have analyzed the impact that personal skills/ performance play in the execution of Engineering, Procurement and Construction (EPC) projects. During the author's career at Mobil Oil Corporation, in the Engineering Department, we arrived at the following general conclusion and, in so doing, determined the part that personal performance played in the capital cost of projects.

MAJOR EFFECTS ON PROJECT COSTS

The evaluation determined the following:

- The Design Basis contributed to 80% of the cost.
- The "complete" project management program contributed to 20% of the cost.

The project management program is comprised of a combination of project execution methods/procedures and personnel skills. Effective methods, good personnel skills and adequate resources are essential for a quality project management program. High quality methods and advanced personnel skills can result in project cost saving of 20% of the total project cost. Conversely, a poor program and low skills can increase the costs of the capital projects program by 20% or more. It is probable that the downside risk of cost increases is much greater.

Figure 11-1 illustrates a detailed breakdown of the 20% savings; individual percentages to the six major phases of an E.P.C. project are allocated, and probable variations for large and small projects are estimated. The most significant variation is that of project management, where the impact of an individual on small projects can be the largest, single cost factor.

Figure 11-1
Project Management Program
(20% Cost—Project Management Program)

	Large Project	Small Project
Engineering	4%	3%
Procurement	4%	3%
Construction	6%	4%
Planning & Scheduling	3%	3%
Estimating/Cost Control	2%	2%
Project Management	1%	5%
Total	20%	20%

PERSONAL PERFORMANCE—ORGANIZATIONAL INTERFACE

In addition to a quality program and advanced skills, the organizational structure surrounding the execution of projects can have a major influence. It is recognized that a combination of skills/experience in the following key areas is essential for effective project execution, particularly of major plant retrofits and shutdowns:

- Operations
- Maintenance
- Project Engineering

Lack of departmental cohesion and cooperation within the above three areas is commonplace in many companies. In such cases, it has been found that cost overruns and schedule slippages are often the result. Most operations and maintenance personnel have few project management skills and yet many companies allocate the primary project management responsibility to these personnel. In addition, lack of project management training and lack of cohesion of the plant matrix organization are commonplace. It is vital that the skills and organizational interfaces of these three departments be "captured" for the execution of projects. The combining of these skills and the reduction/elimination of the matrix interfaces will directly result in lower project costs.

HOW TO COMBINE THESE SKILLS — THE BEST WAY

The "best way" is to combine the skills/experience of operations, maintenance and project engineering in a single person: the project manager or the shutdown coordinator. Some advanced companies have recognized this need and are developing their personnel through training in project engineering and through rotational assignments in a planned career development program.

HOW TO COMBINE THESE SKILLS— AN ALTERNATIVE WAY

As it takes time to develop personnel with skills/experience of operations, maintenance and project engineering, an organizational approach can be an alternative. This approach focuses on the lack of cohesion and problems of the plant/company matrix organization and attempts to create a condition of **project consciousness.** This condition requires the operations and maintenance groups to recognize, understand and commit to the project objectives and commit to the effective execution of projects. This is no small task; senior management must also demonstrate that they are dedicated to project consciousness. In return, the project managerlshut-down coordinator must always be sensitive to the relationship and needs of the operations and maintenance groups. Departmental rivalries and organizational conflicts within the matrix organization must be eliminated and/or reduced. If the projects are sufficiently large to work with a project team/task force, it is recommended that operations and maintenance personnel be assigned to the project team. This can greatly increase the cohesion and cooperation of the two departments to the project functions. The result of a quality project management program is the reduction of project costs and a significant savings in the company investment program.

TECHNICAL COMPETENCE NOT ENOUGH

At the Council for National Academic Awards (CNAA), the major theme was expressed by the keynote speaker, Prudential's chief executive Brian Cosby, as follows: **"Technical proficiency alone** is **now unlikely to be sufficient for effective performance."** Mr. Cosby further emphasized that his company has identified the following key attributes as essential for the project management function:

- Communication
- Motivation
- Personal Qualities
- Interpersonal skills
- Decision-making
- Management

Another conclusion reached was that "only ongoing company training can develop these basic attributes into competent skills." Quality training will, therefore, be a major consideration for the 1990's.

COMPANY ORGANIZATIONS FOR THE 1990'S

Recent studies conclude that the downsizing and personnel reduction programs of the past ten years have greatly changed environment to be attracted. If treated casually, they will respond casually. Management should consider further training, provide some status and privileges, and pay for holidays and sick leave.

The Three Groups — Conclusions

The most difficult of policy-making will be the activities and composition of the core. Company organizations will be smaller, more intense, and younger. The company culture or esprit *de* corps will be of paramount importance. It will be difficult for older personnel to stand the pace and remain technologically up-to-date. There will be no room for incompetence and "passengers" in the developing core.

This will lead to the need for greater sensitivity at core entry and greater competition to obtain quality core workers.

REMOVING BARRIERS TO A PROJECT'S SUCCESS

A quality EPC project requires the early resolution of many issues and problems. With many projects, the early problems are not only technical issues, but people problems. These "people problems" can be caused by an individual's lack of communication skills, lack of experience and lack of commitment to projects.

THE MATRIX INTERFACE CONFLICT (MIC), IS THE MOST SIGNIFICANT DETERRENT TO SUCCESS

Matrix Theory

Most projects are executed in a matrix organization environment where projects are executed by many departments carrying out the work, usually without adequate decision-making authority of the project manager.

The fundamental of "matrix theory," in a project engineering environment, requires the project objectives and schedule/critical path(s) to be clearly defined so that all working groups would then accept, commit to, and work to, those objectives and schedule. There would be unanimous support from all, so that all would be working to the same set of priorities and objectives.

With a strong, project management culture and effective management leadership the matrix organization should work. In practice, it has failed. This new approach, is sweeping the industry and, when correctly implemented, does solve the MIC problems.

MICs Reality

The author's experience has shown the existence of MICs to be the NORM, where most "matrix" supporting groups ignore "the program" and replace it with their own approach.

All major studies carried out in the last ten years have come to the same conclusion. Our failure to make the matrix work, is the single, biggest problem. One such study, carried out in 1982, by Folger & Company, was entitled, "The Project Manager Speaks Back" and was a survey of project managers, working in a matrix organization, for twenty major contractors and ten large owners.

The following, was one of the survey's conclusions:

"... The consensus opinion is that most problem areas are INTERNAL rather than external in nature. Over 90% of the project managers stated that conflicting interests and struggles with department managers was their chief problem."

