PLANNING, ESTIMATING, AND CONTROL OF CHEMICAL CONSTRUCTION PROJECTS

SECOND EDITION
REVISED AND EXPANDED

PABLO F. NAVARRETE
WILLIAM C. COLE

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FOREWORD TO THE SECOND EDITION

Pablo has done it again. In collaboration with Bill Cole, he has updated and extended the coverage of his outstanding First Edition to incorporate an even wider perspective of state-of-the-art, business-driven capital project delivery processes and techniques. The added coverage relating to framing and selecting the "right project", the Venture Manager, regulatory compliance, risk analysis, and plant start-up now embrace the full capital project delivery system. Unlike many other books on this subject this is clearly an excellent, convenient, self-contained reference for "hands on" practitioners. It addresses the "what," "why," "who," "how," and "when", with clear examples and a valuable database of frequently used metrics. A must reference for today's lean and mean capital project practitioner.

Louis J. Cabano, President
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Cherry Hill, New Jersey

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PREFACE TO THE SECOND EDITION

Some people manage projects, other people write books about it.

The first edition of this book was written mainly for the hands-on Project Engineer's running small projects. It provided a bird's-eye view of all facets of project execution (the what) and provided tools to perform the basic project legwork (the how).

The book was used as the basis for several seminars presented in the United States and abroad to groups of project engineers working for chemical companies. The great majority of participants had a very positive reaction. However, being good project engineers, they had many questions beyond the scope of the book.

They wanted information and guidelines on:

- Project development/economics
- Plant startup
- Overall venture management
- Estimating offshore projects
- Risk analysis
- Environmental permits

My experience in those areas is very limited. Having no intention of bluffing my way through the answers, I relied on my co-presenter at the time, Bill Cole, who jumped into the breach to hold the line, fielding all questions. Bill, with his vast experience in the operations and business end of the chemical industry (as Plant Manager, Startup Manager, Venture Manager, and Business Group Leader) is the ideal person to make up for the shortcomings of the first edition.

When Marcel Dekker approached me about a second edition I saw it as a great opportunity to expand the scope of the first edition, filling in the obvious gaps and making it a true "A to Z of Chemical Projects Execution." Bill graciously accepted my invitation to cooperate in this second edition and made time in his busy schedule to write all the new chapters.

- **Project Goals/Choosing the Right Project** (Chapter 4) discusses all the elements that make the "right" project:
  - Definition of goals.
  - Need for an experienced integrated Project Team.
  - Evaluation and economical analysis of alternatives.
  - Conscious risk analysis of both market and technology.
  - Testing and confirmation of tentative selection.
- **The Integrated Team/The Venture Manager** (Chapter 3) deals with the concerns and responsibilities of the Venture Manager throughout the project from project inception and development to plan startup, including securing environmental and operating permits on a timely basis. It emphasizes the need for adequate front end loading (FEL) and the Venture Manager's responsibility to choose the "right" project.
- **Regulatory Compliance** (Chapter 7) deals with the various permits that must be obtained and local, state, and federal regulations that must be met in addition to a multitude of technical codes and specifications that must be complied with in order to design and build a chemical facility.
- **Risk Analysis** (Chapter 8) provides a guideline to try to eliminate "unforeseen" risks and avoid or minimize the impact of all "foreseeable" ones.
- **Plant Startup** (Chapter 18) provides guidelines for the activities, organization, and split of responsibilities of startup teams in order to insure prompt and safe startups.

In addition to the above chapters this edition includes several new appendices that complement the text of both the first and second editions:

- **Execution Plan/Master Project Schedule for Case Study** (Appendix E.)
- **Construction Progress Monitoring-Case Study** (Appendix H.)
- **Semi-Detailed Estimate Example-Case Study** (Appendix L; illustrates the application of all the estimating procedures presented in Chapter 19.)

- **Accuracy of the Modified TFCF for Conceptual and Check Estimates** (Appendix M; an analysis of the performance of the modified total field cost factor, discussed in Chapter 19, in two actual projects.)
- **Offshore Estimating Example** (Appendix N; presents a rational way to convert U.S. base estimates to offshore locations.)
- **Plant Testing, Acceptance, and Commissioning Instructions** (Appendix O; comprehensive list of all the tests and activities that must be conducted by both contractor and Owner before the official transfer of "custody, care, and control" from contractor to Owner.)

Finally, Chapter 19, **Semi-Detailed Estimating System,** has been updated and expanded as follows:

- All costs have been updated and projected to early 2001 using the Chemical Engineering plant cost index of 420 which projects approximately to the first quarter of 2001.
- A section discussing the conversion of U.S. based cost estimates has been added.
- Section 19.15 on quick conceptual estimates has been expanded to cover a wider range of projects including retrofits.

Bill Cole rightfully indicated to me that many projects miss the desired goals because of the failure, during the project development stage, to identify the "Right Project" (scope) before proceeding to the execution stage and recommended that we try to do something about this situation in the second edition. The first edition put the emphasis on executing a project "right," overlooking the fact that the "wrong" project would always fall short of its goals regardless of how "right" was the execution. In the second edition we have tried to close this gap, giving business and venture managers food for thought and guidelines on how to come up with the "right" project, thus shifting the emphasis from how to **execute** a project **right** to how to **choose** the **right** project and **execute** it **right**.

We tried to write a book on "Everything You Always Wanted to Know About Chemical Project Execution But Were Afraid to Ask." I hope we have succeeded and that a copy of this book will eventually find its way to the desk of every engineer and businessperson associated with the execution of chemical projects.

Pablo F. Navarrete
William C. Cole

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ACKNOWLEDGEMENTS

I would like to acknowledge the contributions of my friends who made the time in their busy schedules to review and comment on the manuscript.

Lou Cabano, Jim Houle, and Wayne Schrock read the entire manuscript and adding many valuable comments and suggestions. Carlos Levy and Parker Dean reviewed the chapters on Project Control and Environmental Protection and contributed valuable comments.

Many of their comments and suggestions have been incorporated in the final text and have enhanced the value of the book. I thank all of them.

My daughter Teresita Arritt deserves a very special mention. Not only did she do a wonderful job of formatting, art work, and preparation of camera ready material, but provided invaluable advice in editing and interfacing with the publisher.

Thank you Tere, I could not have done it without you.

Pablo F. Navarrete

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FOREWORD TO THE FIRST EDITION

I wish that as a young engineer starting out in project management I had had this book. Experienced project managers had their collections of data, and one could always find books on the theory of project management; however, the data available were often inconsistent, and there was rarely an explanation of what it actually represented. Understanding the theory is great, but it does not give one the data and detail required to actually manage, estimate, schedule, or contract.

In our contacts with plant project managers, we at FMC recognized that this informational void still existed and commissioned Pablo Navarrete to fill it. This book represents the result of that effort. In addition to committing his knowledge to writing, Pablo has conducted many courses for our plant project managers and found that this material is just what they needed.

Although real data are a unique strength of this book, the text also provides theory and valuable guidance through checklists, *do's* and *don'ts*, and typical problems and corrective actions. As novice project managers plan, estimate, schedule, contract, and actually execute their projects, they will understand what is important, the *whys* as well as the *whats*.

William K. Wakefield, Director
FMC Engineering Services
Princeton, New Jersey

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PREFACE TO THE FIRST EDITION

An engineering project can be defined as a one-time endeavor to achieve finite quality, cost, and schedule objectives. When so defined the term applies to more than just the megaprojects initiated at a high corporate level and managed by experienced senior project managers supported by teams of project engineers and specialists, as well as purchasing agents. The term also applies to the small projects initiated by plant operations and/or maintenance and executed, practically single-handedly, by plant project engineers or, occasionally, by junior members of corporate engineering departments.

A vast majority of projects in the chemical industry fall under the last category. Yet, during my many years as a project engineer/manager reading books and going to seminars about project management and control, I found that most of them are addressed to project and business managers. They deal mostly with the business and financial aspects of projects rather than with the actual execution details. They take much for granted and fail to delve into the *what* and *how* of the basic project legwork. It was always very difficult to find hard, practical data I could use in my day-to-day work.

I hope to fill the vacuum I perceive in the current project execution literature by offering project engineers and budding project managers a bird's-eye view of all facets of project execution (the *what*) and providing tools to perform the basic project legwork (the *how*).

This book is written for the hands-on project engineer, the guy in the trenches, the project roustabout, who "makes things happen" and insures smooth project execution, the guy who can make or break a project, without whom very few projects would be successfully completed.

Although this book is essentially a guideline for the execution and control of small projects, the concepts and techniques discussed can be applied to the various levels of project expertise and project complexity as well as the types of involvement in the project execution process. This book will be valuable to all those involved in the development, execution, and monitoring of chemical projects:

- For the **student** as well as the **novice project engineer/manager**, this book will provide the project ABC's.
- For the **managers** of small projects, it will be a tool box for their hands-on participation in all execution activities either by actual performance or checking the contractors performing them.
- For **seasoned project managers** in charge of major projects, it can be a refresher course in project management and a thorough checklist of project activities. It also provides quick and easy ways to spot check the general contractor's work.
- The **supporting staff, business, production** and, especially, **venture managers** will find the material presented of the utmost interest. The insight it provides on the execution of chemical projects will certainly enhance their performance and benefit all projects.
- **Engineering contractors** will also find the estimating tools presented in Chapter 12 very useful for the quick preparation of the preliminary estimates frequently submitted with proposals, as well as for checking their own definitive estimates.

This book reflects my personal observations, project execution practices, and opinions on how projects should be run. The procedures and guidelines presented were developed through the years to preserve and document those practices and ideas that not only proved to be accurate and time effective, but could also be implemented by simple manual means.

The proposed estimating and control procedures are not intended as substitutes for the detailed and sophisticated methods normally employed by contractors and propounded through the commercially available computerized programs for project management and control. They are intended to be tools to help the project engineer/manager evaluate project alternatives or monitor contractors' estimates and progress reports with limited in-house resources.

Like most project managers, I have been involved in and/or observed my share of bad projects. I am firmly convinced that most of the bad ones could have been avoided if these estimating and control procedures had been available and the recommended execution guidelines had been in effect.

I would like to share my experience with other project engineers/managers in the hope that doing so will promote their thinking, spur their creativity, enhance their performance, and result in a very high rate of successful projects.

In the summer of 1991, FMC Corporation asked me to prepare a Project Execution Guideline for the project engineers assigned as project managers for small projects that cannot justify the cost of a designated project team or a full-blown engineering and construction contractor.

A project manager working under those circumstances must be versatile and capable of personally executing many of the project tasks. To do so, the project manager needs tools. Thus, what was initially perceived as a rather simple guideline had to be complemented with a "tool box." For that purpose, I dug into my personal files for information compiled and/or developed through 30 years of project work and updated and organized it for easy use by the project managers. The final product is not merely a guideline for the execution of small projects. It can also be a powerful tool for the project manager monitoring engineering and construction contractors executing projects of any size.

This is not a design book nor is it a cookbook. It is a guideline and thought provoker to point project managers/engineers in the right direction and promote creative thinking. They should become familiar with the proposed tools and view them not as ultimate goals, but rather as starting points to either modify them or develop new ones that reflect their own experience and address specific needs. To improve your own chance of success, it is important to remember that:

- Simple tools are the best tools.
- Every project is unique.
- There is no such thing as a recipe for successful project execution.

I want to express my gratitude to FMC Corporation and its Director of Engineering Services, Bill Wakefield, for their cooperation and patience during the last three years. In supporting the publication of this book, they have reaffirmed their commitment to the CICE guideline of sharing project execution information in order to enhance the performance of the entire construction industry.

Many friends and coworkers contributed in one way or another. Some, like Nancy Buschman, Jack Gallagher, Jim Houle, and Bill Wakefield, provided very valuable comments and suggested changes. Others, like John Nabors, Manny Oconer, and Dick Troell, allowed me to use some of their personal notes. Finally, Wayne Schrock's proofreading made this a better book. I thank all of them.

A very special acknowledgment must go to my good friend, Jay Stewart, for making time in his busy schedule to develop the cost data for the electrical estimating procedure. I could not have done it without his help. Thank you, Jay!

Pablo F. Navarrete

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CONTENTS

PLANNING, ESTIMATING, AND CONTROL OF CHEMICAL CONSTRUCTION PROJECTS

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CHAPTER 1
INTRODUCTION

No project is so big you don't have to worry about the details. No project is so small you can't screw it up.

1.1 Scenario

The Owner in the text is assumed to be a multidivision, medium sized chemical company with manufacturing operations in various locations. The execution of engineering and construction projects is handled by a Corporate Engineering Department (CED) with a large process engineering and control section also staffed by a group of project managers, control engineers, and a limited number of specialists:

- Estimating.
- Cost control.
- Contracting.
- Mechanical.
- Electrical.

The project managers are usually assigned to the larger projects that are executed in a conventional manner through engineering contractors acting as general contractors. The project engineers are normally assigned either to support the project managers in conventional projects or to act as project managers in smaller projects.

Although CED has a strong process engineering group, it has minimal, detailed design capabilities and relies heavily on engineering contractors and, to some extent, on plant engineering groups, some of which have limited capabilities. CED expertise is in the areas of process engineering and project management and control.

Projects are initiated, developed and sponsored at the Division level. The Division in turn delegates the execution of engineering and construction to CED, while retaining the overall responsibility for all project activities. The Division discharges its responsibilities through a venture manager who coordinates the work of the various groups: R&D, marketing, production, CED, etc. In this scenario, the Venture Manager represents the business interests and has the ultimate responsibility for all phases of the project from the marketing studies to the start of the facility. The physical execution of the project - process design, engineering, procurement and construction - is the responsibility of a CED Project Manager/Engineer reporting to the Venture Manager. The typical coordination procedure in Appendix C illustrates the responsibility breakdown among the members of a venture team.

On the larger projects, CED takes a conventional approach and assigns an experienced project manager, supported by an in-house project team, to direct and supervise the activities of the contractor(s) retained to do the actual work.

CED must also execute many small projects that, if handled in the conventional way, would increase cost and overstrain the limited in-house resources. These projects are assigned to versatile, hands-on engineers (not necessarily experienced project managers) capable of performing personally some of the activities involved in project execution and control.

1.2 The Small Project

The determining criterion to differentiate major projects from small projects is the degree of complexity, not necessarily the project cost. Occasionally, an expenditure of tens of millions of dollars could be simple enough that it might be better handled using the small project approach to conserve spending, rather than following the conventional approach used in major projects.

- A major project involves up to several hundred equipment items and purchase orders versus several dozen in a small project.
- The engineering of a major project requires dozens, maybe hundreds of thousands of home office hours, while a small project rarely requires more than 10-15 thousand.
- Construction hours in a major project usually add up to several hundred thousand. On small projects they are usually less than 50 thousand.

The complexity of the project dictates the execution approach. The coordination of a major project requires a well-structured organization, with formal lines of communication and procedures to insure quality, schedule and cost control. To achieve this, the direct execution and project control responsibilities are assigned to an engineering and/or construction firm to act as general contractor under the supervision of the Owner's Project Manager. In the conventional approach required for major projects, the general contractor is a must.

The activities associated with a small project are basically the same as a major project. However, the reduced complexity does not warrant the elaborate and formal organization provided by a large engineer/construction contractor or construction manager. In small projects, the Owner retains the direct execution and project control responsibilities and uses engineering and construction contractors, as well as in-house resources, to perform specific project activities. The Owner becomes, in fact, the general contractor. Substantial savings can be retained through the small project approach when applied to the right size of project.

In any case, the Owner's Project Manager has the overall responsibility for achieving the project objectives (cost, schedule, quality) while keeping management well informed and doing so within the framework of the applicable policies and standards.

In a major project, in addition to the general contractor, the Project Manager is usually assigned a team of engineers specifically dedicated to support the project and follow up on the details of the work to be performed and monitor progress. The Project Manager's role is mainly to provide overall direction, ascertain that proper controls are established and monitor their implementation to insure compliance to project objectives and specifications.

In a small project, there is no general contractor and the staff support will be on a limited as-needed basis. Therefore, in addition to having the overall responsibility, the Project Manager must insure that the vacuum left by the lack of general contractor is adequately filled, and must spend much of the time "in the trenches" doing things or making them happen. Since there is limited support staff to be delegated, the Project Manager must be prepared to take on many roles.

In a major project, the Project Manager is an experienced project manager. whereas the small project manager could be a project engineer or even a process or specialty engineer with a varying degree of project experience. The small project manager must compensate for any lack of experience with a high level of energy and willingness to be immersed in all aspects of the project. The Project Manager for a major project must be:

- A thinker.
- An organizer.
- A delegator.

- Able to maintain perspective.

On the other hand, the small project Project Manager must be:

- Versatile.
- Flexible.
- A doer.
- Someone with a can-do attitude.

Both must be:

- Proactive.
- Decision makers.
- Able to get along with people.
- Someone with a good feel for cost!

PROJECT MANAGERS CANNOT ACHIEVE FULL POTENTIAL WITHOUT A GOOD SENSE FOR COST.

This book will provide all project managers and engineers acting on behalf of owners effective yet simple tools and guidelines to optimize all phases of project execution, thus enhancing the overall project performance.

CHAPTER 2
THE PROJECT

Projects are like life itself – they have a beginning and they have an end. If a project does not have an end, then it is not a project.

2.1 Introduction

A project may be defined as a one-time deliberate effort to achieve a set of clearly predefined objectives.

The term applies to many types of endeavors. Some entail intellectual work: e.g., writing a book, doing some specific R&D work, developing a computer program. Others deal with physical work: buildings, roads, industrial plants, etc.

Although some of the principles and guidelines proposed in this book could be applied to any type of project, they are specifically intended for the construction or rehabilitation of chemical plants.

As shown in Table 2.1, the project activities are divided into three well-defined parts:

- Front End Loading (FEL).
- Engineer, Procure, Construct (EPC).

Table 2.1 The Project

VENTURE MANAGER					
	PROJECT MANAGER				
FRONT END LOADING				EPC	STARTUP
Business Planning	Project Development	Preliminary Engineering	Contractor Selection	EPC	Startup & Operation
Market Study				Basic Engineering	
Process Selection	Site Selection		Bid Preparation		
Project Economics				Detailed Eng.	Check Out
Risk Analysis			Bidders Selection		
Process Engineering				Procurement	Startup
Conceptual	Phase 0	Phase 1	Bidding		
Estimating				Construction	Operations
Order of Magnitude	Preliminary	Appropriation	Evaluation		
Initial Plan of Action	Execution Plan / Master Schedule			Construction Management	
	Preliminary	Firm	Award		
			Contract		
Regulations Compliance					
Project Control					
Communications					

- Startup.

The execution of a project involves a series of activities covering a wide range of management, engineering, and control functions. It is the responsibility of both project managers and venture managers to insure the thorough and timely execution of those activities in order to bring projects to a successful conclusion.

To fulfill their responsibilities, project managers must participate actively and in a deliberate manner by actually performing some of them and directing or coordinating the others. This is particularly true in small projects where the Owner's project team must perform the functions normally done by the general contractor.

The succeeding paragraphs summarize the project activities, discuss the Project Manager's participation, and emphasize the differences between small and major projects.

Although 85-90% of the costs are incurred during the EPC part the of the project, quality, cost, and schedule is determined during the front-end-loading stage.

2.2 Front End Loading

Business Planning/Project Development

Projects are initiated at the management level either to take advantage of a perceived business opportunity or to comply with a mandatory government regulation, usually concerning environmental protection.

The initial work is done under the direct responsibility of the Venture Manager:

- Market studies.
- Process/site selection.
- Project economics.
- Risk analysis.
- Process design.

The Project Manager usually joins the project during the project development stage and supports the Venture Manager by providing:

- Order of magnitude and preliminary cost estimates.
- Initial plan of action.
- Execution plan and master schedule.

Initial Involvement/Plan of Action

Promptly after being assigned to the project, the Project Manager must contact the Venture Manager to review the project scope and objectives and determine whether further scoping is required. This meeting should be documented with a memo confirming the Project Manager's understanding of the scope and objectives. The Project Manager must then prepare and publish, as soon as possible, an initial plan of action. This plan of action must address all the activities required for the preparation and approval of an AFE (authorization for expenditures) and assign execution responsibilities within the organization. The plan of action must also address the feasibility of the desired schedule and, when necessary, sound the alarm and propose remedial alternate solutions.

Process Design (Phase 0/Phase 1)

A process design package is the detailed definition of the proposed facility and must be completed before the detailed engineering activities can start and proceed effectively. Although the actual process design is done by others, the Project Manager must participate actively, providing project engineering and cost input to insure a cost-effective design.

Estimating

Estimates for large projects are normally prepared by staff estimators or a contractor. However, the Project Manager must be capable of at least spot-checking them and ascertaining that sufficient information is provided to prepare realistic execution plans. On small projects, the Project Manager is frequently required to prepare estimates and is expected to be capable of doing so.

The semi-detailed estimating system and related procedures presented in this book will allow project managers to prepare reasonably accurate estimates very quickly and confirm the validity of estimates prepared by others even quicker.

Project Execution Plan/Master Project Schedule

One of the most important project management activities is the preparation of realistic execution plans. Project execution plans can, and should, be prepared for any type of estimate: conceptual, preliminary, and definitive. It is the Project Manager's responsibility to prepare them. A thorough execution plan must address:

- Engineering, equipment delivery, and construction schedule.

- Interdependence of key activities.
- Contracting strategy.
- Assignment of responsibilities.
- Home office and field staffing (average and peak).
- Base progress curves.

2.3 Engineer, Procure, Construct

Contractor Selection

Contractor selection is probably the activity that has the most lasting effect on project execution. A poor design or a bad estimate can always be revised and, if caught in time, the effects minimized. Changing a contractor after the work has started is a very difficult proposition that always has a negative impact on project cost and schedule.

The prime responsibility of contracting falls upon the Project Manager who must live with the selected contractor and make it perform. It behooves the Project Manager to take a very active participation in contracting activities and be thoroughly familiar with all contractual terms and conditions.

Detailed Engineering

Detailed engineering in a small project is a mixed bag and could be executed by a combination of the following:

- Plant engineers.
- Staff engineers.
- Small local engineering firms.
- Large engineering firms.

Note: When engineering firms are retained, the scope of their work must be limited to clearly defined design work.

In all cases, the Project Manager must coordinate and monitor the activities of all groups and generally provide the management usually provided by a general contractor.

Procurement

Procurement in a small project is usually a joint effort between CED and the plant's purchasing department. Normally, the Project Manager, with help from CED specialists, as required, writes the requisitions, and the plant writes the purchase orders. Expediting and inspections can be provided by either one. However, it is up to the Project Manager to keep up with delivery schedules and take the necessary action to correct slippages.

Construction Management

This activity in small projects is directly performed by the Owner. The Project Manager is also expected to be the Construction Manager. Frequently, the work is delegated to another engineer or to a member of the plant staff, but the overall responsibility remains with the Project Manager.

The Construction Manager is expected at a minimum to:

- Organize and supervise all field work.
- Coordinate the interface between the various contractors.
- Coordinate construction with plant activities:
  1. Control change orders.
  2. Enforce plant rules and regulations.

Project Control

> PROJECT CONTROL IS A CONTINUUM AND IS EXERCISED THROUGH THE EFFECTIVE EXECUTION OF ALL PROJECT ACTIVITIES.

The Project Manager is expected to identify and correct cost and schedule variations and make accurate forecasts of both, and to keep management informed on a timely basis. In a major project, the Project Manager's activities are usually limited to monitoring and spot-checking the general contractor's reports. On a small project, the Project Manager must establish and implement control procedures to monitor work progress with minimum effort and reasonable accuracy.

Contract Administration

The Project Manager's concern is not only the physical conduct of the work, but also the implementation of all contractual conditions, especially those asserting the Owner's right of approval and control of the purse strings.

Communications

Keeping management well informed avoids unpleasant surprises and allows it to exercise overall project control. It is essential that the Project Manager report accurately, factually, and promptly all problems, errors, significant cost variations, and potential problems. The most critical requirement of any report is that it "tells it like it is."

> PROBLEMS AND POTENTIAL PROBLEMS MUST BE FACED REALISTICALLY TO PERMIT TIMELY CORRECTIVE ACTION.

Regulations Compliance

The ever-increasing concerns about safety and environmental protection have resulted in very stringent government, federal, and state regulations to control the design, construction, and operation of chemical plants. Failure to comply with them will result in severe penalties.

It is up to Venture and Project Managers to be aware of all applicable regulations and insure that they are complied with. In certain cases the law makes them personally responsible and liable for accidents or damages resulting from noncompliance.

2.4 Startup

The project is not finished until the new facilities are demonstrated at design conditions. This takes an intense effort led by the Manufacturing Manager, engineers, operators, and other craftsmen. The rest of the project team are waiting in the wings to assist the Startup team in correcting any deficiencies that must be addressed before the project is considered complete.

CHAPTER 3
THE INTEGRATED TEAM/THE VENTURE MANAGER

Make sure your management keeps the same people on the team – without continuity good integration is not possible.

3.1 Preamble

In the last chapter we discussed the phases of a project: what was occurring, who had primary responsibility, and the role of the Project Manager during each phase. This chapter deals in more depth with the integrated project team charged with carrying out the project, and the Venture Manager who bears the ultimate responsibility of selecting the "right" project.

> THE STUDY OF SUCCESSFUL PROJECTS BY MANY COMPANIES HAS SHOWN THAT PROJECTS THAT HAVE AN INTEGRATED TEAM WITH CONTINUITY OF MEMBERSHIP PERFORM BETTER THAN PROJECTS NOT HAVING THOSE COMPONENTS.

3.2 The Integrated Team

Responsibilities

The **responsibilities** of the integrated team include:

- Providing a clear definition of the project scope.
- Identifying all reasonable alternatives to meet the scope.
- Selection of the best alternative to meet the scope.
- Development (or oversight) of an adequate Front End Loading (FEL) package.
- Oversight of the prime contractor to ensure the timely and cost-effective execution of the design, procurement, construction, and startup.
- Representing the various stakeholders during the project execution.

The integrated team will be formed as early in the project sequence as possible. Membership will include but is not limited to the following full-time members:

- Venture Manager.
- Project Manager.
- Technical Manager.
- Manufacturing Manager.

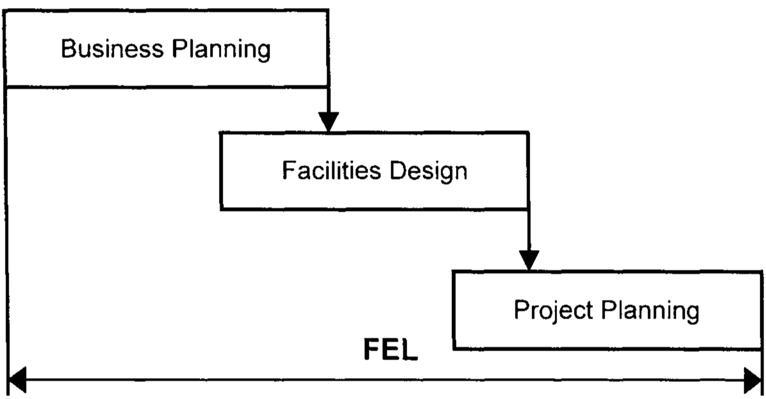


Figure 3.1 Front End Loading.

As viewed in Figure 3.1, the front end loading has three phases: business planning, preliminary engineering, and project planning.

- As a project develops, **business planning** is where the options are selected.
- The **preliminary engineering** phase is where the options are designed and costed. Financial analysis is conducted and the options are recycled to business planning in an iterative fashion.
- **Project planning** is conducted when the final option is selected. More detail on this activity is provided in the next chapter, "Selecting the Right Project."

Who's in Charge

One of the most important criteria of the integrated team is that each member bring functional competence to the project. Because no single person usually has the necessary qualifications to adequately represent all the stakeholders, a team is required with the Venture Manager administratively in charge of the entire project from conception through startup. However, as a project progresses though the phases, each of the permanent members will take a lead role in his/her skill area.

- The **Venture Manager**, as the business representative to the team, is the leader during the business analysis portion of the FEL.
- Since the preliminary engineering phase is principally process engineering, the **Technical Manager** is the lead during this phase.
- Project planning is the venue of the **Project Manager,** who continues to take the lead during the EPC phase.
- Once construction is complete, the **Manufacturing Manager** takes the lead during the startup phase.
- During each phase **additional personnel** (functions) may come on board the project to ensure proper execution. These added functions will be dependent on the project itself and the complexity of each functional requirement.

Phase	**Lead**	**Added Functions**
Business Planning	Venture Manager	Financial Analyst
Preliminary Eng.	Technical Manager	Process Engineers
		Safety Engineers
Project Planning	Project Manager	Scheduler
		Estimator
		Contracts Engineers
EPC	Project Manager	Mechanical Engineer
		I/E Engineer
		Purchasing Agents
		Inspectors
		Construction Superintendent
Startup	Manufacturing Manager	Startup Engineers
		Operators
		Mechanics
		Shift Supervisors

Since only very large projects in companies with large internal resources could fill all the positions mentioned, let's go back to the reality of the smaller project and concentrate on the four functions that have to be present in all chemical construction projects. Notice the emphasis on **functions**, not personnel. As a project reduces in size and complexity, more than one of the above roles may be performed by one person.

> IN VERY SMALL PROJECTS, ALL FOUR FUNCTIONS MAY OFTEN BE HANDLED BY ONE PERSON, THE PROJECT MANAGER.

Primary Functional Responsibilities

- **Venture Manager** has overall responsibility for the business success of the project. Overall leader from conception through startup. More about him in a minute.
- **Project Manager** has overall responsibility for Detailed Engineering, Procurement, and Construction. The Venture Manager and Project Manager are the two key managers in every successful capital construction project. The major part of this book is aimed at "how tos" for the Project Manager.
- **Technical Manager** has overall responsibility for process design and process safety. In projects involving new products, may represent the R&D or Process Development departments. In cost reduction or profit

maintenance projects, may represent the plant's technical department or a central engineering process functions. More about this activity in Chapter 6.

- **Manufacturing Manager** has overall responsibility for operability of the project. Specifically takes a leadership role in layouts, safety, and startup. More about startups in Chapter 18. The Manufacturing Manager is the site's representative to the integrated team and ensures that the key plant functions are involved at appropriate times in the project. These functions include environmental, production, maintenance, purchasing, shipping and receiving, etc., depending on the areas addressed by the project.

More detailed descriptions of responsibilities, including those of the additional team members, can be found in the typical coordination procedure in Appendix C

3.3 The Venture Manager

As the leader of the Owner's project team, the Venture Manager is ultimately responsible for the successful execution of the "right" project.
Ideally, the Venture Manager:

- Provides continuity by being involved from the very onset of the project through the startup and operation of the facility.
- Should combine a solid background in management, project economics, and operations with a working knowledge of process engineering and project management.
- Serves as a screen to help the project team stay free of extraneous outside pressures.
- Delegates the day-to-day activities of running the project to the other members of the team.

The Venture Manager helps the integrated team focus their energies towards accomplishing the project's goals. Specifically, these actions will be concentrated in ensuring:

- That the "right" project is selected. We will cover this in more detail in the next chapter. However, for now, this will involve:
  - An accurate statement of the business goals of the project.
  - Identification of all reasonable alternatives.
  - A sound financial analysis of the alternatives.
  - A thorough risk analysis of the alternatives to insure that the selected one has acceptable risk.

- That a thorough AFE Request has been prepared for corporate approval. This means that sufficient FEL has been completed on the alternative selected to ensure that the estimate and justification are accurate enough for a good decision to be made.

  Note: The Construction Industry Institute (CII) has an excellent protocol for the quantitative measurement of the amount of FEL completed. This measurement is known as the Project Definition Rating Index (PDRI). They have established a rating that defines where the amount of FEL is sufficient for decisionmaking. Use of this system can provide a rapid, yet effective, measure.

- That sufficient and competent resources are available to complete the project.
  - The integrated team members are identified and made available for the duration of the project.
  - All team members are experienced in the functions that they represent.
  - The integrated team can adequately represent all the major stakeholders of the project.
  - The additional part-time members are identified and made available for the portions of the project where they are needed.

- That appropriate procedures and controls are in place to help ensure that the project maintains a focus on the project goals. These would include the following procedure and tracking tools:
  - Coordination procedure. This shows, *in writing,* the responsibilities and authorities of each of the integrated team members. A sample of one of these appears in Appendix C.
  - Change procedures. This covers the determination of what each type of change requires as to approvals, documentation, and tracking.
  - Cost and schedule tracking. As part of a Venture Manager's monthly report, this tracks and forecasts how well a project is doing in regards to meeting the spending and timing requirements.

- That management is kept informed of anything that affects the outcome of the project, including their actions or lack of actions.

- That management does not dictate arbitrarily unrealistic schedules and estimates that would doom the project to failure unless the scope of the work is changed.

HELPING THE INTEGRATED TEAM AVOID THESE SITUATIONS CAN BE THE HARDEST PART OF THE VENTURE MANAGER'S JOB.

3.4 Additional Considerations

Alignment of Project Goals

It is vital that early in a project all members of the integrated team understand the project goals and that each drives to accomplish them. Without agreement as to the goals, the Project Manager may be driving toward fast completion. The Manufacturing Manager may be driving to a high degree of automation. The Venture Manager may be driving to lowest capital cost. Their individual goals may not be in harmony with the overall project goals. Get this straightened out early.

Project Cost

Project cost is the biggest single driver in calculating the economic measurements. This is the project investment. It is a negative cash flow. In general, added project cost without commensurate returns hurts the project economics. Any project cost control program must be able to analyze the impact of scope changes to a project. All members of the integrated team must accept the challenge to meet the project's economic goals.

Project Schedule

The project schedule is also a big driver. In a typical two-year project, most of the investment occurs in the first year. That means another year goes by without any return for the investment. If a project can be speeded up it usually means that the rate of return of a project increases. Typically a three-month schedule improvement could mean 3 to 4% better return on the project. This can mean the difference between a profitable and non-profitable project. In many industries being the first to market a new product could have a huge impact on the long-range profitability of the project.

No matter what type of project, doing it faster is almost always better than doing it slower. Early in the project analysis, the value of the schedule should be determined and prioritized against other parameters.

THERE IS AN OPTIMUM SCHEDULE FOR EVERY PROJECT THAT MINIMIZES PROJECT COST. ANY PROJECT CAN BE SHORTENED FROM THIS OPTIMUM AT A COST. THERE IS ALSO A MINIMUM REASONABLE SCHEDULE THAT SPENDING MORE MONEY WILL NOT SHORTEN.

It is up to the project team, under the leadership of the Project Manager, to determine what that minimum schedule is.

Again, the whole project team should agree on the priority and value of doing the project quickly. They should also agree with each other before committing that the project **can be done faster.**

THE PROJECT TEAM SHOULD NEVER AGREE TO A SCHEDULE THAT IS NOT ACHEIVABLE. DON'T PROMISE SOMETHING IF YOU DON'T KNOW THAT YOU CAN DO IT.

CHAPTER 4
PROJECT GOALS/CHOOSING THE RIGHT PROJECT

Not every project deserves to be done, even is you spend months trying to justify it. The "wrong" project undone is money in the bank.

4.1 Introduction

Many companies have critically examined their capital construction programs and have determined that, overall, the financial returns of their projects only average 1/3 to 1/2 of the amounts shown in the project justification documents.. These same companies along with project management consultants have determined that the major reason for these missed objectives is generally not due to the project execution, but is due to the project selection. Yes, bad project execution can be devastating to a project's success, but the selection of the wrong project will **guarantee** failure.

DOING THE RIGHT PROJECT CAN BE FAR MORE IMPORTANT THAN DOING A PROJECT RIGHT.

4.2 Project Goals

It is important to remember that in the commercial world there are only two reasons to execute a capital construction project:

- To add to the company profit.
- To maintain the current profit.

Examples:

- Profit adding:
  - Increase capacity of a sold-out plant.
  - Add a new product.
  - Improve production efficiency, i.e., yields, energy, etc.
- Profit maintaining:
  - Replace a worn-out reactor.
  - Meet a governmental consent order.
  - Comply with an OSHA regulation.

These are the only two reasons for executing a capital project.

Note: Often a project is difficult to measure as to whether it adds to profit. An example would be building a new visitor building/guard house at a plant site. This would be justified by making a favorable impression on existing and new customers. Eventually, this should result in increased business. Quantifying this new business would be extremely difficult. A project like this may be categorized as profit-maintaining even though it has an ultimate objective of adding profit.

4.3 Setting the Scope

When the project team assembles, the first order of business should be to put in writing the project objectives. Why are we doing this project? This should be stated in the most basic terms.

Example

The objective is to improve the quality of product Q from its current state of 90% purity to an improved state of 99% purity. This will permit selling of the improved product Q to a new customer. If we do this, the new customer will buy 10M pounds per year. This is new business and will improve our profit by $5M per year less the incremental operating costs.

How will we know the project is a success?

By traditional methods, a project is considered successful if it is **built on time, is in the money, and technically works.** This method of analyzing project success is one of the reasons returns on projects are so low. With this method, we have not measured how well we have achieved the scope.

For the example project the measure of success **should** be:

- How much product did the customer buy?
- How much incremental profit did the company make with improved product Q?

The success of a capital project now rests on the entire business team not just the project execution team.

Notice, the objectives have not said anything yet about how the improvement in quality will be accomplished. The project goal is to improve profits through quality improvement. Making sure the integrated team understands this difference is critical. The goals should be stated in the most basic terms.

4.4 Identifying the Alternatives

The next step of the process is to examine the alternative pathways to achieve the project objective. Technically, there may be two or three ways to achieve the improved quality. We must now compare the alternatives. In examining the different alternatives, many factors may be considered. However, these factors generally boil down to a few basic areas: technical performance, cost requirements, schedule requirements, and relative risk.

Defining and Comparing Alternatives

This is often an area where companies tend to get bogged down. The temptation is to examine an infinite number of cases. This is often an excuse for management to avoid making a decision. The job of the project team will be to pare down the cases to a few reasonable alternatives and examine them in detail.

Back to our quality improvement project. The project team, at this point led by the Technical Manager, finds three different methods to remove the offending impurities. Technically, all three will produce an acceptable product Q for the new customer. Now the fun begins. Which project do we select? **How do we make sure we do the right project?**

Each alternative must now be looked at critically. Process design will specify the equipment needed. Estimating will give the capital cost. It is important that each alternative is designed and estimated on a relatively equal basis. The absolute cost will be important eventually, but, at this point, the relative cost of each alternative is more important. Don't forget to include all costs, not just capital. Operating costs for the new system must be known to allow project profitability to be calculated. When defining each alternative, make sure the project risks are specified. These will include but may not be limited to:

- **Technical risks**. How sure are we that the alternative will perform as required. Have we done pilot or bench scale tests? Is this new technology that is not yet routinely used in the industry?
- **Equipment risk.** Is this a "serial number 1" of a new equipment offering? Does the vendor have Failure Mode and Effect Analysis (FMEA) data? Has this equipment been used industrially for similar products?
- **Schedule risk**. If the equipment is not delivered on time, what is the impact on the project? How likely is the equipment to be shipped when needed?
- **Cost risk**. What is the sensitivity of the project to project cost slippage? Operating cost slippage?
- **Marketing risk**. Has the new customer signed a letter of intent? How sure are we that the customer's use of the new product will continue?

Example

For our Product Q project, we have determined that there are 3 alternatives that may be considered reasonable:

- **Distillation**. A 20-inch high column, 3-inch in diameter, with seven plates can make the desired separation according to Aspen analysis. Estimating shows capital costs to be $10.5M. Operating costs would add $0.03/pound to the existing product Q. This plant can be built in 16 months.
- **Solvent extraction.** Lab tests indicate that acetone extraction will produce the required product. Capital costs are estimated at $5.4M. Operating cost

increase would be $0.17/per pound. This plant could also be built in 16 months.

- **Supercritical extraction.** Bench scale runs show this could produce the desired product. Capital cost, $7.0M. Operating costs add $0.09/pound. Due to equipment delivery, the project will take 24 months to complete.

Once the performance, cost, schedule, and risks have been reasonably examined, it is more than likely that the number of alternatives can be reduced. Keep alternatives in the loop if the differences are small. In our example, there may be no alternative that can be eliminated yet.

So far we have only made side-by-side comparisons to see if any of the alternatives are significantly better than the others. We have not yet made the evaluation that any of the alternatives should be done. When we do side-by-side analyses, we only know the best alternative. We have not yet determined that the best alternative is the right project.

> REMEMBER, ONE OF THE ALTERNATIVES TO ANY PROJECT IS TO DO NOTHING.

4.5 Choosing the Best Alternative

The most common way to examine whether or not any project should be done is usually accomplished through economic analysis. On profit-maintaining projects, this is often simplified by management making the statement that we want to remain in the particular business. Once this is determined, then the selection of an alternative is simplified to choosing the least costly alternative.

When a project is a profit-adding project, the economic analysis is usually much more rigorous.