EXAMPLES OF MICs:

Below are some common examples of issues which contribute to organizational conflicts.

- "Turf" Protection Issues
- Conflicts of Interests
- Misplaced Departmental Loyalties
- Management/Supervisory Egos & Jealousies
- Empire Building
- Lack of "Project" Understanding
- Little/No Commitment to the Project Management Function
- Negative Policies & Procedures — Project Management Inequality
- Adversarial Relationships ("Us & Them")

Overcoming MICs

Based on the author's direct, personal experience, only one company has developed a Culture that has substantially overcome MICs. The major reason for this success, is that this company has an effective Quality Improvement Process/Program (QIP) in place and operational. However, it will take many years for the industry, as a whole, to develop an effective QIP. In the interim, the only effective tool to overcome the MICs, is a well developed project management power base(s). Paul Hersey and Walter Natemeyer, developed these "power bases" as tools for influencing others. Once developed, these "power bases" were then sent to a "survey group" of 146 project managers, all of whom were working in a matrix environment. The project managers were asked to rate the power bases in relation to an outstanding project manager.

The material on these project management power bases has been developed as a workshop and requires the project teams to carry out a function, similar to that of the 146 project managers, by assessing the components which make up each power base.

Typical Examples **of** MICs

Where the tail, constantly wags the dog. The dog, is the project manager and the tails are, all supporting work groups.

a) Operations & Production Interface (Owner Operation)

In this example, the operations/production group are the project manager's client.

Conflicts of interest and lack of project understanding, by the client, are common problems. This results in poor scope definition, constant changes in scope, lack of project discipline and the development of adversarial relationships, whereby costs increase and schedule slips. Company structure and policy often contribute to the problem. On the one hand, company management holds the operations/production group directly responsible for the efficiency, quality and volume of the plant. Management, then holds the engineering department responsible for ensuring that all plant capital projects, required to meet production goals, are technically and economically viable. This gives the company "protection" through a "Check and Balance" system, but it can and does, create people problems through the "divided responsibility."

Operations, functioning as the client, believe their stated needs are adequate and simply require the project engineering group to "do the work" and immediately. Technical and economic evaluations are unnecessary, they say. and when the evaluations demonstrate that the "stated needs" are not adequate, a MIC can easily occur, and does occur; and is exacerbated by the inequality of the project manager.

This is not to suggest that the "check and balance/divided responsibility" structure should be changed. What is required is that senior management reinforce the project management function and raise its status within the company, so that the image and responsibility of the two groups became more equal and balanced. Constant training of project management and upgrading the program would also reduce the "GAP" between the two groups. Lack of training and poor programs are common.

b) Purchasing Interface

By company policy, project and discipline engineers are often not allowed full access to commercial information on equipment/material bids. This has led many procurement departments to a "pre-eminent" position and, essentially, become "the tail, wagging the dog." The project management function should include the business analysis and decision-making role, particularly for all equipment and material purchasing.

The purchasing department should be in the support position and provide a "full service" function.

If discipline or project engineers cannot properly evaluate technical and commercial considerations at the same time, or cannot be trusted with sensitive commercial information, they should be trained to handle these responsibilities.

Many owner project managers resolve this problem by contracting out the purchasing function to contractors, (usually reimbursable basis), where they have direct control.

c) Accounting Interface

Accurate and timely cost data is essential for effective project control. The accounting/cost reports need to be available some three days after the cut-off reporting period.

This is rarely the case!

The common situation, is for the accounting/cost report to be issued two/four weeks after the cut-off date. In many cases, the project engineering/project control groups establish their own cost commitment data base at significant cost and effort.

The problem is that capital project work is a small part of the financial activities of most accounting groups. Also, many accountants have little understanding of the need of project personnel for accurate and timely cost commitment figures.

Resolving the problem is relatively simple. It is to establish a project cost accounting group (two or three people, usually,) within the accounting department with these people receiving daily direction from project engineering. To say it is relatively simple in solving the problem is a complete understatement, as most company managements do not have the understanding or the will to direct that such a group be established. Most accounting groups belong to financial divisions of a company where the financial V.P.. or controller is in charge. Such individuals are rarely conscious of, or sympathetic to, project management needs. MICs occur at senior management levels, as well as at intermediate and junior levels.

The New Company Culture

This new culture has resulted from the self-examination that many companies have undertaken, or are now undertaking, in order to improve their quality of performance. The major focus has been on the principles and process of leadership, customer requirements/satisfaction, employee needs, market share, and a detailed examination of the oraanizational structure.

Typical and common programs of the self-examination process include the following:

- Personnel leadership at all levels
- Employee involvement in company policy
- Benchmarking (methods and procedures)
- Employee empowerment
- Management inspection process
- Manager as a role model

Personal Leadership At All Levels

The focus is that the company is a quality company and that its employees are the heart and engine of the company. Quality improvement through the exercise of leadership skills is, therefore, the responsibility of every employee. This results in the following:

- Positive, open personal relationships
- Effective personal/departmental communications
- Commitment to company/project objectives
- Constant evaluation of quality of services

Employee Involvement In Company Policy

Employee involvement efforts typically require group problem-solving. Standing committees or quality groups are established to develop and monitor organizational relationships, operating procedures, quality standards, personnel appraisals, job duties and work expectations.

This effort develops company esprit de corps and the feeling that the employee is directly involved in company policy and its decision-making process.

Benchmarking (Methods and Procedures)

Benchmarking identifies the gap between current company methods and procedures and the latest state-of-the-art. The gap identifies the need for change, the dimension of the change, and the result that can be achieved by changing. The need for change is evident only when the latest state-of-the-art techniques are recognized and it is realized that current company methods are outdated.

The problem experienced by many companies is in actually knowing the latest state-of-the-art techniques. A quality training program and methods development department can greatly assist with this problem.

Employee Empowerment

With the focus on quality and leadership, employees are given the authority to make changes to improve their work processes. This results in building a more effective and productive work force. However, individual employees can abuse the empowerment process through lack of thought and lack of experience and can, therefore, reduce their productivity and effectiveness.

Typical examples of empowerment are the self-quality responsibility of manufacturing lines, where the production workers can stop production for poor quality. At the same time, they must identify the problem/cause to management.

Management Inspection Process

The manager is the key. The manager is a key link in the implementation of the new "culture." The manager's role is to learn, use, teach, and inspect the new processes and tools. The inspection process has special meaning in this context. This type of inspection is not the traditional concept of evaluating results, but W. Edwards Deming's notion of inspecting the steps (the process) used to accomplish the results. Inspection is a vital ingredient in continuous quality improvement. The emphasis is on coaching, not judging. The manager continually asks "why?" in order to understand actions, conclusions, and decisions. He or she ensures that the team is consciously following the correct processes and applying appropriate tools to identify, analyze, solve problems, and continuously improve. This process helps to prevent errors or wasted efforts. It also requires that the manager coach people in their current work; teach them the use of quality processes and tools; and encourage them to become self-inspecting.

The following guidelines support the inspection process:

- Begin and end with positive feedback.
- Do not overload the team with information.
- Reduce/control negative feedback.
- Where possible, include specific answers.
- Ask questions; obtain specific answers.
- Do not do all of the talking.
- Focus on improvement, not the errors/problems.
- Help the group to summarize the necessary action items.

It is essential, if the process is to work, that the manager be skilled in the development and application of the working tools.

If the manager is not skilled, the process will fail.

The manager's behavior. Key interactive behaviors that are recommended for use by the manager in the inspection process include:

- Seeking full and complete information
- Testing understanding of each team member
- Observing carefully
- Listening actively
- Supporting, positively
- Building, constructively
- Proposing options and alternatives
  Summarizing the complete process
- Giving information, as required
- Disagreeing, when necessary

The Manager As A Role Model

Development and implementation of the leadership/quality processes and tools require significant support and initiative from managers at all levels of the company. The role of the manager includes activities. such as a teacher and leader, to establish work processes in the work group that are commensurate with the principles and guidelines of "leadership through quality performance." Managers are expected to do the following:

- Provide consistency, clarity, and continuity of purpose for the organization based on meeting customer requirements and project objectives for his or her group

- Seek ever more creative ways for involving people in solving the problems they face in pursuit of their goals

- Ensure that the processes and solutions being implemented are cost effective

- Be responsible for continually improving the system in which subordinates perform their tasks

- Ensure that employees within the organization diligently practice the quality performance and leadership processes, monitor their efforts, make suggestions, help in the implementation, and evaluate improvement.

- Ensure that subordinates receive training and reinforcement in quality methods and procedures to monitor the performance of their activities

- Act as a role model in these same skills by learning and using them.

The manager is required to develop skills and practices to coach and facilitate the process. He or she will set standards that fully meet quality performance and support their employees' team activities to solve problems and help improve the system. It is important for the manager to learn the required processes, use the processes, teach by example and by direct involvement, and inspect the use of the process.

The "New Culture" — Summary

Effectively carried out, the new company culture can result in the following:

Company Philosophy

- We succeed through satisfied customers.
- We value our employees.
- We aspire to deliver excellence in all we do.
- We require a cost effective program.
- We use the latest methods and procedures.
- We behave responsibly as a company citizen.

Company Priorities

- Meeting and beating project objectives.
- High customer satisfaction.
- Improved company profitability.
- Increased market share/company reputation.
- Developing highly skilled personnel.

Appendix A
Sample Schedules

This appendix includes schedules based on actual engineering and construction of various facilities.

Included are the following:

A-1 Schedule of an Energy Cost Reduction Project
A-2 Schedule of a Solid Waste to Energy Facility
A-3 Schedule of a Simple Cycle Combustion Turbine Cogeneration Project

A-1 Project Schedule for an Energy Cost Reduction Facility

Based upon the information provided to engineering/construction firms regarding execution approach and preliminary assessment of the size and duration of thirteen (13) months from receipt of "Authorization to Proceed" to "Commercial Operation" was prepared. The Proposed Project Schedule is included herein.

Engineering and design effort indicated on this document is estimated to require a duration of six (6) months from "Authorization to Proceed." Four (4) months have been allotted for the "Pre-Construction Phase - Part A" and nine (9) months have been allotted for the "Construction Phase - Part B" from award of the first subcontract to "Commercial Operation."

The schedule has been prepared based upon the following assumptions:

- The use of multiple subcontract construction labor to expedite the flow of work and optimize the schedule duration.
- Client will provide timely reviews of and approvals of specifications, bid tabulations and engineering and design drawings.
- Existing plant documents, drawings and calculations are assumed to be available and will be provided in a timely fashion to support engineering and construction requirements.
- Vendor information for equipment purchased by client will be available to support design.