Economic Analysis

Although companies differ somewhat in how they calculate the indicators, they all look for similar outcomes:

- **Internal Rate of Return (IRR).** This is a measure of how much improvement in cash flow results from the investment (project cost) as measured by a percent return. This is roughly equivalent to the interest rate that an investment would earn if invested in a bank or in bonds. A company usually has a measurement called a hurdle rate that defines the minimum acceptable rate that a "profit-adding" project must have before it is approved for expenditure. In many companies, this rate is the rate it could obtain funds from a bank plus the rate of inflation. Others calculate it from its strategic plan needs.

- **Net Present Value (NPV).** Whereas IRR measures rate of return, i.e., interest rate, NPV is a calculation of the size of the return in total dollars as measured at today's economics. This calculation involves a number of operations and requires knowledge about length of the project, when investment is to take place, when returns will start, the assumed inflation rate, and the reinvestment rate (how much return can be assumed for cash inflows). Companies have different assumptions when calculating the NPV, however, they all are useful in the same ways. If there is positive NPV, the project will make more money than placing it in a bank and, therefore, is probably economically justified. The larger the NPV, the higher the justification. This is a useful way to prioritize different projects where funds are not available to execute all "good" projects. NPV also gives us a better feel about risk. Projects that have high NPV's can usually support taking more risk. Projects with low NPV's may still be attractive, but should not have significant risk associated with them.

- **Payback.** This is a measure of how quickly the investment will be paid back. This is a time measurement. Some companies have hurdle times that dictate that a project must be paid back in a certain number of months before it will be approved. This is often done to overcome the "hockey stick" curves where returns are so far out that meeting them is very questionable.

Table 4.1 Example results

Option	Cap Cost, $M	Proj. Time, Mos.	Incremental profit, $M/yr	IRR %	NPV $M	Payback, Yrs.
A. Distillation	10.5	16	4.7	28	13.7	3
B. Solvent Extraction	5.4	16	3.3	38	10.7	2
C. Supercritical Extraction	7.0	24	4.1	30	11.6	3

Table 4.1 indicates that all alternatives are profitable. Option B has the lowest capital and the lowest payback. However, it also has the lowest NPV. Option C has the highest capital and the highest NPV. From the analysis, it is not extremely clear yet which is the best option.

Risk Analysis

If the economic analyses as shown in Table 4.1 were the only information available, then our selection would probably be option A, Distillation. This option has the best NPV. However, there is some information we have not yet discussed, the amount of risk being taken with each option.

Risk analysis can be an extremely complicated activity. Large corporations often have whole departments charged with performing risk analysis. They usually concentrate on high-level strategies, but the principles are the same at all levels.

Risk analysis tries to answer two basic questions:

- If our assumptions are not correct, what is the impact on the business?
- What is the likelihood that our assumptions are not correct?

For the risk analysis of a capital project, the risks are generally divided into several parts:

- **Market or business risk:**
  - Market forecast.
  - Potential customer viability.
- **Project risk:**
  - Capital cost.
  - Schedule slippage.
  - Technical performance.
- **Manufacturing risk:**
  - Operating costs.
  - Operability of the new facility.

For each of the risks we must determine the impact of our assumptions being incorrect. The most common method to determine this is to perform a **sensitivity analysis**. To do this, each risk is examined and a reasonable upside and downside are determined and the economic analyses are recalculated.

The most used methods for upside and downside determination include:

- An arbitrarily chosen percentage, i.e., capital cost – 20% higher, market volume – 30% lower, operating costs – 20% higher.
- Examination of each risk and selection of percentages based on state of knowledge of each risk area.

- A backward integration that calculates what downside potential would cause the project not to be approved. The likelihood of that downside occurring can then be examined.

This third method, although more time consuming, can be the most effective way of determining the real risks and making the decision as to whether to accept them.

Common ways to perform this method:

- **Market risk**. Lower the volume and the price until the project is no longer profitable. If these numbers are feasible then the risk to the project is high. If they are out of the question, than the project risk is low.
- **Capital cost**. Raise the capital until the project is no longer profitable. Often, this number may be so high that the project is deemed to be insensitive to capital.
- **Schedule**. Examine the market requirements. Is there a drop dead date beyond which the customer will no longer take the new product? Is there a completion date that makes the project unprofitable?
- **Technology.** What are the non-performance scenarios? Is there a drop dead performance issue? Environmental projects often have legal performance criteria. Profit-adding projects are based on meeting performance in volume, quality, and/or cost. What is the impact of not meeting a criteria? Can the performance be short of meeting the criteria and still be profitable?

The sensitivity analysis gives the impact of not meeting the assumptions. The next analysis determines the likelihood of the unprofitable event occurring. As in the sensitivity analysis, the combined knowledge of the integrated team and their assistants will be required to effectively answer the question of likelihood.

Although it is not possible to cover every known risk possibility, here are some of the most common questions an integrated team should consider when doing a risk analysis:

- **Market forecast:**
  - How good is the customer's commitment to buying the product in the volumes needed?
  - Are contracts in place?
  - Has customer shared risk analysis with us?
  - What is the expected life of the product?
  - What are the competitive products?

- **Capital costs:**
  - Are equipment costs based on firm quotes?
  - Are subcontract costs based on competitive bids?
  - How much engineering has been done at the time of the AFE? (FEL?)
  - How much contingency is in the estimate?
- **Schedule:**
  - Has a detailed CPM type schedule been developed?
  - How many critical paths have been identified?
  - How important is labor productivity to schedule and what is the local history?
  - How important is weather predictability?
  - Is project being constructed inside an operating plant?
  - Are extensive tie-ins to an existing plant required?
  - What is performance history of key equipment suppliers? Are their shops full now?
  - What is the performance history of key subcontactors? How heavy is the local contractor activity?
- **Technical performance:**
  - What is the state of the technical knowledge? Were tests run in a full-scale plant? Pilot plant? Bench scale? Computer simulation only?
  - What version of the equipment is being purchased? Serial number 10,000 or serial number 1? Does FEMA data exist? Have we visited other buyers of this equipment?
  - Has the equipment been used in similar service? Our exact service?
  - How good are operating cost data? Energy? Material prices and efficiencies? Labor requirements?
- **Regulatory performance:**
  - Have permits been applied for? Has hazard analysis been done?
  - Are regulatory performance criteria "set in stone"?
  - Will performance shortfalls result in plant shutdown?
  - Are we on a consent order for schedule and/or performance?

4.6 Choosing the Right Project

Accepting risk is a delicate operation.

- **The first alternative:**
  - Has the lowest project risk: old, proven technology; well-known cost and schedule; and proven operating costs.
  - Has the highest cost and highest NPV, but appears to have a low project risk.

However, if the market forecast is suspect, this may not be the best project due to highest invested capital.

- **The second alternative:**
  - Has the lowest capital and the project risks are also low.

However,

- The manufacturing costs are driven by an outside company doing solvent recovery.
- This may initially be a high risk, but the lower capital cost may offset any market forecast risk.

After operation and sales have been proven, the solvent recovery may be brought back in-house. A cost analysis of doing this in the third year improves the economic analysis. The estimate showed that the in-house solvent recovery could be done for $2M and would improve the profitability in the fourth year to $4.0M. The revised project, done in two phases, has an overall IRR of 42%, a payback of 2 years, and an NPV of $13.0M.

Note: We threw in this as an example of what actually happens during this process. As knowledge is assembled, more options may evolve that prove to be even better alternatives. The hardest thing for a team to decide is when to stop looking at options and pick the best one at the time and with the most reasonable amount of knowledge available.

- **The third alternative:**
  - Has the longest schedule with the longest schedule risk.
  - New technology for this business is also a high risk area.

If the business is risk adverse because of product maturity or other strategic reasons, this may not be the best approach. However, if this were also the start of a new business family, the strategy may support going to new technology. In a young business with a good market forecast, this could prove to be the best option.

You may be reaching the conclusion that choosing the right project is not a simple exercise. **You would be right.** The integrated team is charged with locating the technical alternatives to achieve a business goal. These alternatives are analyzed as to economic viability and degree of risk.

The selection of what degree of risk is acceptable is NOT the job of the integrated team, alone. This is a corporate decision and the corporation, through the appropriate business manager, is ultimately charged with accepting the risk. The integrated team must participate in this decision. The team must do its job in gathering the right data and assessing the risk potential. Only the amalgam of the knowledge and experience of the integrated team and the business managers can successfully choose which project is best for the business.

Note: In the above analysis, most mature companies with mature product lines would choose option B. It keeps the initial capital low until the product line proves itself, and offers upside potential if the business acts as forecasted.

Summary

- State the true project objectives early. These should be based on business performance goals. There should be a written statement with three to four short sentences that describes how the project success will be measured.
- Develop the alternatives. The list should be pared down to a few, reasonable alternatives.
- Analyze the alternatives. Look at the major areas and develop an incremental analysis: costs, schedule, operability, and risks.
- Be prepared to recycle as the analysis uncovers other attractive alternatives.
- Pick the best. Analyze in detail.
- If the best meets the project objectives and meets the company's strategic requirements, this can now become the project. **You have selected the right project.**
- You can now concentrate on doing the project right.

4.7 Executing a Project Right

So far in this chapter, we have talked about choosing the right project. This is only the first step in executing a successful project. Executing a project right is just as important. Most of the rest of the book will concentrate on this aspect. From now on, we should concentrate on doing the "right" project right.

Companies and project managerial consultants, after examining thousands of projects, have identified the precursors to a successful project.[1] These precursors to a successful project can be summarized as:

- Selection of the "right" project (covered in this chapter).
- Project team quality, continuity, and coordination (Chapter 3).
- Control of changes (Chapter 15).
- Use of competitive technology.
- Continuing use of Value Improvement Practices (VIP's).
- Sufficient Front End Loading (FEL).

Before beginning this journey through the tools for helping the Project Manager do a project right, we need to say a few words about several of the precursors mentioned above:

- **Use of competitive technology.** It is obvious to managers throughout the manufacturing world that new technology is the biggest driver to increasing profits. Project teams should always be ready to consider using new technology to help their companies be competitive. However, a word of caution is appropriate now. Do not try to bring in **unproven** technology at the time of a project. The risks of doing this are huge. New technology should be developed and tested before the project is begun. There is always the temptation to use the venue of the project to bring in new technology while the funding is available under the project. Resist this temptation. There are plenty of other challenges to meeting the project objectives without adding an additional complication.

- **Value Improvement Practices (VIP's).** These well-proven practices should be applied on an as-needed basis as the project evolves. Table 4.2 shows the various areas of potential improvements, their likely time of application and the potential impact on the project value.[2]

- **Sufficient Front End Loading.** The amount of Front End Loading done at the time of project authorization has been shown to directly affect the ability of a project to meet its goals. We have mentioned Front End

Loading several times already, and will continue to refer to this important period. One of the ways to determine if sufficient front end loading has been done is by completing a survey known as the Project Definition Rating Index (PDRI). The Project Definition Rating is a technique developed by the late John Hackney (Hackney, J.W. "Control and Management of Capital Projects," 2nd Edition, McGraw-Hill Inc., 1992) and propounded by the Construction Industry Institute (CII).[3] It provides a rational system for a quantitative and objective evaluation of the status of the engineering. It is a very useful tool to determine the level of contingency required for the various types of cost estimates and also to determine the FEL.

Table 4.2 Value Improvement Practices (VIP's)

VIP	Period to Use	Overall Value to Project
Technology Selection	R&D	Highest
Process Simplification	R&D, FEL	High
Classes of Facility Quality	FEL	High
Waste Minimization	FEL	High
Energy Optimization	FEL	High
Process Reliability Modeling	FEL	Medium
Customization of Standards	FEL	Medium
Predictive Maintenance	FEL	Medium
Design to Capacity	FEL	Medium
Value Engineering	FEL, EPC	Medium
Constructability	EPC	Low

The FEL period produces the most valuable of the project documents. These will dictate the whole efforts of the upcoming EPC phase of the project. FEL deliverables include:

- Project Scope (covered in previous chapters).
- Project Execution Plan (Chapter 9). This includes the contracting plan, the preliminary schedule, and the preliminary estimate.

- Permit Applications (Chapter 7). In most states, construction cannot begin without an approved permit. A permit will not be approved without significant engineering being completed.
- Preliminary Engineering (Chapter 6). This includes process engineering through P&ID's, preliminary layouts, control strategy, mechanical/ electrical specifications, and one-line diagrams.
- Preliminary Estimate (Chapters 10 and 19).
- Project Schedule (Chapter 9).
- Project Coordination Procedure (Appendix C).
- Project Definition Rating (Chapter 4).

Additional activities would include these areas that often have a significant impact on the cost and schedule of a project and, therefore, must be completed early in the FEL phase:

- **Site Requirements**. This includes soils data, utilities available, tie-ins, and work restrictions, if any, due to construction in an operating facility. This would include operating philosophy. Formal plant agreement to design and operating philosophy is strongly recommended. Nothing can blow apart a good project plan more than added requirements not included or anticipated during the FEL.
- **Process Hazard Analysis**. With some chemicals and some processes, this will have a significant impact on design and cost.

4.8 Conclusions

At the conclusion of the seminars based on the first edition of this book, the attendees were asked to tell what they had learned. The responses could be summarized in three proposals:

- DO YOUR HOMEWORK.
- BE DELIBERATE.
- DON'T TRY TO BE A HERO AT THE BEGINNING OF A PROJECT. BE A HERO AT THE END.

We hope these concepts have come across in these early chapters. They will be just as important in the following chapters.

Notes

1. IPA – Independent Project Analysis, Inc., 11150 Sunset Hills, Reston, VA.
2. IPA – Independent Project Analysis, Inc., 11150 Sunset Hills, Reston, VA.
3. Project Definition Rating Index, Industrial Projects, CII, July 1996.

CHAPTER 5

INITIAL INVOLVEMENT AND PLAN OF ACTION

*"'Where shall I begin, please your Majesty?' he asked.
'Begin at the beginning,' the King said, very gravely,..."*

Lewis Carroll

5.1 Initial Involvement

Overview

Promptly after being assigned to the project, the Project Manager must contact the requester, usually the Venture Manager, to:

- Define and understand the scope - what do you want and when do you want it?
- Determine client needs.
- Gather enough information for the preparation of a sensible initial plan of action.

In a nutshell: "Tell me what you need and I will think it over and be back to you ASAP with my recommendations."

If the assigned Project Manager has limited experience, a senior project manager or a supervisor should also participate in this meeting.

It is very important that this meeting be documented formally in a memo of understanding to:

- Document the basis of the project and its goals.
- Confirm the Project Manager's understanding of the scope and various clients' requirements.
- Keep CED management and appropriate key personnel informed.

The memo of understanding should be discussed with the Venture Manager before issuing it. This will avoid potential arguments and should not take more than a brief conversation.

Memo of Understanding

As mentioned in the Preface, this guideline is not intended as a cookbook; it does not recommend the use of standard formats for project memos.

- Each project is unique.
- The circumstances of the first contact with the "client" are different.
- Every Project Manager has a different approach and a different writing style.

As a result, each memo of understanding could be different, but will always:

- Document the scope of work.
- Formalize the initial request of the project sponsor and the expected CED involvement.
- Apprise the Venture Manager of the additional scope information that must be developed before a meaningful planning effort can begin.

5.2 Initial Plan of Action

General

The Project Manager is specifically responsible for planning the overall project execution, ascertaining the validity of the input, and establishing realistic cost and schedule objectives. A complete execution plan cannot be finalized until a detailed scope and a good quality estimate have been developed. However, planning must start at project inception so that serious roadblocks can be identified and avoided early in the game.

The Project Manager must develop and document, as a minimum, an initial plan of action addressing the activities required to prepare the funding request and justification, assigning responsibilities, setting a realistic timetable, and providing an estimate of the required staff-hours and associated costs required during the early project stages.

The initial plan of action must also address a proposed overall project execution strategy in order to promote creative thinking as early as possible. If the objectives set by the project sponsor are not realistic, it is the responsibility of the Project Manager to bring up the realities of life and, working closely with the Venture Manager, develop achievable goals.

The initial plan of action must be prepared for a project, large or small; and in all cases, it will require the direct hands-on participation of the Project Manager and the review and approval at the appropriate management level.

The scope definition provided during the initial contact may or may not be sufficient to prepare a meaningful plan of action. If not, the Project Manager must work closely with the Venture Manager to develop it.

> PROJECT MANAGERS MUST DO THE BEST THEY CAN WITH THE INFORMATION DEVELOPED IN THE FIRST CONTACT WITH THE VENTURE MANAGER.

The determining parameter for establishing the duration of any project activity is the hours required to execute it. Consequently, the engineering and construction hours, especially the latter, determine the project duration. If they are not available, the Project Manager must develop them. The scope provided by the project sponsor must contain sufficient information to develop, through literature and/or company files research, the approximate Total Installed Cost (TIC) of the proposed facility and/or equipment count. Both are used in the preparation of conceptual engineering and construction hours estimates.

Approximate Construction Hours

Construction labor costs can be derived from the TIC with the aid of the Lang Factors discussed in Chapter 10.

Construction Labor Cost = TIC x 0.38

The approximate hours can then be calculated dividing the cost by $45/hr, which is a typical rate for union labor in industrialized states, including subcontractors, indirects, overhead, and profit.

The weakness of using TIC is apparent, but if approximate TIC is the only information available at this time, the Project Manager must make do with it.

A more rational approach can be followed when the approximate equipment count is available. Then:

Construction Hours = Equip. Count x Growth Factor x 1700

The growth factor is a function of the status of the process design:

– Conceptual design	1.30 - 1.50
– Preliminary design (Phase 0)	1.10 - 1.30
– Complete design (Phase 1)	1.05 - 1.10

As discussed in Chapter 19, Section 19.1, equipment count also offers a rational approach to estimate TIC, especially for liquid process organic chemical plants. The scope of equipment count is defined in Section 19.11.

Approximate Engineering Hours

Engineering hours are intimately related to equipment count and type. When a complete equipment list is available, the procedure included in Chapter 19 can be used to prepare accurate estimates. However, this is seldom the case in the early stage of any project and the project managers must do the best they can with the information they have.

If the approximate TIC is available, the engineering hours can be developed with the aid of the Lang Factor.

Engineering Cost = TIC x 0.16

The approximate hours can be calculated dividing the cost by $75, which is the average cost in the northeastern states.

When the equipment count is available:

Engineering Hours = Equip. Count x Growth Factor x 650

Process Design Hours

The Engineering hours required for process design are not only related to equipment count and type; they are also very sensitive to the type of process and stage of development of the process design. Experience shows that these factors can produce very wide variations in the hours required.

Since the process design hours determine the cost and duration of the initial project activities, it is very important that the initial plan of action be based on realistic estimates. Unfortunately, as mentioned before, the level of information required to prepare accurate estimates is rarely available at this stage of the project. Nevertheless, this section tries to provide some criteria and guidelines to allow project managers to make the best out of the scant information available.

Analysis of actual cases shows that the hours required to prepare a complete and formally documented process design package (Phase 1) including drafting and all required engineering disciplines vary widely depending on the type of project.

Low	Average	High
30 hr/item	75 hr/item	150 hr/item

The following factors determine the location within the range:

High End

- New technology.
- Hazardous service.
- Process complexity.
- Large equipment.
- Low equipment count.
- Process options.
- Execution by contractor.

Low End

- Simple process.
- Simple equipment.
- Repeat project (old Phase 1 manuals).

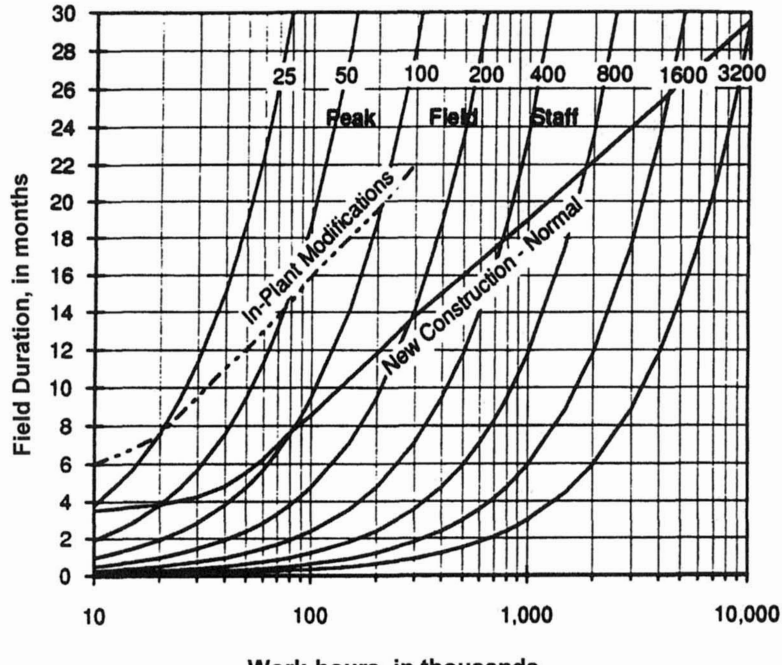
– All work in-house.

If equipment count is not available, the approximate hours for a Phase 1 package can be developed using 12% of the engineering hours derived from the Lang Factor.

The preparation of a preliminary process design package (Phase 0) would require approximately 40% of the hours of a Phase 1 package.

Project Duration/Peak Staffing

The duration of the construction period as well as the peak staffing required can be determined from Fig. 5.1.



Note:

- Field duration from start of pile driving or foundations to mechanical completion.
- Field hours include all direct hired, subcontractor, and supervision hours.

Figure 5.1 Construction duration chart.

In a typical chemical process plant, the duration of the construction phase is approximately 80% of the total project duration from the start of engineering (after completion of Phase 1) to the mechanical completion of the construction work. The remaining 20% is the lead time required for engineering and procurement activities before construction can start in a cost-effective manner. It must be noted, for initial planning purposes, that the lead time allowed should not be less than three months. Historically, the engineering hours spent during this period are normally between 30 and 40% of the project total.

The total project duration and anticipated engineering and process design staffing can now be easily approximated.

Example

Given:	Construction Hours Engineering Hours	80,000 28,000
From:	Approximate TIC or Equipment count	
Then:	Construction duration from Fig. 5.1 Peak construction staff	7 months 100 workers
So:	Total duration is 7 ÷ 0.8	9 months
And:	Engineering lead time is 9 - 7	2 months
	But 2 months is less than minimum	
So:	Total duration is 7 + 3	10 months
And:	Engineering hours used during lead period are 35% of 28,000	9800 hr
Equivalent to:	9800 ÷ 3 mo. 3300 ÷ 160 hr/mo. 21 x 1.6	3300 hr/mo. 21 persons avg. 34 persons peak
Also:	Phase 1 hours 28,000 x 0.12	3400 hr
Assuming:	5-6 process engineers can be made available	
Then:	Phase 1 duration	approx. 4 months

Plan Contents

The initial plan of action must address the following subjects:

- Viability of sponsor's cost and schedule objectives. If required, recommend realistic ones.
- Preparation of the process package: engineering hours, duration, and proposed execution method.
- Project funding philosophy and schedule.
- Responsibility for the execution, anticipated CED involvement.
- Project execution approach: small/conventional.
- Approximate engineering and construction staff requirements: average and peak.
- Preliminary schedule.
- Contracting strategy.
- Contractor selection timetable.

Planning Rules of Thumb

The following is a brief summary of the tools, discussed early in this chapter, that will enable project managers to prepare sensible plans of action very early in the project with minimal information:

Construction Hours

- TIC x 0.38 ÷ $45/hr.
- 1,700 hr per equipment item.

Engineering Hours (After Phase 1 Design)

- TIC x 0.16 ÷ $75/hr.
- 650 hr per equipment item.

Equipment Count "Growth"

- Conceptual to final 1.30 - 1.50.
- Phase 0 to final 1.20 - 1.30.

- Phase 1 to final 1.05 - 1.10.

Process Design (Phase 1) Hours

- Engineering hours x 0.12.
- 75 hr per equipment item.

Total Project Duration

- Construction duration ÷ 0.8.

Engineering Lead Time

- Total project duration x 0.2 or 3 month minimum.

Lead Engineering Hours

- Engineering hours x 0.35.

Peak Staff

- Average staff x 1.6.

5.3 Case Study

Initial Contact

The sponsor asks CED to take over the design and construction of a liquid organic chemical plant, of known technology, to be located at an existing site. Marketing needs dictate that the facility be in production 18 months from the initial contact but management does not wish to spend money on contractors before formal approval of the AFE.

The sponsor's R&D Group has prepared a conceptual process design showing 50 pieces of equipment and estimated a total installed cost of around 12 million dollars.

Project Manager's Contribution

TIC Validation

- Anticipated equipment count growth 25%
- Anticipated TIC

50 items x 1.25 x \$263K/item (from Section 19.11)	\$16.4M

The 40% cost difference should be of concern to the project sponsor but is still within the range of accuracy of conceptual estimating.

Preliminary Construction Hours

- Based on Anticipated Cost:

Low	(12M x .38)/\$45 per hr	=	101,300
High	(16.4M x .38)/\$45 per hr	=	138,500

- Based on Equipment Count:

50 items x 1.25 x 1700 hr/item	=	106,000
		Avg.: 115,300

Preliminary Engineering Hours

- Based on Anticipated Cost:

Low	(12M x .16)/\$75 per hr	=	25,600
High	(16.4M x .16)/\$75 per hr	=	35,000

- Based on Equipment Count:

50 items x 1.25 x 650 hr/item	=	41,000
		Avg.: 33,900

Engineering/Construction Duration and Peak Staff

Given:	Construction Hours	115,300
	Engineering Hours	33,900
Then:	Construction Duration	9 months
And:	Peak Construction Staff	(1) 121
So:	Engineering & Construction Duration 9 ÷ 0.8	11.25
And:	Engineering Lead Time 11.25 - 9	2.25
	But 2.25 months is less than minimum	
So:	Engineering & Construction Duration 9 + 3	12 months
And:	Engineering Hours used during lead period are 35% of 33,900	11,900
Equivalent to:	11,900 ÷ 3 months	4,000 hr/month
	4,000 ÷ 160 hr/month	25 avg. staff

And: Peak Eng. Staff 25 x 1.6 40 peak staff

(1) 115,300 ÷ 9 ÷ 170 hr/mo. x 1.6 (Rule of Thumb) = 121

Process Design Hours and Duration

– Based on equipment count:

50 x 1.25 x 75 hr/item 4,700

– Based on engineering hours:

33,900 x 0.12 4,100

Avg.: 4,400

A team of 6 persons would require 4.5 months to prepare the process design.

Total Project Duration

Normal execution

The completion of this project requires a series of steps that would normally be executed in a consecutive manner:

Step	Duration (Months)	Comments
- Form project team	0.5	Judgment required.
- Select contractor	1.5	To perform Phase 1.
- Approve funds for Phase 1 work	---	$330K to pay for 4400 hours Special permission must be obtained to start spending before AFE approval.
- Complete Phase 1	4.5	
- Prepare AFE estimate	0.5	
- Approve AFE	2.0	Dictated by company procedures
- Start detailed eng.	3.0	Minimum lead time.
- Construction	9.0	
- Startup	1.0	Judgment
TOTAL:	22.0	

The total duration far exceeds the 18 months dictated by the marketing requirements. In this particular case study, the picture is complicated by a long delivery item that, under normal circumstances, would be delivered to the field more than 19 months after project start. Refer to Fig. 5.2.

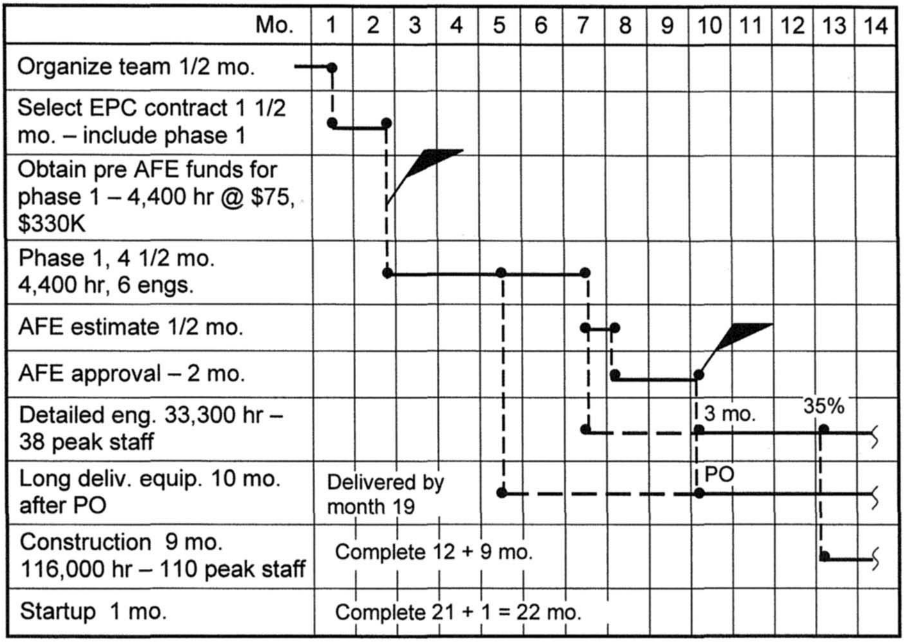


Figure 5.2 Initial plan of action example – normal execution.

Fast track execution

Although the initial pass at the schedule indicates a potential delay of 4 months, the situation can be corrected if management is willing to risk an additional 1.0 million dollars in pre-AFE funding and increase the engineering costs slightly.

The following actions will bring the total duration back to the required 18 months.

Action	*Risks*
- Reduce Phase 1 duration to 3 1/2 months by adding 2 process engineers.	Potential loss in productivity.
- Increase pre-AFE funding to 1.4 million dollars to cover 3 months of detailed engineering and cancellation costs for the long delivery equipment.	Lose all pre-AFE expending if project is not approved after the estimate.
- Start detailed engineering before completing Phase 1.	Wasted design hours due to false starts and recycles.

The fast track approach is illustrated in Fig. 5.3.

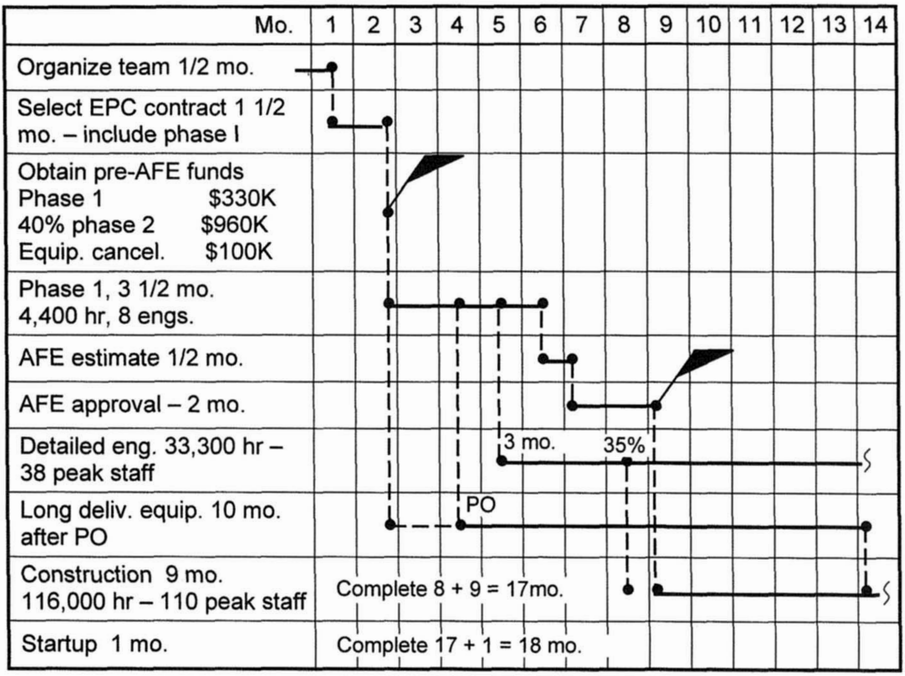


Figure 5.3 Initial plan of action example – fast track execution.

Preliminary execution analysis

Execution Approach

The estimated hours for both engineering and construction exceed the limits of the definition of small project in Section 1.2. This project should definitely be approached as a major project through an EPC contractor.

Size of Engineering Contractor

Ideally, the engineering contractor staff should be 2-5 times the anticipated peak. In this particular case, the bidder list should be restricted to small and medium sized firms with 80 to 160 employees.

Peak Construction Staff

If the site cannot absorb 125 workers and supervision during the peak period, the schedule must be delayed or consideration given to work time more than 40 hours per week either by double shift, overtime, or some other arrangement.

Construction Subcontractor's Size

The estimated construction hours and the anticipated peak staff suggest that the project could be beyond the reach of the small local contractors. Consideration must be given to attracting larger contractors or splitting the work and employing several small work contractors.

CHAPTER 6

PROCESS DESIGN – PHASE 0/PHASE 1

A process design tells what goes in, what comes out, and what happens in between.

6.1 Overview

Process design is the first action step in the execution of a project. Process design packages are normally prepared to serve as the starting point for more advanced design stages as well as the basis for the various types of cost estimates required to make progressive project decisions. For example:

- A Conceptual Design is the starting point for a basic process design (Phase 0) and can be used to prepare both order-of-magnitude and conceptual estimates to support initial business planning decisions.
- A Phase 0 Design is the starting point for a complete process design and engineering specification (Phase 1) and is also the basis for the preliminary cost estimate required to optimize a process and/or decide to continue or cancel it.

- A Phase 1 Design is the starting point of detailed engineering and mechanical design. It is also the basis for the definitive cost estimate required for appropriation and formal project approval.

The determining criteria for falling into any of the three categories of process design is the soundness of the basic process information and/or assumptions, rather than the degree of detail. A process design including detailed materials and energy balances and even Piping and Instrumentation Diagrams (P&ID's) will still be a conceptual design if it is based on a theoretical process that has not been proved beyond the laboratory level. On the other extreme, a simple reference to an existing plant of a given capacity can be equivalent to a Phase 0 or even a Phase 1 if all the conditions are similar.

The actual preparation of the process design is the responsibility of the Owner's process engineering group or a contractor under the direction of a Technical Manager. However, as mentioned in the introduction, the Project Manager must participate actively to insure a cost-effective design. A process design cannot be considered complete without project engineering input. The greatest cost saving opportunities are found in the early stages of any project and it is the greatest challenge to the assigned Project Manager to identify those opportunities and influence the process design team to make the most out of them.

During the Phase 1 stage, the Project Manager is specifically responsible for:

- Planning the overall project execution.
- Setting realistic preliminary schedules.
- Ascertaining the adequacy of the input to estimating.
- Providing on a continuing basis cost and execution viability input to insure optimum project cost and schedule.

In all cases the Project Manager must review, and/or insure review at the appropriate level, all process designs, especially Phase 1 packages, for compliance to the stated project objectives.

6.2 Process Design Packages

Conceptual Design

A conceptual design:

- Permits the process engineering group to start developing the technical data and perform the design work required for a basic process design (Phase 0).

- Allows a cost engineer to put an approximate price tag on the proposed facility.
- Provides the business people with sufficient information to assess the risks involved and make meaningful economic evaluations.

A conceptual design could be based either on the application of proven technology and unit operations or on new and incompletely demonstrated technology.

In the first case, the required detail of information is minimal and a decent order-of-magnitude estimate can easily be developed through a literature search. Preparing any kind of estimate for an unproven process is a different story. A process configuration must be conceptualized so that equipment lists, including estimated sizes and construction materials, can be developed to serve as the basis for an estimate.

The following is a suggested outline of the information that should be included in conceptual design packages for unproven processes:

General

- Description of the proposed facility.
- Purpose for which it is intended.
- Function or products.
- Desired completion date.
- Size or capacity.
- Proposed or possible location.
- Alternative cases which are being considered.
- Mention of any previous scopes, designs, and estimates or actual costs for the same general type of project. Differences between previous project and this one.
- Basic philosophy of project: e.g., temporary, long-term, fast track, or minimum cost.
- Other facilities or operations at proposed site.

Technical

- Major raw materials, products, by-products, wastes and effluents (compositions or specifications insofar as known).
- Annual design capacity for each product or grade.
- Approximate usages and efficiencies (raw materials and energy).

- Brief process description.
- Health and safety information.
- Environmental considerations.
- Process configuration (preliminary process flow diagram).
- Preliminary process equipment list with approximate sizes and best guess of construction materials.
- Use of existing facilities or services.
- Off-site requirements, including, e.g., storage, handling, shipping and utility supplies.
- Status of process definition:
  1. Unproven/undemonstrated chemical reaction.
  2. Laboratory piloting.
  3. Large scale piloting

Phase 0 Design

A Phase 0 design provides the general definition of a proposed chemical processing facility. It provides the basis for development of operating costs and economics for business decisions. A Phase 0 design is the starting point for development of detailed process design and engineering specifications (Phase 1) and is the basis for a preliminary cost estimate.

The Phase 0 design is normally based on information available from research and development work, experience with a commercial unit, or from an outside licensor. In the latter two cases, there might be abundant knowledge and experience, but for significantly different capacity, local conditions, or other factors which require an essentially new design. The following criteria give general and state-of-the-art information which would permit preparation of a Phase 0 design:

- The chemistry has been demonstrated. Major reactions are known. There is some knowledge of side reactions and important by-products.
- A basic flow diagram has been drawn.
- Yields are known, at least approximately.
- Separations and purifications, if demonstrated at all, may have been done only by laboratory techniques which are not necessarily realistic for commercial practice.
- Principal process steps and major equipment have been described.

- Usually, though not necessarily, the most economical materials of construction have been identified.

A Phase 0 package should include essentially the same items suggested for a conceptual design package. However, the information is no longer the result of conceptual work, but is based on hard data derived from actual pilot and/or commercial operations:

- The process configuration is based on complete process flow diagrams (PFD's) and material and energy balances that show the main recycle streams and control loops.
- The equipment list includes all the major process equipment sized to reflect the material balances.
- The equipment list includes basic descriptions adequate for budget pricing.
- The PFD's and material balances identify all waste streams and, as a minimum, propose viable disposal methods and/or schemes.
- The PFD's and material and energy balances also identify the required utilities and provide approximate consumptions.
- The instrumentation philosophy and type must be specified.
- All the required buildings must be listed with brief descriptions and preliminary sizes.
- The preliminary layouts should include all equipment and buildings, show paved areas and roads, and identify on-site requirements.
- Incomplete and/or soft areas subject to significant change must be clearly identified.

Phase 1 Design

The Phase 1 design is the detailed definition of the project. Ideally, a Phase 1 package should contain sufficient information to:

- Have a competent contractor design and build the proposed facility without further input from the client.
- Permit a cost engineer to prepare a preliminary or even appropriation-type cost estimate.

The Phase 1 design is normally based on a Phase 0 package and on a fully demonstrated process, including waste and effluent handling. The process may have been demonstrated either in actual plant operation or through a sufficiently large pilot operation.

At the end of Phase 1, the project must be completely defined:

- Plant location and size as well as the expandability philosophy have been set.
- Raw materials sources have been identified and tested.
- Process steps have been optimized for material and energy efficiencies.
- Recycles and purges have been realistically tested or simulated for control.
- Instrumentation and control systems as well as degree of computerization have been established based on preliminary instrument engineering.
- Product quality and grades have been established; sample or market-test batches have been prepared.
- Product specifications and test methods have been set.
- Packaging and shipping methods have been specified or selected.
- Physical and chemical property data are available for all materials to be handled.
- Materials of construction have been selected or narrowed to an acceptable number of alternatives.
- Energy saving options have been studied and selections made.
- Any remaining process uncertainties have been analyzed and defined.
- Environmental compliance requirements have been established.
- Appropriate hazard analyses have been made and the impact on design reported. Special hazard protection devices have been defined.
- Insurance requirements have been determined.
- Process engineering including material and energy balances as well as equipment sizing have been completed.

In addition to the information listed under Phase 0, the Phase 1 package must include:

- Complete physical and chemical data of the raw materials, products, by-products, intermediate products, and wastes.
- Complete material and energy balances including average and peak uses of all utilities.
- Capacity turn-down requirements.
- Projected future capacity and philosophy of expandability.
- Complete piping and instrumentation diagrams (P&ID's) showing all equipment, instruments, and sized process and utility lines, all properly numbered.
- Preliminary equipment arrangement drawings and proposed layout of required buildings.
- Design data sheets for all equipment items.
- Complete list of instruments with basic description and, when appropriate, manufacturer and catalog number.
- Complete motor list showing estimated total connected and average loads.
- Equipment and piping insulation requirements that can be shown on the P&ID's.
- General specifications for:
  1. Equipment.
  2. Piping and valves.
  3. Electrical.
  4. Insulation.
  5. Other.

6.3 Project Manager's Role

Cost Optimization

During the process design stage the Project Manager can start controlling the final project cost and avoid unpleasant surprises by:

- Providing on-the-spot assessment of the cost and schedule impact of the various process alternatives considered during process design.
- Tracking cost and making projections as the design progresses, thus providing sound criteria for timely action by the Technical Manager and, when required, Owner's management.

- Insuring that all factors with potential cost impact are taken into account so that they can be included in the cost estimates and considered in the project schedule.
- Helping the Technical Manager in the development of cost-effective layouts and equipment arrangements.
- Insuring that the specifications are adequate and do not include unnecessary gold plating:
  1. Excessive corrosion allowances and minimum vessel thickness.
  2. Ultraconservative materials of construction.
  3. Superfluous blocks and bypasses for control valves.
  4. Unnecessary installed spare pumps when process allows for short unit shutdowns.
  5. Structural design for concurrent adverse conditions.

Phase 1 Review

The Project Manager is not supposed to be an expert in every project-related field but should be knowledgeable and astute enough to ask the right questions, promote constructive thinking, and ascertain if others have done their homework. The Project Manager should have a healthy skepticism, be bold enough to challenge the experts to justify their position and/or recommendations, and be adamant in demanding quality work from team members as well as contractors.

The following is not intended as a complete checklist but a reminder for the Project Manager of the important points to be covered as part of a Phase 1 package review.

- Compliance to the process design and engineering specification.
- Input/review by appropriate groups/individuals:
  1. R&D.
  2. Production.
  3. Maintenance.
  4. Environmental.
  5. Corporate Health/Safety/Hazards.
  6. CED Specialists.
- Schedule viability.
- Adequate information to estimating.
- Coordination with plant:
  1. Work in operating areas.
  2. Shutdown.
  3. Tie-ins.

- Constructability.
- Reasonable specifications.
- Challenges:
  1. Minimum vessel thickness.
  2. Need for high-price alloys.
  3. Installed spares.
  4. Expanded layouts.
  5. Winterizing practices.
- Soft areas / allowances.

Phase 1 Specifications

The specifications define the quality of the design and fabrication of the equipment in the project as well as the related commodities - piping, civil, electrical, etc. It would be impossible to build a plant without some sort of specifications.

Specifications are also a very important factor in the capital cost of a project since they define design criteria, materials of construction, design safety factors, etc., all of which can influence cost substantially. The Project Manager controls both quality and cost by ascertaining that the specifications included in Phase 1 design reflect the quality level established in the project scope as well as the environmental and safety standards mandated by company management and/or applicable laws and regulations, while avoiding extravagant and costly requirements.

Specifications can be classified in two general groups:

General Specifications/Standards

These define design criteria, applicable codes and preferences consistent with code requirements. They should reflect the minimum quality requirements while setting a limit to costly practices.

Project Specifications

These must be prepared for each project to reflect its specific requirements - process, site conditions, safety, specific equipment, etc. A complete project specification must go into the details of equipment design data sheets, spelling out all the information, process, and/or mechanical, required to fabricate a piece of equipment.

Ideally, a Phase 1 package should include a complete Project Specification. However, this is not always possible. Some owners don't have the in-house expertise in all the design disciplines to cover the necessary details. Normally the specifications included in the Phase 1 packages concentrate on process-related requirements and certain critical mechanical items, leaving most of the mechanical and structural details to the engineering contractor. On many occasions, specifications from previous projects are included in Phase 1 packages. This is a dangerous practice since they are not necessarily updated and/or applicable to the current project. The Project Manager must avoid this trap carefully and always keep in mind that a good general specification is much better than an outdated, or even incorrect, detailed specification.

On large projects, where detailed engineering is performed by an outside firm, the Project Manager can rely on the engineering contractor to critique, complete, and/or update the Owner's specifications as required. On small projects, the Project Manager is at a great disadvantage and must compensate by being continuously cost conscious and bold enough to challenge the "experts."

6.4 Conceptual Plant Layout Guidelines

General Considerations

Preliminary plot plans and conceptual equipment layouts must be developed during the Phase 0/Phase 1 work in order to determine the plot requirements and help the estimators visualize the proposed facilities and prepare realistic cost estimates.

This information will be useful for estimating:

- Site development - roads, railroads, fences, etc.
- Civil work - foundations, buildings, structures, etc.
- Tank farms and other off-site facilities.
- Process and yard piping and other distribution systems.

Preparation of final, optimized layouts is a time-consuming process requiring participation of many experienced people. On the other hand, conceptual layout adequate to meet the above objectives can be easily prepared by a process or project engineer. The ensuing guidelines will be useful for doing so. They should also be useful for reviewing layout work done by the contractor.

The recommended parameters and criteria included in these guidelines reflect insurance and OSHA requirements as well as good practice standards. They are biased on the conservative side and their application should result in a layout that could be optimized during detailed engineering without unpleasant surprises.

The following information is the minimum required for the preparation of a conceptual layout. It is occasionally provided as part of a conceptual design package and must certainly be provided in the Phase 0 package:

- Equipment list with approximate dimensions and motor horsepower.
- Process flowsheets or preliminary P&ID's showing relative elevations.
- Off-site requirements - buildings, tank farms, diked areas, railroads, cooling towers, storage areas, etc.
- Hazard considerations.
- Process buildings and/or structure requirements: open/closed.
- Future expansion considerations.

Safety Considerations

Safety and protection of human lives must be the paramount concern in the preparation of layouts. The following considerations are by no means totally inclusive; they are only those that would have a substantial impact on the plant dimensions and capital cost:

- For adequate fire protection, any part of the plant should be accessible from at least two directions.
- Process units handling flammables should be separated to minimize possible spread of fires.
- All areas protected with sprinkler or deluge systems must be contained with provisions for rapid drainage to large remote reservoirs.
- Process vessels with substantial inventories of flammable liquids must be located at grade.
- Flammable materials must be stored outside in diked areas and away from process units and other active areas, control room office change rooms, etc.
- Equipment subject to explosion hazard must be set away from occupied buildings and areas.
- All operating areas must have at least two means of access and exit. On elevated areas, at least one should be a stairway.

Maintenance Considerations

A plant that can not be maintained properly will deteriorate gradually and eventually become inoperable. Good plant maintenance ability is the result of well-thought-out layouts. The following guidelines affect plant dimensions and must be kept in mind when developing layouts:

- All equipment should be accessible by either crane or lift truck.
- Space for maintenance and dismantling must be provided around compressors.
- Bundle removal space must be allowed for shell-and-tube exchangers.
- Sufficient suction head must be allowed for pumps handling hot liquids.

Recommended minimum clearances

General

- Property Line: All process units and auxiliary buildings, except the front office and the guard house, must be at least 30 ft. from the property line.
- Primary Roads: Width 30 ft.; headroom 22 ft.; distance from buildings and process areas 10 ft.
- Secondary Roads: Width 20 ft.; headroom 20 ft.; distance from buildings and process areas 5 ft.
- Pump Access Aisleways: Width 12 ft.; headroom 12 ft.
- Process Areas Main Walkways: Width 10 ft.; headroom 8 ft.
- Process Areas Service Walkways: Width 4 ft.; headroom 7 ft.
- Stairs: Width 3 ft.
- Railroads: Headroom 24 ft.; clearance from track centerline to obstructions 10 ft.
- Main Pipe Racks: Headroom 22 ft.
- Secondary Pipe Racks: Headroom 15 ft.
- Floor Elevations: The vertical distance between operating levels must be no less than the height of the tallest process vessel plus 8 ft. or the tallest tank plus 6 ft.

Around Hazardous Areas

– Flare stacks	100 ft.
– Cooling towers	100 ft.
– Medium flammability liquid storage	50 ft.
– High flammability liquid storage	100 ft.

– Explosion potential	100 ft.

Around Process Equipment

– Tank Farms:	
1. Between tanks	1/2 dia.
2. From tank to dike wall	5 ft.
3. Access around diked area	10 ft.
4. Dike capacity	Largest tank plus 10%
– Around Compressors	10 ft.
– Between Adjacent Vertical Vessels:	
1. 3 ft. dia.	4 ft.
2. 3-6 ft. dia.	6 ft.
3. Over 6 ft. dia.	10 ft.
– Between Adjacent Horizontal Vessels:	
1. Up to 10 ft. dia.	4 ft.
2. More than 10 ft. dia.	8 ft.
– Between Horizontal Heat Exchangers	4 ft.
– Between Vertical Heat Exchangers	2 ft.
– Around Fired Heaters	50 ft.

Miscellaneous equipment dimensions

– *Pumps:*	
1. Up to 3 HP	1 ft. x 3 ft.
2. 10 HP	1.5 ft. x 4 ft.
3. 30 HP	2 ft. x 5 ft.
4. 75 HP	2 ft. x 6 ft.
5. 200 HP	3 ft. x 7 ft.
– *Compressors:*	
1. Up to 50 HP	3 ft. x 6 ft.
2. 100 HP	4 ft x 8 ft.
3. 250 HP	6 ft x 12 ft.
4. 500 HP	6 ft. x 16 ft.
5. 1000 HP	6 ft. x 20 ft.

– *Heat Exchangers:* use nomograph in Fig. 6.1.

Typical building dimensions

– Control room	20 ft. x 40 ft.
– MCC room	20 ft. x 40 ft.
– Transformer switch gear	20 ft. x 30 ft.
– Maintenance shop	30 ft. x 60 ft.
– Gate house/first aid	30 ft. x 40 ft.
– Male/female change rooms	30 $ft.^2$/employee/shift
– Lunch room	20 $ft.^2$/employee/shift
– Office building	300 $ft.^2$/employee

Figure 6.1 is also used to approximate the external area in order to estimate the cost of insulation when applicable.

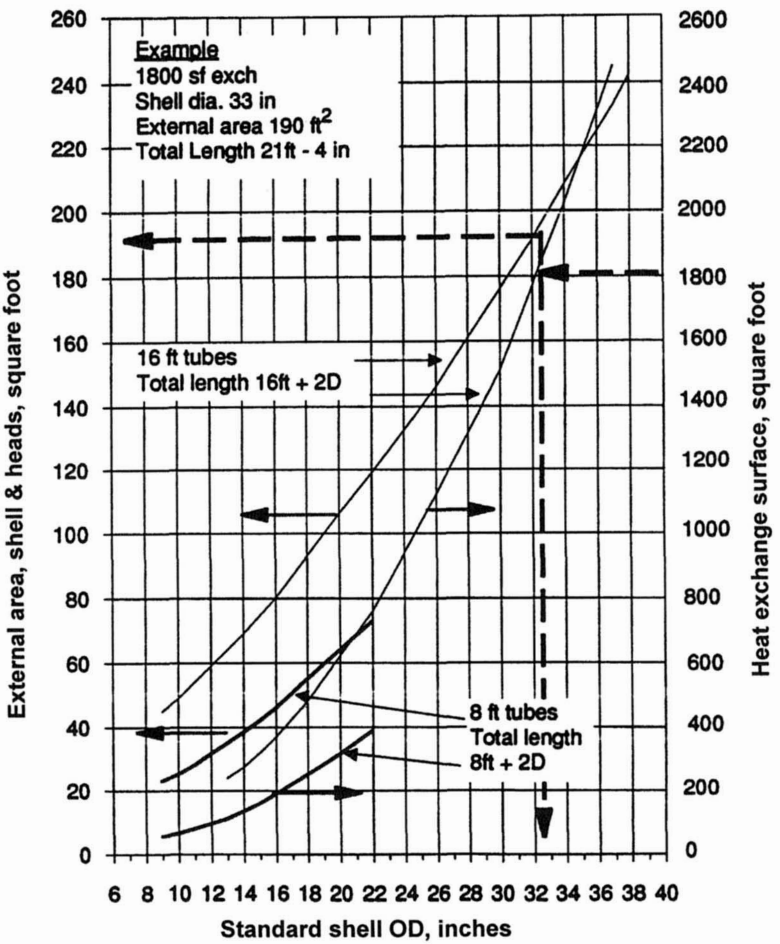


Figure 6.1 Shell diameter and external area.

CHAPTER 7
REGULATORY COMPLIANCE

Every job is a government job.

7.1 Introduction

All projects, no matter where in the world they are executed, come under some type of regulatory control. Even in the more advanced parts of the world, these regulations are changing on a routine basis.

It is important that the impacts of these regulations are planned for in the early project stages.

- It is common that the permitting process for a project is on the critical path.
- Meeting the regulatory requirements on a chemical processing project can often be the biggest cost item in the estimate.
- Understanding the requirements should be among the first things considered when choosing the best alternative for a project.
- Understanding the permitting requirements is a critical element of the Front End Loading.

Regulations are governmentally imposed requirements. In general, they are in place to protect the employees, the neighbors, and the environment. They are not imposed to protect the stockholders. Since the Venture Manager is required by most companies to meet the goals of all stakeholders, including employees, neighbors, and the environment, regulations should be viewed as minimum standards to be achieved.

Although the regulations may seem counterproductive to the Project Manager, their intent is actually consistent with the goals of the project.

> MEETING THE REGULATIONS AND COOPERATING WITH THE REGULATORY AUTHORITIES ARE REQUIREMENTS FOR ALL PROJECTS.

7.2 Local Regulations

General

For most parts of the world, local regulations include those promulgated by municipalities, counties, or regions. The most common among these regulations are those concerning:

- Use of land (zoning).
- Life safety of inhabitants (fire protection and building codes).
- Impacts on the neighborhood (noise, odors, and traffic).

Most projects in the chemical industry involve additions or modifications to existing plant sites. Most of these plant sites are located in areas zoned for heavy industry.

- Zoning modification permits are almost never needed for the majority of projects. Building permits are almost always needed when the structure involves personnel habitation such as offices and control rooms.
- Noise and odor compliance seldom need permits. However, there are almost always local regulations concerning noise, odor, and air pollution.

The Venture Manager should be aware of anything in the project that could impact these regulations.

However, many projects are done in grassroots sites or done in sites that are not zoned heavy industrial, but are grandfathered due to the age of the original site. In these projects, local regulation compliance can be extremely complicated and time consuming.

Zoning

If the project is done in a grandfathered plant site, a zoning modification or a zoning variance may be required. The mechanism for achieving this varies widely but often involves several components:

- Proof that the modification under consideration does not change the basic nature of the site or the neighborhood.
- A public hearing where all interested parties can be heard.

Often the project in question is not, by itself, the concern of the neighbors, and the public hearing will often turn out to be a sounding board for an accumulation of problems. It is important for the Venture Manager to recognize the nature of the public relations and be prepared to do some negotiating with the zoning board.

The zoning board is bound under regulations to rule according to the laws, not the emotions of the public. However, they are not immune to public outcry. It is often in the public interest for the Venture Manager to respond to concerns, even if outside a regulatory requirement. The project team should be prepared to negotiate for additional project items that could help sell a project to the community.

Building Permits

Almost every project will need a local building permit. This could be a very simple matter such as the addition of a work shed or be an extremely complicated matter such as a 100,000 sq. ft. office building. When a building permit is required it almost always involves the submittal of:

- Detailed civil/structural drawings,
- Detailed fire protection system drawings,
- Detailed site drawings,
- Detailed electrical drawings, and
- HVAC drawings in any occupied buildings.

It will be required that these drawings be stamped by a registered professional engineer.

IT WILL ALSO BE REQUIRED THAT THE BUILDING PERMITS BE APPROVED BEFORE CONSTRUCTION CAN BEGIN.

This can have a serious impact on the schedule, especially if the schedule is based on concurrent engineering and construction.

If there is a large schedule impact, most municipalities have provision for phased building permits: concrete and underground, steel and enclosures, etc. This requires a good relationship with the building commission but can often mean that a "fast track" project stays on schedule.

Neighborhood Impacts

Most other neighborhood impacts are covered in some type of regulations. These would include general nuisance impacts:

- Noise.
- Odor.
- Traffic.
- Visual pollution.

All of these items are usually measured at the fence line. A general rule of thumb:

- If the project causes a new noise, odor, or significant change in traffic patterns, it could be a problem.
- If a project causes a big, distasteful visual impact, it could be a problem.
- The Venture Manager must stay aware of anything that could adversely impact the neighborhood and be prepared to mitigate it.

7.3 Federal Regulations

There have been very few things that have changed as significantly in the past 30 years as federal and state regulations. Protection of workers, the neighbors, and the environment have produced a plethora of regulations, especially in the chemical industry. A project manager of the 21^{st} century must be intimately aware of all of the regulations in order to produce a project that meets all the cost, schedule, performance, and regulatory goals.

Protection of Workers – OSHA

By federal law, both the workers who build the project and those who will use it after it is built must be protected. The Occupational Safety and Health Administration (OSHA) has been empowered by Congress to promulgate regulations to achieve this end.

- **Construction workers**. It is paramount that the construction site be safe. Most plants will have a Construction Safety Procedure that is in place to protect the plant, its workers, and the construction personnel. This procedure should be included in every prime and sub contract.

  The safe conduct of the construction is not only the responsibility of the contractor. The Owner has a strong interest in the project being executed safely and must project, through the Project Manager and the entire Project Team, a strong presence on the job site, demanding that all personnel follow the appropriate safety rules.

  OSHA has definite procedures for the safe conduct of construction. These include:

  - High work procedures.
  - Hot work.
  - Confined space entry, etc.

  Officially, OSHA will hold the direct supervisor responsible for the safety of its workers. However, OSHA can also fine and hold responsible the Owner for not having made sure the contractor is working safely. OSHA certainly has the authority to shut down a work site if the safety record warrants it. This is not in the best interest of anyone and therefore demands excellent safety performance during construction.

- **Workers who will use the project.** Design of the project must include provision for worker safety. Since its inception in 1972, the OSHA regulations have moved from a standards based system to a performance based system. This gives the designers more leeway in the actual design, but puts a strong burden on them to make sure that the plant will be safe. Most of the required personnel safety issues are now a routine part of design and include consideration of:

  - Stairways.
  - Alternate escape routes.
  - Safety shower locations.
  - Handrails.
  - Marking and signage, etc.

The Project Manager should be careful that nothing out of the ordinary exists that might require something very expensive that has been overlooked.

Process hazard analysis (PHA)

In the aftermath of the Bhopal disaster, OSHA's Process Safety Management (PSM) has come into play and dictates the procedures to minimize the possibility of fire, explosion, or chemical release. If a project contains a regulated hazardous chemical, a process hazards analysis must be conducted to ensure that the likelihood of a fire, explosion, or release of hazardous chemicals is minimized and that equipment and facilities are included to minimize the effects of a fire, explosion, or release, if one does occur.

Most companies whose facilities are covered by PSM have adopted a multi-tiered analysis program for new projects.

- The **first pass of the PHA** will include examining the inherent hazards of the chemicals and processes involved. This is usually done early in the conceptual design. This conceptual hazards analysis will alert the business and engineering teams when high risk and thus higher costs may be the outcome of a design. This must be done early in the Front End Loading to permit alternative processes and alternative chemical routes to be explored if the risks uncovered are not acceptable to the business.

- The **second pass of the PHA** is done after the P&ID's and preliminary layouts are complete. This second analysis will indicate what equipment, installation methods, and process controls will be required to operate the plant safely. This analysis should be completed before the estimate for the Authorization Request is generated.

  This is also a good mechanism for doing a complete process review. If the project has had a thorough process hazards review, it means the process is very well understood. This is critical for the overall success of the project.

- The **third pass of the PHA** is done after the detailed design is about 90% complete. At this stage, the analysis concentrates on the physical facilities. This review ensures that the detailed design has appropriately captured the safe operating principals developed during PHA-II.

- The **fourth pass of the PHA** is done after construction and before startup begins. This is a physical check of the facilities to be sure the plant has been constructed as per the detailed design. This analysis is usually called the Pre Startup Safety Review (PSSR). This review would also include checking that all control logic and safety protective devices are appropriately calibrated and are working properly.

The Hazards reviews should be conducted by the integrated project team Technical Manager and key team members with participation of representatives from:

- Plant operating, safety, and maintenance.
- Corporate safety, health, and environmental departments.
- Insurance company.
- Outside consultants, if required.

Protection of Environment - EPA

General

The US Government, over the past 30 years, has been involved in trying to protect the environment. Their efforts, starting in the early 1970's, have brought a tremendous amount of regulation in air, discharge water, ground water, and solids handling and disposal, including waste minimization efforts. Practices once very common in the 1960's are now unheard of.

The regulations are also constantly changing. Practices that are common today will probably disappear over the next decade. It is imperative that the Project Manager stay abreast of the regulatory climate. Projects are built for today but also have to meet tomorrow's environmental thrusts.

Luckily for the Project Manager, most companies have extensive Safety, Health, and Environmental organizations that stay up to date on these regulations. During the Front End Loading, representatives of these organizations must be involved in the project reviews. Any high risk environmental concerns must be identified early in the process. Like safety, these concerns must be identified to ensure that any major cost and schedule impacts are known and accounted for at the time of the funding authorization.

Risk management program (RMP)

This is a program with extensive regulations that parallels the OSHA PSM program. There are two major differences. One is that OSHA covers plant workers; RMP covers offsite conditions. The second is that the lists of regulated chemicals are different. Since these lists are subject to periodic changes it is very important that the Project Manager insures the participation of the company Health and Environmental experts in all PHA reviews.

The Project Manager is responsible for the implementation of the Process Safety Management (PSM) and Risk Management Programs (RMP) and must appoint a qualified hazard study leader to conduct hazards evaluations and insure that the results are incorporated into the Process Hazards Analysis and Review.

Air permits

EPA has given most states the jurisdiction to review, approve, issue, and audit air and water permits. In cases where the project is going into an existing facility, there is usually a Site Regulatory Manager who interfaces with the appropriate state authorities for air and water permits. Most chemical plants will have permits. The Project Manager must consult with the Regulatory Manager to determine how the project will affect the current permit.

- **Registered emission points**. Plants with current permits have registered emission points. Depending on the chemicals released, these are controlled by monitoring and reporting. If the project has releases that will change the pollutant loading from existing registered points, the permit will have to be modified. If the new loading is unacceptable to the state, control equipment modifications must be installed. Depending on the nature of the chemical, e.g., a zero release chemical, this could be a very expensive modification. Identifying this early is vital. Permit modifications could take months and involve public hearings. Like building permits – no construction can take place until the permit is issued.
- **Greenfield plants** could face even stricter regulations. Regulators are usually slightly more lenient with existing facilities, especially if they have good compliance records. There is some degree of understanding that forcing an older plant to retrofit may result in the closing of a facility. This is not the case with a greenfield plant. Regulators tend to be stricter in interpreting the regulation for a facility not yet built. They are more inclined to insist on best known technology for the control equipment. Should emissions from new plants be large in quantity, extensive and lengthy new source reviews could be required by the agencies. This can require that the new source off-set the emission increase by reducing emissions from existing processes at the site, or existing processes at another site in the area. All this will lengthen the permit process and add difficulty to any negotiations and planning.
- For a greenfield plant, the Venture Manager must take the lead in **setting up relationships with the state authorities**. There are good consulting firms in each state (usually located in the state capital) that specialize in this activity. They usually have both engineering and legal personnel to help the companies establish critical relationships and to help companies understand the state regulations.

Water permits

- Every plant that discharges into a waterway is covered by the **National Pollutant Discharge Elimination System (NPDES)**. Each plant must have an NPDES permit.

  This permit usually contains the volumetric flow allowed and the allowable concentration or poundage of listed materials that may be discharged. If your project increases anything in the permit, the plant must obtain a permit modification. Recently, agencies have begun to require Toxicity Studies to asses any impact on aquatic life. Such studies are lengthy and costly.

- **The permit modification procedure** is cumbersome and also contains provisions for the state to open up the entire permit for review and modification. If a plant has what the state contends is a contentious permit, they will often use the request to open up the permit for negotiation before the expiration date. This may be a big problem for the plant. The negotiation may be lengthy and the results more expensive than planned.

  The recommendation is to try to make sure that the project does not alter the NPDES permit conditions. This may take some heroic efforts and add money to the project. This may be better than reopening the permit.

  If this cannot be done, then start the discussions with the regulators early. This may be a good time for the plant to discuss the permit. Often, trades can be made. The state may be amenable to allowing new pollutants if other, more hazardous pollutants can be reduced or even eliminated. Do this early. Be sure the estimate includes the necessary funding for this activity.

- If a plant discharges to an **outside water treatment facility** owned by the local municipality, the plant may not have its own NPDES permit. However, the treatment facility will have a NPDES permit.

  Your discharges cannot cause the treatment plant to exceed its permit. Have discussions with the facility personnel as early as possible. There may have to be testing to ensure that the municipal plant is not adversely affected by receipt of your discharge. There may have to be changes in the contract with the facility. All of these take time. Start the process as early as possible.

Note: The trend is for states to require NPDES permits for plants who discharge to outside treatment facilities. In these cases, the permit modification procedure may come into play for the new project. Again, start discussions early. Cost and schedule risks may impact the project.

Solid waste permits

- A new facility which will generate solid wastes, or liquid wastes that cannot be directly discharged to an outside water treatment facility or under an NPDES permit, may face additional regulatory requirements.
- To the Venture Manager, it is paramount that licensed waste disposal outlets are found for the proper handling, treatment, and disposal of wastes, before the new process begins operation and the waste is, in fact, generated. While this obligation may appear too obvious to even mention, finding such outlets can prove difficult and time consuming. This will require a characterization of the waste, providing samples (from pilot or laboratory work) to the potential outlets for their analysis and for the outlets to secure permission and/or permits from their regulatory authority in order to legally receive and treat the waste.
- If the wastes to be generated are "hazardous" as defined by the US **Resource Conservation and Recovery Act**, permits may be required of the generator, the Owner of the new process, to legally generate, treat, store, or dispose of the new wastes. This can add considerable length to the permitting process and to administrative and engineering costs. Waste management issues (and waste minimization obligations) should be carefully considered, as they are equally important as are air and water matters.

Environmental impact studies

Occasionally, a project may involve movement of facilities into "protected" areas, i.e., wetlands. These projects may involve the submission of an Environmental Impact Study. This can be extremely costly and time consuming and could involve:

- Endangered species impacts, flora and fauna.
- Protection of migratory birds.
- Surface and ground water studies.
- Set back requirements from protected areas or surface waters.
- Anything else covered by the environmental regulations.

If this study is required, it must be identified as early as possible. Projects have been known to have been held up years by this process.

RECOMMENDATION – AVOID A PROJECT WHERE THIS STUDY IS REQUIRED.

7.4 Other Codes and Standards

The local, state, and federal regulations dealing with workers and environmental protection are not the only ones the Project Manager has to deal with. The design and construction of all plants have to conform also with a number of codes and standards that regulate the design, fabrication, and erection of all the physical components of the project.

Some of the most common in the United States are:

- ACI - American Concrete Institute
- ANSI - American National Standards Institute
- API - American Petroleum Institute
- ASME - American Society of Mechanical Engineers
- ASTM - American Society of Testing Materials
- AWA - American Waterworks Association
- NEC - National Electric Code
- NEMA - National Electrical Manufacturers Association
- NFPA - National Fire Protection Association
- TEMA - Tubular Exchangers Manufacturers Association
- - Uniform Building Code

All these codes are updated on a regular basis and it is the Project Manager's responsibility that the contractors as well as the Project Team Specialists conform and enforce the latest revision.

Many Owners, especially large ones, have developed and promulgated and made mandatory their own sets of standards and specifications that supplement those normally used in the industry. The Project Manager must see that those are also enforced on contractors and vendors.

7.5 Documentation

All regulations mentioned in this chapter include definite requirements for formal documentation to support that they have been complied with, especially in the areas of safety and environmental designs.

- The **engineering contractor** must submit calculations to support, among others:
  - Process design.
  - Structural design.
  - Control valves sizing.
- The **equipment fabricators** and material suppliers must submit:
  - Design calculations for pressurized equipment.
  - Proof that the materials and employees meet the quality specified.
  - Copies of ASME, TEMA, etc., code stamping.
  - Proof of welders' qualifications.
  - X-rays when required.
  - etc.
- The **construction contractors** or construction manager must submit:
  - Copies of their health and safety programs and Emergency Response Plan.
  - Minutes of their regular safety meetings.
  - Accident reports and follow-up.
  - Proof of welders' qualifications.
  - Reports of an equipment and piping integrity test.
  - X-rays when required.
  - etc.

The Project Manager must implement a permanent filing system to turn over to plant operators at the completion of the project.

A thorough project documentation could save the Owner millions of dollars in case of a major mishap during the life of the plant.

7.6 Impact of Regulations on Project Cost

Compliance to and documentation of regulations increase the engineering hours required to execute the project and the Project Manager must ascertain that they are acknowledged and the impact on cost, and sometimes schedule, is included in the cost estimate and project execution plan.

An alert Project Manager could minimize the schedule slip and cost increases by following the advice of a seasoned Venture Manager:

Schedule slip:

- Get help early from corporate staffs or consultants.
- Find out early what permits will be required.
- Learn what is required to be submitted for environmental, building, and operating permits.
- Know how much time the regulators require for permit approvals.

Cost increases:

- Will extra engineering and documentation be required?
- Do the PHA's, risk analyses, and environmental engineering before the AFE is submitted.
- Leave extra contingency for changes driven by safety and environmental needs.

CHAPTER 8
RISK ANALYSIS

All of life involves risk: Saying hello to your mate in the morning is a risk.

8.1 Preamble

RISK CAN BE DEFINED AS ANY ISSUE WITH THE POTENTIAL OF CAUSING A SIGNIFICANT DEVIATION TO PROJECT OBJECTIVES.

Chapter 4 emphasizes the importance of selecting the "right" project and the timely and realistic execution planning to insure that it is done "right."

THESE TWO GOALS ARE BEST ACHIEVED BY THE IMPLEMENTATION OF A DELIBERATE AND THOROUGH RISK ASSESSMENT AND ANALYSIS.

The purpose of Risk Analysis is threefold:

- **Evaluate and select options.**
  - Estimate their cost.

- Understand the benefits and risks of each one.
- Prioritize them by order of potential business opportunities.
- Compare with each other and with the "do nothing" option.
- Select the preferred one.

- **Authorize a project.**

  Decide:

  - Whether it meets business needs.
  - Whether it meets investment "hurdle" criteria.
  - If it should proceed to the next stage of development or be authorized to move to completion.

- **Manage the project effectively.**
  - Maximize opportunity for success.
  - Make acceptable the risks of underperformance.
  - Minimize surprises.
  - Insure control and accountability.

Risks are encountered and must be assessed at three well-defined levels of project execution:

- Business strategy level – Protection of business values.
- Venture level – Selection of the "right" project.
- Project execution level – Doing the project "right."

Risks at the business strategy level are the concern of top corporate management. Although the Venture Manager may occasionally be asked to participate in that level of decisionmaking, the main responsibility must remain with top corporate management.

Risk analysis at the venture and project level fall, of course, squarely on the shoulder of the Venture Manager and Project Manager. Although the brunt of responsibility shifts from Venture to Project Manager as the project proceeds the team concept will prevail and both must be intimately involved at all times.

In all cases risks must be:

- Identified,
- Evaluated,

- Classified, and
- Managed,

so that they can be avoided or that response plans and fallback positions can be developed so that corrective action can be implemented quickly and effectively.

The post-mortem of unsuccessful projects reveals, more often than not, that failures are attributable to risks that could have been avoided, or their impact mitigated, had they been identified during the early project stages.

Frequently those failures are blamed on "unforeseeable risks." However, as experienced venture and project managers have learned the hard way, even if some risks are "unavoidable," there is no such thing as "unforeseeable" risks, only "unforeseen" ones.

The ultimate goal of risk analysis and risk management is to eliminate "unforeseen" risks and avoid or minimize the impact of all "foreseeable" ones.

8.2 Risks at Business Strategy Level

Risks at this level are mainly those that could threaten the business values:

- Achievement of corporate goals.
- Business continuity.
- Company stock price.
- Stockholder value.
- Public acceptance of a new project.
- Competitors' responses.
- National economy.
- World economy.
- Rate of inflation.
- Interest rates.
- Availability of money.
- Corporation cash flow.
- etc.

Assessment and management of these risks are the responsibility of top corporate management and fall outside of the scope of this book.

8.3 Risks at the Venture and Project Execution Levels

As discussed previously the Venture Manager is responsible for the selection of the "right" project with the Project Manager being responsible for executing it "right." That being the case, they will share the glory or the shame resulting from the outcome and must support each other throughout its duration.

> BOTH THE VENTURE MANAGER AND THE PROJECT MANAGER MUST PARTICIPATE ACTIVELY, AND LEAD THE PROJECT TEAM, IN ALL THE RISK ASSESSMENT AND ANALYSIS ACTIVITIES.

- Risks at the **Venture** level are those that could threaten the commercial success of the project and are mostly of financial nature:
  - Capital cost.
  - Financial performance – rate of return/net present value/etc.
  - Operating costs – raw materials/labor/utilities.
  - Marketing – sales volume/market growth/competition/product price.
  - Safety, health, and environmental (SHE) considerations.
  - Permits – construction/operating.
  - Technological performance, yield/product quality, etc.
- The risks at the **project execution** level are those that could have a negative impact on the specific project objective of quality, cost, and schedule:
  - Capital cost.
  - Schedule.
  - Changes – scope/design/execution.
  - Vendors' performance – quality/schedule.
  - Contractors' performance – engineering/construction.
  - Labor productivity/unrest.
  - Weather.
  - Process design soundness.
  - Field safety/security.
  - Interface with existing facilities – scheduled shutdowns/welding permits /traffic/access to work area/evacuation alarms, etc.

All risks of venture and project execution must be addressed jointly by both the Venture and the Project Managers with input from the key stakeholders.

8.4 Assessment and Analysis

- Experience shows that most successful projects took the time in the early stages to analyze risks by:
  - Identifying.
  - Evaluating – cost/schedule/impact.
  - Classifying – obvious/potential.
  - Avoiding the obvious ones.
  - Developing mitigating and control strategies for the potential ones and estimating their cost if implemented.

  Experience also shows that the success of this exercise is vitally dependent on the active participation of knowledgeable representatives from the key stakeholders, each with prior relevant experience.

- When such expertise is not available in the assigned project team it should be temporarily supplemented during the risk analysis exercise with a qualified third party.

  An experienced and independent third party risk analysis facilitator has proven to be an effective aid to project leaders in such situations. This completely detached person can ask probing, sensitive questions which may be awkward or politically incorrect for any of the project team members to ask.

- Additionally, someone skilled in the art of conducting such sessions, who can also contribute directly to the risk analysis, would be a cost-effective, value-added influence.

The effort invested in the risk analysis must be commensurate with the size, type, and importance of the project.

- On **small projects**, like the ones addressed in this book, risk analysis can be handled in an informal manner between the Venture and Project Managers and the key members of the project team.

- On **large and important projects,** where risks could have substantial financial impact or, even worse, affect the corporate image, risk analysis must be taken very seriously and approached in a very deliberate and formal manner mustering the best available risk management expertise from inside as well as outside the corporation.

Once risks have been identified, understood, and evaluated they must be managed.

8.5 Risk Management

The key elements of successful risk management are:

- A good dose of common sense.
- Lots of homework.
- Some luck.

To be effectively managed, risks must be classified by:

- Probability of occurrence – avoidable/unavoidable.
- Potential impact.
- Feasibility and cost of preventing actions.
- Cost of correcting actions.

Avoidable Risks

- At the **Venture** level.

  RISKS AT THIS LEVEL DISAPPEAR OR ARE GREATLY MITIGATED WHEN PROJECTS ARE BASED ON REALISTIC EXPECTATIONS AND ACHIEVABLE GOALS.

  These goals include:

  - Capital cost.
  - Schedule.
  - Sales volume.
  - Product price.
  - Product quality.
  - Process yields.

- Production costs.
- etc.

Even when the assumptions are realistic the economic studies must be complemented with sensitivity analysis to determine the impact of uncontrollable variances in the basic assumptions.

Wishful thinking is not compatible with successful projects. Projects driven by greed are usually based on over-optimistic cost estimates, schedules, and marketing projections. They definitely are not the "right" project and will be doomed from the start.

It is up to the Venture Manager to inject a dose of common sense and a healthy detachment to the initial decisionmaking discussions with the business groups and corporate management. That participation would insure the selection of the "right" project.

- Risks at the **project execution level** can usually be taken care of by effective project execution and solid homework of the Project Manager and the project team:
  - Realistic cost estimates.
  - Realistic estimates with allowances for bad weather and evaluation alarms.
  - Intelligent contracting strategy.
  - Checking the credentials of contractors and suppliers.
  - Awarding contracts on technical value, not on political considerations.
  - Thorough checking of field conditions.
  - Establishing and implementing project control procedures.
  - etc. Read the book and you will find others.

Notwithstanding their effectiveness, these preventive measures are not infallible and must be complemented with a contingency allowance consistent with the stage of project development and the quality of the available information.

It is the Project Manager's nontransferable responsibility not only to implement the risk prevention measures, but also to contribute to the venture level discussions with realistic cost estimates and schedule information to evaluate the various options under consideration.

Unavoidable Risks

Some risks even if foreseeable are unavoidable, e.g.,

- Natural disasters.
- Acts of war.
- Political unrest.

There is no option but to accept these as part of life and prepare for them by setting emergency response and damage containment plans.

8.6 Risk Management Plan

The culmination of the risk analysis process is the **Risk Management Plan** (RMP). The RMP must be incorporated into the execution plan and contain provisions for:

- Formal periodic **risk reviews**, by the key stakeholders, to determine if changes have occurred in probability of the foreseen unavoidable risks or if any others, previously unforeseen, are raising their ugly heads.
- Setting up emergency response and damage-containing programs and designated teams, trained for the purpose.
- Designating a "Risk Manager" with a direct line to the Venture Manager.
- Setting "risk awareness" indoctrination programs for the project teams, contractor's supervisory team, and even construction workers.

The complexity of the plan must be commensurate with the size and importance of the project. A large project would justify a dedicated Risk Manager who could even have a dotted line responsibility to a corporate risk management director.

A small project does not require such a formal approach. An experienced Project Manager would be fully familiar with all the "conventional" risks and pitfalls encountered in project execution and will avoid or mitigate them following the deliberate approach propounded in this book and basing the project execution plan on the guidelines included herein.

CHAPTER 9
PROJECT EXECUTION PLAN/ MASTER PROJECT SCHEDULE

The real purpose of plans and schedules is not to put a bunch of dates and figures on paper, it is to discipline your mind.

9.1 Overview

Trying to execute a project without an execution plan and a master project schedule (MPS) is like trying to drive from here to there without a map or a clock. Eventually you will get nowhere, you will be late getting there, and you won't even know it. A project execution plan combined with the MPS provides a road map with criteria to judge where you are at any time and to know when you have arrived. It also provides the basis for the control system and is an excellent communication tool.

The project execution plan is intimately related to the cost estimate; each one depends on the other and neither can be totally complete without the other. For example, the total number of construction hours may be a determining factor in the contracting strategy, while the contracting strategy will affect productivity, which in turn impacts on the hours. Furthermore, both will influence schedules. Ideally, each type of estimate, conceptual, preliminary, definitive, and/or detailed, should be accompanied by a corresponding execution plan and schedule to complement the scope of work.

The level of a project execution plan discussed in this book is basically a master bar chart schedule showing the required labor loading, indicating the contracting strategy and the expected rate of progress.

Each project has different requirements and unique problems which dictate different approaches. However, all execution plans must basically address and convey the following information:

Preliminary Activities Schedule:

- Process design.
- AFE estimate and approval.
- Engineering contractor selection.

Procurement Schedule:

- Purchase and delivery of equipment emphasizing long delivery items.

Engineering Schedule:

- Overall summary of engineering, broken down by principal design activities.

Subcontracting Strategy and Schedule:

- Most important subcontracts, indicating type of contract (lump sum/ reimbursable, unit price, competitive/negotiated).

Loaded Construction Schedule:

- Overall summary of construction broken down by conventional field activities showing the spread of the estimated hours over the duration of each.

Total Staffing Curve.

Construction Progress Curve.

Conceptual and preliminary execution plans can certainly be covered in 20 or 22 activity lines and, therefore, can be documented on one page. Definitive (sometimes) and detailed (always) plans could require several dozen activity lines and several pages. However, for the benefit of management, they must be summarized on one page. The Project Manager must use ingenuity to come up with a meaningful summary.

Project execution planning is one of the most important responsibilities of the Project Manager in both large and small projects. In the early stages of all projects, it requires hands-on participation. In large projects, the execution responsibility is eventually assigned to a general contractor who will be responsible for engineering and/or construction. Detailed planning will then be done by the contractor under the supervision of the Project Manager. The managers of small projects don't have the luxury of a general contractor and they have to cope with all levels of planning. The criteria, tools, and guidelines included in this book can be useful to all project managers but are specifically intended for the managers of small projects.

> THE PROJECT MANAGER MUST KEEP A VERY OPEN MIND CONCERNING THE PROJECT EXECUTION APPROACH AND NEVER FORGET THAT NO TWO PROJECTS ARE EXACTLY ALIKE. THE FACT THAT A GIVEN APPROACH WAS SUCCESSFUL IN ONE PROJECT IS NOT, PER SE, SUFFICIENT JUSTIFICATION TO USE IT IN ANOTHER.

9.2 Thoughts on Scheduling

It seems that once a project is initiated, everybody wants to see a schedule immediately. It is up to the Project Manager to provide one. There are all types and levels of schedules ranging from simple bar charts and/or logic diagrams to very complicated computerized networks. All of them have a niche in project execution.

Usually the Owner's Project Managers don't get directly involved in complex and sophisticated schedules; when the size of the project requires that level of scheduling, there will be an engineering firm and/or a general contractor to perform the required work. The level of scheduling handled by the Owner's Project Managers, especially those in charge of small projects, should not go beyond that required for a master schedule involving 100-200 activities at the most. That is all that is required to develop a project execution plan.