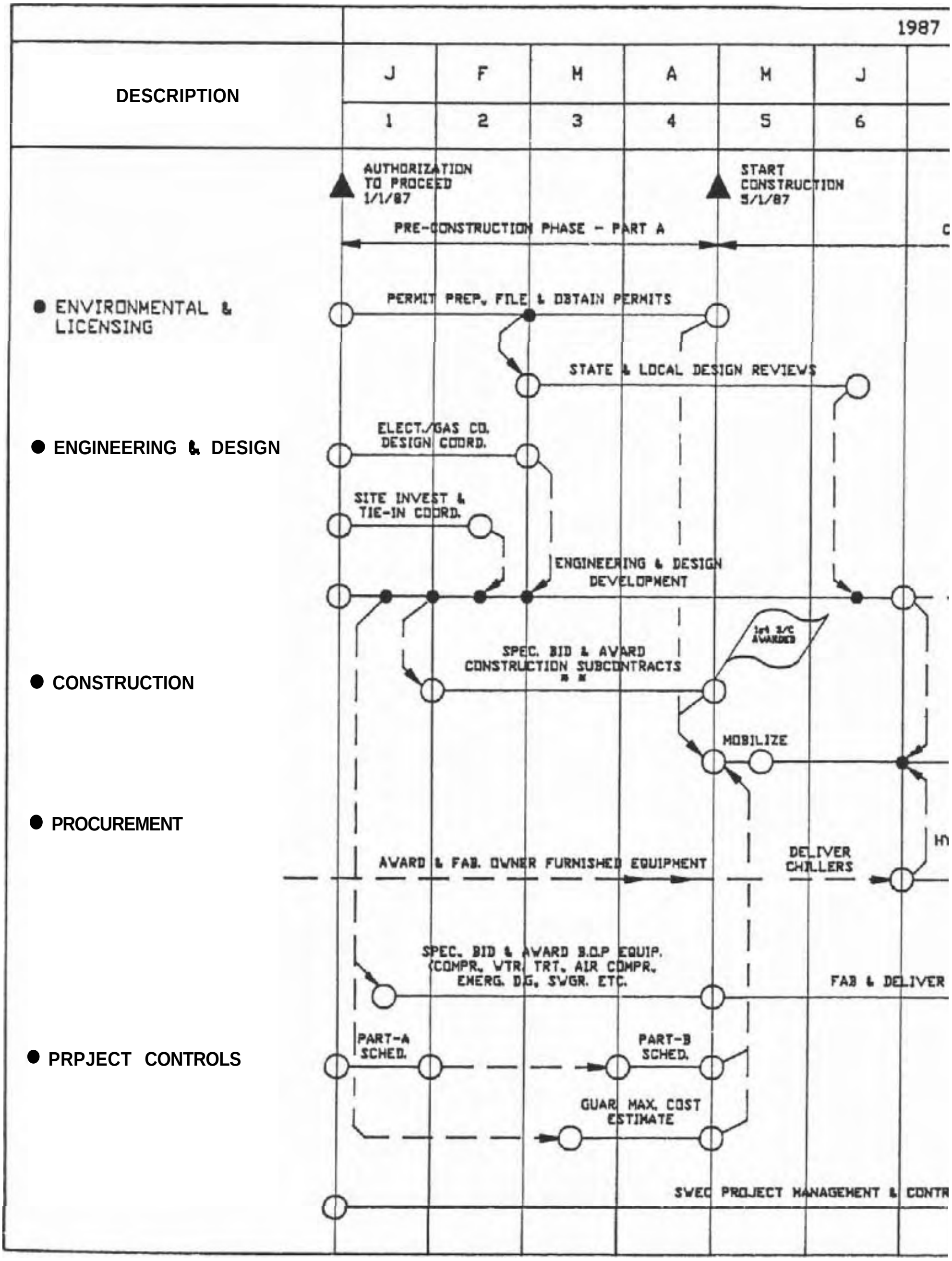
- Equipment deliveries for equipment purchased by client will be satisfactory to the construction schedule proposed.
- Material and equipment deliveries are based upon present market conditions which are assumed to prevail for the duration of the project.
- Interfaces with existing plant systems can be accomplished within the allocated time periods.
- All permits required to start construction will be obtained by client and will not delay the start of construction as planned.
- Access to the construction site will not be inhibited during the period of construction.

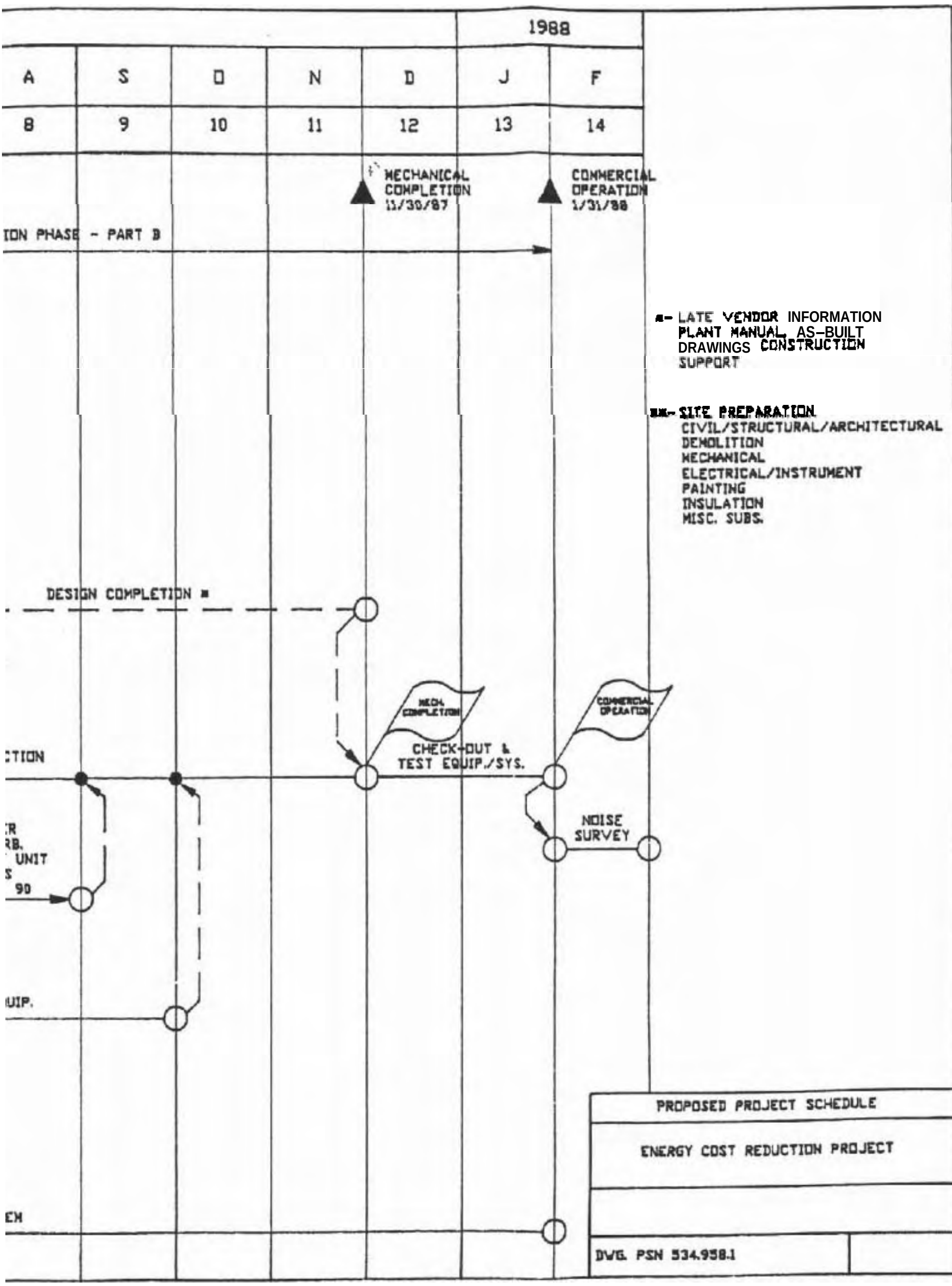
At this time, the overall schedule duration presented seems to be achievable. However, a re-evaluation will be made towards the conclusion of the "Pre-Construction Phase - Part **A**" when more technical, quantity and tie-in information is available. This document will be reviewed, expanded and optimized immediately after the project is authorized and kickoff meetings are held.