It must be noted that while a schedule is a stand-alone document, the execution plan could not exist without the master project schedule.

9.3 Influential Factors

All the factors listed below can affect project cost and/or schedule. Some will have a favorable impact, others a negative one. Some are controllable, while others are not. Since no two projects are alike, the effect will vary with the circumstances surrounding each one. Every factor must be considered and analyzed before finalizing the project execution plan. The Project Manager must "make things happen," make the most out of the favorable and controllable factors while striving for ways to minimize the impact of the negative ones and working around the uncontrollables.

- Process design execution.
- Execution approach - small/conventional.
- Contracting/subcontracting strategy.
- Schedule - normal/fast track.
- Permits - environmental/construction.
- Procurement:
  1. Long delivery items.
  2. Expediting.
  3. Shipping.
- Engineering hours:
  1. "Normal" duration.
  2. Average/peak staffing.
- Construction hours:
  1. "Normal" duration.
  2. Average/peak staffing.
  3. Availability of qualified workers.
- Modular construction.
- Weather conditions.
- Local economy.
- Labor source - union/open shop.
- Site conditions:
  1. Work in operating areas.
  2. Shutdown work.
  3. Laydown/parking areas.
  4. Welding permits.
  5. Working hours.
  6. Local contractors.

9.4 Preparation Guidelines

General

As mentioned before, the execution plan and master schedule go hand in hand with the cost estimate. Neither can be completed without the other. The project execution plan is the best tool to identify and avoid pitfalls early in the project. It must be prepared as early as possible. A preliminary plan, based on whatever available information, will do the job until a firm plan can be prepared.

If one worker requires ten days to perform one activity, it may be argued that ten workers could perform it in one day. Unfortunately, that is not the case in project execution; all projects involve hundreds, even thousands, of activities, many of which must be performed sequentially. If the activities to be performed in ten days were ten sequential ones instead of a single activity, ten workers could not perform them in one day. More likely, they would perform them in three or four days expending thirty or forty man-days instead of ten. The shortest possible schedule is dictated by the longest string of sequential activities as well as the minimum chronological time and labor hours required to perform each one. The duration of the construction effort is dependent on a number of factors:

- Total construction hours.
- Availability of:
    1. Accurate design and installation details.
    2. Necessary equipment and materials.
    3. Construction equipment and tools.
    4. Qualified personnel.
- Size of construction area.
- Weather conditions.
- Number of hours worked per week.

Fig. 5.1 included in Chapter 5 represents the average of many chemical and pharmaceutical projects. It relates the construction hours to construction duration for "normal" grassroots and retrofit projects indicating the peak staffing expected. It assumes the timely availability of accurate design information, materials, and qualified construction personnel. This chart, together with the planning rules of thumb included in Chapter 5, is used as the starting point for all execution plans.

Preliminary Execution Plan

A firm Execution Plan cannot be firmed up until:

- The appropriation estimate and the master project schedule are available.
- The execution approach - small or conventional - has been decided.
- Long equipment and materials deliveries have been determined.

- The engineering and construction contracting strategies have been established.
- The timing of environmental and construction permits has been firmed up with the pertinent agencies.

However, the preparation of execution plans is a bootstrap operation, where a preliminary plan must first be developed to make the execution decisions, which in turn may impact the original data and determine the firm execution plan. The information required to prepare a preliminary project execution plan is essentially the same as that required for the initial plan of action discussed in Chapter 5, except that it is now based on more accurate data. Whereas the latter is based on conceptual data and educated guesses, the preliminary execution plan must reflect, at least, a Phase 0 design and a preliminary or conceptual cost estimate.

The annotated equipment list developed in the Phase 0 design (see equipment list and cost estimate in Appendix L) will permit the Project Manager to prepare, as indicated in Section 19.1 a conceptual cost estimate including:

- Equipment cost.
- Engineering cost and hours.
- Total direct construction hours broken down by major construction activities.

Such an estimate, for the case study, is illustrated in Table 9.1

It must be noted at this point that Fig. 5.1 is based on total field hours, direct and indirect, and that the construction hours shown in the estimates must be adjusted before being used to determine project durations.

The direct hours must be adjusted by adding 15% to account for supervision and miscellaneous indirect craft labor plus the contingency or growth factor included in the estimate.

Project durations and peak engineering and construction staffing can now be estimated with the aid of Fig. 5.1 and the pertinent rules of thumb in Section 5.1.

With this information on hand the Project Manager can check the Validity of the conceptual data developed at the project onset with the Order of Magnitude (OOM) estimate.

Table 9.1 Conceptual estimate summary.

Basis: Annotated equipment list from Phase 0 design (60 items)

		$K
Equipment (from Sect. 19.2)		1,930
Engineering (from Sect 19.8) (27,300 hr @ 75)		2,050
Total Field Costs (from Sect. 19.11) (60 x 149)		8,940
Freight (5% equipment)		100
Startup Assistance (7% labor cost)		350
Subtotal		13,370
"Growth" Factor 15%		2,030
	Total	15,400

Total field hours 60 x 1,700 = 102,000

Total Field Costs Breakdown (from Table 19.36)

	Work Hours	Thousand Dollars Material	Labor	Total
Equipment Erection	8,000	--	435	435
Piping	50,000	1,080	2,424	3,504
Instrumentation	7,400	738	354	1,092
Electrical	9,400	266	444	708
Site Preparation Fire Protection	5,000	132	222	354
Concrete	11,300	111	510	621
Structural Steel	6,100	414	312	726
Buildings	1,700	132	84	216
Insulation	1,700	132	84	216
Paint	1,400	21	63	84
Subtotal	102,000	3,026	4,930	7,956
Field Indirects		20% Labor		964
Total Field Costs				**8,940**

Validity Check

	OOM Estimate	Conceptual Estimate
TIC M$	16.4	15.4
Engineering Hours	33,900	31,400(1)
Construction Hours	115,000	141,000(2)
Eng. Peak Staff	40	37(3)
Const. Peak Staff	116	133(4)
Construction Duration	9 mo.	10 mo.

	27,300	
(1) "Growth" 15%	4,100	
		31,400
(2)	102,000	
15% S.C., Ind.	15,300	
5% Startup Asst.	5,100	
	122,400	
"Growth" 15%	18,600	
		141,000

(3) $31{,}400 \times .35 \div 3 \text{ mo.} \div 160 \text{ hr/mo.} \times 1.6 = 37$

(4) $141{,}000 \div 10 \text{ mo.} \div 170 \text{ hr/mo.} \times 1.6 = 133$

The validity check shows a construction duration of 10 months, one month longer than anticipated in the Initial Plan of Action in Chapter 5. Since an 18-month total project duration is important due to business considerations this delay could have a serious impact on the project economics and corrective action must be taken.

Fortunately, with the tools provided in Chapter 19, the Project Manager was able to prepare quickly, before completion of Phase 1, a conceptual estimate that revealed the potential delay early enough to take meaningful corrective action.

Some of the steps that come to mind are:

- Expedite the approval of the AFE.
- Work some overtime in the engineering office.
- "Sole source" both equipment purchases and subcontractor selection.
- Subcontract construction on unit price basis.
- Execute some work offsite e.g., prefabrication of pipe.

These steps could be easily implemented at a reasonable cost; besides, the problem could prove to be a false alarm when Phase 1 is completed and the appropriation estimate and firm plan of action are prepared.

In the meantime, the breakdown of the construction hours by disciplines provided with the conceptual estimate enables the Project Manager to refine, with the aid of the scheduling guidelines in Fig. 9.1, the staffing requirements and prepare a firm plan for contracting the construction work.

This can be done easily by first laying out the duration of the various construction activities over the estimated 10-month construction duration period in the sequence indicated in Fig. 9.1. The estimated hours for each activity are then distributed over their corresponding durations and totaled, as illustrated in Fig. 9.2, to draw the projected construction staffing and progress curves. The staffing curve peak is 115 versus the 135 estimated with the rules of thumb in the conceptual estimate.

The preliminary execution plan must then be analyzed to determine its compatibility with the realities of local weather conditions, plant production schedules, and other constraints specific to the project.

Project Specific Durations

The durations developed so far represent an average for "normal" project execution and must be adjusted to reflect specific conditions, mostly weather and plant operations.

Weather:

- Excavation and concrete work in freezing weather can be very expensive and should be avoided. In some instances the construction site may have to be shut down during the winter months.
- Outdoor mechanical work in rainy and/or extremely cold weather could be a safety hazard and should be restricted unless temporary sheltering is provided.

Operating Restrictions:

- When plant shutdowns are involved construction durations are mostly dependent on the production schedules.
- Construction work in active operating areas, if at all allowed, usually must be performed with limited crews at a low productivity level and its duration will extend well beyond "normal."

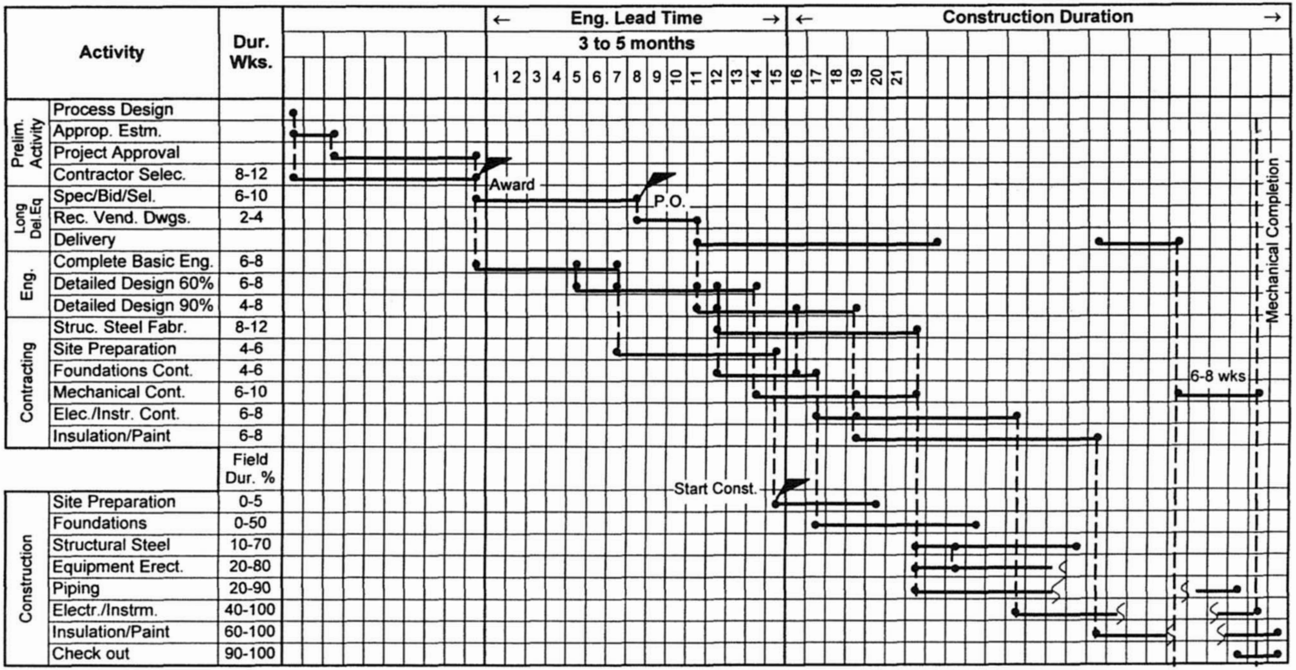


Figure 9.1 Scheduling guideline.

Description		% Total Duration	Construction Duration 9 months											
			1	2	3	4	5	6	7	8	9	10	11	
Site work		0-5												
Fire protection		Judgement												
Concrete		0-50												
Structural steel		10-70												
Buildings		Judgement												
Equip. erection		20-80												
Piping erection		20-90	Fab		Erection									
Electrical		40-100												
Instrumentation		40-100												
Insulation/paint		60 - >100												
Startup		–												

	Months		1	2	3	4	5	6	7	8	9	10	11	
Site work/Fire Prot	30	100	10	12			8						100	
Concrete	66	80-	8	16	18	18	6							
Structural steel	35			4	8	8	8	5	2				80	
Buildings	10	Field Staff				2	3	3	2					Percent Completion
Equip. erection	46	60-			4	8	8	10	12	4			60	
Piping fab/erection	295	40-	7	20	20	40	40	52	52	42	22			
Electrical	55					4	8	8	9	10	10	6	40	
Instrumentation	43	20-				2	6	7	8	8	8	4		
Insulation/paint	18							2	2	4	4	4	2	
Startup	32											16	16	
	630	Monthly staff	25	52	50	82	87	87	87	68	44	30	18	
		Cumulative	25	77	127	209	296	383	470	538	582	612	630	
		% Completion	4	12	20	33	47	61	75	86	93	97	100	
		Peak staff 87 x 1.15 (S.C. Superv.) x 1.15 (Growth) - 115												

Figure 9.2 Preliminary execution plan progress curve/field staff.

After the durations have been adjusted, the estimated hours adjusted for productivity, if required, are distributed over the new durations to develop a revised peak staffing and construction progress curve.

Questions/Decisions

The revised preliminary execution plan promotes thinking and raises questions that must be answered in order to refine the plan and prepare an accurate appropriation cost estimate.

- Can the plant facilities absorb the peak construction and supervisory staff without impairing the safety of the production activities? Can so many workers perform efficiently in the designated construction areas? If not, extended overtime or shift work must be considered. Otherwise the schedule must be extended.

  Note: Many contractors consider that a labor density of 5 workers per thousand sq. ft. based on total construction area is a reasonable allowance for good productivity.

- Could a single local contractor handle all the work efficiently? If not, consider national general contractors and/or break construction into discrete portions that could be handled by the available local contractors.
- Can the Owner come up with sufficient qualified personnel to perform the Phase 1 design in a reasonable time - say 3 or 4 months? If not, Phase 1 must be contracted or extended to match the available resources.
- Since the engineering hours are well beyond the range of the small project approach, the execution plan should be based on retaining a full-service engineering firm with construction management capabilities. Based on the anticipated peak engineering staff, the contractor screening should be limited to firms with staffs ranging from 150 to 400 (2 to 5 times the expected peak).
- The preliminary execution plan provides sufficient information to permit the project team to conduct a meaningful survey of available local construction contractors and establish a viable contracting plan.

Master Project Schedule

The master project schedule (MPS), like the appropriation estimate, is a stand-alone document that must be completed before a firm execution plan can be developed. However, a meaningful MPS could not be prepared without the construction hours input from a semi-detailed preliminary cost estimate.

This section offers simple, yet effective, guidelines for the development of the MPS and proposes a level of detail that would satisfy the Owner's needs in most projects.

Fig. 9.1 summarizes the guidelines for MPS development. It is essentially a typical bar chart schedule showing the principal project activities, their interdependence, and their normal range of durations. Small projects will fall on the low end of the ranges, while very large projects could very well exceed the high end. The guidelines for field activities are of a very general nature and must be specifically analyzed for each individual project.

The master schedule should include the following general activities. Further breakdown is not warranted at this time.

Preliminary Activities:

- Process design.
- Appropriation estimate.
- Funding approval.
- Engineering contractor selection: bid package, bidding, evaluation, and award.

Procurement Activities (All Process Areas):

- Specify/bid/P.O./vendor drawing/delivery:
  1. Vessels, as a group.
  2. Pumps, as a group.
  3. Heat exchangers, as a group.
  4. Special and long delivery equipment, individually.

Engineering Activities (for Each Process and Utility Area):

- Basic engineering:
  1. Approved for design P&ID's.
  2. Arrangement drawings.
- Civil design - 60% and 90% complete.
- Mechanical design - 60% and 90% complete.
- Electrical/instrument design - 60% and 90% complete.

Subcontracting Activities (for Each Subcontract):

- Bid package, bid, evaluation and award.

Construction Activities (for Each Process and Utility Area):

- Site preparation.
- Foundations.
- Structural steel.
- Equipment erection.
- Piping - field fabrication, erection, heat tracing, testing.
- Electrical - power wiring, lighting, checkout.
- Instrumentation - installation, loop checking.
- Insulation.
- Painting.
- Final checkout (by Owner).

A master schedule prepared as indicated above would include 70-85 activities for a single area project and 170-180 activities for a project divided into three process and utility areas. Those activities could, respectively, be condensed into 30-35 and 65-70 lines of activities.

Appendix E illustrates the MPS developed for the case study. It includes approximately 50 engineering and 75 field activities and has the potential of being either expanded of contracted.

Please note that the schedule delay feared at the conceptual estimate did not materialize and the construction duration has been reduced to 8 months.

Firm Execution Plan

Once the basic execution decisions have been reached, the long deliveries determined, the MPS prepared, and the appropriation estimate completed, the firm execution plan can be prepared. The plan must include sufficient execution details and schedule information to become the baseline for an in-house progress monitoring system. Such a plan can be prepared with a reasonable effort from the information contained in a Phase 1 design package and a preliminary semi-detailed cost estimate like the one in Appendix L.

The construction activities are broken down to reflect the MPS and the appropriation estimate breakdown and "loaded" with the corresponding hours from the estimate. The resulting construction progress curve becomes the base for the in-house monitoring system discussed in Chapter 15.

The minimum capital cost execution plan is rarely consistent with the optimum cost when marketing requirements are taken into consideration. Sometimes a delay in the completion date may result in loss of several million dollars in sales if a campaign is missed. In this case, the project driving force is a push for early completion, even at the expense of higher capital costs, and the execution plan must be tailored to incorporate schedule reduction steps. The firm execution plan must reflect the most cost-effective approach consistent with the schedule demands imposed by marketing and other business considerations.

If the project duration were longer than the project requirements and the site can absorb a higher manpower loading, the recommended approach would be to find ways to increase the labor density without productivity loss.

Increasing labor density by overloading the work areas without impacting the productivity can only be done to a certain extent. After work areas reach the saturation point, productivity falls dramatically to the point where an increase in forces will result in a decrease in the actual work output. The most practical way to increase labor density without affecting productivity is to open up new work areas and assign additional crews of cost-effective size.

If the cost of execution were the only consideration, the optimum schedule would also be the minimum cost case, and any schedule compression would automatically result in a cost increase. When that is not the case, the obvious explanation is that the initial schedule was not the optimum one.

> NORMALLY, ANY SCHEDULE IS SUSCEPTIBLE TO COMPRESSION, AT A REASONABLE COST, UP TO A POINT. WHEN THAT POINT IS REACHED THE COST OF FURTHER COMPRESSION RESULTS IN EXPONENTIAL COST INCREASES AND VERY SOON ADDITIONAL IMPROVEMENTS BECOME A PHYSICAL IMPOSSIBILITY, REGARDLESS OF HOW MUCH MONEY AND OTHER RESOURCES ARE APPLIED TO THE PROJECT.

Trying to compress the schedule by more than 10% could be very dangerous. Studies on the subject suggest that while a 10% reduction would impact the project cost by 3-5%, a 20% reduction could be unaffordable for most projects.

The Project Manager developing the project execution plan has the responsibility to:

- Determine the minimum cost schedule.
- Evaluate the various schedule/cost trade-offs to develop a reasonable risk compressed schedule and estimate the associated cost penalty.
- Make sure that management is aware of and understands the risks and the magnitude of the additional costs.
- Incorporate the costs of compressing the schedule into the estimate and adjust the contingency to reflect the related risks.

Presentation

A detailed project execution plan prepared by a contractor for a large project can take dozens, maybe hundreds, of pages, breaking the schedule and the work into minute details. This level of effort may be cost effective for certain critical projects, but could be wasteful for many others. After all, it is not easy to foresee the future in precise details. Fortunately for the Owners' project managers, they don't have to go into that level of detail. However, their execution plans must be concise, yet clear, and convey all the essential information outlined in Section 9.1.

A firm execution plan for a medium sized chemical facility with up to three process and utility areas should not require more than ten pages:

- A six to eight page bar chart MPS, including 150-200 activities condensed to 60-80 lines.
- A single page memo highlighting the selected contracting strategy and any out of ordinary schedule maintaining scheme.
- A single page bar chart summary.

The summary must show:

Preliminary Activities:

- Process design, AFE estimate, AFE approval.
- Engineering contractor selection - bid package, bid, evaluation, and award.

Procurement:

- Long delivery equipment - specifications, bid, P.O., vendor drawings, and delivery.

Engineering (All Areas):

- Basic design - approved P&ID's, plot plans, and equipment arrangements.
- Civil design at 60% completion and 90% completion.
- Piping design at 60% completion and 90% completion.
- Instrument and electrical design at 60% completion and 90%completion.

Subcontracting (Indicate Type of Contracts):

- Structural steel fabrication - bid, evaluation, award, and fabrication.

- Concrete work - bid package, bid, evaluation, and award.
- Mechanical work - bid package, bid, evaluation, and award.
- Instrument and electrical work - bid package, bid, evaluation, and award.
- Other contracts - bid package, bid, evaluation, and award.

Construction (All Areas):

- Site preparation.
- Foundations/miscellaneous concrete.
- Structural steel.
- Equipment erection.
- Piping - field fabrication, erection, heat trace, and testing.
- Buildings.
- Electrical.
- Instrumentation - installation and checkout.
- Insulation and paint.
- Final checkout.

Fig. 9.3 is a typical executive summary of the Execution Plan prepared for the case study.

The observant reader will notice some differences between this and the preliminary execution plan, including:

- The construction work hours are lower: 437 versus 466 months.
- Construction duration is shorter: 8 1/2 versus 10 months.
- Peak staff is lower: 96 versus 103.
- The contingency allowance is lower: 12% versus 20%.

All these changes are typical in the development of any project and in this case result from the reduction of construction hours at the job site due to the transfer of pipe fabrication to offsite shops and the leveling of the peak staff over a three month period.

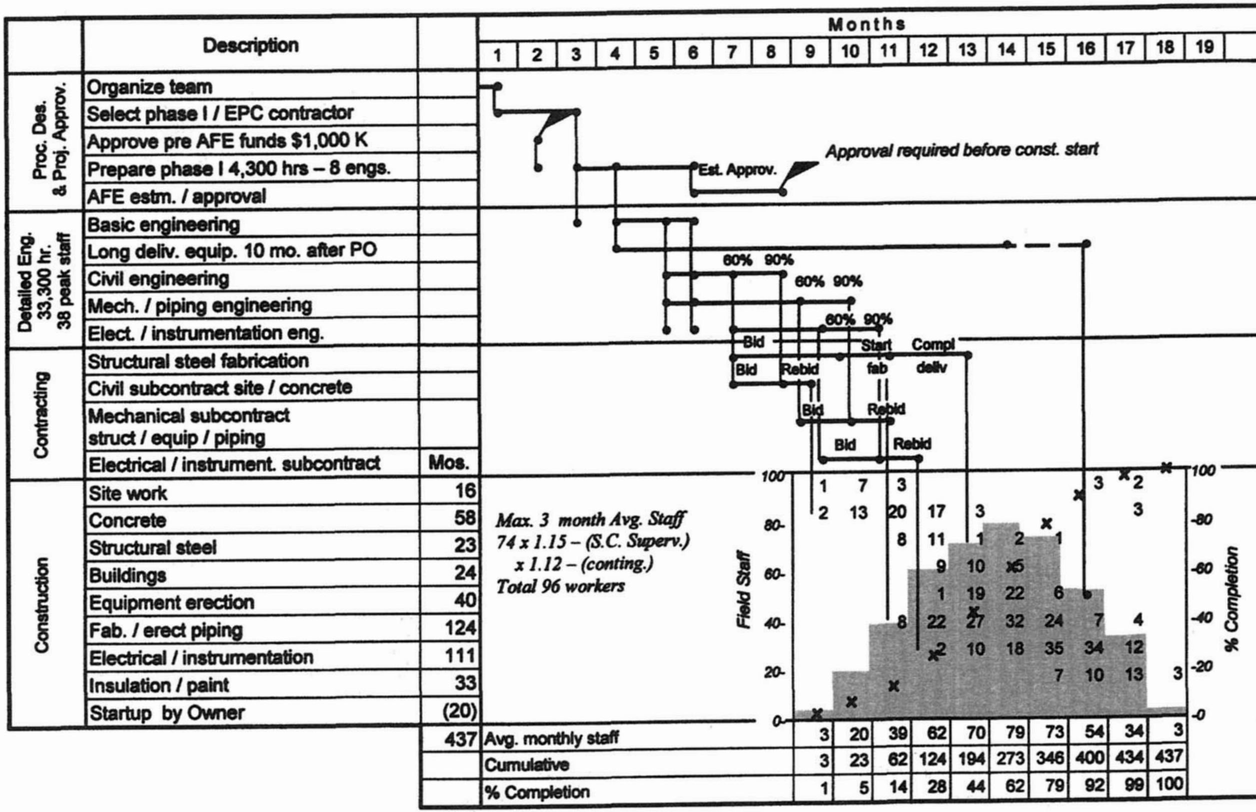


Figure 9.3 Firm execution plan summary.

9.5 Compressing the Schedule

As mentioned in Section 9.4, the minimum capital cost execution plan is rarely consistent with the optimum overall project cost when marketing and other business considerations are taken into account. When the project driving force is the push for early completion, the execution plan must be adjusted through the introduction and implementation of viable schedule reduction measures. The most cost-effective measures are those that can be implemented during the early execution stages when the majority of the activities fall on the critical path.

The following schedule reduction schemes are some of the most frequently used and are listed in order of the project execution progress, which seems very close to the order of increasing costs and potential drawbacks:

- Approve funding to start engineering and procurement of long delivery equipment prior to formal project approval.
  Potential Drawback - wasted engineering and losing the cancellation charge on early purchases.
- When engineering work is being held, waiting for decision on alternative schemes, proceed with both in parallel until a decision has been reached.
  Potential Drawback - wasted engineering.
- Work regular overtime in the engineering office.
  Potential Drawback - 3-5% of engineering cost on overtime premium and drop in productivity.
- Place bulk orders of heavier-than-expected structural steel before the design is complete.
  Potential Drawback - premium for heavier materials or, worse, finding that the "overdesign" was not enough.
- Purchase bulk materials from existing stock rather than wait for longer deliveries from the steel mills and/or fabricators.
  Potential Drawback - pay higher prices.
- Authorize tanks and vessel fabricators to order materials before drawings approval.
  Potential Drawback - risk of ordering inadequate materials.
- Pay premiums for early delivery of equipment.
  Potential Drawback - higher cost.
- Waive competitive bidding.
  Potential Drawback - lose the advantage of lower competitive prices.
- Break down construction into several discrete subcontracts and plan detailed engineering to support a staged subcontracting plan.

Potential Drawback - multiplication of subcontracting efforts. Lose advantage of better price for larger subcontract packages.

- Start the construction bidding process when engineering is 60% complete. Continue engineering during the bid preparation and ask the two low bidders to rebid on the upgraded design. Continue upgrading the engineering during the rebidding and finally ask the chosen bidder to adjust its proposal to reflect the status of the design at the time of award.
  Potential Drawback - higher subcontracting costs. Possibility of making final award on less than complete engineering and higher than normal field extras.
- Place early bulk orders of material usually provided by subcontractors.
  Potential Drawback - cost of placing additional purchase orders and double handling in the field.
- Execute construction on direct hire basis and/or reimbursable subcontracts.
  Potential Drawback - lose competitive lump sum advantage. Field costs could increase by 15-20%.
- Overstaff the field.
  Potential Drawback - drop in productivity since only a limited number of workers can work efficiently in a given area.
- Execute construction on multiple shifts.
  Potential Drawback - premium pay for night work, drop in productivity, and additional fixed costs for preparing the site for night work.
- Work extended overtime.
  Potential Drawback - the combination of overtime premium pay and a substantial drop in productivity could increase field costs by 50 to 60%.

Note: The effect of extended overtime on productivity is discussed in some detail in Section 19.9.

9.6 Project Coordination Procedure

Although the coordination procedure is not part of the execution plan, per se, it is very relevant to it and should be issued, as far as possible, concurrently with it. The coordination procedure shows the project organization chart, defines group and individual responsibilities and sets the basis for financial control. It must include the following information:

- General information:
  1. Project description/location.
  2. Sponsor.
  3. Contractors (if any).
- Group responsibilities:
  1. Division.
  2. Plant.
  3. CED.
  4. Environmental.
  5. Health.
- Individual responsibilities:
  1. Venture Manager.
  2. Project Manager.
  3. Technical Manager.
  4. Project Engineer.
  5. Plant Representative(s).
  6. Process Engineer(s).
  7. Accountant(s).

  Note: All must be identified by name and position within the owner's organization.

- Limits of approval for project expenditures.
- Scope change procedure and limits of approval.

Appendix C includes a typical organization procedure for an actual project in a chemical company.

CHAPTER 10
ESTIMATING

The only guarantee that can be offered for a cost estimate is that the final cost will be different.

10.1 Thoughts on Estimating

- In an estimate, the total cost is always more dependable than the cost of each individual portion.
- As mentioned in a previous chapter, estimating and project execution planning go hand in hand; neither can be completed without input from the other. It is the Project Manager's responsibility to insure, through direct and/or supervisory action, that the crossfeeding takes place and that both the estimate and the execution plan are thorough and realistic.
- An estimate is not complete without project management/engineering input. The estimator must review the estimate with a project manager/engineer

before issuing it. An estimate, to be useful for execution planning, must deal not only with dollars but also with construction and engineering hours. That information is needed to realistically determine duration and staff requirements. An estimating system providing only dollar information may be very useful to management and accountants but has a very limited value to those in charge of planning and executing the project.

- Normally, project managers don't have to prepare cost estimates; estimators will do it for them. However, on small projects, the Project Manager quite frequently must also wear the estimator's hat. Furthermore, on all projects, large and small, the Project Manager must review and approve all cost estimates, thus accepting the ultimate responsibility. In order to discharge that responsibility in an effective manner, the Project Manager must have a good working knowledge of estimating and estimate checking techniques.

The Project Manager wearing the estimator's hat is not expected to prepare definitive or engineering estimates nor to use computerized techniques, but is expected to:

- Have a good understanding of and a feel for costs.
- Develop sufficient estimating skills to be able to prepare conceptual and/or preliminary estimates when so required.
- Be capable of reviewing all types of estimates to ascertain their reasonableness, completeness, and accuracy.

- Estimates can be conceptual, preliminary, definitive, or engineering, depending on the quantity and quality of information available and the effort applied to their preparation. Estimating techniques range from simple factoring to sophisticated computerized programs, which, if used properly, can produce very accurate estimates. Estimate checking techniques, on the other hand, are probably all manual and the result of experience.
- Accurate estimating is a very important factor to a successful project. A very high estimate could abort a potentially good project, while a low estimate, on the other hand, can lead to embarrassing overruns, a lot of aggravation, or worse.

THE ESSENTIAL REQUIREMENTS OF AN ACCURATE ESTIMATE ARE A REALISTIC AND THOROUGH SCOPE OF WORK AND A SOUND ESTIMATING APPROACH.

- A realistic scope must be based on:

- Accurate and complete technical information:
  1. Process description and flowsheets.
  2. Drawings.
  3. Specifications.
  4. Site information.
- Reasonably accurate take-offs:
  1. Materials.
  2. Hours.
  3. Labor rates.
  4. Indirects.
- Realistic unit prices/work hours.
- Thorough and systematic review of all items with potential cost impact.
- Realistic execution plan/schedule.

• The main ingredients of a sound estimating approach are, in order of importance:
  - Common sense and experience.
  - Hard work.
  - Estimating techniques/systems.

The common sense and hard work applied to thorough project scoping and good execution planning will determine the quality of the estimate regardless of the estimating technique used. They can only be provided by the estimators and/or project managers/engineers. Estimating techniques are, of course, important, especially when they also provide a database. However, they are no substitute for hard work and experience. As mentioned before, estimating techniques range from very simple to very sophisticated. There is a niche for each technique. However, simple ones are normally quite adequate for small projects.

• Sometimes it seems that accuracy has little to do with the effort and sophistication of the resources applied to the preparation of estimates. Occasionally a 15 minute, back-of-an-envelope estimate turns out to be more accurate than a detailed estimate prepared after weeks of engineering using complicated and expensive techniques. However, these are extreme cases, and a back-of-an-envelope estimate should not be relied upon for appropriation nor for cost tracking or control.

- The estimate must provide sufficient information to establish its credibility and contain sufficient details to permit cost and progress tracking. To accomplish this with reasonable accuracy and minimum effort and paperwork should be the prime goal of estimators and project managers/engineers. While a minimum of detail is required even in conceptual and preliminary estimates, extensive details are overwhelming without adding any accuracy to the estimate.

  Factored estimates, especially when used for repeat plants, can be accurate and adequate for appropriation purposes but don't provide the information required for cost and progress tracking. They should be followed as soon as possible with more detailed estimates containing sufficient and suitable information for tracking. On the other hand, the detailed estimates normally prepared by engineering contractors after a certain amount of design work are time consuming and expensive and should be used sparsely.

- Some owners prefer to base the formal approval of a project on a detailed cost estimate prepared by an engineering firm and are willing to release funds to do the front-end design required for the estimate. Others, even if they would like to have the cost and progress tracking capability, are very hesitant to start spending on engineering before formal project approval.

  The Project Managers then find themselves between a rock and a hard place. Although there is nothing they can do to change management policies, they are still expected to come up with good quality appropriation estimates no matter how meager the available resources are.

THE SEMI-DETAILED ESTIMATING TECHNIQUE PROPOSED IN CHAPTER 19 PROVIDES THE OWNER'S PROJECT MANAGERS WITH A SIMPLE WAY TO PREPARE QUALITY ESTIMATES WITHOUT RESORTING TO CONTRACTORS OR TO COMPLICATED TECHNIQUES.

10.2 Estimating Definitions

Cost estimates are categorized according to the quality of the basic process information available rather than on the meticulousness of the estimating procedure and the details included in the estimate.

A PRECISE ESTIMATE IS NOT ALWAYS AN ACCURATE ESTIMATE.

For example, under certain circumstances, a series of theoretical and/or test tube chemical reactions could be the basis of a conceptual but impressive-looking design package with enough information to prepare a detailed estimate. However, regardless of the details, the resulting estimate cannot be anything but conceptual.

Order of Magnitude Estimate

These estimates provide only ballpark costs and are sometimes required in the very early stages of project development as decisionmaking tools. The basis could be no more than a given capacity of a generic product; the estimating procedure, a simple search of existing literature and, if required, the application of the proportioned estimating method.

Conceptual Estimates

Conceptual estimates are typically prepared during the advanced R&D and early process design stages. They are normally used to build the preliminary project economics, prepare preliminary execution plans, and develop cost estimates for the preparation of a complete process design (Phase 1) and a definitive cost estimate. The Phase 0 design package, described in Chapter 6, contains all the information required for conceptual estimates. See Table 9.1 for an example of a conceptual estimate.

Preliminary Estimates

These estimates are prepared when the basic process design is essentially complete and the scope of the offsite and waste treatment facilities has been established but not completely defined. Preliminary estimates are normally used to prepare firm project execution plans, to complete the project economics, and, frequently, for appropriation purposes. The Phase 1 design package, described in Chapter 6, contains the necessary information for the preparation of a preliminary estimate. In fact, a thorough Phase 0 package could also be used for this purpose. Appendix L illustrates a preliminary estimate.

Definitive Estimates

The definitive estimates are prepared after the project has been totally defined, including offsites, waste treatment, site conditions, equipment arrangements, etc. This stage of definition requires the involvement of an engineering contractor to complete the so-called basic engineering referred to in Chapter 12.

It is advisable to complete the definitive estimate before the fabrication of expensive equipment and start of construction as a protection against major, unexpected cost variations which could have a negative influence on project approval.

Engineering Estimates

They are prepared at various points during the detailed engineering mainly as a control and cost tracking tool.

10.3 Estimating Methods

The estimating methods normally employed fall in five categories:

- Proportioned.
- Factored.
- Computerized simulations.
- Detailed.
- Semi-detailed.

Proportioned Method

The proportioned method is used to estimate the cost for a new size or capacity from the actual cost of a similar completed facility of known size or capacity. The relationship has a simple exponential form:

$$\text{Cost 2} = (C_2/C_1)^n \times \text{Cost 1}$$

where: C_1 = known capacity or size
C_2 = new capacity or size
n = cost capacity factor

This method should be used only for order-of-magnitude estimates.

Since this formula is assumed for the same time period and location, the results must be adjusted by using an escalation index such as Chemical Engineering Plant Cost Index.

The cost capacity factor (n) has an average value of 0.6 for most plants and equipment but can vary over a wide range. The factor can be obtained from published data or historical records.

Factored Method

In the factored method, the total cost, broken down by the main accounts, is arrived at by multiplying the cost of equipment by certain empirical factors which take into account whether the process involves handling fluids, solids, or a mixture of both.

Since the original factors were developed by H.J. Lang, the method is known as the Lang Factor method. However, through the years, contractors and owners have developed their own factors to reflect their particular experiences.

Tables 10.1, 10.2, and 10.3 illustrate a set of factors used by one chemical firm for fluids-handling and solids-handling plants. The factors and ratios used to break down the total cost into the various direct and indirect accounts are based on a 100% subcontract construction where most of the labor-related field indirects are collected with the subcontract labor costs and the "field indirects" account refers to only the construction management and the site general conditions costs. Field indirects are discussed in more detail in Section 19.9.

Note: These factors are based on Gulf Coast productivity, a field labor rate of approximately \$45/hr and an engineering rate of approximately \$75/hr, both including contractors' overhead and profit. Since the cost of materials does not vary much throughout the United States, adjustments for higher or lower rate areas must be made after computing the hours for the base case.

The ranges of the factors recommended for the various cost accounts are very wide and the accuracy of the estimate of each one will be much lower than the accuracy of the total cost. Additionally, the resulting estimate would not be suitable for cost tracking.

Some of the driving forces determining the location of each factor within the ranges are:

- **Process** - Dry process usually has more equipment, less piping, less instruments, less engineering, more electrical, and about the same civil and structural requirements.
- **Toxicity** - Highly toxic or hazardous processes can drive all categories higher, but usually piping, instrumentation, and equipment are the most affected.
- **Corrosiveness** - Highly corrosive processes drive piping, equipment, and instrumentation costs up.
- **Capacity** - May dictate oversized equipment, etc., for increased production. This would tend to drive civil and structural accounts higher.
- **Site Conditions** - If unfavorable, would drive the civil and structural accounts higher.
- **First-of-a-Kind Unit** - Would tend to drive engineering disproportionately higher.
- **Weather/Location** - Drive labor overheads higher.

Table 10.1 Typical Factors – All-Fluid Plants

	Range % Equipment	Usual Factor Fraction of Equipment Material	Labor	Total
Direct Costs				
Equipment	-	**1.00**	**0.20**	**1.20**
Piping	120-200	0.50	1.10	1.60
Instrumentation	25-75	0.30	0.15	0.45
Electrical	20-50	0.12	0.20	0.32
Site development	4-8	0.01	0.05	0.06
Fire protection	5-15	0.05	0.05	0.10
Concrete	10-50	0.05	0.25	0.30
Structural steel	20-45	0.20	0.15	0.35
Buildings	1-15	0.04	0.06	0.10
Insulation	5-30	0.06	0.04	0.10
Painting	2-8	0.01	0.03	0.04
Subtotal		**1.34**	**2.08**	**3.42**
Total Direct Costs		**2.34**	**2.28**	**4.62**
Indirect Costs				
Home office		20% of directs		0.93
Field		20% of labor		0.45
Total Indirects				**1.38**
Total Installed Cost (TIC)				**6.00**

Home Office 0.93 / 6.00 = 0.16 TIC
Labor 2.26 / 6.00 = 0.38 TIC

Table 10.2 Typical Factors – Fluid/Solid Plants

	Range % Equipment	Usual Factor Fraction of Equipment: Material	Labor	Total
Direct Costs				
Equipment	-	**1.00**	**0.20**	**1.20**
Piping	60-160	0.35	0.65	1.00
Instrumentation	20-70	0.27	0.13	0.40
Electrical	25-60	0.15	0.25	0.40
Site preparation		0.01	0.05	0.06
Fire protection	5-15	0.05	0.05	0.10
Concrete	12-55	0.06	0.29	0.35
Structural steel	25-50	0.23	0.17	0.40
Buildings	1-15	0.04	0.06	0.10
Insulation	5-15	0.05	0.03	0.08
Painting	3-8	0.02	0.03	0.05
Subtotal		**1.23**	**1.71**	**2.94**
Total Direct Costs		**2.23**	**1.91**	**4.14**
Indirect Costs				
Home office		20% of directs		0.83
Field		20% of labor		0.38
Total Indirects				**1.21**
Total Installed Cost (TIC)				**5.35**

Home Office 0.83 / 5.35 = 0.16 TIC
Labor 1.89 / 5.35 = 0.35 TIC

Table 10.3 Typical Factors – All-Solids Plants

	Range % Equipment	Usual Factor Fraction of Equipment		
		Material	Labor	Total
Direct Costs				
Equipment	-	**1.00**	**0.20**	**1.20**
Piping	30-80	0.20	0.40	0.60
Instrumentation	20-70	0.27	0.13	0.40
Electrical	25-60	0.15	0.25	0.40
Site preparation	4-8	0.01	0.05	0.06
Fire protection	5-15	0.05	0.05	0.10
Concrete	15-60	0.06	0.32	0.38
Structural steel	25-60	0.25	0.20	0.45
Buildings	1-15	0.04	0.06	0.10
Insulation	5-10	0.04	0.03	0.07
Painting	4-8	0.02	0.03	0.05
Subtotal		**1.09**	**1.52**	**2.61**
Total Direct Costs		**2.09**	**2.28**	**3.81**
Indirect Costs				
Home office		20% of directs		0.76
Field		20% of labor		0.34
Total Indirects				**1.10**
Total Installed Cost (TIC)				**4.91**

Home Office 0.76 / 4.91 = 0.15 TIC
Labor 1.70 / 4.91 = 0.35 TIC

In general, the factored method is recommended only for conceptual estimates or those cases when reliable information is available on the actual cost of similar projects.

Computerized Simulations

This method is a valuable tool for the estimator. The system calculates the purchased price for each piece of equipment as well as simulates (based on preprogrammed models) quantity take-offs to generate field material and field labor for installation of each equipment item as well as the entire project. Engineering, overheads, and fees are also calculated. Certain minimum information must be input to the computer for equipment costs. More data given per piece of equipment results in a more accurate cost estimate of the equipment and project as a whole.

The computerized method is an excellent tool for conceptual and even preliminary estimates but should not be used for definitive estimates unless applied by experienced estimators fully familiar with the algorithms and unit prices built into the program for developing takeoffs and calculating material costs and labor hours.

Detailed Method

The detailed method of estimating is usually employed by engineering firms and/or contractors. This method is, as its title implies, much more time consuming than the previous methods.

- Take-offs are made from actual drawings.
- Quotes are obtained on major equipment and subcontracts.
- Detailed bulk material take-offs are made and priced.
- All the field labor hours are estimated based on quantity take-offs.
- The engineering hours and costs, supervision and field expenses, and other items, such as freight, duty and taxes, insurance, etc., are all detailed and priced.

The preparation of a detailed estimate involves a team effort. There must be an extensive review and checking process before the estimate can be completed to ensure that every item is accounted for.

This method is best suited for contractors preparing estimates to bid work on a lump sum basis. The additional time and cost required could be difficult to justify even for the preparation of appropriation estimates.

Semi-Detailed Method

The semi-detailed method described in Chapter 19 can be as accurate as the detailed method at a fraction of the time and cost. It is essentially based on equipment count and preliminary take-offs of comprehensive, yet comprehensible, units priced with equally comprehensive unit prices and unit hours.

While a detailed estimate could not be prepared without the benefit of some detailed engineering, a good semi-detailed estimate can be prepared with the information available at the completion of the Phase 1 design.

- Equipment list and specifications.
- Complete P&ID's.
- Plot plans.
- Preliminary equipment arrangements.

The quality of a semi-detailed estimate will, of course, be enhanced if it is prepared at the completion of the basic engineering.

10.4 Anatomy of an Estimate

General

The cost estimate must be consistent with the Project Execution Plan and reflect the execution approach. If the approach is to use multiple construction contractors, the estimate backup must contain sufficient details so that it can be recast with minimum effort to reflect the scope and cost of each contract.

An appropriation estimate, whether prepared in-house or by outside contractors, must clearly identify the project, its location, and the quality of the estimate. It should be issued in the form of a formal, stand-alone, report or package addressing and documenting the following areas:

- Cost summary (direct and indirect).
- Basis of estimate/scope definition.
- Execution approach.
- Milestone schedule.
- Accuracy and risks.
- Estimating technique/approach.
- Backup.

Although the extent of documentation required will be different for each project, it should be generally consistent with the succeeding paragraphs.

- The cost summary must contain sufficient information to allow management to calculate and analyze the traditional factors and ratios to ascertain their consistency with industry standards and past experience. The following information must be included:
  - Breakdown between direct and indirect costs.
  - Breakdown of directs by equipment and commodities, materials, labor, and subcontracts.
  - Equipment count by type.
  - Major take-offs - total cubic yards of concrete, tons of steel, number of motors, area of buildings, etc.
  - Estimated engineering hours.
  - Estimated field hours including subcontracts.
  - Breakdown of indirects by engineering, field indirects, other costs, escalation, and contingency.
  - Expense items.

  Table 10.4 is a typical example of a cost estimate summary. The suggested allocation of costs to the various accounts is discussed in Section 10.5.

- Every cost estimate is based on a specific scope which may range from a single phrase (e.g., "One 20 MPY Oxinitro Plant in Brazil") to an engineering package complete with Approved for Construction drawings and specifications. For the size of projects discussed in this book, the scope would usually be based on in-house Phase 0/1 design. When the available information is incomplete, the Project Manager must make conservative educated assumptions to prepare the estimate. The basis of the estimate, as well as the assumptions made, including any specific inclusions and/or exclusions must be clearly defined and documented as part of the estimate package.

- The execution approach and contracting strategy will affect engineering costs, labor productivity, and field indirects. Since the cost impact could be substantial, the estimate package must include at least a simple description of the execution plan.

  The time frame in which a project is expected to be executed impacts several important cost areas:

Table 10.4 Cost Estimate Summary Case Study

		Thousand Dollars			
	Work	Subcontracts			
Direct Costs	Hours	Material	Labor	M & L	Total
Equipment	-	1,739	-	242	1,981
Equipment erection	8,300	-	346	-	346
Freight + 5% equip		90	-	-	90
Piping	31,000	930	1,470	270	2,670
Instrumentation	9,200	932		587	1,519
Electrical	10,100	524	486	-	1,010
Site preparation	1,100	-	-	118	118
Fire protection	1,500	-	-	174	174
Concrete	10,000	-	-	517	517
Structural steel	4,000	497	206	-	703
Buildings	4,100	-	-	464	464
Insulation	5,300	-	-	600	600
Paint	500	-	-	60	60
Total Directs	85,100	4,712	2,508	3,032	**10,252**
Indirect Costs					
Field Indirects	.175 x S.C. Labor + .11 x M & L S.C.				770
Contract Engineering	27,900 hr @ $75/hr				2,090
CED costs	Not Included				-
Taxes	Not Included				-
Spare parts	10% Equipment				200
Startup	7% (2,510 + 0.40 x 3,015)				260
Total Indirects					**3,320**
Directs + Indirects					**13,572**
Escalation		Not included			-
Target Estimate					**13,572**
Contingency 22%					2,928
Total Installed Cost					**16,500**

- Labor rates.
- Contract negotiations.
- Labor availability.
- Contractor's work load.
- Escalation.
- Plant tie-ins and shutdown work.
- Weather effects.

Although fast tracking could ultimately have a beneficial impact on the project, its cost will always be higher than optimum. If the project is to be fast track, it must be taken into consideration when the cost estimate is prepared.

All estimates must be accompanied by at least a simple milestone schedule to highlight the important dates. When variations in the project time frame could have a substantial impact on cost, the estimate package must also include a discussion on the subject.

- Determining the accuracy of an estimate and the risk of variations is an extremely difficult proposition. Trying to quantify them is like playing Russian roulette. However, no matter how arduous the task, the questions must be addressed as part of the estimate package. Several methods are available to mechanize the determination of estimating accuracy. However, ultimately, it is up to the Cost Engineer and/or Project Manager to apply their experience and common sense and evaluate the accuracy of the estimate through the analyses of the entire estimating process:
  - Details of scope.
  - Engineering input.
  - Source of equipment and materials prices.
  - Estimating techniques utilized.
  - Take-off allowances.
  - Source of labor rate and productivity data.
  - Viability of construction approach.

The degree of accuracy and the level of risk can be controlled through the judicious addition of resolution allowances to the various accounts and escalation and contingency to the estimate total. The application of these cost adjustment factors is discussed in Section 19.10.

All information used and/or developed for the estimate must be documented and kept at least until the project is completed and audited. This includes drawings, take-offs, preliminary sketches, vendor quotations, etc. The backup information is required for cost and scope tracking and control as well as final cost analysis.

Physical Breakdown

With the exception of factored estimates, all others, from conceptual to engineering, must have the potential of being broken down into discrete components that can be related to the project schedule. The estimate breakdown is a very important tool for project planning as well as scope, cost, and progress tracking. In the case of conceptual and preliminary estimates, the breakdown is required to prepare the master schedule and project execution plan (see Chapter 8). In the case of definitive and engineering estimates, it is essential to the preparation of the cost tracking and construction progress monitoring systems. The extent of the breakdown is dependent on the availability of time and scope details. However, a thorough one must be provided with appropriation estimates or when there is a high probability of executing the project.

> THE COMPONENTS OF THE ESTIMATE BREAKDOWN MUST BE QUANTIFIABLE AND SMALL ENOUGH TO BE EASILY COMPREHENDED AND EVALUATED BY SIMPLE OBSERVATION WITHOUT GOING TO THE DETAILS OF COUNTING AND TRACKING "NUTS AND BOLTS."

The estimate can be broken down to various levels of detail consistent with the:

- Availability of information.
- Magnitude of the project.
- Need to keep components small enough for evaluation by simple observation.

The first level of breakdown is obviously the one shown in the Cost Estimate Summary (Fig. 10.4). This level is sufficient for the preparation of preliminary execution plans and master schedules.

The second level would be the breakdown of all first level components by process areas or steps, utility areas, and common facilities. This breakdown is required for more advanced planning.

The actual cost and progress tracking, especially on larger projects, require further breakdown of cost items, such as:

- **Equipment Cost, Erection, Insulation** - by items.
- **Site Preparation** - by type of work (fences, roads, railroads, site clearance, piling, etc.)
- **Concrete and Steel** - by physical area and/or equipment item.
- **Piping/Insulation** - by system and/or line.
- **Electrical** - by motors, feeders, substations, illuminated areas, etc.
- **Instrumentation** - by systems, equipment item and/or "balloon" count.

More details on cost breakdowns are included in Chapter 15.

Some engineering and construction firms, as well as some of the computer programs in the market, carry the breakdown to the level of nuts and bolts (square feet of forms, pounds of rebar, field welds and bolt-ups, individual instruments, etc.). That level of detail might be important to some nitpicking accountant or perhaps to an efficiency expert in the field, but has no use for the Owner's Project Manager interested in the overall picture.

Breaking down an estimate requires a certain degree of engineering and materials take-offs. In the case of definitive and engineering-type estimates, this will usually be done by an engineering contractor and the details will be more than adequate for cost tracking.

In the case of conceptual and preliminary estimates prepared in-house, this work usually must be done by the Owner's engineers. In the specific case of small projects, the Project Manager is expected to perform the required conceptual engineering and preliminary take-offs as part of the estimating work. The proposed semi-detailed estimating method described in Chapter 19 provides tools to prepare quality estimates with sufficient breakdowns for execution planning, cost tracking and progress monitoring.

10.5 Cost Allocation

Although most owners and contractors break project costs along similar lines, there are always differences that could distort the analyses of cost factors and ratios. To avoid distortions and the resulting erroneous analyses, each Owner should standardize the manner in which costs are allocated in the estimate and insist that contractors recast at least their cost summaries following the same system. This section is intended as a guideline for project costs allocation to be used by the project managers as well as outside contractors estimating projects for them when there is no standard. The guideline is consistent with the subcontracted construction approach recommended in Chapter 11 and the estimating method described in Chapter 19.

The very basic cost breakdown is by directs and indirects. The directs include all materials that physically go into the project and the cost of the labor required to install it. The indirects include engineering, field indirects, spare parts, taxes, start-up, etc.

The suggested basic allocation of directs, applicable to all the estimate accounts is by:

- Materials.
- Subcontracted labor.
- Material and labor subcontracts.

The materials column includes all the equipment and materials usually purchased by the Owner and/or general contractor - to be installed by the subcontractors. The subcontracted labor column includes all costs, direct and indirects, incurred by the subcontractors for the installation of these materials. Construction equipment rentals as well as contractor overhead and profit must also be included. The accounts traditionally treated in this manner are:

- Equipment.
- Piping.
- Instrumentation.
- Electrical.
- Structural steel.

The subcontract column includes those items where a vendor or a subcontractor supplies both materials and erection. The cost includes materials, labor, labor indirects, construction rental equipment, and contractor/vendor overheads and profits. The following accounts are traditionally executed and estimated on a subcontract basis.

- Vendor-erected equipment.
- Site preparation.
- Sewers.
- Fire protection system/fireproofing.
- Concrete.
- Buildings.
- Painting.

- Insulation.
- Dismantling.

The estimated construction hours, even those related to subcontract work, must also be shown in the estimate cost summary. That information is vital to prepare the execution plan and the construction monitoring systems.

The direct costs must also be allocated by accounts, and each account, of course, broken down by materials, labor, and subcontracts. The succeeding paragraphs discuss the allocation to each of the accounts.

- The **Equipment** account could be broken down by types of equipment and, in definitive and engineering estimates, even by equipment item. Electrical equipment, transformers, switch gears, etc., should be included in the electrical account. Freight must be included with the equipment cost either as a separate line item or included with purchase cost of each item.
- The **Piping** account covers all process and utility piping, as well as chutes and ducts, above and underground, including:
  - All piping materials and welding supplies.
  - Hangers and supports.
  - Receiving/storing/handling.
  - Shop and field fabrication.
  - Erection.
  - Cleaning and testing.
  - Tie-ins.
  - Safety showers and eye washes.
  - Heat tracing - both steam and electric.

  The following items should be excluded from the piping account:

  - Sewer (with Sewers Site Preparation).
  - Storm drains (with Site Preparation).
  - Fire protection systems (with Fire Protection).
  - Engineered pipe supports (with Structural Steel).
  - Instrument air from distribution point to individual instrument (with Instrument).
  - Utility supply to battery limits (with Site Preparation).

- Pipe racks and sleepers (with Structural Steel or Concrete).

When the piping installation is subcontracted, the subcontractor frequently supplies the bulk materials. Even if that is the case, the account should show the breakdown between material and labor to permit the analysis of the material/labor ratio.

- The **Instrumentation** account includes:
  - All field and panel instruments and installation materials.
  - Control panel/TDC/PLC.
  - Receiving/storing/handling.
  - Calibration.
  - Installation.
  - Loop checkout.
  - Instrument air piping from distribution point to the individual instrument.
  - Electrical wiring from the individual instruments to control center (TDC).

Normally, the installation of instruments is subcontracted with the subcontractor supplying the installation materials. Those materials should be included together with the subcontract labor in the subcontract column.

- The **Electrical** account should include:
  - All electrical equipment:
    1. Unit transformers and associated switch gear.
    2. Lighting transformers.
    3. Motor control centers/breakers.
    4. Local panels.
  - All materials required for high and low voltage distribution from the main substation (excluded) down to the last lighting fixture.
    1. Poles, towers and miscellaneous supplies.
    2. Conduit and trays.
    3. Wiring and bus ducts.
    4. Junction boxes.
    5. Terminals and connectors, push buttons, etc.
    6. Lighting fixtures and receptacles.
    7. Lighting panels.

8. Welding and utility receptacles.
9. Grounding.

- All labor required to install the above materials.

The following items should be excluded from the electrical account:

- Electric heat tracing (with Piping).
- Main substation and related switch gear (see note below).
- Instrument wiring (with Instrumentation).
- Lighting of buildings contracted in design-build basis (with Buildings).
- Foundations and structural steel supports for the electrical equipment (with Concrete and Structural Steel).

When the electrical installation is subcontracted, the subcontractor frequently supplies the bulk materials. If that's the case, the materials should still be shown in the materials column to permit the analysis of the Material/Labor ratio.

Note: Usually only true grassroots projects require a high voltage (main) substation. Most of the projects contemplated in this guideline would be built on existing developed sites and will require only unit substations (480 V). Including the main substation, if required, in the electrical account will distort the traditional factors and ratios used in checking the estimate. The main substations and high voltage distribution should be included with the site preparation account or as a stand-alone item.

- The **Site Preparation** accounts should include:
  - General excavation, backfill, shrubbing and grading.
  - Piling/soil stabilization.
  - Roads, fences, railroads, parking areas, culverts, etc.
  - Retention ponds and lagoons.
  - Spillways/rip-rap.
  - Storm and sanitary sewers.
  - Underground process sewers to off-plant treatment facilities.
  - Utility supplies:
    1. Power supply feeders.
    2. Water/gas/other.

The following items should be excluded:

- Process sewers to in-plant treating facilities (with Piping).
- Pavement around process areas (with Concrete).
- Excavation and backfill related to equipment and structural foundations (with Concrete).

- The **Fire Protection** account should include:
  - Fire water distribution systems including hydrants, monitors, etc.
  - Sprinkler/foam systems.
  - Valve and hose houses.
  - CO_2/halon system.
  - Fireproofing.

  The following should be excluded:

  - Fire water storage tanks and pumps (with Equipment).
  - Fire water lagoons (with Site Preparation).
  - Fire protection of buildings contracted on design-build basis (with Buildings).

- The **Concrete** account should include:
  - Concrete tanks/basins/sumps.
  - Pile caps.
  - Ground and elevated slabs.
  - Paved process areas.
  - Dikes, fire walls, and trenches.
  - Excavation and backfill associated with the above.

  The following should be excluded:

  - Foundation for buildings contracted on a design-build basis (with Buildings).
  - Main substation foundations (with Site Preparation).

- The **Structural Steel** account should include:
  - All equipment supporting structures, including platforms, stairs, ladders, railing, etc.

- Pipe racks.
- Miscellaneous structures attached to equipment unless provided as part of the vendor's supply.
- Truck and railcar loading and unloading platforms and arms.

The following items should be excluded:

- Structures associated with buildings contracted on a design-build basis (with Buildings).
- Standard hangers and supports for piping, instrumentation and electrical (with corresponding accounts).

Normally the structural steel is fabricated under a purchase order and erected on a subcontract basis.

- The **Buildings** account should include:
  - Shelters - roof and walls added to process structures.
  - Control and motor control rooms - usually in the same building.
  - Warehouses, shops, change rooms, offices, etc.
  - All HVAC and lighting associated with the above.
- The **Painting and Insulation** accounts should include:
  - Equipment painting and insulation.
  - Piping, painting, and insulation.
  - Structural steel painting.
- The **Dismantling** account should include:
  - All equipment, piping, and other removals and/or relocations required to prepare an existing area for the installation of the facility.
- The **Field Costs** cover all costs associated with construction management and are discussed in detail in Sections 19.9. They do not cover the indirects associated with subcontracted labor included in the labor column.
- **Contractor Home Office** covers all engineering costs including contractor's overhead and fees. When engineering is done in-house, the costs also may be included in this account and identified as a separate item from contract engineering.
- The **Startup** account is intended to cover items like:
  - Minor changes required to start up the facility.

  - Correcting minor errors.
  - Supply standby personnel during startup.
- All other indirect accounts are self-explanatory:
  - CED costs.
  - Taxes.
  - Spare parts.
  - Royalties.
  - Catalysts and chemicals.

Finally, all estimates must include, as part of the individual accounts, a resolution allowance, plus escalation and contingency added to the bottom line. These cost items are discussed in the next section.

10.6 Adjustments

Resolution Allowance

When an estimate is based on firm vendors' quotes and materials take-offs, experience shows that, invariably, some items affecting cost will be overlooked and left out of the estimate. To compensate for these oversights, it is appropriate to include in the estimate allowances for the unlisted items. These are called Resolution Allowances.

The resolution allowances are intended to cover costs that experience shows will be incurred during the course of the project and, therefore, should not be considered contingency but should be included with the various cost accounts. The amount of resolution allowance applied to each account is dependent on the stage of development of the information used to determine equipment costs and prepare materials take-offs. However, in the final reckoning, they reflect the judgment and experience of the Cost Engineer and/or the Project Manager. Chapter 19 includes a guideline recommending the amount of resolution allowance that should be applied to the various cost accounts at different stages of engineering.

Escalation

Estimates are prepared based on prevailing prices at the time of the estimate, while actual expenditures will be incurred some time in the future at prices pushed up by inflation. The cost estimate must, therefore, be adjusted by an escalation factor to account for inflation and bring it as close as possible to the actual cost at the time of completion. Although the techniques employed to arrive at the escalation factor will vary, all are based on published inflation indexes and projections.

The simplest method, quite adequate for small projects, is to apply the current inflation projection to the mid-life of the project; i.e., if the estimated duration is 14 months and the projected annual inflation rate is 6%, the escalation adjustment will be:

$$(14 \text{ months} \div 12 \text{ months/year}) \times 0.5 \times 6\% = 3.5\%$$

On large, extended projects where the escalation allowance could become a substantial number, it is more appropriate to calculate the escalation for each of the major cost accounts based on the projected inflation rate and the project schedule. By doing so, every cost account will be escalated to the time in which most of the actual expenditure is projected.

Special care must be taken in escalating labor costs since the rates are determined by labor agreements lasting two or three years, and it is quite possible that no change in rate occurs during the project.

Contingency

No matter the high degree of scope definition or the sophistication of the estimating techniques, a cost estimate is still a forecast of events to come and as such it cannot be perfectly accurate. The contingency is a bottom line addition to the cost estimate to convert it to the most likely final cost.

It is intended to cover:

- Take-offs and arithmetical errors and oversights.
- Variances in equipment and material prices.
- Variance in labor rates and productivity.
- Schedule delays.
- Changes in economic and environmental conditions.
- Changes in execution approach.
- Miscellaneous design changes not affecting the basic scope, including:
  1. Addition of equipment and instrumentation.
  2. Size changes in equipment, piping, wiring.
  3. Changes in pipe and electrical tray routing.
  4. Moderate changes in environmental regulations.
  5. Lower than expected labor productivity.

The contingency is not intended to cover changes affecting the basic project parameters as defined and accepted in the scope, such as:

- Capacity.
- Raw materials and products mix, quality, and specifications.
- Facility life expectancy.
- Major changes in environmental regulations.
- Force majeure events (strikes, acts of God, etc.).

As in the case of the resolution allowances, the magnitude of the contingency is dependent on the stage of development of the information used in the estimate and reflects the judgment and experience of the Cost Engineer and the Project Manager. Contingency is a forecasting and control tool that is never to be treated as a "checking account." It should be re-evaluated every time the project is re-estimated and adjusted according to the prevailing circumstances.

10.7 Checking Criteria and Guidelines

Regardless of who prepared the estimate, the Project Manager is ultimately responsible for the project cost and must take an active role in the monitoring, as well as in the review and approval of all estimates. This applies to in-house as well as contractors' estimates.

The involvement must be far more extensive than the mere review of the final product. The Project Manager must also review the basis of the estimate and the estimating approach to insure that the estimating efforts are commensurate with the information available and that the product will include sufficient details to satisfy the project's further need for planning, cost tracking and progress monitoring.

Finally, the Project Manager must document (or insure that the Cost Engineer does) the estimate review in sufficient detail to be useful for future reference. The review should be part of the estimate package discussed in Section 10.4: Anatomy of an Estimate.

The determining factors in the quality of an estimate are:

- The firmness of the scope and soundness of the design basis.
- The extent of the engineering developed for the estimate.
- The thoroughness of cost items identification (take-offs).
- The validity of unit prices/man-hours used to build up the total cost.

To assess the firmness of the scope and design basis, the Project Manager must question the project sponsors as well as the engineers (process, production, specialists) responsible for the development work to ascertain that they have done their homework and to promote further thought.

The Project Manager must also investigate the extent of the engineering work performed prior to the estimate and the overall quality of the documentation provided to the estimators.

- PFD's and P&ID's:
  1. Preliminary.
  2. Reviewed/approved by Owner.
  3. Approved for design and/or construction.
- Layouts/equipment arrangements:
  1. Preliminary.
  2. Reviewed by owner.
- Detailed engineering by discipline:
  1. Conceptual.
  2. Preliminary.
- Estimating tools.

As discussed in Section 10.4, the breakdown of cost items (take-offs) can go down to the level of nuts and bolts (detailed) or be based on larger, more comprehensive units (semi-detailed). Both approaches are valid provided that the scope of the unit prices corresponds to the units and that adequate resolution allowances are included to compensate for omissions and oversights. The estimate review must address the breakdown philosophy to ascertain that the unit prices and resolution allowance are consistent with the details of the take-offs.

The Project Manager must spend time with the estimators to understand the overall estimating technique, discuss the take-off methodology, and be satisfied that all cost items have been considered. The Project Manager should also perform quantity spot checks and challenge any variations greater than 20%.

- **Concrete and Structural Steel** quantities can be easily checked with the quick estimating procedures in Chapter 19.
- **Instrumentation and Electrical** take-offs can be checked by quick balloons and motors count on selected areas.
- **Piping** take-offs can be checked by quick count of lines and valves on randomly selected P&ID's.

After the accuracy and thoroughness of the take-offs have been established, the validity of the materials and labor cost information must be determined. This can be done by determining the source of the data used by the estimator and checking it against an independent source and/or the unit prices/hours in Chapter 19. Any variation of more than 15-20% should be challenged and investigated.

Even if the validity of the basic unit costs and hours has been established, the Project Manager must ascertain that the composition of each unit price is consistent with the scope of units; i.e., if the unit is cubic yards of concrete and includes excavation, rebar, and forms, the cost and hours per cubic yard must include a reasonable pro rata of all the cost components. Chapter 19 provides enough data to make this analysis.

The unit hours in the estimating procedures, in Chapter 19, are based on so-called Gulf Coast productivity which tends to be conservative since it is mainly based on a direct-hire situation and unionized labor practices. They very seldom find their way into an estimate but are adjusted, up or down, to reflect specific project requirements, contracting strategy and general business conditions as well as local labor availability and atmosphere. It is up to the Project Manager to ascertain the validity of the labor productivity used in developing construction man-hours. Labor productivity is discussed in some detail in Chapter 19.

Indirect costs must be investigated separately to determine whether they have been independently estimated or simply factored from the direct materials and labor costs.

- Estimating **Field Indirects** as a factor of labor costs is quite appropriate providing the factor recognizes the difference between direct labor costs and subcontract labor costs, which already include a large fraction of indirects as well as the impact of fast track schedules on field indirects.
- On the other hand, estimating **Home Office** (engineering) costs as a factor of directs is a dangerous practice. Engineering costs should be estimated separately or related to equipment type and count.

The Project Manager must also make an in-depth review of the resolution and contingency allowances included in the estimate, understand the estimator's rationale, and be satisfied that they are consistent with the estimating approach and not over- or understated.

Finally, the Project Manager should make, as a check, rough estimates of the equipment-related accounts (instrumentation, electrical, and engineering) using the costs data and guidelines included in Section 19.11.

The following lists some of the cost items often overlooked in estimates:

- "Spaghetti" piping:
  1. Steam tracing supply and condensate return.

   2. Instrument pneumatic supply.
   3. Safety showers and eyewash stations.
   4. Utility stations.
   5. Inert gas blanketing.

- Freight:
   1. Equipment.
   2. Miscellaneous materials.
- Bulk materials discounts.
- Spot overtime.
- Utility tie-ins.
- Capability of existing utilities to support new project requirements.
- Fast tracking costs:
   1. Regular overtime.
   2. Field productivity losses.
   3. H.O. productivity losses.
   4. Over-ordering of materials.
   5. Double bidding subcontracts.
   6. Vendor's overtime/bonuses.
   7. Additional field extras.
   8. Premature start of field work.

The estimating checklist in Appendix D should be a very useful tool for checking the completeness of estimates.

10.8 Offshore Cost Estimates

Overview

In this age of multinational companies most project managers/engineers will be asked sooner or later to come up quickly with a cost estimate to build a given facility at an offshore location.

The ratio of TIC's between the United States and various offshore locations is readily available through several publications. This information would be sufficient when the intended location is an industrial country (Western Europe or Japan). However, for other locations, especially in the so-called Third World, the TIC ratios do not give any insight into specific local conditions that could impact seriously the execution of the project. Owners would be well advised to do the location conversion account by account rather than base it only on the TIC ratios.

With luck there will be an estimate, broken down by accounts, of a similar facility, at a US location, that could be used as a starting point. If not, the guidelines and procedures proposed in this book can be used to prepare quickly an in-house estimate of the quality and details of the case study in Appendix L.

The information required for the conversion must be obtained from contractors with actual recent experience in the intended location. All of the major US engineering and/or construction firms have offices and active presence in most parts of the world and would be more than happy to respond, as a business promotion, to any reasonable request.

The information required to make a meaningful conversion from US costs to those of another location is of a general nature as well as specific to each of the cost components.

General Information

- **The degree of industrial development** is a very important factor. Many developing countries are trying to develop a manufacturing industry and are capable of fabricating many components of chemical plants

  Whether the quality and price of their products are good or not, the governments protect local industry and enforce the use of national products and/or impose heavy tariffs on foreign imports. The impact on project cost could be major.

- **Labor productivity and total labor cost** is another important factor with a heavy impact on the total cost of the project. Even if there is a hard-working labor force their productivity could be affected by the lack of the proper hand tools and construction equipment.

  In some instances an apparently dirt cheap base labor rate can be doubled, tripled, or more by government-imposed fringe benefits that in some cases include food and shelter for the workers and their families.

Specific Information

- The availability of **equipment and materials** of local manufacture must be investigated and typical prices obtained, e.g., vessels, exchangers, pumps, piping and electrical materials, etc.

  When information on the availability of equipment and materials is not reliable or, worse, is negative, the conservative approach would be to assume 100% US purchases and apply freight costs and import duties to the cost.

- The availability of **local subcontractors**, civil, mechanical, electrical, and insulation, and typical unit prices must be obtained.
- Finally, the capability of performing detailed engineering productivity and cost must also be investigated.

Appendix N illustrates the conversion of the study case estimate to an offshore location.

CHAPTER 11
CONTRACTING

The contractor's Project Manager can become a very valuable addition to the integrated team.

11.1 Overview

Contractor selection is probably the activity that has the most lasting effect on project execution. A poor design or a bad estimate can always be revised and, if caught in time, the effects minimized. Changing a contractor after the work has started is a very difficult proposition that always has a negative impact on project cost and schedule. The most important consideration affecting contracting is whether the project will be executed as a large project or as a small project. This decision must be made by management prior to the start of the contracting activities.

The considerations involved in contracting for large and small projects are different. The contractors involved are also different. Naturally, the factors affecting contractor qualification and selection must also be different. Although this book addresses the execution of small projects, the material and guidelines presented in this chapter are appropriate for all projects regardless of size.

The prime responsibility of contracting rests with the Contract Engineer working for CED. However, the Project Manager must live with the selected contractor and make it perform. The Project Manager must have an active participation in contracting activities from the development of the strategy to the contract award and be directly responsible for all technical aspects of the contracting process - bidder qualification criteria, scope of work, bid evaluation criteria, and the technical evaluation of bids.

After contract award, it is the Project Manager's responsibility to implement all contractual provisions and have a complete understanding of the contract in general and, in particular, of those clauses asserting Owner's rights of technical approvals and control of the purse strings for reimbursable charges.

11.2 General Considerations

The contract is one of the most important project documents and regulates the relation between Owner and contractor(s). It must clearly define the what, the who, the how, the when, and the how much.

WHAT: The scope of the work must be clearly and accurately described.

WHO: The responsibility of both owner and contractor must be clearly defined.

HOW: The scope of the work must also define the execution mode(s) to be followed.

WHEN: The completion date and any critical intermediate dates must also be part of the contractual agreement.

and last, but not least,

HOW MUCH: Commercial terms and financial arrangements.

There are many different types of contracts that will be discussed briefly in the succeeding paragraphs. However, there are two specific alternatives, applicable to all types, that merit separate mention.

- **The Agency Agreement.** In this type of contract, the contractor is made the agent of the Owner and carries all contract activities in the name of the Owner.
- **The Independent Contractor Agreement.** Under this type of contract, the contractor is engaged to act as an independent entity, fully responsible for all actions taken during the execution of the work until acceptance by the Owner.

UNDER THE AGENCY CONTRACT, THE OWNER ASSUMES THE RESPONSIBILITY AND LIABILITY FOR THE ACTIONS OF THE CONTRACTOR. IT SHOULD BE AVOIDED.

11.3 Types of Contracts

Contracts for engineering and construction of a chemical facility can fall under any, or a combination, of the following variations.

By Mode of Selection

Negotiated or Competitive

- If you are a hard-nosed experienced negotiator with a thorough understanding of project costs and are fully versed in the technical aspects involved, a negotiated contract could be a very attractive alternative. Unfortunately, few meet these criteria, and the down-to-earth Project Manager should shy from negotiated contracts and promote competitive situations.
- If time is of utmost importance, a negotiated contract would be the quickest way to get a project rolling, at a price. Conversely, a competitive contract would result in lower costs and a potential schedule delay.

A WELL-THOUGHT-OUT EXECUTION PLAN MUST ALLOW FOR COMPETITIVE CONTRACTING AND SUBCONTRACTING.

By Breadth of Scope

Single or Multiple

- A single engineering/procurement/construction (EPC) contract consolidates responsibilities and leads to more effective execution. The EPC approach, also referred to as design-build, is a very attractive approach but could be costly and time consuming for major projects, especially if a lump sum price is sought.

- The project scope and execution responsibility can also be split into several contracts to be awarded gradually as the project information and design develop, i.e., engineering, civil work, mechanical work, etc. This approach imposes a heavy load on the Owner's Project Manager and is suitable for small projects only.

By Mode of Reimbursement

Lump Sum or Reimbursable

- When the scope is defined in sufficient detail, the **lump sum** approach would minimize Owner's risk as well as project schedule, since contractors normally assign their best and most productive personnel to the lump sum work. Lump sum contracts are more appropriate for construction work, especially when the scope can be divided into discrete parts of homogeneous composition. However, they are not recommended for EPC work because of the potential schedule delay and additional costs to both owners and bidders.
- The **unit price** contract is a viable alternative to lump sum and permits contracting, and even starting construction work, with minimal engineering. Unit price contracts should be converted to lump sum as soon as possible based on take-offs developed from the final design drawings.
- **Reimbursable** contracts, also known as time and materials (T&M) or cost-plus, are the least desirable for construction work. However, they could be the only alternative for engineering work when the scope has not been fully defined and/or the Owner wants to exercise full control in order to protect proprietary information. They should be tied to a fixed fee to discourage the contractor from incurring unnecessary expenses.
- The **guaranteed maximum price** (GMP) contract is essentially a reimbursable fixed-fee contract with a price cap that is usually established without the benefit of complete engineering. The Owner approves all expenditures and major decisions and agrees to share the underrun with the contractor based on a mutually agreed upon formula.

All of these types of contracts are normally used in industry and each one offers advantages and disadvantages to both owners and contractors.

Two factors must be weighed against each other when choosing the type of contract:

1. Availability of time and resources required for bidding.
2. The degree of risk the Owner is willing to assume.

For example, a single EPC lump sum contract awarded on competitive basis will place most of the risk on the contractor's shoulders but require a very thorough, lengthy and expensive bid preparation process that could discourage contractors from submitting bids.

On the other end of the spectrum, a reimbursable contract, whether competitive or negotiated, requires minimum bidding effort by both parties but leaves most of the risk on the Owner's shoulders. Between these two extremes, there are several options and combinations which, if discretely managed, could optimize bidding costs and schedule and result in an equitable sharing of risks. The best of all worlds would be to have:

- Independent contractor agreements.
- Competitive bidding.
- Single lump sum EPC contracts.

However, that's not a desirable arrangement for an owner trying to protect a proprietary process.

> IN THAT CASE, THE RECOMMENDED APPROACH WOULD BE A MODIFIED REIMBURSABLE EPC CONTRACT REQUESTING THAT THE CONTRACTOR EXECUTE CONSTRUCTION THROUGH COMPETITIVE LUMP SUM OR UNIT PRICE SUBCONTRACTS.

The most cost-effective way to execute the construction work is through competitive lump sum contracts. Engineering, on the other hand, should be performed on a fixed-fee reimbursable basis to ascertain that the level of engineering effort and details is sufficient to insure a sound and safe design as well as minimal field questions and extras.

11.4 Contracting Strategy Criteria

General

The contracting strategy is an important element of the Project Execution Plan, affecting cost and schedule, that must be developed early in the project between the Project Manager and the Contract Engineer. It must be reviewed and approved at the proper management level.

The decision on how to most effectively execute a project using contractors depends on a number of factors. Some of the most important are:

- How big is the project? How many engineers are required? How many contractors (or subcontractors) will be required?
- How complex is the project? How many engineering and construction disciplines will be required?
- Is this a "first of a kind" or an "off the shelf" project?
- Is this a "fast track" project?
- Is this project highly sensitive to capital cost?
- Are there any significant technical risks associated with this project?

The contractor/project size fit must be an overriding consideration in the development of the contracting strategy. Engineering for a large project must be performed by engineering firms with sufficient human and material resources to meet the project needs. This will allow for essential controls and ensure adequate staffing at peak periods. Retaining a small contractor, no matter how good, for a large project is a very dangerous proposition. Without sufficient personnel to cover the project needs, the contractor will inevitably fall behind schedule, resort to temporary help, cut corners, or, worse, a combination of the above.

Large engineering contractors may not accept the ground rules of the small project approach, but even if they do, they will inevitably require more hours than small contractors. This, of course, is an important consideration when engineering is done under a cost-reimbursable contract.

Construction is normally handled through competitive lump sum contracts and, experience shows, small local contractors can be more effective than large national contractors providing that the work can be done with their regular permanent staff. Many small contractors get into deep trouble when the work exceeds their capabilities. It is important that the execution strategy for a small project recognizes this fact so that the engineering effort can be geared to the preparation of discrete packages consistent with the capabilities of the local contractors.

The construction of a large project could, in theory, be executed by several small local contractors. This, however, is not practical. Even if enough local contractors were available, the complexity and cost of coordinating them would outweigh the potential benefits.

Always remember:

> THERE IS NO SINGLE CONTRACTING STRATEGY THAT EFFICIENTLY FITS ALL PROJECTS.

The Project Manager, together with the Contract Engineer, must decide on the best approach to execute the detailed engineering and construction and develop a contracting strategy to do so. The following criteria outline the main options, and the information required for choosing among them, and discuss the advantages and risks associated with each option.

Engineering

Options

- Do it in-house.
- Contract it:
  1. Single contractor.
  2. Multiple contractors.
- Do part in-house, part by contractor.

Required Information

- Design expertise required.
- Estimated hours by discipline.
- Availability of specialized contractors close to the site.
- Availability of CED and division personnel.

Discussion

- Doing all engineering in-house is not a real alternative. The Owner should not assume the responsibility and liabilities associated with structural design even if it has qualified professional engineers. That responsibility should always be delegated to a well-qualified engineering firm.
- Using a single engineering firm would simplify coordination and consolidate responsibility for potential delays. However, it should be made very clear that project management and control will be the Owner's responsibility.
- Using small local contractors familiar with the plant for structural and/or electrical detail design could be less expensive and also promote local goodwill. However, they should be screened carefully to make sure they have adequate resources.
- In the mixed approach, the Owner could do the instrumentation and maybe the purchasing. The coordination of all design activity, in-house and contracted, is the responsibility of the Project Manager.

Construction

Options

- Single contractor.
- Multiple contractors.

Required Information

- Construction hours.
- Schedule requirements.
- Local contractors' size, availability, and experience.

Discussion

- Retaining a single contractor would simplify the construction management effort but may be more expensive since a single contractor would probably need to subcontract some of the work and incur another level of construction management costs. If that's not the case, then a single contractor could be the right choice, provided it does not impact the schedule.
- The use of multiple contractors would be beneficial to the schedule since construction work would start well before engineering is completed.

11.5 Selecting EPC Contractors

- The competitive lump sum contract seems to be the preferred execution approach in the petrochemical industry where most processes are of public domain and many contractors have their own proven technology.
  - It places most of the risks on the contractor's shoulders.
  - It would result in lower costs and reduced engineering and construction schedules.

However,

- The elaborate bid package and longer bidding period required could offset the cost and schedule advantage.

- On the other hand, in the organic chemicals industry a large percentage of projects involve proprietary, and even experimental, technology. The owners naturally want to protect their technology and maintain control of the design. These goals can be achieved through the use of reimbursable

EPC contracts requiring that construction is subcontracted on a lump sum competitive basis. This is the approach discussed in this section.

Although the evaluation and selection process is practically the same for all contracts the EPC contract is more complex and requires more work and attention to details, so the essentials of this guideline can be used for all types of contracts.

The basic steps for contractor selection are:

- Preparation of bid package.
- Bidders selection.
- Preparation of bids.
- Bids evaluation and contractor selection.

Preparation of Bid Package

General

A thorough bid package insures a meaningful bid. The bid packages required for lump sum EPC contracts for large facilities are elaborate and voluminous and require a lot of attention to details. They must include every detail that could impact the cost.

On the other hand, the bid package for a reimbursable contract, no matter how large, could be quite simple but still requires attention to all details. If the scope is not accurate and the instructions precise and clear, the bids will not be comparable and their evaluation would be, at best, cumbersome.

A bid package must address commercial terms as well as technical details. The preparation of the commercial selection is the responsibility of the Contracts Engineer. The Project Manager assembles all the technical details and is responsible not only for the technical section but for the overall completeness of the package. After all, it is the Project Manager who has to live with the contractor and make it perform.

Commercial section

The commercial section must contain the following information:

Instructions to Bidders

- Bid submission date.
- Award date.
- Number of copies required.
- Addresses/telephone numbers.