A-2 Facility Milestone Schedule for a Solid Waste to Energy Facility

Milestone	Months from Notice To Proceed
1. Initial Design Review	2
2. Completion of Specifications and Construction Drawings	7
3. Final Design Review and Modifications	5
4. Complete Major Equipment Procurement	6
5. Completion of Site Preparation	2
6. Completion of Piling	4%
7. Completion of Foundations	11
8. Completion of Superstructure	13
9. Completion of Equipment Installations (Excl. Boilers, Air Pollution Control, Scale and Residue Handing)	13
10. Completion of Construction	17
11. Completion of Start-Up	20½
12. Completion of Acceptance Testing	21
13. Scheduled Acceptance Date	21

A-1


1987
DESCRIPTION
J F M A M J
1 2 3 4 5 6
AUTHORIZATION TO PROCEED 1/1/87
START CONSTRUCTION 5/1/87
PRE-CONSTRUCTION PHASE – PART A
● ENVIRONMENTAL & LICENSING
PERMIT PREP., FILE & OBTAIN PERMITS
STATE & LOCAL DESIGN REVIEWS
● ENGINEERING & DESIGN
ELECT./GAS CO. DESIGN COORD.
SITE INVEST & TIE-IN COORD.
ENGINEERING & DESIGN DEVELOPMENT
● CONSTRUCTION
SPEC. BID & AWARD CONSTRUCTION SUBCONTRACTS
MOBILIZE
● PROCUREMENT
AWARD & FAB. OWNER FURNISHED EQUIPMENT
DELIVER CHILLERS
SPEC. BID & AWARD B.O.P EQUIP. (COMPR., WTR. TRT., AIR COMPR., ENERG. D.G., SWGR. ETC.
FAB & DELIVER
● PRPJECT CONTROLS
PART-A SCHED.
PART-B SCHED.
GUAR. MAX. COST ESTIMATE
SWEC PROJECT MANAGEMENT & CONTR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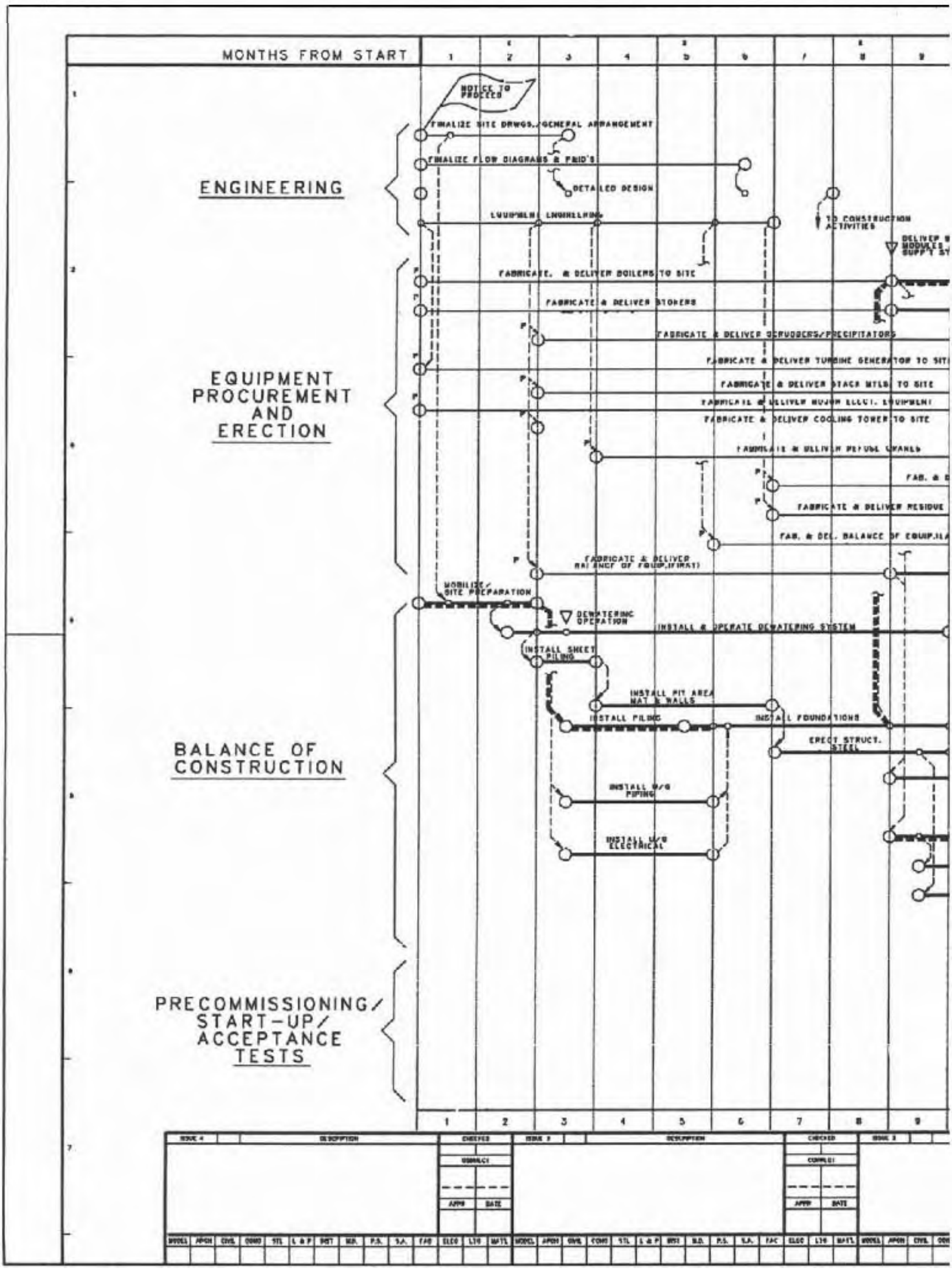
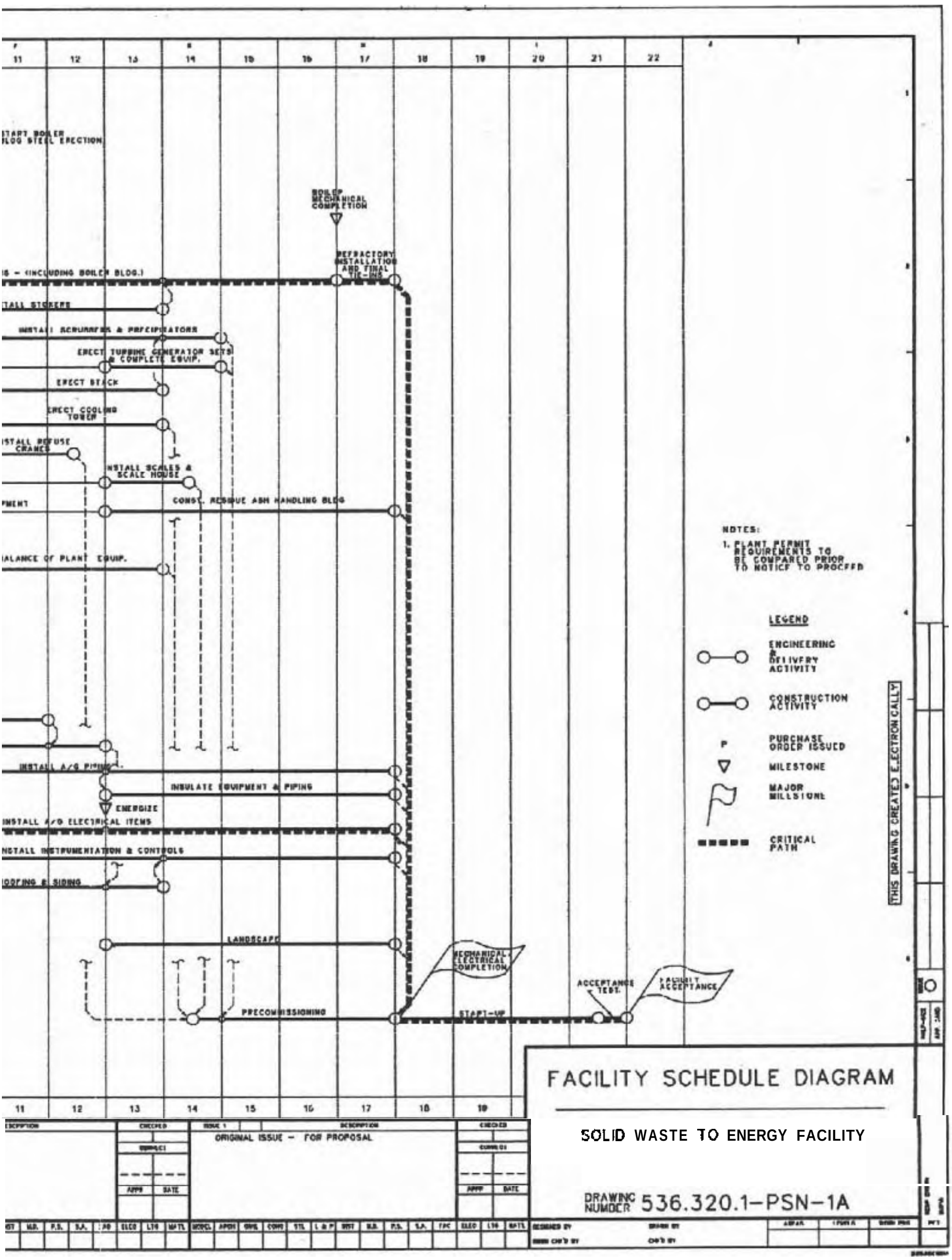
F
8
9
10
11
12
13
14
MECHANICAL COMPLETION 11/30/87
COMMERCIAL OPERATION 1/31/88
ION PHASE - PART B
* - LATE VENDOR INFORMATION PLANT MANUAL, AS-BUILT DRAWINGS CONSTRUCTION SUPPORT
** - SITE PREPARATION
CIVIL/STRUCTURAL/ARCHITECTURAL
DEMOLITION
MECHANICAL
ELECTRICAL/INSTRUMENT
PAINTING
INSULATION
MISC. SUBS.
DESIGN COMPLETION *
MECH. COMPLETION
COMMERCIAL OPERATION
CHECK-OUT & TEST EQUIP./SYS.
NOISE SURVEY
UNIT
90
UIP.
PROPOSED PROJECT SCHEDULE
ENERGY COST REDUCTION PROJECT
DWG. PSN 534.958.1