- Handling of questions/answers.

Contractual Conditions

- List of acceptable reimbursable costs.
- Type of contract.
- Typical contract.
- Secrecy requirements.

Proposal Contents (information requested from bidders)

- Schedule of reimbursables.
- Bare reimbursable salaries.
- Schedule of overheads (home office and field).
- Travel policy.
- Reproduction costs.
- Proposed execution approach.
- Relevant experience.
- Key personnel resumes.
- Work backlog.
- Estimated home office hours broken down by disciplines.
- Proposed project schedule.
- Proposed construction subcontractors.
- Contractor's fee.

Technical section

The technical section is essentially the scope of the work. It must provide a good understanding of the technical aspects of the project so that the bidders can prepare meaningful proposals, including accurate estimates of the engineering and construction management hours.

Process Information

- Type of process: solid/liquid/gas, batch/continuous, pressure, temperature, organics/inorganics, unit operations, retrofit, hazards, etc.
- Process background: known process/prototype, stage of process development, scale-up factor, etc.

Hardware Information

- Equipment count by type and size corrected for growth allowance.
- Materials of construction.
- Electrical: motor count, average size, substation and distribution system requirements, uninterruptable power supply requirements, etc.
- Instrumentation: control philosophy, sophistication control room requirements, etc.
- Buildings and structures: number, dimensions, materials, function, etc.

Site Information

- Location.
- Grassroots/existing site.
- Availability of utilities.
- Soil conditions.
- Construction and layout areas.
- Site access, parking.
- Environmental information.

Execution Information

- General: new plant/rehab/retrofit, shutdown work, plant rules, special control requirements, completion date, long delivery items, etc.
- Design: general specifications and standards, layout criteria, expected life, etc.
- Construction: direct hire/subcontracted, union/merit shop, etc.

Contractors' Work

- Phase 0/Phase 1: process responsibility, support owner, extent and areas of support location, etc.
- Phase 2: limits of responsibility, owner's approvals, design manuals, mechanical catalogs, reporting, control requirements, etc.

Owner's Supply

- Process design.
- Site information.
- Permits.
- Etc.

Note: A bid package for a lump sum contract must also include complete P&ID's, equipment and piping arrangement drawings and a complete set of project specifications

Bidders Selection

Potential bidders must be screened thoroughly to determine their technical competence as well as their organizational capability and/or willingness to meet project specific requirements, size fit, construction approach, etc. Contractors should not be placed on the bidders slate unless they are considered fully capable of performing quality work within the criteria established in the project execution plan. The criteria are the responsibility of the Project Manager, who must consider, as a minimum, the following factors:

- Relevant Process Experience
  - Organic/inorganic/solids.
  - Developmental/first of a kind.
  - Specialized process design programs.
- Relevant Execution Experience
  - Experience in geographical area.
  - Retrofit/rehab work.
  - Remote areas, construction camps.
  - Direct hire/subcontracting, construction management.
  - Control of cost, schedule; quality.
- Specific Engineering Expertise
  - High-pressure/temperature technology.
  - Materials handling.
  - Special equipment applications.
  - New technology applications.
- Size Fit
  - Engineering staff: 3-5 times expected peak.
  - Average size of projects normally handled.
- Location of engineering office.
- Interest shown by management.

- Work load.

Preparation of Bids

The Owner's direct participation during this phase is limited to answering requests for clarifications and/or additional information. All of these should be handled officially through the Contracts Engineer, who in turn must refer technical matters to the Project Manager.

All answers must be documented in a formal manner with copy to all bidders unless they refer to a particular bidder's proprietary know-how or alternate proposal to execute the project in a uniquely different manner. These unique alternatives could be welcomed, and even encouraged, but should never be considered unless the bidder responds first to the bid package.

Bids Evaluation and Contractor Selection

Bids evaluation must be a well-organized and deliberate effort that culminates in the selection of a technically qualified contractor capable of executing the work in the most cost-effective manner.

It is a good practice for the Project Manager and Contract Engineer to conduct independent technical and commercial evaluations with the technical evaluation being conducted without any prior knowledge of the proposed commercial terms. It is also a good practice that technical evaluation criteria be prepared by the Project Manager with input from process engineering and plant operating groups.

Technical evaluation

The following is a checklist of the points that should be considered for technical evaluation criteria. The relative weight applied to each will depend on project specific conditions.

General Considerations

- Approach to project execution.
- Approach to construction.
- Proposed control system.
- Management commitment to project.
- Flexibility.
- Approach to procurement.
- Size of project handled.

- Size of company.
- Stability of company.

Specific to Project

- Process:
  1. Relevant experience of proposed team.
  2. Availability of up-to-date design systems and tools.
- Design disciplines:
  1. Relevant experience.
  2. Depth and breadth.
- Key personnel:
  1. Experience together in function.
  2. Project Manager/Engineer.
  3. Process Leader.
  4. Cost Engineer.
- Understanding of scope of work.
- Experience in geographical area.
- Experience with other Owner's projects.

Technical evaluation is a subjective process and, as such, should reflect the consensus of several evaluators working both independently and as a group. Appendix F is an example of an actual technical evaluation for a conventional project.

Commercial evaluation

The commercial evaluation is essentially an arithmetical exercise to determine the optimum combination of estimated hours, bare salaries, and contractor's mark-ups. Bidders must be required to submit this information as part of the bid.

- Some bidders will do their homework and prepare realistic hours estimates. Others may try to impress the Owner by submitting the lowest estimate they can ethically justify. The Owner's best protection against this eventuality is to prepare in-house estimates and apply them to all the bids. However, some contractors can perform the same work in fewer hours than others, either by running a lean and mean organization or by being very proficient with up-to-date drafting techniques, such as 3D CAD. If that difference is detected during the evaluation, it should be taken into account in the final decision.

- Bidders usually submit their salary schedule as a range for each discipline; some will also indicate what the average is. The average has no contractual value and could be misleading. The most objective evaluation approach would be to calculate the overall average rate for each bidder and apply it to the total hours estimated by the Owner. The overall average rates must be calculated using the middle of the ranges and the discipline mix proposed by each bidder.
- The contractor's mark-ups represent the total of payroll-added costs (PAC's), overheads, and profits.

  The PAC's are actual out-of-pocket costs, dictated mostly by laws and regulations, and could vary from area to area to reflect local regulations. The bidders must provide, at Owner's request, a verifiable breakdown of these costs.

  The overheads and profit reflect contractor's cost of doing business, operating costs, management, marketing, etc., and is usually the determining factor in the commercial evaluation.

Another important consideration in the commercial evaluation is the bidder's reaction to the Owner's pro forma contract included in the bid package. A strongly negative reaction could be an insurmountable obstacle, especially if it pertains to ingrained management principles. However, this would be an extreme case and in real life reasonable people will negotiate a mutually satisfactory agreement.

Contract award

Occasionally the best technical rating coincides with the most favorable commercial conditions. The decision then is very easy. Unfortunately this is not a frequent occurrence and a choice must be made after evaluating the extent of the differences and the potential impact on the overall project performance, quality, schedule, and cost. The final decision should be based on the following considerations:

- All the bidders were prequalified and found capable of a good performance, and unless an unexpected factor turned up in the final evaluation, they are still capable.
- Usually many of the technical reservations are related to the proposed key personnel and can be easily corrected by requesting alternative candidates and securing formal commitments for the preferred ones.
- The final contractor's costs on a reimbursable contract depend on total hours, actual salaries, and mark-ups. The latter is the only contractually

guaranteed factor. The total hours would be a reflection on the contractor's management and technical ability and the actual salaries could fall anywhere within the ranges indicated in the proposals.

Some Owners engage in the practice of "bid shopping," using information or ideas from one bidder to squeeze concessions from another. This practice not only tests the limits of ethical behavior but will ultimately backfire on the user. Eventually bidders will catch on to this practice and include a negotiation factor in their bids and the Owner will likely end up paying a higher price.

11.6 Subcontracting Construction Work

Overview

By definition, the Project Manager on a small project acts as general contractor and, as such, is also the construction manager, with an active participation in subcontracting, working closely with the Contract Engineer. As already mentioned, the most effective way to perform the construction work is through competitive lump sum contracts. This section is specifically addressed to that type of subcontracting.

The subcontracting process entails the same basic activities of EPC contracting:

- Bid Package.
- Bidders qualification.
- Bidding.
- Bid analysis and contract award.

The Project Manager and the Contract Engineer must have a good understanding of the scope and the cost of the work in order to evaluate bidders and analyze the bids. To do so, they need a good cost estimate with detailed or semi-detailed take-offs.

Ideally the original cost estimate should contain sufficient details to recast the various costs associated with each particular subcontract. However, if the details are not available and/or the scope of the work has changed, it is up to the Project Manager to provide a cost estimate with sufficient details.

Bid Package

General

The bid package must provide a clear understanding of the scope of work, execution requirements and commercial conditions that will permit the bidders to prepare a realistic lump sum proposal. It must include technical and commercial information, as well as clear project execution and bidding instruction.

Technical information

This section is usually prepared, under the supervision of the Project Manager, by whomever performs the detailed engineering. It must include all pertinent drawings and specifications.

Project execution instructions

The Project Manager must have a direct participation in the preparation of the execution instruction. They must address:

- Schedule requirements.
- Testing extent and responsibility.
- Site conditions affecting cost and schedule:
  1. Soil data.
  2. Plant rules.
  3. Work interferences.
  4. Availability of construction utilities.
- Reporting requirements.

Commercial information

The commercial section of the bid package is the responsibility of the Contracts Engineer and must address the contract, invoicing procedures, handling of extras, etc.

Bidding instructions

These require the direct participation of both the Project Manager and the Contracts Engineer. In addition to information concerning bid submittal date, format, and required pricing structure, the bidding instructions must include a complete list of the information that must be provided by the bidders as a prerequisite to having their bids evaluated, including:

- Cost breakdown by materials, labor, and indirects.
- Materials take-offs and estimated work hours by craft.
- Unit prices and work hours to serve as the basis to evaluate extra work.

- List of proposed subcontractors, if any.
- Preliminary schedule and execution plan showing proposed staffing.
- Key supervisors' resumes.
- Exceptions to proposed contractual conditions, if any.

The Project Manager must avoid imposing project control requirements that could be beyond the capability of the small subcontractors usually employed in small projects. A better approach is to wait and see what the bidders propose.

If the proposed controls are not satisfactory but the bidder is still preferred by other overriding reasons, the Owner must make provisions to complement the contractor's capabilities and adjust the projected cost accordingly.

Bidders Qualification

The Project Manager must work with the Contract Engineer to qualify and select capable bidders. If the project is in an existing plant site, the selection process must be done in close cooperation with the plant personnel since they must approve all contractors working in their plant. In the case of small projects, especially if the execution approach calls for multiple subcontractors, the volume of work will not be large enough to attract national contractors and the choice will be among small or medium-sized, local contractors.

Usually when the work is to be done in an existing plant, the potential bidders are well known to the local personnel and may even be working at the site on a regular basis. This, or course, will expedite the bidders qualification process. However, it could also be a source of potential trouble due to:

- Pressure to favor a particular contractor.
- Reluctance to develop new bidders for plant work.
- Having the same contractor doing lump sum subcontract work and reimbursable plant work.

In that case, the Project Manager must walk a very fine line when trying to qualify new contractors to bid against the regulars.

When the project site is a new location and the information available on local contractors is limited, the bidders qualification process must be more elaborate. Contractors must be interviewed and their references must be checked to determine their qualifications for the specific project.

Size

- Volume of work - lump sum/reimbursable.

- Average size of project.
- Largest project staffing.
- Permanent employees.

Relevant Experience

- With similar projects.
- In area.
- In specific plant.

References

- Dun & Bradstreet.
- Banks.
- Safety record/insurance rating.
- Other clients.

Bidding

Once the bidders have been qualified and accepted by the plant, the bid packages are given to them and a pre-bid meeting is held with all bidders, preferably about one week later. The pre-bid meeting is co-hosted by the Contracts Engineer and the Project Manager. The objective is to:

- Insure good understanding of scope and contractual conditions by every bidder.
- Answer and clarify questions for the benefit of all bidders.
- Make any last minute changes to the scope and/or contractual conditions.

The Contract Engineer will issue minutes of the pre-bid meeting within two days.

All questions raised by the bidders during the bidding period will be answered formally with copies of all answers sent to all bidders, except for items deemed to be proprietary by the bidder. Technical questions will be handled by the Project Manager and contractual questions by the Contract Engineer.

Bid Analysis and Contract Award

The Project Manager and the Contract Engineer will conduct independent reviews of the technical and commercial parts, respectively.

As part of the technical analysis, the Project Manager must analyze bidder take-offs to ascertain the bidder's understanding of the scope and will also analyze unit costs and estimated hours for reasonableness and consistency. To do so, the Project Manager must develop, using the same information sent to the bidders, independent take-offs and estimated work hours. Major deviations from the estimates must be discussed with the Contract Engineer to determine how to approach the bidder on the subject.

If the low bidder has reasonable take-offs and unit prices and shows good understanding of the scope, the decision will be very easy. Unfortunately, that's not always the case.

In most cases, final meetings have to be held with each of the two most promising bidders to clarify questions, ascertain their understanding of the scope and confirm the validity of their bids. Usually, as a result of these meetings, the bidders have to make changes and/or additions to the bids.

Both the Project Manager and the Contract Engineer must be very careful that their statements won't relieve the bidders of any of their obligations nor give anyone an unfair advantage over the other. Section 11.8 offers more advice on the subject.

Finally, the Project Manager and Contract Engineer will prepare a formal bid analysis with their joint recommendation and have it reviewed and approved at the proper management level.

11.7 Contracting Engineering Services

The extent and complexity of the engineering services associated with small projects is substantially less than for major projects. For small projects, engineering firms are usually retained to do only the detailed engineering and assemble technical specifications to purchase equipment and materials and subcontract construction work. Occasionally, the design work is broken down by disciplines and farmed out to small, local consulting firms or even done partly in-house. Purchasing and expediting may or may not be included in the detailed engineering contract depending on the availability of Owner personnel to assume that responsibility.

As mentioned in Section 11.1, engineering should be contracted on a reimbursable basis to allow the Project Manager to exercise close control of quality and overall project cost. Engineering firms doing design on a lump sum basis may try to minimize the number of hours used by reducing the amount of documentation and detail shown in the drawings and specifications. They will argue that doing so does not affect the soundness of the design. In many cases, that will be true; however, the number of drawings and the detail of information shown on them may not be sufficient to prepare a meaningful construction bid nor to build the project properly. The result would be higher construction costs for:

- Field extras.
- Additional field supervision and engineering follow-up.
- Costly field errors.

Frequently, all the detailed engineering, and even purchasing, is contracted with a single engineering firm. In that case, it becomes very important that the contractor understands that the scope of the contract work is strictly detailed engineering and procurement and that the Owner will assume the project management and control responsibility.

Occasionally, the Project Manager will run into a proposal to do the detail engineering on a lump sum basis at a fraction of the budget cost. Before falling into the temptation and accepting the offer, the Project Manager should first:

- Ask the bidder for a complete list and scope of the documentation intended under the lump sum.
- Sit down with the operating personnel and CED specialists to determine what is the minimum information required for proper record keeping and plant maintenance.
- Make sure that the bidder understands the bid requirements and has included the related costs in the proposal.
- Reaffirm the Owner's right of review and approval, establish a review and approval cycle, and make sure that the resulting schedule and cost impact is included in the lump sum.
- Ask the bidder for a formal confirmation of all of the above and, if required, a revised proposal.

Although contracting engineering services for small projects does not entail the use of the more sophisticated procedures followed in large projects, the considerations are essentially the same. The contracting guidelines in Section 11.5 are intended for conventional projects, but they could also be very useful for small projects.

11.8 Dos and Don'ts of Contracting

The following bits of wisdom have been voiced by experienced contract engineers and project managers:

- DO have a scope and an execution plan before starting the contracting process.

- DO review the commercial bidding instructions before they are issued to insure that the special conditions documents are consistent with the particular project.
- DO insist that bidders respond to the base case before even considering their proposed alternatives.
- DO develop your own estimates of the work involved prior to receiving the bids.
- DO review bidders' take-offs and challenge them if they are more than 20% off your own take-offs.

BUT

- DON'T let them know whether they are high or low.
- DON'T ask for price adjustments without a corresponding change in the scope.
- DON'T use general terms like "smooth," "exact level," etc. Give tolerance figures.
- DON'T accept any price reduction during the bid evaluation without a real justification.
- DON'T change technical specifications during the negotiations without checking with the appropriate specialists.
- DON'T socialize with bidders during the bidding process.
- DON'T award a lump sum contract with less than 90% engineering.
- DON'T award a contract until all questions have been satisfactorily answered in writing by the bidder.

AND

- NEVER use a purchase order to award contracts.

11.9 Typical Contract

The contract is the fundamental document in project execution, as mentioned in Section 11.2. It defines the what, the who, the how, the when, and the how much. It includes a basic document (the agreement) and a series of attachments (sometimes called appendices or schedules) that define all details of the scope, regulates the communications between contractor and Owner, and establishes the rights and obligations of each.

The Agreement

The agreement is the document that recapitulates, by either direct mention or reference, all the elements of the contract (scope, schedule, general and special conditions, commercial conditions, etc.) and formalizes them through the signatures of the parties involved. The agreement can also be the vehicle to clarify, reinforce, and even override some of the conditions incorporated in the attachments.

The following information should be included in the agreement:

- Clear identification of all signing parties.
- Brief description and exact location of the work.
- Project completion date.
- Preset fixed costs:
  1. Lump sum.
  2. Fixed fees.
  3. Guaranteed maximum price.
- Liquidated damages clause, if any.
- Arbitration procedure.
- List of all attached contractual documents with clearly established precedences.

Scope of Work

The scope of work documents must include:

- Scope on which the bid is based.
- Minutes of pre-bid meetings.
- Addenda and/or clarification of the scope issued during the bidding process.
- Minutes of the pre-award meeting.

On a lump sum EPC contract, the scope documentation is extensive and bulky. It includes:

- Drawings.
- Engineering standards.

- General specifications:
    1. Civil.
    2. Mechanical.
    3. Electrical.
- Detailed specifications:
    1. Equipment.
    2. Site.
- Execution instructions:
    1. Owner's approval.
    2. Documentation requirements.

On the other hand, the scope of a reimbursable contract requires minimum documentation; it could be as simple as a one-page, verbal description.

General Terms and Conditions

The general terms and conditions set the rules that regulate the implementation of the contract and define the contractual rights and obligations of each party. The most relevant, typical clauses are summarized below:

- The contractor operates as an independent contractor.
- The contractor shall comply with all federal, state, and local laws and codes including all provisions of Executive Order 11246 concerning equal opportunity employment.
- The contractor shall, if so required, remove from the job any employee the Owner deems to be incompetent or undesirable.
- The site and subsurface information provided by the Owner is supplied for the contractor's convenience only. The contractor shall confirm it to its satisfaction, assume the responsibility and promptly notify the Owner in writing of any actual or latent physical condition differing from those indicated in the contract.
- The contractor holds the Owner harmless from any claims and associated costs related to infringement of any patent arising from the use of materials supplied by the contractor and/or personal injury and/or property damage resulting from work performed by the contractor.
- The contractor shall be responsible for the protection of all work in progress and shall comply with all safety regulations and standards.

- The Owner has the right to inspect at all times any work covered by the contract onsite and offsite.
- The contractor shall maintain a clean environment and avoid any kind of pollution.
- The Owner reserves the right to direct the contractor to schedule the order of performance of its work in a manner which does not unreasonably interfere with the performance of the work.
- The contractor shall submit advance working schedules and take the necessary steps to achieve them. Failure to do so provides ground to terminate the contract.
- The Owner may at any time make changes and/or request the contractor to perform extra work. The contractor shall comply immediately, if so requested, and submit a formal estimate of the cost and schedule impact within 10 calendar days.
- If the contractual schedule is delayed for any reason beyond its control, the contractor shall give the Owner written notice at the time that delay occurs. Failure to do so shall be sufficient reason for denial of all schedule extension.
- If the contractor fails or refuses to provide sufficient resources to perform the work, the Owner has the right to terminate the contract for default after giving the contractor prior written notice and has then the right to do whatever is required, including taking over the contractor's resources, to complete the work.
- The Owner also has the right to terminate the contract at any time for its convenience and reimburse the contractor for all reasonable expenses incurred to date.
- Any controversy or claim arising out of the contract shall be settled by arbitration in accordance with the rules of the American Arbitration Association.

The following subjects should also be addressed in the general terms and conditions:

- Insurance requirements.
- Requirements for contractor safety program.
- Handling and approval of contractor's drawings, purchase orders, subcontracts, and materials certification.
- Requirement for contractor's contingency plan.

- Owner's right to examine contractor's records.
- Contractor's reporting requirements and progress and coordination meetings.
- Employment eligibility verification.

Special Terms and Conditions

The special terms and conditions are intended to address matters specific to each project and/or each site such as:

- Availability of utilities.
- Services provided by Owner.
- Project schedule.
- Plant regulations.

Proposal Information

Some of the documents submitted with the proposals must be included in, and officially made part of, the contract. Those more frequently included are:

- Pro forma proposal offer.
- Schedule of prices broken down as requested.
- Key personnel list.
- Contractor's safety and CICE programs.
- Schedules.
- Safety data forms.

Reimbursable Costs Schedule

This schedule is applicable only in cost reimbursable contracts and must clearly identify the cost items that will be reimbursed to the contractor under the terms of the contract. It would be to the Owner's advantage to include the following clauses:

- Make all clerical and secretarial help non-reimbursable and part of the overhead.

- Make the cost of word processing, CAD equipment, and the like part of the overhead.
- Don't accept mark-ups or overhead charges on agency personnel (job-shoppers), local field hires, or subcontracts. Treat them as a pass-through charge.
- Don't pay overhead on overtime work.

CHAPTER 12
DETAILED ENGINEERING

Detailed engineering can be dull and unimaginative work. So can the results.

12.1 Overview

Detailed engineering is the project phase where the difference in execution between small and major projects is most noticeable. It is also a phase that presents opportunities for substantial cost reduction without jeopardizing quality. In the context of this guideline, detailed engineering includes:

- Upgrading P&ID's to approved for design (AFD) status.
- Preparation of detailed project specifications - approved for design.
- Execution of the detailed engineering and preparation of approved for construction (AFC) drawings for all disciplines.
- Preparation of purchasing packages for competitive bidding of construction work.

On a major project, the Owner would normally select a large full service engineering and/or construction firm to act as general contractor under an EPC contract to perform all the functions required to carry the project to a successful completion. These functions normally comprise much more than detailed engineering and include:

- General specifications.
- Estimating.
- Scheduling.
- Cost Control.
- Procurement/subcontracting.
- Project management.
- Construction or construction management.

To perform all of these functions effectively, the EPC contractor must have a well-structured organization with formal procedures and lines of communication. Such an organization entails a high overhead burden:

- The ratio of supervisory and support personnel to designers is high.
- Reviews and approvals are elaborate.
- Response is slow.
- Learning curve is long.
- The relative cost is higher.

However, the degree of complexity of a major project requires a complex organization in order to insure quality, schedule, and cost control. In a major project, an EPC contractor is a must, and the price has to be paid to insure the integrity of the project.

The lesser degree of complexity of a small project does not warrant the complex and formal organization provided by a large contractor. Experience shows that the ratio of unproductive to productive hours increases as the size of the project decreases. Substantial savings can be achieved through the small project approach where the Owner assumes the project execution and control responsibilities and uses small engineering and construction contractors, as well as in-house resources, to perform detailed engineering, procurement, and construction. In doing so, the Owner becomes, in fact, the general contractor.

To be successful, the small project approach must be followed only:

- On the right size project.
- If the Owner has adequate human resources with the right experience at the right time.

Following the small project approach is not a decision that can be taken in haste. It requires careful consideration, participation and approval at the right management level.

The purpose of this chapter is to:

- Give the Owner's Project Manager an insight into the workings of an engineering office with its execution and checking procedures, internal documentation, etc.
- Discuss the various ways in which detailed engineering could be executed to minimize project costs without impairing quality and alert the Project Manager of the potential pitfalls.
- Provide guidelines for the coordination of the detailed design activities to fill the vacuum left by the general contractor.

The discussions are limited here to only the execution of detailed engineering. All other related functions, project and construction management, purchasing and subcontracting, as well as project controls, are discussed in other chapters.

12.2 Execution by Contractor

An Owner's Project Manager assigned to the office of a sophisticated engineering contractor is seldom aware of all the behind-the-scenes activities that must take place before the final product is submitted for Owner's approval.

All of those activities are regulated by complex internal procedures and protocols, such as:

- Scope definition and change control.
- Checking of design.
- Reviews and approval at various levels.
- Intersquad coordination.
- Progress evaluations.
- Resource allocation.
- Variance reports.
- Cost tracking.
- Design procedures.
- Communications formats.
- Others.

In the case of large contractors, these procedures can be very strict and inflexible.

Some of those procedures are intended only to protect the contractor's interests, control internal costs, and gather data for internal use. Most of them would not be required for small projects.

Other procedures and activities are directed to controlling project quality, cost and schedule. They must be included, at least in essence, in the protocol of all projects.

Finally, and especially in larger organizations, there may exist procedures and activities that serve no useful purpose other than to impress the client. The Project Manager should review these carefully and, in the case of reimbursable contracts, take exception and refuse to pay for them.

Although this is not always the case, smaller contractors are usually more flexible and informal than large ones.

This section provides insight into the behind-the-scenes workings of an engineering contractor's office, discusses the procedures that govern them and focuses attention on those that should be followed and/or enforced by the Project Manager during the detailed engineering phase.

Basic Engineering

Immediately after receiving a package from a client, the first thing contractors do is review it for completeness by going through their standard questionnaires to determine what is missing and how much basic engineering must be done to bring the project to the point where detailed design can start and proceed efficiently. This is usually much more than most owners think.

To illustrate the point, it should suffice to note that the Phase 1 package described in Chapter 6 requires approximately 10-12% of the total home office man-hours, while most contractors estimate that their basic engineering consumes approximately 20% to 35% including process design.

The following paragraphs list the main activities that must be accomplished before the project can be declared approved for design.

Note: Items marked with an asterisk require direct participation of the Owner's Project Manager.

- – Review client's process design and material balances.
- * Prepare and issue project coordination procedure and assign responsibilities
- * Develop engineering man-hours budget for each discipline.
- * Prepare project execution plan, determining:
    1. Firm engineering schedule.

2. Client's review and approval requirements.
3. Preliminary construction schedule.
4. Subcontracting strategy.

- Refine P&ID's for approved-for-design issue:
  1. Confirm hydraulic calculations (line sizing) for compressor circuits and establish compressor differential.
  2. Confirm relief protection philosophy, select location of major relief valves, and determine vessel and exchanger design pressure and temperatures.
  3. Confirm hydraulic calculations on all pump circuits and establish pump NPSH and minimum equipment elevations.
  4. Confirm and, if required, complete sizing of lines and control valves.
  5. Confirm that all relief valves as well as vent and drains are shown.
- Review all equipment data sheets and incorporate all pertinent mechanical information to make them ready for procurement.
- Prepare project control documentation, including:
  1. Drawings and requisitions lists.
  2. Vendors lists.
  3. Line schedules.
  4. Painting and insulation schedules.
  5. Procurement logs.
  6. Equipment and instrument control indexes.
- Compile and issue project specifications.
- Obtain site-related data if not available at contract award, such as soil conditions, site surveys, topographical maps, etc.
- Prepare equipment arrangement drawings.
- Develop electrical one-line diagrams and electrical loads lists.

Detailed Design

The detailed design phase or production engineering, as some people call it, consumes approximately 50% of all home office man-hours. It is during that phase that the bulk of the documents directly required for procurement and construction are generated:

Civil Engineering

- Site studies, plot plans.
- Soil studies, piling design.
- Storm and process sewers.
- Roads, fencing, parking, paving.
- Structural calculations - concrete, steel.
- Foundation drawings, rebar schedule.
- Structural steel drawings - plans, elevations.
- Miscellaneous building design and drawings.

Piping Engineering

- Equipment arrangement drawings.
- Piping plan and elevation drawings.
- Isometric drawings.
- Model.
- Stress analysis.
- Bills of materials and requisitions.
- Valve schedules.
- Heat tracing system layout.

Instrument Engineering

- Instrument specifications and data sheets.
- Material list and hook-up drawings.
- Interlock system.
- Drawing for emergency electrical system.
- Standard drawings for field instruments.
- Layout drawings for cable ducts, joint boxes, and joint plates.
- Schematic drawing for instrument air supply piping.
- Schematic drawing for instrument heat tracing.
- Panel board face layout and wiring.
- Wiring diagrams for interlocks.

- Requisitions suitable for purchasing of all instrumentation items.
- Review bids for conformance to specifications.
- Uninterrupted power supply (UPS) power source and distribution.

Electrical Engineering

- Mechanical and material specifications for all electrical services.
- Single line wiring diagram, motor lists.
- Load schedule, power factor correction scheme, relay coordination study and diagram.
- Lighting system drawings showing arrangement of lighting panels, lighting requirements, and specific details as required.
- Layout of power cables and specific requirements for switchgear and motor control centers, including mounting details.
- Grounding drawings and specific details.
- Emergency lighting source for control room and field.
- Layout and detail drawings of cable duct, if any.
- Arrangement of above-ground conduit and cable trays.
- Layout drawings of overhead piping for power, lighting, and instruments.
- Layout of substation room including arrangement of switchgear, MCC, and outdoor transformers.
- Outline of MCC and switchgear.
- High-voltage and low-voltage switchgear schedules.
- Motor control diagrams.
- Wiring diagram of switchgear.
- Hazardous area classification drawing.
- Requisitions suitable for purchasing of electrical items.
- Composite bill of materials.
- Emergency power source.

Insulation Painting and Fireproofing

- Schedule of type, thickness, and covering of insulation of equipment and piping.

- Requisitions to purchase insulation and painting materials and services.
- Fireproofing schedule.
- Drawings covering specific details for fireproofing.

Coordination and Control

Even a small project ($3 to $5 million) will require a staff of 15 to 25 people during the peak of the detailed engineering effort. Each of them must receive the correct information at the right time and, in turn, complete the assigned tasks correctly and on time. Additionally, all of the activities must be performed within the frame of the budgeted hours. This can only be achieved by imposing a project control system.

A control system, regardless of the size of the project, must include:

- Detailed project schedule.
- Coordination.
- Quality assurance and control (QA/QC).
- Productivity and progress measurements.

For large projects, where the home-office staff peaks in the hundreds, the system must be elaborate and expensive but is absolutely necessary. On a small project, all of the required control functions could be performed by an experienced project engineer with assistance from the discipline leaders. However, a large contractor used to handling megaprojects might find it impossible to adapt to the realities of small projects. As mentioned in Chapter 15, it is up to the Project Manager to analyze the organization of potential contractors and steer away from those with large and inflexible control organizations.

12.3 Small Project Execution Options

General Considerations

As mentioned before, on a small project, the Owner acts as a General Contractor assuming the responsibilities of:

- Process engineering.
- Project management.
- Construction management.

- Subcontracting.
- Project controls - estimating, scheduling, and cost control.

Occasionally the Owner would also perform:

- Procurement.
- Instrumentation engineering.

Rarely, only on very small projects, the Owner could also perform some mechanical, electrical, and/or piping design. Civil and structural engineering and, usually, mechanical, electrical, and piping design are assigned to one or more engineering firms, preferably small or medium sized ones.

The execution of detailed engineering on a small project is a mixed bag. It could be performed by any combination of:

- In-house engineering - CED, division, or plant.
- Engineering firm - large or small.

The selection of the proper mix is a pivotal decision that has a lasting effect on the fate of the project and requires participation of the Contract Engineer as well as participation and approval of management. It requires very careful consideration of:

- Range and depth of engineering expertise required.
- Availability of in-house personnel.
- Size of project and engineering hours.
- Size and qualification of proposed engineering firms.

It is up to the Project Manager to develop sufficient data so that the correct decision can be made. The Project Manager must:

- Estimate the hours required to perform the detailed engineering in-house as well as by contractors.
- Work with the specialists to determine if any particular engineering expertise is required to insure safety and health protection or for special technology needs.
- Evaluate the capabilities of the in-house resources and their availability on a timely basis consistent with the project schedule.

- Secure commitments at the proper management level.
- Evaluate, together with the Contract Engineer, the availability and capability of local engineering firms.

In-House Engineering

In-house engineering is probably the least expensive approach of any case, particularly when it can be performed by personnel who would be involved in the monitoring of a contractor's work anyway, such as CED instrument engineers.

For small projects, CED and/or plant mechanical and electrical engineers can take hands-on participation in equipment design and purchasing specifications.

Some plants have engineering departments with design and drafting capabilities and are quite capable of doing equipment layouts and piping design as well as electrical and instrumentation schematics and loop drawings.

A WORD OF CAUTION:

> DOING ALL DETAILED ENGINEERING IN-HOUSE IS NOT A DESIRABLE ALTERNATIVE. THE OWNER SHOULD NOT ASSUME THE RESPONSIBILITY AND LIABILITIES ASSOCIATED WITH STRUCTURAL DESIGN EVEN IF QUALIFIED PROFESSIONAL ENGINEERS ARE AVAILABLE. THE RESPONSIBILITY FOR CIVIL AND STRUCTURAL DESIGN SHOULD ALWAYS BE ASSIGNED TO WELL-QUALIFIED ENGINEERING FIRMS.

For a small project, executed at plant level by plant project engineers, in-house engineering is the ideal approach provided that adequate resources are available in the plant engineering department, because:

- The required engineering design hours could be as low as 50% of those required by an outside contractor.
- The out-of-pocket costs would be minimal.

Small projects, where most of the detailed engineering can be done by the plant engineering department, should also be managed at the plant level by a plant project engineer, rather than by CED. Communications, coordination, and supervision should be more effective since the project engineers, design engineers, draftsmen, and even the "client" will be working, if not for the same supervisor, at least in the same operations unit within the Owner's organization.

Contracted Engineering

When the required engineering effort exceeds the resources of the local plant engineering department, the work must be performed by a contractor.

There are several options to contract engineering work:

- A single large engineering firm.
- Several small engineering firms.
- A single small or medium sized engineering firm.

The large engineering firm option will be the most expensive and should be avoided unless the project demands a very specific expertise only available through a large firm.

Most large contractors, with their elaborate communication and checking procedures, are inflexible and could not function without them. Forcing them to do so would be flirting with disaster. The potential savings of the small project approach would be limited to the hours related to project control function retained by the Owner. No savings should be expected in project management since a large contractor would assign a project manager or project engineer to the job anyway.

When a special expertise is required, it may be possible to avoid the large engineering firm by shopping around for individual experts to support the efforts of smaller contractors.

Another option is to farm out the detailed engineering among several specialized local firms familiar with the plant and its requirements. This approach would be ideal for a retrofit job where a local civil engineer can design a couple of foundations and the engineering section of the friendly local electrical contractor could handle a few motors connected to an existing MCC, and so forth. This option, although financially attractive, could easily overload the Project Manager to the point where the entire project would suffer.

Retaining a small or medium sized full-service engineering firm to perform all the detailed engineering, and even the purchasing, would be the ideal option for the run-of-the-mill project that does not require any particular design expertise.

Small contractors usually have, and, in this case, the selected contractor must have:

- Adaptability to accept the direct participation of the Owner's Project Manager in the design activities.
- Qualified personnel with the flexibility to perform without their normal organization constraints.

Should the Owner fall short in providing the Project Manager with staff support to perform any of the design-related functions under its responsibility, a full-service contractor could provide qualified back-up on minimal notice.

12.4 The Project Manager as General Contractor

In the absence of a general contractor, the Project Manager must step in to fill the breach and insure, through hands-on action and/or direct supervision, that the essential activities required for proper coordination and control of the detailed engineering phase are performed on a timely basis. Those activities include:

- Engineering coordination procedure:
  1. Resolving bottlenecks in project schedule.
  2. Continued interdisciplinary coordination.
  3. Design checks and approvals.
- Detailed specifications.
- Documentation.
- Monitoring engineering costs and progress.
- Staffing.
- Preparation of subcontracts' technical packages.

The extent of the Project Manager's participation depends on the option followed to execute the detailed engineering. Under the single contractor approach, hands-on participation will be minimal, while in-house engineering will result in the most work for the Project Manager.

- Detailed engineering could not be performed without clear and detailed coordination procedures defining the scope of work and responsibilities assigned to each participant. When engineering is performed by a single engineering firm, large or small, the contractor will do what it always does and issue its own internal job coordination document. The participation of the Owner's Project Manager will be limited to reviewing the contractor's procedures and ascertaining that they are consistent with the scope of the contract and do not generate additional work.

  When the engineering is executed in-house or through several engineering firms, the burden of coordination falls squarely on the Project Manger's shoulders. The Project Manager must prepare and issue a coordination procedure and insure that all concerned comply with it. Failure to do so would have a negative effect on the project.

- Some owners only have general specifications and rely on engineering contractors to provide their own detailed project specifications. When the engineering is done in-house, they would use the specifications from some recent project in the same location. In that case, it is the Project Manager's responsibility to review and update them and, above all, make sure that they provide quality and safety consistent with the project requirements without unnecessary gold plating.

- Formal documentation of any communications affecting the execution of the work, especially the scope, is an absolute must to good project management. Normally, engineering contractors are very good at it, but it is up to the client's Project Manger to ascertain that the confirmation memos and minutes of meetings are accurate and truly reflect what was discussed and that proper emphasis is placed where it belongs.

  When engineering is done in-house or by multiple firms, the Project Manager must take a proactive approach and assume the leading role in documenting relevant project activities, especially those related to defining changes in scope and/or schedule.

- The Project Manager must have hands-on participation in the monitoring of engineering costs and progress even if the contractor is using its own methods. In all cases, the Project Manager must establish control systems to make independent checks of the contractor's reports and evaluations. Chapter 15 and Appendix H include procedures and forms that will enable the Project Manager to perform the control functions.

- Each contractor executing the detailed engineering will manage its forces and allocate them to the various active projects. The Owner's Project Manager must be alert to insure that the project is neither over- nor understaffed, nor shortchanged in quality of personnel. It would be wise for the Project Manager to review and approve on a regular basis the personnel assignments with the contractor's Project Manager.

- When engineering is done in-house, the Project Manager must be continuously evaluating and making accurate forecasts of the remaining work to the appropriate local engineering managers so that they can make the necessary arrangements to meet the project staffing needs.

- The scope of work of any engineering firm doing the detailed engineering should include the assembly of a technical package to select construction contractors on a competitive basis. However, where the engineering is done in-house, it is up to the Project Manager to do that work.

CHAPTER 13
PROCUREMENT

The procurement department is there to screen you from the salesmen, use them.

13.1 Overview

On major projects, the selected EPC contractor handles the procurement function: purchasing, expediting, inspection, receiving, and accounts payable. All the equipment and some of the critical bulk materials are purchased by the contractor. Bulk materials are generally supplied by the construction subcontractors as part of their scope of work.

Occasionally, as in the case of long delivery items, the Owner initiates the procurement process, (requisitioning, bidding, and even placing of purchase orders) to insure timely completion of a project. Once a contractor is selected, the purchase order will be assigned to the contractor as part of the scope.

On small projects, procurement could either be assigned to the contractor doing the detailed engineering or performed by the Owner. In-house execution will undoubtedly minimize out-of-pocket expenses and seems like the desired option. However, the approach will only be viable for very small projects or on locations where an experienced and well-staffed purchasing department is available.

When procurement is performed in-house, the Project Manager assumes a very serious responsibility. Procurement involves much more than just placing purchase orders.

- Vendors must be screened.
- Approved vendors lists must be prepared.
- Certified vendors' drawings must be expedited for timely submittals.
- All vendors' activities must be expedited.
- Vendors' shops must be inspected and fabrication techniques approved.
- Equipment has to be inspected, tested, and accepted.
- Equipment must be shipped and delivered.

Failure to perform these activities within the project time frame will result in schedule delays and a corresponding impact on engineering and construction costs. A compromise option, worth considering, would be to carry the in-house work up to the issue of purchase orders and assign all the follow-up and delivery responsibility to the engineering or the construction contractor.

If procurement is to be done in-house, a qualified purchasing agent must be assigned to the project team. It would be a grave mistake for the Project Manager to do purchasing personally. Effective procurement requires a tremendous amount of paperwork and recordkeeping, including:

- Preparation and issuance of inquiries.
- Bid analysis documentation.
- Communication with bidders/vendors.
- Procurement logs:
  1. Requisitions.
  2. Purchase orders.
  3. Inspection and acceptance.
  4. Invoices/payments.
- Claims processing.

In the absence of a contractor, all the paperwork has to be done in-house, and it would be impossible for the Project Manager to keep up with it without abandoning other duties and losing the overall perspective.

Although the guidelines in the following section are intended for project managers working with general contractors, they are also appropriate for small project managers.