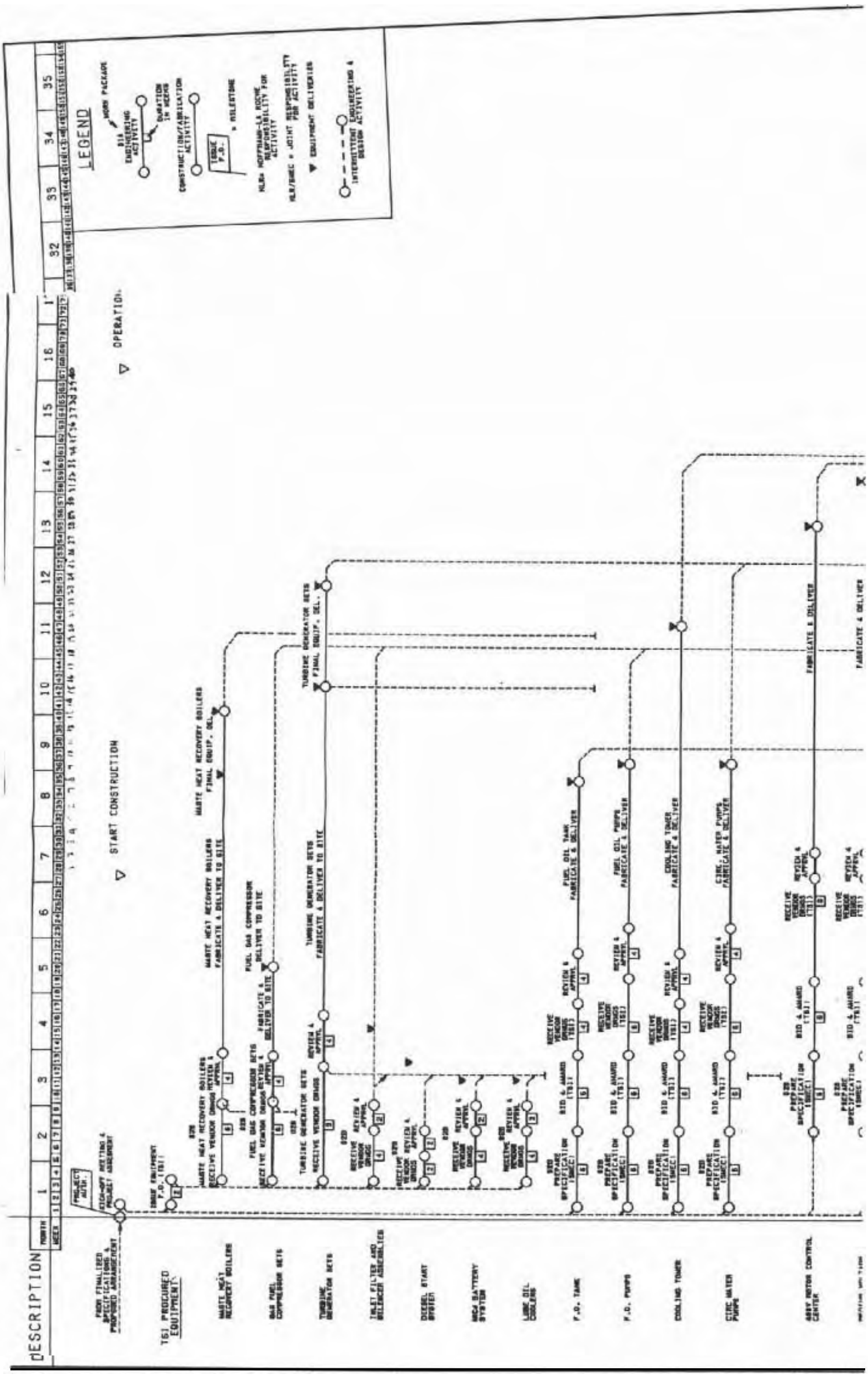
A-2

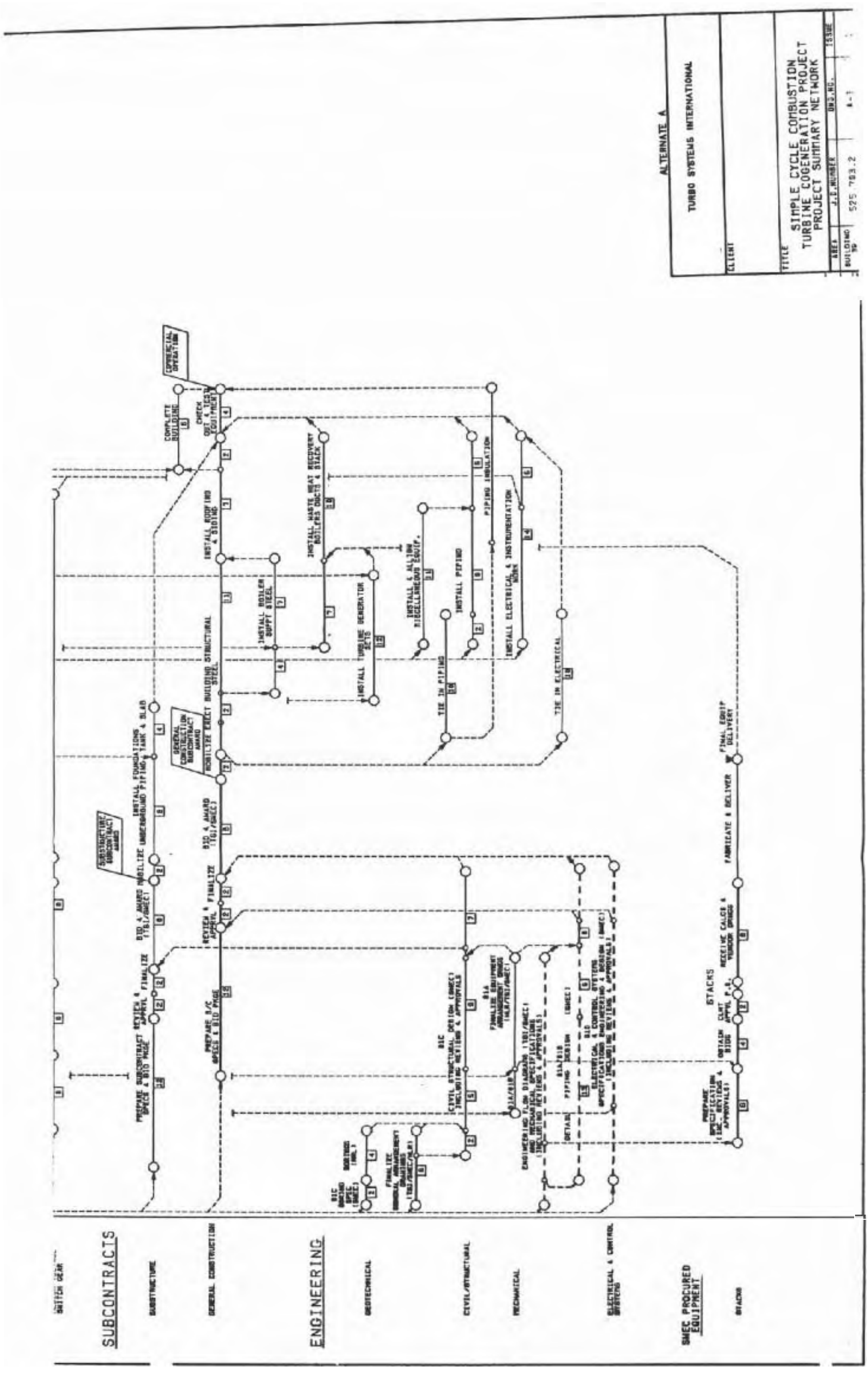

MONTHS FROM START
1
2
3
4
5
6
7
8
9
NOTICE TO PROCEED
FINALIZE SITE DRWGS./GENERAL ARRANGEMENT
FINALIZE FLOW DIAGRAMS & P&ID'S
DETAILED DESIGN
EQUIPMENT ENGINEERING
TO CONSTRUCTION ACTIVITIES
ENGINEERING
FABRICATE & DELIVER BOILERS TO SITE
FABRICATE & DELIVER STOKERS
FABRICATE & DELIVER SCRUBBERS/PRECIPITATORS
FABRICATE & DELIVER TURBINE GENERATOR TO SITE
FABRICATE & DELIVER STACK MTLS. TO SITE
FABRICATE & DELIVER COOLING TOWER TO SITE
FABRICATE & DELIVER RESIDUE
FAB. & DEL. BALANCE OF EQUIP.
FABRICATE & DELIVER BALANCE OF EQUIP.(FINAL)
EQUIPMENT PROCUREMENT AND ERECTION
MOBILIZE/SITE PREPARATION
DEWATERING OPERATION
INSTALL & OPERATE DEWATERING SYSTEM
INSTALL SHEET PILING
INSTALL PIT AREA MAT & WALLS
INSTALL PILING
INSTALL FOUNDATIONS
ERECT STRUCT. STEEL
INSTALL U/G PIPING
INSTALL U/G ELECTRICAL
BALANCE OF CONSTRUCTION
PRECOMMISSIONING/START-UP/ACCEPTANCE TESTS
DESCRIPTION
CHECKED
APPR
DATE