13.2 Guideline for Purchasing

Inquiry

- Bidder list must be based on qualifications and ability to perform. Arbitrary restrictions will limit cost-saving opportunities.
- Specifications must be complete and sufficiently detailed to insure meaningful bids.
- Avoid overspecifying. It may unintentionally exclude less expensive but acceptable equipment.
- Search market to determine which vendors are hungry.
- Pre-qualify bidders of special equipment. This will insure acceptable bids.
- Premature inquiries increase home-office costs and probably will not save any time.
- Allow reasonable time for bidding. Rush bids tend to be incomplete and will require more analysis and clarification.
- Requests to extend bidding deadline may be an early indicator of future troubles. Vendor may be getting into more work than it can handle. It could also be an indication of unreliability.
- Competitive bidding is highly desirable, but under certain circumstances sole sourcing may be the right way to go.
- Sole sourcing must be justified and documented by the Project Manager or whoever requests it.
- Request firm price quotations, including unit prices for potential changes (nozzles and miscellaneous attachments) and spares, if required.
- All contacts with bidders/vendors should be channeled through the purchasing agent.

Technical Bid Evaluation

- The basic proposal must specifically respond to the inquiry and satisfy the technical specifications.
- If economically attractive alternatives are offered, determine whether they are technically acceptable.
- Evaluate operation and maintenance costs as well as potential impact on layouts, piping, and spare parts inventories.

Commercial Bid Evaluation

- Make sure that costs for extras are properly segregated.
- Place a value on the operating and maintenance costs, as well as intangibles.
- If delivery is not acceptable, determine cost of improvement, if viable.
- If delivery is critical, ascertain feasibility of proposed schedule.
- Bids must be compared with budget estimates. The cause of substantial deviations must be determined.
- When the low bidder is not the recommended bidder, the reason must be justified and documented. A notation in the bid summary will suffice in most cases.

Purchase Order

- Make sure that all changes that have been negotiated are properly incorporated.
- On critical items, make sure that verbal confirmations are documented immediately by telex or fax.
- If the purchase order involves startup and/or checkout assistance, make certain that the appropriate documents and information are included with the purchase order: insurance certificate, travel policy, site conditions, etc.
- Do not issue open-ended purchase orders.

Inspection and Expediting

- Define frequency and extent for every item at the beginning of the job.
- Beware of contractors with large inspection and expediting groups; unless controlled, they may overdo it.
- Force contractors to do their job. Don't do it for them. You should not relieve them of their responsibility.

13.3 Expediting and Inspection Criteria

Selecting a vendor and placing the purchase order is only part of procurement, usually the easiest part. If the article is not delivered on time or does not meet specifications, the entire procurement effort will be wasted and the project may not be completed within schedule and budget.

- Purchase orders must be expedited to insure timely delivery.

- Fabrication of equipment and materials must be inspected to insure quality.

On projects handled through a general contractor, procurement (including expediting and inspecting) is performed by the contractor under the supervision of the Owner's Project Manager. Frequently, the Owner's specialists will also participate in the inspection of critical items.

On projects handled under the small project approach, expediting and inspection are handled differently. Expediting is handled by whoever is doing the procurement, while the inspection is almost invariably handled by the Owner's specialists.

Large contractors usually have expediting and inspection departments and, naturally, they would like to keep them busy all of the time, especially on reimbursable contracts. If left to themselves, being human, they could be tempted to expedite and inspect every nut and bolt in the project.

Regardless of the project execution approach, the Project Manager must sit with the contractor and/or the in-house specialists, early in the project, and prepare a sensible program for selective expediting and inspection. Doing so will insure quality and schedule without unnecessary costs.

Expediting

Expediting of bulk materials and standard and/or off-the-shelf items can normally be done through periodic telephone follow-ups by the purchasing agent or even an inexperienced clerk. Expediting of large and/or critical equipment involving custom engineering and fabrication requires field expediting through visits to the vendor's office and fabrication shops by qualified personnel. Contractors normally use field inspectors or, sometimes, design engineers to do field expediting. The Owner would use, depending on the type of problem, either a CED specialist or the Contract Engineer. On a difficult expediting visit, the Project Manager is frequently called upon to lend weight to the undertaking.

The field/shop expeditor is expected to:

- Ascertain that the vendor prepares meaningful schedules and verify their viability.
- Concentrate initial efforts on early completion of vendors' drawings requiring approval.
- Obtain vendors' procurement schedules for long lead or critical items and verify their consistency with promised delivery dates.
- Obtain unpriced copies of vendor's suborders. For major subcontracted items, obtain permission from the vendor to expedite and inspect at sub-vendors' shops.

- Review shop fabrication schedules and observe progress of work in the shops and receipt of outside purchased equipment. Evaluate and determine if the shop scheduled versus actual work performance by the manufacturer is meeting the overall schedule.
- Continually evaluate the vendors' schedule and progress of work to discover potential problem areas.
- Apply intensive expediting effort on critical problems that may affect the delivery schedule.
- Prepare reports following each contact with the vendors to inform the Project Manager of progress being made and of problems requiring special attention.

Inspection

Inspection entails much more than examining a piece of equipment before shipment. It includes:

- **Pre-Purchase Inspection**
  - Survey vendor facilities to determine their qualifications. Capabilities assessment includes engineering, shop equipment, fabrication techniques, welding certification, and QA/QC systems.
- **Post-Purchase Inspections**
  - Verification of materials of construction.
  - Verification of all pre-weld and post-weld heat treatment to be used.
  - In-process inspections, such as fit-up prior to welding, back gouging, in-progress dimensional checks and non-destructive examination (radiography, etc).
  - Pressure and tightness tests.
  - Performance tests on rotating and mechanical equipment.
  - Final inspection for cleaning, preparation for painting and preparation for shipment.
  - Review and acceptance of all required documentation.
  - Release for shipment.

Inspection must be performed by qualified personnel. Large contractors usually have a staff of qualified inspectors, while smaller contractors would use their mechanical or electrical engineers. Even when inspection is handled by a contractor, the Owner must retain the option to do an independent inspection or do it together with the contractor.

The Project Manager is not expected to perform any inspections but only to have sufficient knowledge of the inspection process to ascertain that it is properly done. Obviously, inspection has to follow a selective program. It would be a serious misuse of resources to subject every piece of equipment to a rigorous inspection procedure. As already mentioned, the Project Manager must develop a sensible program with the contractor and/or the CED specialists.

The following equipment would normally be included in an inspection and testing program:

- Tanks and pressure vessels.
- Heat exchangers.
- Processing equipment (dryers, mills, filters, mixers, centrifuges, etc.).
- Compressors and turbines.
- Special pumps.
- Custom or special valves.
- Boilers/furnaces.
- Packaged equipment (equipment consisting of several components, mounted in a frame and piped and wired together).

Performance Testing

Certain equipment will require testing either in the vendor's shops or in the field after installation. The degree of testing to be performed should be established prior to issuing the purchase order.

Testing may be simple no-load running to establish vibration levels and the functioning of auxiliary equipment, such as lubricating systems. It could also be an extended full performance test to be performed either at the vendor's shop or in the field. When full-scale performance tests are specified, detailed procedures should be prepared. Frequently, these procedures are available from organizations such as ASME, API, and others.

CHAPTER 14
CONSTRUCTION MANAGEMENT

All the design errors show up in construction. The Project Engineer/ Project Manager should correct them on site. It will give him a certain humility.

14.1 Overview

In a normal project, approximately 50% of the cost is incurred in the field:

- Construction:
  1. Bulk materials.
  2. Labor.
- Field Indirects:
  1. Labor related.
  2. Supervision and quality control.
  3. Construction equipment rental.
  4. Temporary facilities.
  5. Rework.

6. Construction management.
7. Other.

Additionally, the construction phase probably involves more risks, natural and legal, than any other project phase:

- Weather.
- Accidents and injuries.
- Physical interferences.
- Contractual disputes.
- Labor disputes:
  1. Plant personnel.
  2. Contractor personnel.
- Labor productivity.

Although some costs may be controlled by good project planning and engineering, and risks minimized by transferring them to contractors through intelligent contracting, there remain sufficiently undefined areas to make construction a phase of great opportunities and risks. It is up to the Construction Manager to identify cost saving opportunities as well as risks implementing the former while avoiding the latter. The quality of construction management can make or break a project.

Except in very small projects where construction is done with maintenance personnel, construction is always performed by outside contractors following any of the options discussed in Section 14.2, Construction Options.

The construction management function can be performed, depending on the construction option applied, by the construction general contractor (G.C.), by an independent construction manager (C.M.), or by the Owner.

In all cases, the Owner's Project Manager has the ultimate responsibility of coordinating all parties involved and insuring that their work conforms to specifications and contractual conditions.

The purpose of this chapter is to:

- Discuss the various options open to performing construction and construction management.
- Give the Project Manager insight into the activities that take place as part of construction management.
- Provide the Project Manager with guidelines and tools to do an effective job as C.M. on small projects.

14.2 Construction Options

Construction can be done using several approaches, most of which have been employed by the author on various projects:

- As a continuation of a reimbursable EPC contract where the contractor is responsible for the construction using either:
  - Direct hire.
  - Subcontractors.
- As a separate reimbursable construction contract where the contractor is responsible for the construction using either:
  - Direct hire.
  - Subcontractors.
- As a separate, single, competitive lump sum contract.
- Through a construction management agreement where the Owner retains a C.M. to act as its agent to coordinate and manage several construction contracts awarded directly by the Owner.
- Through multiple competitive lump sum contracts managed directly by the Owner, who thus becomes in fact the C.M.

The first two options are more suitable for large projects. Lately many owners have been shunning the direct hire situation, and reimbursable EPC contractors are specifically instructed to perform the work through competitive lump sum subcontracts. Doing construction with a single, competitive lump sum contractor would be the ideal option for all projects if sufficient time were available to complete the design and prepare meaningful bids. Unfortunately, that never seems to be the case, especially in large and complex projects.

It is usually easier to arrange for a single, competitive lump sum contract on a simple, small project requiring less engineering and shorter bidding time. The only caveat to this option is that the chosen contractor must be able to perform most of the work without help from subcontractors. The use of subcontractors will add a layer of costs that need not be incurred if the Owner has the capability to do the construction management.

The construction management option of an independent C.M. does not seem to offer any advantages to either large projects or small ones. It is essentially the same as the first two options, executed through lump sum subcontracts, with the disadvantage that the Owner must retain a C.M. and still assume the responsibility instead of the contractor. On small enough projects, the Owner should act as its own C.M. and save construction management fees.

In many companies, it is normal that, once engineering is complete, the Project Manager will follow the job to the field to look over the contractor's shoulder with some construction supervisory assistance from either the plant or CED staff. Under the small project approach, the Project Manager and/or the Field Engineer act as C.M. and work directly with the construction contractors. When acting as C.M., the Owner is assuming responsibility and risks normally assigned to the General Contractor. The extent of the risks involved and their probability must be evaluated for each case and weighed against the potential savings.

14.3 Construction Management Activities

The construction phase of all projects includes two well-defined sets of activities, actual construction and construction management.

Actual Construction

The actual construction comprises a variety of activities involving work by different specialized craftsmen:

Civil Work

- Site preparation.
- Underground mains and sewers.
- Foundations.
- Structural steel.
- Buildings.
- Painting.

Mechanical Work

- Relocations and modifications.
- Equipment setting.
- Piping.
- Instrument installation.

Electrical Work

- Power and lighting.
- Instrument wiring.

Specialty Work

- Insulation.

- Fire protection

The work is performed by contractors specialized along the craft lines. Few contractors have the necessary breadth to perform all crafts directly; however, some have capabilities in one or two of the major crafts plus the expertise and resources to subcontract the rest. In doing so, they become General Contractors.

Construction Management

Construction Management involves the coordination, control, and management of the contractors performing the various construction activities as well as providing them with a clean and safe environment. The person, or entity, performing this function is called the Construction Manager (C.M.).

A very important goal of construction management is to promote a safe and pleasant environment conducive to a high level of performance by all construction personnel.

As mentioned before, the C.M. function could be performed, depending on the construction approach, by the general contractor, by an independently retained C.M., or by the Owner. In the latter option, the Project Manager becomes also the Construction Manager. Construction management entails many other activities, some of which are the responsibility of the contractors directly performing the work and others are the responsibility of the C.M.

Contractors

- Staffing.
- Payroll.
- Day-to-day scheduling.
- Direct craft supervision.
- Providing their temporary facilities.
- Craft training when required.
- Providing construction equipment and tools.

Even when construction management is being performed by others (a G.C. or a C.M.), the Project Manager must have hands-on participation in some of these activities and supervise and spot-check all of them. Those requiring special attention are marked with an asterisk.

Construction Manager

- Layout temporary facilities:

1. Parking.
2. Offices.
3. Shakedown areas.
4. Storage areas.

- Develop site agreements with local unions.
- Enforce site safety and substance abuse policies.*
- Communicate potential operating hazards.*
- Organize and implement worker motivation programs.*
- Investigate and document accidents.*
- Provide safety indoctrination.
- Do activity checks.*
- Coordination:
  1. Among contractors.
  2. With plant.
- Prepare and monitor overall schedules.
- Perform progress measurement.*
- Receive, store, and control Owner's purchased equipment and materials.
- Site security:*
  1. Gate control.
  2. Head counts.
- Quality control:
  1. Welders qualification.
  2. Witness tests.
  3. Accept completed work.
- Overall housekeeping.
- Change order control:*
  1. Estimating.
  2. Maintain logs.
  3. Revise subcontracts.
- Provide and check coordinates, base elevations, and locations.
- Verify layouts.
- Review invoices and approve payments.*
- Communications and documentation.

- Prepare emergency response plan:*
  1. Hold regular coordination meetings.
  2. Issue minutes of meetings.
  3. Keep daily logs of all relevant field activities.

14.4 The Project Manager as Construction Manager

Overview

On major projects, the construction management function is discharged either by the G.C. or by an independent C.M. specifically retained for the project. On small projects, the Owner is the Construction Manager. The C.M. activities are performed by the Project Manager and/or a Field Engineer.

All of the C.M. activities mentioned in the previous section are important and should be performed. However, those related to the administration of construction contracts, receiving equipment, and field safety are of the utmost importance and must be performed and documented in order to protect the Owner's interests from potential contractual and/or labor disputes and claims stemming from the construction work.

When acting as C.M., the Project Manager or the Field Engineer must pay very special attention to the following areas:

- Holding weekly meetings with the contractor(s) and documenting all discussions and agreements through minutes.
- Documenting all discussions concerning contractor's performance.
- Enforcing safety rules and substance abuse policies.
- Investigating and documenting all work-related accidents and near misses.
- Documenting and following up on equipment receiving exceptions.
- Reviewing, approving, and documenting extra work orders.
- Keeping daily logs of relevant field activities.

If the project is completed without any major mishaps, all the above may seem like wasted effort. However, should a contractor submit a claim for liquidated damages or a worker sue for a long-forgotten work injury, proper documentation could save the Owner a lot of aggravation and hundreds of thousands of dollars.

Initial C.M. Activities

The initial construction activities require personal attention from both the Project Manager and the C.M., even when the work is performed by contractors:

- Good relations must be established with the local unions.
- Rules have to be established to control the execution of the job and the coordination with other activities, plant operators, and/or other concurrently active projects.
- A security system must be established.
- Temporary construction facilities must be set.

The contractor(s) doing the work has the direct responsibility of dealing with the local unions and/or labor pools. However, the Owner's Project Manager can insure that pre-job meetings are held with the local labor leaders and that reasonable site agreements are set to promote smooth relations throughout the project.

Project procedures

The coordination of project activities with plant and/or other projects' activities is the responsibility of both the Project Manager and the C.M. They must promote and chair meetings with all interested parties to familiarize everyone with the existing plant rules and develop a set of project procedures consistent with them.

The following is checklist of the information that should be obtained prior to developing the project procedures:

- Who in the plant is the main contact?
- Plant safety procedures - specific hazards and dangers near the project and the field office.
- What is the procedure if a construction worker is injured onsite?
- What are the security procedures for engineers and contractors?
- When are permits required? What are the types and how many are required?
- Listing of contacts for plant/corporate engineering project team members and contractors.
- Where in the plant are the contract personnel allowed to go for breaks or lunch?
- What are the area and plant working hours?

- How are fires and accidents reported?
- Which plant facilities, if any, would be available to the project?
- General plant dangers.
- Plant phone system.
- Local union holidays.
- Who is allowed to operate valves, switches, etc., in this plant?
- What contacts must be made when working late, weekends, or holidays?
- What are the preferred plant procedures for handling final checkouts?

Security system

Establishing and implementing a project security system is a joint responsibility of all parties: contractor, Project Manager, C.M., and plant security.

Construction sites have frequently been a prime target for vandalism and theft. There are even cases of labor disorders ranging from incursion to assault. For these and other reasons (e.g., public safety), the security of a construction site is a very important consideration. While usually not requiring Fort Knox-type protection, the Rittenhouse Square-type (wide open and unlimited access) is totally unacceptable.

Some of the considerations when designing a site security system are as follows:

- Is local law enforcement adequate to handle any anticipated problems?
- Is local law enforcement sympathetic with owners, unions, etc.?
- Can a designated gate be established for construction use?
- Should trailers, offices, storage areas, or staging areas be lit at night?
- Fuel tanks should be locked and gas bottles chained.
- Material storage trailers should be locked.
- High-value materials should be stored in secured locations.
- Is 24-hour guard service needed?
- Limit afterhour site access.
- All vehicles leaving the site should be subject to search.
- Limit the number of vehicles allowed on the plant site proper.
- Use gate passes for all materials leaving the site.
- Use high-security locks with non-duplicable keys.

- Union and non-union parking areas should be separate.
- Each employee should have some means of identification, i.e., badge, colored hat, etc.
- All emergency phone numbers should be posted at each phone.
- Are alarm devices on trailers or offices worthwhile?
- Do the security measures taken focus on deterring or delaying criminal actions?
- Is present fencing adequate?
- Are temporary lights required?
- Are firefighting equipment and services available quickly?
- What is the history on frequency and degree of labor militancy?
- If a fence is part of the project, does it make sense to erect it very early?
- Is there adequate lighting at the work site?

A rational layout of the temporary facilities (offices, change houses, shops, parking lots, layout areas, etc.) enhances labor productivity and has a favorable impact on project costs and schedule. One of the main responsibilities of the C.M. is to lay out the temporary facilities in an efficient manner to minimize the distance the workers have to walk from the gate to the work areas and design traffic patterns to avoid jams and bottlenecks.

Recommended Field Reports/Logs

One of the responsibilities of the Construction Manager is to generate, and/or insure that the subcontractors do, sufficient documentation to:

- Monitor and control field activities.
- Keep management informed.
- Collect meaningful data for future projects.

The following list of reports and logs is probably the minimum required to meet the above objectives:

- **Daily Force Report.** Each subcontractor must submit a daily force account broken down by crafts. The Construction Manager must keep a running total for each subcontractor for inclusion in the final project report and for future reference.

- **Look Ahead Reports.** Each subcontractor must submit every week a list of activities planned for the next two weeks with projected staffing. The Construction Manager must compare this information with the overall schedules to gauge subcontractors' performance and promote corrective action if necessary.
- **Progress Reports.** All subcontractors must submit at least every two weeks progress reports comparing actual versus scheduled progress. The Construction Manager should have the means of making quick, independent checks.
- **Progress Meeting Minutes.** The Construction Manager must issue the minutes of the regular construction coordination meetings.
- **Field Logs.** The Construction Manager must keep a field log documenting all important field events as well as verbal communication and decisions concerning execution of the work and relations with the subcontractors.
- **Change Order Log.** The Construction Manager must maintain an up-to-date log of all field changes, approved as well as pending.
- **Accident Reports**. Each subcontractor must submit reports on every lost-time accident. The Construction Manager must participate in the investigation of major accidents and insure that reports on all accidents are promptly filed and kept as protection against potential future legal action.
- **Acceptance Reports**. The Construction Manager must document and file all final equipment inspection and acceptance.
- **Construction Status Reports.** The Construction Manager must issue every month, for management information, a complete report on all construction activities with cost and scheduled evaluation for compliance to the AFE objectives.

14.5 Influence of CICE in Construction Management

In the late 1970's, the Business Roundtable sponsored an extensive study to determine the cause of the diminishing productivity being experienced by the construction industry in the United States and to propose solutions to stop and reverse the trend. A team was formed with representatives of prestigious universities, contractors, and owners from several sectors of industry. As a result of this concerted effort, the Construction Industry Cost Effectiveness report, now widely known as CICE, was issued.

The CICE report identifies and proposes remedies for a series of specific problems directly related to the decline in productivity. Those directly related to the field construction activities are considered to have the most important impact on project costs.

- Poor safety practices.
- Poor construction management practices.
- Lack of worker motivation.

These are areas where all project managers, whether acting as such or as construction managers, must assume the leadership and exert their power to influence the outcome of the field activities and insure successful completion of the project.

The Construction Industry Institute (CII) was established for the purpose of implementing the CICE recommendations and is continuously following up and expanding upon all CICE-related issues. Every Project Manager, active and/or fledgling, must make a point to study and become fully familiar with its recommendations.

14.6 Co-Employmentship

The standard contract usually indicates that the Project Manager speaks and acts for the Owner. When the Owner's representative gives working instructions directly to a craftsman, a situation of co-employership is set up. The workers get their check from one party (the contractor) but their working instructions and directions from another (the Owner). Thus they, in effect, have two employers. The courts hold both employers responsible in case of accident or injury. In cases where co-employership is claimed, both the Owner and the Project Manager are open for legal action.

The best way to avoid this situation is to give all directions through the contractor. It is best for the Project Manager, and other Owner's personnel, not to give directions directly to craftsmen. Even an instruction that appears to be the most harmless and innocent can lead to a legal case of co-employership.

The only time it is proper to give direction to a worker, bypassing the chain of command, is when you see that worker in eminent danger of health or life and immediate action is required. Other than that, always work through the proper chain of command.

CHAPTER 15
PROJECT CONTROL

Project Control is about anticipating, avoiding, recognizing, and correcting trouble on time

15.1 Thoughts on Project Control

Project control is the only activity that spans all other project execution phases.

- Project control is practiced during scoping, process design, and execution planning.
- Project control is exercised when establishing contracting strategy and selecting contractors.
- Project control is also practiced during all phases of engineering, procurement, and construction.
- Project control is the driving force behind progress monitoring and contract administration.
- Project control entails quality, cost, and schedule controls.

PROJECT CONTROL IS INTRINSIC TO GOOD PROJECT MANAGEMENT AND IS ACHIEVED THROUGH THE EFFECTIVE EXECUTION OF EVERY PROJECT ACTIVITY.

Note: Quality, defined as conformance to established requirements must be monitored by process and specialist engineers with minimal direct participation from the Project Manager. Consequently this chapter addresses only cost and schedule control.

Many people confuse cost tracking and/or accounting with cost control; that thinking is far from the truth. The greatest opportunities for real cost control and substantial cost reductions are found in the early project definition and planning stages - site selection, process design, and execution planning. Cost tracking and accounting come into play after the project has been defined and the major costs set. Cost tracking is an important activity that must be performed in order to detect variations, take corrective action, if possible, and make accurate forecasts. However, the opportunities for cost reduction are very limited.

Cost accounting is of little use to the Project Manager other than gathering cost information for future projects. Even that may not be true since on many occasions the accountant's methods are not consistent with the project estimating and control needs.

Costs are set very early in the project and the areas that offer greatest opportunities for real cost savings are project definition and execution planning.

- The decisions made during the initial stage will fix the minimum cost of the project - design criteria, execution strategy, contractor selection, plant layout, project specifications, etc.
- Good planning and scheduling will minimize the project duration and enhance productivity both during engineering and construction.

An alert Project Manager can realize real cost savings in these areas by being inquisitive, having a healthily skeptical attitude and a good sense of cost and value. The Project Manager does not have to be an expert in any particular field but must have a basic understanding of all disciplines involved in project execution.

Project Managers are charged with the responsibility of insuring that projects are executed within the scope, budget, and schedule established in the AFE. Project control is then their prime responsibility.

- Project control is a continuous and live activity requiring constant attention. It cannot be performed effectively on a spot or part-time basis.
- In small and medium sized projects that will not support a full-time Cost Engineer, the Project Manager must take an active hands-on role in cost control.
- When doing so, the Project Manager must seek the advice of the cost control specialists to insure their participation in setting the project control systems and checking certain key activities.
- Large projects can support and do require a full-time Cost Engineer to work very closely with and keep the Project Manager continuously informed of all variations and/or potential dangers.
- Good project control implies both thought and action. **It means**

  - **Anticipating** (Thought)
  - **Avoiding** (Action)
  - **Recognizing** (Thought)
  - **Correcting** (Action)

  → **TROUBLE ON TIME!!**

  If this is done, the project will be under control. If it is not, the project will run into trouble no matter how elaborate the control procedures are or how thick and detailed the cost report is.

15.2 Project Control and the Project Manager

As previously mentioned, project control is a continuing and live activity that requires constant attention from the Project Manager. It begins at inception and must continue throughout the life of the project until final completion.

THE PROJECT MANAGER EXERCISES CONTROL BY TAKING A DELIBERATE APPROACH TO INSURE THE EFFECTIVE EXECUTION OF ALL PROJECT ACTIVITIES.

Cost Control

The greatest cost-saving opportunities are found during project development, definition, and execution planning. They include:

- Site selection.
- Phase 0/Phase 1.
- Project Execution Plan.
- Contracting.

These activities are normally performed in-house, thus allowing those involved the greatest opportunities of influencing costs, either favorably or adversely. It behooves the Owner's management to implement a protocol of checks and balances to guarantee:

- The application of uniform standards and procedures.
- The participation of people with solid project management/engineering experience and good cost background.
- Reviews and approvals at proper levels.

Ideally, the assigned Project Manager should be the one personally providing project execution and cost input during the initial phases. If that is not possible, somebody else with project management/engineering experience should be assigned until the Project Manager is available.

Once the project is defined, cost control must continue, mainly as a tracking and monitoring activity during the execution phases of:

- Engineering.
- Procurement.
- Construction.

Although the cost-saving opportunities during project execution are limited, the tracking and monitoring are very important activities. Through them the Project Manager can:

- Detect variations early enough to . . .
- Take corrective action if feasible or, in any case, . . .
- Make accurate forecasts.

In a conventional project, the execution stages are performed by an engineering and/or construction contractor who acts as general contractor (G.C.) and has its own so-called cost control system. They are actually tracking and/or monitoring procedures. When the execution is contracted on a cost-reimbursable basis, the Owner is interested in both cost tracking and progress monitoring. In lump sum contracts, the Owner's concern should focus primarily on progress monitoring.

Some of the contractors' systems are very sophisticated and all are good, if properly implemented; unfortunately, those systems are frequently only partially implemented and, occasionally, not implemented at all. It is the responsibility of the Project Manager to insist that contractors implement their systems.

It is also the responsibility of the Project Manager in cost-reimbursable projects to insure that the sophistication and cost of the control system employed by the contractor is commensurate with the project requirements.

Word of Caution: The best practice is to let the contractors use their own systems. Imposing an Owner's systems could be a grave mistake.

The cost control activities of the Project Manager during the execution stages are practically the same for both conventional and small projects. In any case, in order to exercise control of his project, the Project Manager must:

- Become the project team's cost conscience and act as devil's advocate in all matters affecting cost.
- Have a good sense of cost and be capable of making on-the-spot cost evaluations to minimize wasteful and time-consuming studies.
- Challenge, and make the originator justify, any changes that imply deviations from the basis of the appropriation estimate.
- Make independent spot checks of the cost information supplied by contractors, subcontractors, and other team members.

Schedule Control

As in project cost, the greatest opportunities to influence project schedule are found during the initial project stages. Cost and schedule are intimately related and the schedule corresponding to the minimum execution cost is the optimum one. Any deviations could have a negative cost impact.

Schedules are very frequently dictated by business considerations and, as discussed in Chapter 8, rarely coincide with the lowest execution cost. In extreme cases the dictated schedule may only be achieved at an outrageous cost. It is the responsibility of the Project Manager, during the planning stage, to:

- Warn management whenever the desired schedule is not consistent with the minimum execution cost.
- Develop cost-effective schedule improving schemes.
- Prepare a realistic master project schedule and firm execution plan to support the appropriation estimate (Chapters 8 and 10).
- Work closely with the selected engineering contractor to ascertain that the final execution plan and project schedule are consistent with the goals stated in the AFE.

Once engineering is complete, the project moves to the field, and construction is contracted, preferably on lump sum basis. Schedule then becomes the prime responsibility of the construction contractor(s). However, the Project Manager must make independent progress evaluations to confirm that the work is proceeding according to schedule and no expediting action is required.

15.3 Control in the Early Stages

At the risk of being repetitive, it must be said once more that the greatest opportunities of real cost savings are found during the initial project stages.

It is in this period when experienced project management is most needed. Unfortunately, it is also when decisions are sometimes made without the benefit of project management input. The probability of success of every project is greatly enhanced when project management is invited to participate in the very early stages.

Project managers should always be on the alert for instances where projects are being developed without project management input and bring this to CED management's attention.

The best contribution the Project Manager can make in the scoping and process design stages is to:

- Come up with quick conceptual estimates to evaluate the cost impact of proposed alternatives.
- Evaluate possible construction methods.
- Generate and maintain a cost awareness in the design team.

The succeeding paragraphs include guidelines and tips applicable to the various initial project stages.

Site Selection

Site selection is probably the activity with the single greatest potential cost impact. The site factors affecting cost can go well beyond those affecting capital cost; some, like those listed below, would also impact production and marketing costs.

- Raw materials cost.
- Utility costs.
- Accessibility to major markets.
- Local availability of qualified personnel.
- Living conditions for "imported" personnel:
  1. Housing.
  2. Schools.
  3. Hospitals.
  4. Entertainment.

Some of these factors fall outside the Project Manager's scope of work. They are evaluated by the business groups and the decisions are taken by management.

When it comes to factors affecting the capital cost, it is the responsibility of the Project Manager to develop the information and estimate, conceptually, the cost impact of site factors such as:

- Local construction labor:
  1. Availability.
  2. Productivity.
  3. Rates.
- Availability and capabilities of local contractors.
- Availability and proximity of utilities.
- Site conditions:
  1. Soil bearing.
  2. Area drainage.
  3. Topography.
- Environmental requirements.
- Permitting.

Phase 0/Phase 1

During the Phase 0/Phase 1 design, the Project Manager can start controlling the ultimate project cost and avoid unpleasant surprises by:

- Providing on-the-spot assessment of the cost and schedule impact of the various process alternatives considered during process design.
- Tracking costs and making projections as the design progresses, thus providing sound criteria for timely action by the technical manager and, when required, Owner's management.
- Insuring that all factors with potential cost impact are taken into account so that they can be included in the cost estimates and considered in the project schedule.
- Helping the Technical Manager in the development of cost-effective layouts and equipment arrangements.
- Insuring that the specifications do not include unnecessary gold plating:
  - Excessive corrosion allowances and vessel thickness.
  - Ultraconservative materials of construction.
  - Superfluous block and bypass for control valves.
  - Unnecessary installed spare pumps when process allows for short unit shutdowns.
  - Structural design for concurrent adverse conditions.
  - Disproportionate instrumentation because the control system has the extra capacity.
  - Requests for needless contractor documentation.

Project Execution Plan/MPS

A well-thought-out and timely issued project execution plan chooses the most cost-effective route and avoids costly vacillations, false starts, and unexpected changes in direction. It anticipates and avoids pitfalls and plans alternate routes for the blatant ones.

> THE RESPONSIBILITY OF PLANNING THE EXECUTION OF ALL PROJECTS, LARGE OR SMALL, FALLS SQUARELY ON THE SHOULDERS OF THE PROJECT MANAGER. IT IS A RESPONSIBILITY THAT SHOULD NEVER BE DELEGATED.

The minimum capital cost execution plan is usually one based on executing the entire project through a competitive lump sum contract based on a firm and accurate scope.

- This goal is rarely a practical one. In chemical plants, especially when the process is based on Owner's technology, the Owner wants to keep control of the extent and depth of the engineering performed to assure quality. The Owner also wants to maintain flexibility to explore design alternatives without having to hassle with the contractor over who should pay for any added costs. To meet these requirements, engineering should be performed on a cost-reimbursable basis.
- Even if engineering is performed on a cost-reimbursable basis, construction should always be done on a lump sum competitive basis through a single G.C. contract or through several single subcontracts managed either by the Owner or by the engineering contractor acting as Construction Manager.

The best contribution that the project manager can make to project control in this stage is to develop a viable execution plan based on maximal use of competitive lump sum contracts, a realistic schedule, and an accurate cost estimate.

In a nutshell:

> THE PROJECT MANAGER MUST BUILD THE PROJECT ON PAPER IN ORDER TO ANTICIPATE, AVOID, RECOGNIZE, AND CORRECT TROUBLE ON TIME.

Contracting

Intelligent contracting reduces project costs and enhances the probability of success. The Project Manager must work closely with the Contracts Engineer to develop a contracting strategy that results in the selection of the contractor(s) most likely to do a quality job at a minimum cost.

Contracting construction on a lump sum competitive basis is a simple proposition even if engineering is not 100% completed. Once the bids have been qualified and found acceptable, the low bidder will provide the minimum cost.

Contracting engineering services on a cost-reimbursable basis, for projects of any size, is a far more complicated undertaking, requiring subjective evaluation of many intangibles. Different contractors, depending on their size, organization structure and degree of sophistication, will require different hours to perform the same work. It is up to the Project Manager to sort out these variables and select the contractor most likely to execute a particular project at minimum cost.

- Large contractors normally have long chains of command and highly structured organizations. They will employ 10-20% more people than small contractors with flat organizations.
- Some small contractors also have long chains of command. Their hours will also be high.
- Contractors, large or small, committed to sophisticated project management and/or control systems may be incapable and/or unwilling to use simple methods that could be more cost effective and quite adequate for small projects. Their hours will be high.
- Small contractors may not be able to provide the staff required to do the work within the required time frame. Choosing them could be disastrous.
- If a large, inefficient contractor has a unique expertise required for a particular project, it will be worth trying to retain it as a consultant on the particular area and award the bulk of the work to a small, more efficient contractor.

The Project Manager can minimize engineering costs by doing the necessary homework to assist the Contracts Engineer in the bidder selection process. The Project Manager should:

- Prepare an estimate of home office hours.
- Determine the staff loading required at the peak of the engineering activity. A single project should not use more than one-third of the contractor's staff.
- Determine if a particular expertise is required for the project at hand.

Table 15.1 illustrates the potential cost impact of the various alternatives for executing detailed engineering. It was developed with the engineering hours estimating procedure included in Chapter 19 and assumes that in the case of the small projects, the Project Engineer/Manager assigned to the job takes an active role in managing the detailed design activities as well as implementing project controls

15.4 Control in the Engineering Office

General

The basic design has been completed and an engineering contractor has been selected. The project is now ready to move into the contractor's office for detailed engineering and, in most cases, procurement. Normally the work will be done under any of the various options discussed in Chapter 11. Although the material presented in this chapter is specifically addressed to a cost-reimbursable situation, the basic concepts are also applicable to lump sum contracts.

Table 15.1 Engineering Execution Alternatives

		Work-hours per Equipment Item			
			Owner		
Project Approach	Contractor Size	Contractor	Eng.	Purch.	Total
Large	Large	690	0	0	690
Large	Small	540	0	0	540
Small	Large	491	0	35	526
Small	Single Small	364	0	32	396
Small	Several Small	306	0	30	336
Small	Maximum In-House	55 [(1)]	174	28	252

[(1)] Only Civil and Structural Engineering

The contractor is legally bound to perform the work according to the contract. It has also assumed the professional responsibility and will be liable for failures stemming from the mechanical design and/or execution provided under the contract. It has a contractual right to take the necessary steps and incur reasonable expenses to protect its liability.

On the other side of the coin, the Owner's Project Manager is generally responsible for making the contractor fulfill the contractual obligations and insuring that the costs incurred are reasonable. However, in doing so, care must be taken to not abrogate the contractor's responsibility placing it on the Owner's shoulders. Such a step could have very grave consequences and should not be taken without consulting with management. Specifically, the Project Manager must:

- Ascertain that the contractor, as well as all members of the Owner's project team, fully understand the scope of the work and the cost and schedule objectives.
- Review and approve engineering budget hours.
- Approve all commitments, expenditures, and changes.
- Insist that the contractor actually implement the design and control system promised in the proposal.

- Take active participation, through the contractor's Project Manager, in the planning of the work to insure that the engineering work will support lump sum competitive construction work.
- Make independent progress and productivity assessments.
- Take an active role in checking schedules and cost estimates.
- Instill a sense of cost consciousness in the project team.
- Discourage changes but, if they must occur, make sure they are approved at the right level.
- Direct the Owner's project team, including the part-time specialists, and insure their timely participation to provide adequate technical control and keep the job flowing smoothly and efficiently.

Neither engineering contractors nor the team specialists are omniscient, and the Project Manager should never hesitate to challenge and make them justify their position and/or recommendation. "We always do it this way" is not an acceptable answer.

Plant Layout

Plant layout is one area where real cost control can be exercised because of the impact on material and construction costs as well as on operating efficiency. The final layout, usually developed during the basic engineering stage, requires a high degree of experience and the participation of the entire project team as well as the contractor's specialists and Owner's operations and maintenance personnel.

Establishing a fixed layout early on in the project should be one of the Project Manager's prime objectives since this is a means of insuring effective and economical detailed engineering and early project completion. Achievement of these goals requires:

- Timely participation of all involved.
- Awareness of the costs involved in the various options.
- Adamant resistance to changes of any kind to the approved layout.

Many people believe that the layout of a chemical plant is an art. That may be so, but it is also the result of common sense and an understanding of the costs involved in executing the various alternatives that are usually available.

The cost-conscious Project Manager with a good feel for costs will usually find cost-saving opportunities in the development of plant layouts.

Detailed Engineering

Some cost-saving opportunities may be found during detailed engineering, especially during the early stages when the project design procedures and specifications are being set. However, the contractor working on a cost-reimbursable basis may not take the initiative to propose cost-saving schemes. Therefore, the Owner's Project Manager must watch for those opportunities and have the contractor take advantage of them. This, of course, must be done without relieving the contractor from the responsibility of doing a proper job and keeping schedules.

- The choice of design presentation will have an impact on costs, especially if construction is to be subcontracted on a lump sum basis. If that is the case, engineering work must also be scheduled accordingly.
- Planning the engineering work so that mass purchasing can be done will not only result in fewer procurement hours, but also will be a factor in securing better prices.
- Overly conservative contractors' specifications can be very expensive. The Project Manager must challenge them aggressively.
- Asking the contractor to comment on the cost impact of special Owner's requirements may result in cost savings. In some cases the originator of the request may not be aware of the cost and may very well waive or relax the requirements, If the cost differential is still excessive, the requester should justify the expense.
- Timely participation of experienced construction personnel during the layout work could avoid future installation and operation problems and result in substantial savings during construction.

Here are some ideas that could be considered to reduce engineering and/or construction costs:

- Standardize the configuration of pile caps and foundations.
- Adapt design of structural concrete to shapes that minimize construction work - prefabricated elements, standard reusable forms, etc.
- Neat cut, excavate, and pour foundations directly on the soil. Forming is expensive, concrete relatively cheap.
- Base structural steel design on standard modules.
- Consider using flexible steel tubing for small bore pipes and or shop bent pipe for large sizes.

- Standardize pump casings and piping around pumps.
- Send pipe designers to the field during construction to detail the routing of small-bore pipe, steam tracing, safety stations and service stations.
- Include as much detailed engineering as possible in the scope of competitive lump sum subcontracts and purchase orders for mechanical packages:
  1. Contract buildings on design-build basis.
  2. Have mechanical subcontractors do their own piping isometrics whenever feasible.
  3. Have vendors include as much piping and supports as possible on skid-mounted packages.

The detailed design involved will thus be done on a competitive lump sum basis and some savings will be realized.

Detailed engineering is dull and often repetitive work. It does not often attract really imaginative engineers. When they encounter a design problem that requires innovative thinking they are usually inclined to take the least risky and frequently most expensive approach. In order to minimize cost the Project Manager must monitor their work to identify these problem areas and review their solutions.

Purchasing and Subcontracting

Effective purchasing and subcontracting can provide opportunities for realizing substantial cost savings. Savings can be realized through:

- Better prices resulting from intelligent competitive bidding and/or negotiating and subcontract administration.
- Better quality resulting from proper screening and inspection of vendors and subcontractors.
- Improved completion dates resulting from effective expediting.

Contracting construction work through lump sum competitive bidding can have a very significant impact in construction costs. However, in fast track projects, this requires a concerted planning and coordinating effort by the engineering procurement and construction groups to make it happen. The Project Manager must take a very adamant attitude in insisting that all groups display the utmost ingenuity and flexibility to insure competitive lump sum contracting without impairing the project schedule.

Purchasing practices and procedures are an integral part of the contractor overall organization and should not be changed by a client's Project Manager. The best, and probably only, manner to insure effective purchasing and contracting is to select a contractor with a good and lean organization and procedures.

If the selected contractor does not have a good purchasing department, about the only thing the Project Manager can do is to get help to reinforce supervision, and support the contractor organization if required. This is not the ideal way to run a job but may be the only way to minimize costs and protect the Owner's interest.