BOILER MECHANICAL COMPLETION
REFRACTORY INSTALLATION AND FINAL TIE-INS
ERECT STACK
INSTALL SCALES & SCALE HOUSE
CONST. RESIDUE ASH HANDLING BLDG
INSULATE EQUIPMENT & PIPING
ENERGIZE
INSTALL INSTRUMENTATION & CONTROLS
LANDSCAPE
PRECOMMISSIONING
START-UP
MECHANICAL-ELECTRICAL COMPLETION
ACCEPTANCE TEST
NOTES:
1. PLANT PERMIT REQUIREMENTS TO BE COMPARED PRIOR TO NOTICE TO PROCEED
LEGEND
ENGINEERING & DELIVERY ACTIVITY
CONSTRUCTION ACTIVITY
PURCHASE ORDER ISSUED
MILESTONE
MAJOR MILESTONE
CRITICAL PATH
THIS DRAWING CREATED ELECTRONICALLY
ORIGINAL ISSUE – FOR PROPOSAL
FACILITY SCHEDULE DIAGRAM
SOLID WASTE TO ENERGY FACILITY
DRAWING NUMBER 536.320.1–PSN–1A

A-3


DESCRIPTION
LEGEND
START CONSTRUCTION
OPERATION
T61 PROCURED EQUIPMENT
WASTE HEAT RECOVERY BOILERS
GAS FUEL COMPRESSOR SETS
TURBINE GENERATOR SETS
DIESEL START SYSTEM
F.O. TANK
F.O. PUMPS
COOLING TOWER
CIRC WATER PUMPS
FABRICATE & DELIVER


ALTERNATE A
TURBO SYSTEMS INTERNATIONAL
SIMPLE CYCLE COMBUSTION
TURBINE COGENERATION PROJECT
PROJECT SUMMARY NETWORK
SUBCONTRACTS
ENGINEERING
SWEC PROCURED EQUIPMENT

Appendix B
Cost Estimating References

A variety of publications and computer software is available to aid in cost estimating. This list is not complete but simply serves as a sample of what is available. Since the material presented is updated periodically, the user should contact the publisher for latest prices and editions.

Building Construction Cost Data 1993, Annual Editions, $74.95, available from R.S. Means Co., Inc., 100 Construction Plaza, Kingston, MA 02364, (617) 585-7880. Features of this reference include:

- New materials, fixtures, hardware, and equipment items included in each section.
- All items updated to reflect latest costs and construction techniques.
- Hourly and daily wage rates for installation crews with crew sizes, equipment, and average daily crew output.
- City cost adjustment factors for material and labor costs in 19 categories for each of 162 major U.S. and Canadian metro areas.
- Square foot and cubic foot cost section showing range and median costs for common building types with plumbing, HVAC, and electrical percentages tabulated separately.
- Special cost advantages such as owned equipment, low-cost materials purchases, and low overhead, can be identified and computed separately.
- Over 18 index pages for quick item location and cross-reference.

- Helpful examples, instructions, illustrations, and explanations of how costs were computed.

National Mechanical Estimator, by Victor Ottaviano, $90.00, available from The Fairmont Press, 700 Indian Trail, Lilburn. GA 30247: This 780-page comprehensive source reference for estimators provides accurate manhour figures, effective estimating techniques, and essential statistics on the impact of new technologies. This latest edition contains an expanded sheetmetal section, piping section, and new sections on heating and air conditioning equipment and on computers. Included are new budget prices, the latest sheetmetal programs, the most popular accounting packages, the latest nationwide productivity figures, new SMACNA gauges, 16 of the most common fittings, new industrial ductwork.

Richardson Rapid Estimating Systems, Annual Editions. Available from Richardson Engineering Services, Inc., 909 Rancheros Drive, P.O. Box 1055, San Marcos, CA 92069. The three-volume, 2,400-page set and is used primarily for commercial and industrial projects and covers:

- Civil
- Structural
- Mechanical
- Electrical
- Sitework
- Piling
- Concrete
- Masonry
- Metals Specialties
- Carpentry
- Doors & Windows
- Finishes

Process Plant Construction Estimating Standards, $387.00 per set. The four-volume, 4,000-page set, the Richardson Rapid Estimating System for PROCESS PLANT CONSTRUCTION offers complete and current standards for Chemical Plants, Manufacturing Facilities, Solids Processing, Water Treatment Plants, General Construction Projects and Buildings.

General Construction Standards set contains illustrations, a keyword alphabetical index of the total contents, and is updated quarterly; quick access to the current information.

SDSI Estimating System and the Richardson Data Base is available from SDSI Business Systems, 9528 Miramar Road, Suite 129, San Diego, CA 92126, (619) 452-5123.

Unit Price Cost Files available from ***R.S.*** Means Co., 100 Construction Plaza, Kingston, MA 02364. ***Unit Price Cost Files*** can be used only in conjunction with Lotus 1-2-3. R.S. Mean's software programs, Astro, Galaxy and Pulsar, are now available from Software Shop Systems (800)-354-6192.

Bid Master available from Estimation, Inc., 805L Barkwood Court, P.O. Box 488, Linthicum Heights, MD 21090, 1-800-235-7078.

This computer software system allows estimators to do material takeoff for electrical, mechanical, HVAC systems utilizing a count probe and estimating keyboard. The length probe is used to trace the length of linear area for calculating length of ductwork, pipe, etc., on a blue print. Each item is then factored for material, labor prices and byproducts. As an alternate to estimating keyboard and probes, system can be used with a sonic digitizer. All measurements can be taken off with a stylus and touchpad without touching the keyboard.

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