15.5 Control During Construction

The most effective way to minimize construction cost is to:

> EXECUTE CONSTRUCTION ON A HARD MONEY COMPETITIVE BASIS, EITHER THROUGH LUMP SUM UNIT PRICES CONTRACTS OR A COMBINATION OF THE TWO.

Some contractors, especially large ones, will argue that this approach is not compatible with fast track schedules. This is far from the truth; a flexible engineering contractor committed to the competitive lump sum approach will always find ways to create competitive situations without hindering the schedule, especially if the Owner's Project Manager is adamant on the subject.

- Break down the work into discrete portions and plan engineering accordingly.
- Go through a bidding round when engineering is only about 60% done, continue engineering during the bid preparation and go through a second bidding round, with the two low bidders, when engineering is more complete and maybe a final negotiation with the low bidder and up-to-the-minute engineering.
- Have good definition of the "undefined" as well as the defined work.
- Ask for competitive unit prices based on preliminary take-offs and convert to lump sum based on actual quantities.
- Pre-order 80% of bulk materials normally supplied by the contractors in order to minimize mobilization time.

When construction is awarded on a lump sum basis, most of the risks as well as the cost control function is assumed by the subcontractors. The Owner's main cost control responsibility is limited to controlling extras and monitoring quality and progress. On small projects, the Owner's Project Manager could act as Construction Manager and be directly involved in the cost control activities.

The Owner could also delegate construction management to either the engineering contractor or to a Construction Management (C.M.) firm. Although this approach is more expensive, it could be dictated by the complexity of the field work and/or the lack of the Owner's resources at a given moment. Although the C.M. will bear the brunt of the control work, the Owner's Project Manager must still conduct spot progress checks and be on the alert to avoid overstaffing of the C.M. team.

Whether construction management is being handled by a C.M. or in-house, the Project Manager must assume the leadership in enforcing the highest degree of safety standards, sponsoring workers motivation programs, and, in general, promoting the implementation of the CICE and CII recommendations.

15.6 Control During Project Control

A common trap during project execution, especially when dealing with large EPC contractors, is control overkill. Many contractors will flaunt their "unique" control systems guaranteed to keep any project out of trouble. Most of these systems far exceed the requirements of small, even conventional, projects, and none will keep them out of trouble in the absence of qualified and experienced project management.

Sophisticated control systems are invaluable, and should be obligatory, in mega projects as well as in extensive turnaround work, where all activities must be performed with clockwork precision. However, for small projects, as well as many major ones, they increase execution costs without real benefits. It is up to the Project Manager to ascertain that the controls applied by the contractors are commensurate to the size and complexity of the project.

The Owner's Project Manager and Cost Engineer must have an active participation in setting up the Contractor's control system for cost-reimbursable projects. This must be done at the very beginning of the contract work.

The cost and complexity of the system must be commensurate with the project requirements:

- If a simple manual system is adequate for a small project, there is no need for a sophisticated system.
- If the volume of information can be handled by the Project Manager, there is no need to assign a Cost Engineer.
- Unnecessary information will add to project costs and create confusion.

However, sufficient information must be provided to allow the Owner's Project Manager and/or Cost Engineer to spot check contractors' claims and make independent assessments.

15.7 Anatomy of a Project Control System

As previously mentioned, the greatest opportunities for real cost control and substantial cost reductions are found in the early project definition and planning stages. However, once the basic decisions have been made and their cost impact estimated, a control system must be established.

"Cost control system" is a commonly used misnomer since the decisions having the greatest impact on cost have already been made. "Project tracking" or "project monitoring system" would be more appropriate. However, a good system, in the hands of an experienced Project Manager, will provide more than tracking or monitoring; it is a tool for anticipating, avoiding, and recognizing trouble so that it can be corrected on time. It is really a "project control system."

The prime purpose of a project control system is to provide an accurate, quantitative means of measuring:

- Performance - actual versus estimated costs, hours, and productivity.
- Actual progress against the established targets for both cost and schedule (adjusted for major scope changes).

in order to:

- Detect problem areas in time to take corrective action.
- Identify positive influences and capitalize on them.
- Make valid and reliable schedule and cost forecasts.

The Owner's project control system need not be as sophisticated as the contractor's. It is intended mainly to check the accuracy of the contractor's progress reports and cost and schedule projections or to control small in-house projects. A simple manual system judiciously used should be sufficient to meet the Owner's requirements.

An effective system, simple or sophisticated, must include procedures and provide tools to perform three basic functions:

- Cost tracking.
- Progress monitoring.
- Continuous cost and schedule evaluations and forecasts.

The prompt and accurate discharge of those functions provides project management with the necessary information to take timely corrective action to control cost and schedule and inform upper management of unavoidable deviations.

- The bases of accurate **cost tracking** are:
  - A cost estimate broken down in quantifiable discrete components that can be easily comprehended and evaluated by simple observation without going into the details of counting and tracking "nuts and bolts" (Section 10.4).
  - The discipline to track the cost components - quantities and unit costs and/or man-hours - at the completion of discrete portions of the detailed design of the various physical areas, process sections, and/or disciplines.
- A **progress monitoring system** must include the following elements:
  - A valid and reasonably accurate list of activities to be performed, consistent with the cost estimate breakdown and "loaded" with the estimated manpower and/or cost for each activity.
  - A flexible procedure to assign consistent, relative values to the diverse activities based on any combination of the following parameters:
    1. Dollar value.
    2. Importance to project.
    3. Exposure (potential downside).
    4. Construction and engineering hours.
    5. Physical units – $yd.^3$, ft., ton, etc.
  - An evaluation method, based on specific milestones, to objectively gauge the progress of each individual activity.
- Accurate **cost and schedule evaluations and forecasts** require:
  - Means of measuring the resources (dollars/hours) applied to each activity and the discipline of making continuous comparisons with the estimate.
  - Master and short-term itemized schedules and the discipline of tracking performance and making the contractors live up to their projections, especially the short-term ones. If a contractor cannot meet the goals of a short-term schedule, it will never meet the long-range schedules. The Project Manager has to take immediate action!
  - Bi-weekly performance (productivity analysis and cost and schedule forecasts).
  - Long-range and short-term staffing plans.

- Periodic reports.

The best project control system is totally useless if not implemented. Control is a dynamic activity that requires participation and commitment from the entire project team, contractor's as well as Owner's. Control is exercised through:

- Continuous comparison, by the design leaders, between actual design quantities and control estimate quantities.
- Deliberate efforts to correct unfavorable deviations without impairing quality.
- Proper and adequate project team communications.
- Regular interdisciplinary coordination meetings.
- Comparison between vendors' bids and control estimate.
- Constant comparison of progress with the schedule.
- Continuous monitoring and expediting of vendors' progress.
- Continuous monitoring of subcontractors' performance.
- Regular cost tracking meetings.
- Regular coordination meetings with subcontractors.
- Timely reporting.

15.8 In-House Cost Tracking

As mentioned in the previous section, the only requirements for effective in-house cost tracking are:

- A cost estimate broken down in quantifiable discrete components.
- The willingness and personal discipline to track and compare the original preliminary take-offs and costs with the latest ones as the design develops and firm commitments are made through purchase orders and subcontracts.

The semi-detailed estimating procedure presented in Chapter 19 provides sufficient breakdown for adequate cost tracking by the Owner's Project Manager. The willingness and personal discipline must be provided by the Project Manager. The following cost components, all developed with the aid of the semi-detailed estimating procedure, can be easily tracked by the Project Manager.

- Equipment count - from equipment list.

- Equipment cost - from purchase orders.
- Motor count - from equipment list.
- Plot size - from plot plans and arrangement drawings.
- TDC Control Points - from P&ID's.
- Field Instruments (balloons) - from P&ID's.
- Concrete take-offs - from design drawings.
- Structural steel take-offs - from design drawings.
- Building size - from plot plans.
- Heat tracing required - from P&ID's.
- Insulation required - from P&ID's.
- Piping take-offs - from bills of material and line lists.
- Piping materials costs - from purchase orders.
- Engineering hours - from EPC contractor forecasts.
- Field indirects - from EPC contractor estimates.

The cost tracking activity could become cumbersome and expensive when construction is executed using direct-hire rather than lump sum contracts. In that case, labor productivity becomes an important cost factor and must be monitored closely to determine trends, try to make corrections, and make accurate forecasts.

15.9 In-House Construction Progress Monitoring System

General

All lump sum contractors should be contractually obligated to impose and implement a progress monitoring system. A good system need not be expensive and should not increase contract costs, no matter what a contractor may say.

Notwithstanding whether the contractor implements its own system, it behooves owners to develop in-house systems for confirming contractors' claims quickly and with reasonable accuracy. As already mentioned, the preparation and implementation of a progress monitoring system require the following elements:

- An activity breakdown in discrete components that can be easily comprehended and evaluated by simple observation.
- A flexible procedure to assign consistent relative values, expressed in physical units, to the various activities that reflect, in a rational manner,

not only work hours but also their real value and/or importance to the project.

- An evaluation method based on specific and clear milestones to objectively gauge the progress of each activity.
- A firm project execution plan and MPS as outlined in Chapter 8.

Activity Breakdown

A semi-detailed cost estimate prepared with the procedures and guidelines included in Chapter 19 could easily be dissected into a multitude of comprehensible construction activities that could be integrated, at the Project Manager's option, into a manageable number of discretely sized units. Every single activity could be assigned consistent relative values based on field hours

- Equipment erection - by area and equipment item.
- Foundations - by area and/or equipment item.
- Steel structures - by area, by structure, and/or equipment item.
- Instrumentation - by area and instrument type.
- Piping fabrication - by area or by line.
- Piping erection - by area, by system, or by line.

The proposed estimating system has the capability of breaking down the work activities to the level of each instrument and each pipeline. This level of detail is not required in an in-house system and would defeat its main reason for existence, confirming contractors reports quickly and accurately. A system based on 100 to 200 activities, depending on project size, would provide a good level of accuracy and, once set up, could be easily implemented. The maximum value of each activity should be kept below 5% of the total.

Value System

Once the work has been broken down in activities, relative values must be assigned to each of them in a uniform manner that can be related to simple physical units. The values could be assigned either as work units (W.U.'s) related to field labor or as a fraction of the value for the entire work. Each approach has advantages and disadvantages and the Project Manager must have the flexibility and foresight to tailor the monitoring system to the project needs.

Labor related work unit approach

In this approach, the estimated labor units (hours, days, or weeks) are converted to work units and the one hundred percent completion mark will be a very specific number of W.U.'s that will change with every scope addition or deletion.

Proper application of this approach requires that the estimated field hours for every activity are known and that all have been estimated from the same database (unit hours).

Fraction approach

Frequently it occurs that the impact of some of the major project components far exceeds the relative value based on hours alone. In those cases it is more appropriate to assign values based on a pondered assessment of:

- Dollar value.
- Importance to project.
- Risk exposure.
- Hours.
- Physical units (yd.^{3}, ton, ft., etc.).

Relative values are then assigned as decimal fractions of the total so that the completion target will always be 100% regardless of change. The example in Appendix H illustrates the use of the fraction approach.

Milestone evaluation method

Once all activities have been identified and assigned value, their progress must be monitored and measured in an objective, rational, and consistent manner. This can be accomplished through the implementation of a milestone system that assigns value to each of the steps involved in the execution of a given activity and thus reduces the span of value susceptible to subjective evaluation.

Example - The installation of a pipeline involves seven steps valued as follows:

Activity	% Completion
Material receipt	5
Fabrication	25
Erection	20
Bolt up and weld	20
Install valves, hangers, trim	10
Hydrotest	10
Punch out	10
Total	100

The potential error in the evaluation of a line being erected should not be more than 5%.

Table 15.2 shows typical breakdowns for the most common field activities.

Schedule

A schedule is not required in order to gauge the percent completion at a given moment; all that is needed is a value system applied to the estimate items and a milestone system to gauge progress of each item. However, in order to determine whether the work is progressing as scheduled, a tracking curve is required.

The tracking curve is developed by superimposing (loading) the value of all the items included in the estimate on the project schedule. When the value system employed is based on hours only, the system also becomes, together with the daily force reports, an excellent way to monitor labor productivity.

Monitoring progress through the tracking curve alone could easily lead the project into trouble. While the curve shows that work is being accomplished at a certain rate, it does not indicate whether it is being done in the right areas. The schedule must be monitored to ascertain that the efforts are being applied in the right places and that the critical activities are being completed on time.

A project could be tracking beautifully until somebody finds that critical activity A, which requires one month and should have been completed two months ago, has not been started. Suddenly the project is three months behind schedule and there is not much that can be done about it.

In the ultimate monitoring system, every single estimate item would have a corresponding activity shown in the detailed schedule and a value based on hours. This level of precision can only be efficiently achieved with the aid of computer programs and would defeat the purpose of a quick checking system.

Table 15.2 Typical Construction Activity Breakdown

Activity	Percent Allocation
Concrete Foundations	
Excavate	15
Build and place form work	45
Place reinforcing steel	20
Pour and finish concrete	10
Strip forms and finish	10
Major Equipment	
Material receipt	5
Rough setting	65
Shim and plumb	25
Miscellaneous cleanup	5
Pumps and Compressors	
Material receipt	5
Rough setting	15
Level and grout	30
Align and couple	40
Lubricate and rotate	10
Piping	
Material receipt	5
Fabrication	25
Erection	20
Bolt up or weld	20
Install valves	10
Hydrotest	10
Punch out	10
Structural Steel	
Material receipt and storing	10
Erection	55
Plumb bolt up or weld	20
Trim and finalize	15
Buildings	
Structural frame	10
Roof	20
Walls	20
Doors and windows	10
Lighting	20
HVAC	20
Finish	10

Table 15.2 (Continued)

Activity	Percent Allocation
Instrumentation - Install	
Material receipt	5
Calibrate (by Owner)	-
Install	75
Activate (Loop check)	20
Instrumentation – Wiring	
Install hardware	5
Install conduit, wiring, and junction boxes	60
Instruments and J.B. connections	15
Multi-conductor cable to terminal panel	10
Terminal panel and TDC console connection	10
Instrumentation – Air Hookup	
Install pipe	30
Support pipe	30
Hook up	20
Activate (Press. test)	20
Electrical Power Feeders	
Material receipt	5
Set Motor Control Center (MCC)	5
Install trays, junction boxes, and outlet boxes	35
Lay cable	20
MCC connections	15
Load connections	15
Ring out	5
Electrical - Lighting	
Material receipt	5
Install transformers & panels	20
Install cable trays	25
Lay cable	20
Make connections	20
Install fixtures	10
Insulation - Equipment	
Material receipt	10
Install	40
Cover	50
Insulation - Piping	
Material receipt	10
Install straight runs	20
Install fittings	40
Cover	30

For the in-house system proposed here, the tracking curve is based on the MPS discussed in Chapter 8. If the value system is based on work hours, it should duplicate the construction progress curve included with the Firm Execution Plan.

When values have been assigned based on fractions it is advisable to develop the tracking curve on the same basis. In any case, it is very important to remember that keeping close to the tracking curve could be inconsequential if the critical activities are not being done on schedule.

Progress Computation

Once all activities have been identified and assigned value and a milestone system established, the computation of earned values and overall progress (percent completion) is a very simple operation.

- At a given moment, many activities have not been started while others have been completed. These are credited with zero or one hundred percent of their assigned value.
- The majority of those in progress will be covered by the milestone system and can be credited accordingly.
- The remaining few must be eyeballed. Of these, many will be either in the early stages or essentially complete; eyeballing them should present no problem.
- The potential errors of eyeballing any remaining activities should have a minimum effect on the overall evaluation.

The sum of the earned values divided by the total assigned value is the percent completion.

15.10 In-House Engineering Progress Monitoring System

Detailed System

The home office man-hours estimating procedure in Chapter 19 does not provide the detail of breakdown required for progress monitoring. However, once the list of required drawings and specifications has been prepared by the contractor, this information can be used together with Tables 15.3, 15.4, and 15.5 to prepare a simple monitoring system that will enable the Project Manager to ascertain the validity of the contractor's reports.

Table 15.3 Typical Home Office Work Hour Units

	Phase 0	Phase 1	Detailed Eng. by Contractor	Total
A. Major Drawings				
	Work-Hours per "E" Size Drawing			
PFD's (15-20 Equip. items)	40	40	0	80
P&ID's (6-7 Equip. items)	0	200	240	440
Layouts & Arrangements	0	0	120	120
Piping Orthographics	0	0	200	200
Civil / Struct. / Arch.	0	0	120	120
Electrical	0	0	160	160
B. Equipment Specifications				
	Work-Hours per Specification			
Tanks & Vessels	8	32	40	80
Columns	24	56	64	144
Reactors	16	48	64	128
Heat Exchangers	8	16	16	40
Condensers with Inerts	16	24	24	64
Pumps	8	8	16	32
Utility Compressors	4	12	16	32
Agitators	4	12	16	32
Centrifuges	4	20	24	48
Package Systems, Refrigeration, DMW, Cooling Towers Inert Gas Generation, Steam Eject., etc.	8	24	32	64
Dry Material Handling	4	12	16	32
Miscellaneous Equipment	4	12	16	32
C. Miscellaneous Documentation				
General Specifications	0	80	160	240
Project Schedule	0	0	160	160
Coordination Procedure	0	0	80	80

Table 15.4 Typical Completion Milestones by Specific Activities

Activity	Percentage
Specifications	
Complete draft	20
Write specification	70
Check specification	80
Issue for approval	85
Issue revisions as required	95-100
Flowsheet Drawings	
Complete design calculations	40
Complete drawing	60
Check drawing	70
Issue for approval	80
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
Architectural Drawings	
Complete sketches and general arrangements (GA's)	15
Issue sketches and GA's for approval as required	25
Complete drawing	75
Check drawing	85
Issue for approval	90
Issue for constriction	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
Issue for construction	95
Issue revisions as required	95-100

Table 15.4 (Continued)

Activity	Percentage
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
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

Table 15.3 lists the approximate hours required to prepare various types of drawings and equipment specifications. Although it could be used to check contractor's estimated hours, its prime purpose is to assign relative value to the principal home office activities.

Table 15.4 shows the percentage completion that should be assigned to the various milestones during the execution of each activity.

Table 15.5 shows a suggested breakdown for the engineering and design activities in general.

Table 15.5 Typical Completion Milestones by General Activities

Activity	Percentage
Engineering	
Design criteria and scope of work verified, reference documents secured, process data secured.	0-15
Specification and datasheet complete.	15-40
Specification and datasheet issued to client for approval.	40-60
Client approved and issued for bids.	60-70
Bids analyzed and Purchase Requisition issued.	70-85
Vendor prints reviewed.	85-95
Vendor prints incorporated (does not include as-built activity).	95-100
Design	
Design criteria and scope of work verified; reference documents secured, manufacturer's data secured.	0-15
Design calculations, sketches, instructions, etc., completed; other disciplines coordinated; drawing ready for final drafting.	15-40
Drafting completed and back-checked.	40-70
Independent check of calculations and drawings.	70-80
Fix-up (drafting) and issue to project; project comments incorporated, for approval issue to client.	80-85
Client comments incorporated and issued AFC.	85-95
Vendor prints incorporated (does not include as-built activity).	95-100

Quick System

The Project Manager does not always have the time to prepare and implement a full-blown system. In these cases, the following empirical correlation developed by John Nabors from FMC Corp. can be used between 15 and 80% completion.

% Engineering Complete = Significant Drawing Credit/Drawings Required

where:

Significant Drawing Credit: 0.25 (Drawings Being Worked) + Drawings Issued.

Drawings Being Worked are the number of drawings actually started but not issued for construction. Use only the number actually being worked.

Drawings Issued are the number of drawings currently issued for construction or the number at least 90% complete.

Drawings Required are the number of drawings the contractor now estimates will be required to complete all design work. At the beginning of a project, this number is normally lower than what is finally needed. This should not affect the accuracy of the results, for there is a built-in allowance for this.

Drawings such as piping isometrics, pipe hangers, pipe support locations, instrument schematics, demolition and standard details should usually not be included in the numbers just defined. This normally excludes all drawings requiring less than 80 man hours. The status of such drawings is too volatile and will distort the overall engineering status.

After discounting such types, only 35 to 40% remain from the number of drawings the contractor estimates as being required.

Since the relation is just a simple means of gauging the percentage completed, results should not be considered as exact, but as an indication of the status of engineering. If only a few percentage points' difference exists between the results of this formula and that reported by the contractor, probably no action is warranted. However, if the difference is substantial (more than 4 or 5 percentage points), an investigation is indicated.

15.11 Cost and Schedule Forecasts

Making periodic cost and schedule forecasts is the responsibility of the Project Manager. Management expects, rightfully, that the accuracy of these forecasts increases as the project moves along.

Accurate forecasts require careful analysis of the project performance to date in order to:

- Determine if trends are evolving.
- Understand the causes of deviations from the baselines.
- Determine if the same causes are likely to affect the remaining work.
- Evaluate the effect of any corrective action taken since the previous forecast.

The cost forecasts must be based on the continuing comparison during detailed engineering and construction of the actual versus estimated performance of:

- Equipment and instrument counts as the P&ID's are completed.

- Take-off quantities as discrete portions of the detailed design are completed.
- Equipment and materials prices as firm vendors' quotes are received.
- Labor rates and work hours as subcontracts are awarded.
- Rate of change orders as the field work proceeds.
- Changes in local environment as they occur:
  1. Labor unrest.
  2. Inclement weather.

All cost forecasts must include resolution and contingency allowances to reflect the current level project definition.

The progress monitoring system, outlined in Section 15.9, is an excellent basis for schedule forecasting. It provides information that, when used in conjunction with daily field force reports and spot activity checks, will allow the Project Manager to make accurate schedule forecasts. The procedure for forecasting final subcontract costs in Appendix I is also a good tool for predicting the final projects cost.

15.12 Checking Contractors' Schedule and Execution Plan

General

The project execution plan and master project schedule developed by the Owner's Project Manager during the initial project stages (Chapter 9) set the basis and execution logic for the entire project and, normally, are all that is needed to execute small projects. However, in major projects, the responsibility for the actual execution is eventually turned over to an EPC contractor who must assume the planning and scheduling functions and issue an expanded execution plan and MPS in details commensurate with the size and complexity of the project.

The Owner's Project Manager still has the overall project execution responsibility and must ascertain that the contractor's proposed plan and schedule reflect all the available data and that they incorporate any out-of-the-ordinary action that will be taken in the course of the project to achieve the stated objectives.

- The review of the contractor's execution plan and schedule is a very important milestone. It is the last real opportunity to make corrections in the execution plan and, if required, revise the schedule forecast so that the financial plans can be adjusted to meet the new scenario.

- The approved execution plan and schedule must remain unchanged and become the basis to evaluate project performance. When contractors say "I meet all my schedules," they sometimes mean "I met the **last revision** of all my schedules." Even if the working schedules must be revised as required to preserve their meaningfulness, contractors should never be allowed to change the original approved schedule.

Review Criteria

The following factors must be investigated and taken into consideration in the preparation of the execution plan and schedule; it is up to the Owner's Project Manager to confirm that the contractor has done it in a conscientious manner.

General

- The submittal and approval by the pertinent authorities of environmental, construction, and other permits required to operate the facility.
- The engineering schedule must support the construction contracting plan.
- The construction schedule must support the required startup sequence.
- The schedule must allow adequate lead and/or turnaround time for:
    1. Vendors' and subcontractors' bidding.
    2. Owner's reviews and approvals.
    3. Vendors' drawings submittals and approval.
    4. Equipment deliveries.
    5. Final checkout.
- The critical path and floats must be clearly identified.
- The schedule must be kept as simple and unsophisticated as required by the complexity of the project.
- The use of the major construction equipment must be shown in the schedule.

Construction Staffing

- Available construction and layout areas.
- Available labor pool.
- Qualification and size of local contractors.
- Expiration dates of local labor contracts.

Lost Time Allowances

- Weather.
- Evacuation alarms.
- Holidays.
- Plant interferences.

Project Control

- Major process and/or geographical areas must be shown as independent self-contained schedules.
- Individual activities must be comprehensive and quantifiable.
- Temporary facilities and layout areas must be arranged to optimize the flow of work during construction.
- Ideally, each schedule activity should reflect a cost item in the estimate.

Schedule Constraints

- Every schedule constraint and/or bottleneck must be clearly identified.
- Any specific activity directed to improving the schedule must be identified.

15.13 Avoiding and Correcting Frequent Problems

Project control is about anticipating, avoiding, recognizing, and correcting problems. This section is intended as a tool to help Project Managers to do so. It discusses some of the most frequent problems encountered in project execution, as well as the warning signs, and suggested avoiding and/or correcting action.

In the Engineering Contractor Office

Problem	Incompatibility with existing plant equipment numbering system.
Correction	Early in the project the Project Manager must insure agreement between the contractor and plant operations.
Problem	Ineffective communications. Contractor's personnel trying to follow conflicting instructions from Owner's team.
Correction	Contractor's personnel must be given instructions to listen politely to the Owner's team but act only on instructions coming from their own Project Manager. The contractor must follow up all meetings and project related communications with a written confirmation.

Problem Special unscheduled studies interfere with the execution of the basic scope of work.

Correction Have the contractor assign different personnel to special studies. Never give the contractor a "blank check." Negotiate the hours required to do the work beforehand.

Problem Owner's information and/or approvals are delaying contractor's work.

Correction Owner's project team must realize that the contract is a two-way street. If they cannot live up to the commitments, the Project Manager must request more internal resources or consider assigning some of their work to the contractor.

Problem Poor coordination within the contractor's task force.

Correction Require that contractor's full-time task force members be located physically in the same area.

Problem Frequent changes in contractor's personnel.

Correction Exercise contractual right of previous approval of key personnel changes. Probe the administrative qualification of the contractor's project manager, his/her degree of freedom and authority to approve/reject all personnel assigned to the task force.

Problem Continuous changes in indicated final hours and large jumps between short reporting periods as engineering nears completion.

Correction Require that requests for changes be submitted on weekly basis; approve only those related to change in scope. Refuse to honor those intended to cover for contractor's estimating errors and inefficiencies as well as those submitted after the fact.

Problem Concern for the proper functioning of the contractor's project control efforts.

Correction Periodic reviews of work progress with each discipline supervisor in the presence of the contractor's Project Manager and his/her immediate superior.

During Procurement

Problem Questionable quality of purchased equipment and/or materials.

Correction Vendors must be pre-qualified jointly by contractor's and Owner's specialists.

Problem Qualified vendor's shop's workloads endanger schedule.
Correction Hold pre-bid and pre-award meetings with vendors to develop reasonable schedules. Get firm commitments and spread work over several shops. Work together with contractor's project manager to develop expediting and inspection schedules for major equipment.

Problem Delays in issuing formal purchase orders.
Correction Use telex or fax for immediate confirmation and follow up with formal documentation.

Problem Delays in vendor's drawings jeopardize schedule.
Correction Review and approve drawings for critical equipment at vendor's shop.

During Construction

Problem Due to schedule pressures, the technical section of the bid packages contains holds and/or incomplete areas.
Correction Holds and incomplete areas must be clearly identified and quantified based on the best available information to secure uniform bids. A set of applicable unit prices must be requested as part of the bid to adjust total cost after completion of design. Hold pre-award meeting to remove as many holds as possible.

Problem Inconsistent bids due to different understanding of bid package.
Correction Hold a pre-bid conference at the job site and insist that all bidders walk through the site of the job. Issue minutes of conference and answer all further questions in writing with copy to all bidders.

Problem Available qualified labor in the area is tight due to high construction activity.
Correction Conduct an area labor survey, interrogate prospective local bidders and, if necessary, consider outside bidders who could bring a group of their regular workers.

Problem Improper planning of work by the subcontractor impacts the overall schedule.
Correction The Construction Manager must insist that every subcontractor submit its own labor-loaded schedule and check them for compatibility with each other and with the master project schedule.

If so required, the Construction Manager must prepare, with input from the subcontractors, a new MPS coordinating all work to insure completion by the established date.

Weekly coordination meetings must be held with all subcontractors to insure compliance.

Problem Inability to monitor the subcontractor's work progress.
Correction Demand that all subcontractors base their work breakdown on the direct costs breakdown of the control estimate.

15.14 Work Sampling Guidelines

Work sampling is a technique used to determine the level of activity of a construction workforce. Although it is a good productivity indicator it should not be confused with the more sophisticated techniques used by industrial engineers to measure productivity. Work sampling is a powerful tool for the Owner's Project Manager and should be used in all projects.

While the reason for work sampling is more obvious on reimbursable jobs, observations on lump sum jobs help in determining the efficiency of the contractor's workforce and can alert the Project Manager to potential problems in either cost or schedule. Factual data on performance provides a good base for denying claims for extras when poor field performance is the cause.

Basically, the observer counts the people working and the total people observed. Since the crafts inherently resent work sampling, observations should be made instantaneously and unobtrusively as the observer tours the work area. Only those people actually performing physical work, such as welding, hammering, sawing, bolting, etc., are counted as working. For the purpose of this measurement, personnel carrying hand tools, waiting at the stockroom, waiting for machines or equipment, etc., are not considered as working. Routes and times of day should be varied so that the crafts cannot establish a pattern. Performing other observations at the same time serves to disguise the work sampling impact. It is not necessary to observe the entire workforce for this measurement. Obviously a larger sample provides more meaningful data.

Each run is logged with the date, time, observer's name, number working, total observed, percent working, and remarks. Remarks should include comments on the weather and any unusual working conditions. The accuracy increases with the number of observations and observers.

The ratio of personnel working to total personnel observed provides the data for record. Graphing the daily observations is useful in spotting prolonged trends away from normal. One- or two-day deviations are not meaningful; however, deviations in excess of a week should be investigated actively.

The results can be compared to the data presented below which are based on data from thousands of observations from numerous types of jobs.

Under 30%:	Productivity low, corrective action should be initiated.
30% to 40%:	Barely acceptable, below norm and needs attention.
40% to 50%:	Good productivity.
Over 50%:	Excellent, better than normal.

There are numerous reasons for poor productivity. The most often blamed and most overused reason is a poor attitude. Poor attitude, however, can stem from poor planning by supervision, the lack of tools or material, abusive supervision, unresolved grievances, and numerous other causes. In any event, the cause should be investigated and action taken to correct the problem.

Conversely, sustained above-average productivity is worthy of investigation to ascertain what techniques were used to provide it for future use.

CHAPTER 16
CONTRACTS ADMINISTRATION

Contract Administrators can keep you out of trouble. Use them.

16.1 Overview

The Project Manager's concern is not only the physical conduct of the work, but also the implementation of all the contractual conditions. The Project Manager is also the Contract Administrator. Contract administration requires a total understanding of the contract, especially those clauses that assert the Owner's rights of technical approvals and control of the purse strings. The Project Manager, as well as every member of the project team, must be thoroughly familiar with the contract.

> A GOOD CONTRACT, WELL-UNDERSTOOD BY THE PROJECT MANAGER, WILL MINIMIZE CONFLICTS AND BE A VERY EFFECTIVE CONTROL TOOL.

The Project Manager is not expected to do a detailed audit of all invoices and backup materials, but only to monitor the critical items and point out to the accountants those areas where close scrutiny is warranted. The detailed audit is the job of accounting. It behooves the Project Manager to sit down with the Contract Engineer, at the beginning of the contract work, to review the contract, to understand all the critical provisions, and to summarize them for the benefit of the members of the project team.

16.2 Thoughts on Contract Administration

Dealing with contractors is not an easy proposition. The contractor is neither thy enemy nor is it thy brother. The contractor is a business associate who shares only some of the client's objectives. Any responsible contractor will share the quality objective with the client and, unless otherwise proven, must be given full credit for that. Beyond quality, the objectives usually start diverging:

- The contractor wants to maximize its profits.
- The client wants to optimize the cost/schedule equation.

Both objectives are legitimate and the contract minimizes conflicts by establishing procedures and regulating the actions of both parties. For example:

- In a lump sum contract, the contractor could increase the profits by understaffing and avoiding overtime at the expense of the schedule. This, of course, would conflict with the client's interests. This predicament would be avoided by a contractual clause penalizing the contractor for schedule delays.
- Conversely, on a reimbursable-plus-percent-fee contract, the contractor could overstaff and/or pay overtime in the name of schedule compliance. The result would be an increase in contractor's cash flow and profits but the improvement in the schedule, if any, may not justify the extra cost to the client. However, this situation would be avoided with a clause requiring prior client's approval to premium pay and staffing the job beyond the approved plan.

Although a contract ultimately implies an adversarial relationship, that concept must not be brought down to the day-to-day dealings, especially with the contractor's Project Manager. It is important that both project managers establish a good rapport; after all, they have a mutual objective: a successful project. However, both project managers must remember that they also represent opposite sides of a contract.

16.3 The Project Manager as Contract Administrator

The prime objective of the Project Manager acting as Contract Administrator is to protect the Owner's best interests by insuring that the work is executed in full compliance with the contract. Specific items include:

- Ascertaining that the contractor fulfills the promises made in the proposal and/or during negotiations:
  1. Personnel assignments.
  2. Subcontractors.
  3. Control system.
  4. Timely reports and schedules.
  5. Manpower loading.
- Exercising Owner's rights
  1. Technical approvals.
  2. Approval of expenditures (in reimbursable contracts).
- Reviewing and approving changes.
- Insuring that all the Owner's contractual commitments are met:
  1. Timely supply of information.
  2. Timely approvals.
  3. Permits and licenses.
  4. Communications through authorized channels only.

All contractual communications especially those concerning deviations, even minor ones, from the contract must be documented through:

- Memos,
- Minutes of meetings, or even
- Notes in a personal diary.

If the contract goes sour, a good diary may prove priceless.

Most contractors will take the initiative in issuing minutes of meetings and documenting conversations and scope variations. When doing so, being human, they may tend to emphasize the client's shortcomings while downplaying, or even ignoring, their own. It is up to the Owner's Project Manager to carefully review all their communications to make sure that they truly reflect the essence of what was actually said. When in disagreement, the Project Manager must let the contractor know immediately and document the disagreement. There is no need to write a formal memo; the original document can be returned to the contractor with proper annotations with a copy to the file.

The recommended way to start any contractual work is by holding a kickoff meeting attended by both project managers, their supervisors, and the Contract Engineer. This meeting should be dedicated to the review of the scope and contractual conditions to make sure that everybody has the same understanding.

The concerns associated with lump sum contracts differ from those associated with reimbursable contracts. In the former, the emphasis is on making the contractor live up to promises made in the proposal; the client wants to get as much as possible for the money. In a reimbursable contract, the emphasis is on keeping the contractor from doing, and spending, more than required; the client wants to keep costs to a minimum. In both cases, safety and soundness in design and construction are the compelling concerns.

The following is a list of some of the steps that the Project Manager should take as part of the contract administration function. Those marked with an asterisk apply to both lump sum and reimbursable contracts. The rest are intended mainly for reimbursable contracts.

* At the beginning of the project, sponsor a meeting with the Owner's auditor and the contractor's accountants to work out the details of the invoicing and payment procedures and required backup documentation.

* Refuse any extra charges that have not been approved previously.

* Insist on the timely issue of reports and schedules. If necessary, issue a formal complaint.

* "Tighten the screws," but be careful not to relieve the contractor of its contractual responsibilities.

\- Before contract award, clarify the dividing line between reimbursable services and those covered by overhead and profit.

\- Identify the specific reimbursable personnel authorized to charge to the project and automatically refuse charges from unauthorized personnel.

\- Watch for reimbursable personnel doing non-reimbursable tasks.

\- Review and pre-approve personnel assignments on a weekly basis; follow up.

\- Ascertain that travel and living expenses are approved at the proper level in the contractor organization, consistent with the travel policy included in the contract.

\- Maintain and continuously update a record of all commitments in a manner consistent with the estimate.

* Review the first invoices very carefully. Make a case of any error or omission no matter how minor. This will set the tone of the work.

\- Review all payments made by accounting for consistency with the logged commitments.

\- Have an auditor come and audit the contractor's records at 30% completion and maybe again at 70%.

16.4 Typical Audit Exceptions

The following is a list of exceptions normally taken by auditors reviewing project documentation for compliance with company policy and contractual conditions. This list will help the Project Manager with the contract administration work.

Purchasing - Lump Sum Contracts

- No authorization on increase in contract value.
- Additional work orders were made without a change in the scope of work for the contract on a lump sum project.
- Insurance charges reimbursed contrary to contractual agreement.
- Insurance certificate not on file.
- Expired performance bond.
- Significant rework in the field of vendor equipment without corresponding backcharge.
- Purchasing function not separated from receiving.
- Non-approved subcontractors.
- Expired contractor insurance.
- Subcontracts/purchase orders not written.
- Purchase bids and/or quotes not obtained for purchases over the value established in the contract.
- Purchase requisitions not approved.
- Purchase requisitioner bypassed purchasing.
- Sole-source purchasing not justified or approved at proper level.

Reimbursable Labor

- Construction timesheets not approved by C.M.
- No approval for overtime hours.
- Hours paid exceed hours on clock card.
- Early clock-outs not penalized.
- Time clocks tampered with.
- Fictitious employees.
- Contractor's employees not identified by brass alley attendant.

Material

- Invoices not matched to receiving reports.
- No physical verification of materials received.
- Outbound shipments to be returned are not documented and no follow-up for return.
- Prices not verified to buying agreement.

Equipment and Property

- Records of rental equipment receipt, operation, and departures not maintained nor equipment billings verified.
- Owner-owned property not tagged.
- Surplus equipment not identified.
- Owner-owned construction tools and equipment not physically verified.

Site Security

- Open and unattended gate.
- No security check of vehicles entering or leaving the site.
- No gate log maintained.
- No use of material passes.

CHAPTER 17
COMMUNICATIONS

Don't tell management so much about the project they will want to help you. Don't tell them so little they get nervous.

17.1 Criteria and Guidelines

The Project Manager does not operate in a vacuum; the Project Manager is constantly:

- Receiving information from peers and consultants.
- Giving instructions to subordinates and contractors.
- Informing management.

THE PROJECT MANAGER MUST COMMUNICATE!

Being a good communicator means having:

- Good verbal communication skills.
- Good writing communication skills.
- Good listening skills.

These skills will invariably enhance the Project Manager's performance.

Proper and timely documentation is a necessary complement to communications and goes hand in hand with good project management and control.

- It keeps management informed, allowing it to provide timely input and avoid unpleasant surprises.
- It generates hard records that could be very valuable for future analyses and decisions.
- It may be a catalyst to promote constructive thinking in both the writer and the readers.

On the other hand, over-documentation is cumbersome, will dilute the efforts of the project team, and slow down the project.

Discretion must be exercised to avoid unnecessary paperwork and ensure that the extent and detail of the documentation are commensurate with the size and importance of the project.

Documentation, especially memos and reports, must be clear, concise, and attractive in order to ensure the attention of the recipients. Long, rambling, and cluttered memos are often left unread and, if read, they are frequently misinterpreted.

With the advent of word processing and electronic mail, engineers are doing more and more of their writing on their computers. Obviously, this is a timesaving practice, but often the resulting documents are not the most attractive and/or understandable and are not suitable for issue outside the limited project team circle. On certain documents, engineers should either let qualified secretarial help do the typing or they should take some basic training in letter writing and editing.

17.2 Documentation Checklist

The following list points out the areas that should be documented during the course of a project. In some cases, the responsibility falls on the Project Manager. In some cases, it falls on others. But in all cases, the Project Manager must insist that the documentation is generated.

- **Project Kickoff** - The first formal contact with the client must be documented in a memo spelling out the request, requiring CED participation and client's desired schedule. Immediate action planned by CED should also be mentioned.
- **Initial Plan of Action** - After the client's request has been studied, a memo must be issued to inform all of the plan of action and timetable proposed to

achieve the objectives. If the desired objectives are unrealistic, this must be brought to the client's attention and a realistic plan proposed.

- **Design Criteria** - The established design criteria and any changes to them must be clearly and promptly documented to ensure that both business group and operations personnel, as well as the design team, are fully informed and timely updated.
- **Meetings** - All meetings affecting project execution, decisions, instruction, technical reviews, and approval must be properly documented in the minutes of meetings.
- **Scope** - A thorough and clear scope of work is essential to the start of any meaningful design activity either in-house or contracted. When properly reviewed and documented, it will give both the business groups and operations the opportunity to provide timely comments.
- **Design Packages** - Design packages (Phase 0 and Phase 1) are normally self-explanatory. However, it is advisable to issue them with a cover memo summarizing the basic process information and design criteria followed.
- **Changes** - After the project has been approved based on a given scope, all changes and cost variations must be documented promptly to keep management informed and allow it to exercise the ultimate project control.
- **Estimates** - All estimates must be thoroughly documented. Documentation must not be limited to a cost summary. It must include an analysis discussing the basis of the estimate, estimating methods, areas of high uncertainty, assumptions, qualifications, and contingency criteria.
- **Coordination Procedures** - The names, specific responsibilities, and inter-relation of the key members of the project team and their line supervisors must be documented early for each specific project. Limits of authorization must also be clearly defined.
- **Contractors' Evaluations** - When a contractor is evaluated either for screening purposes or a specific contract award, the information developed must be documented for future reference.
- **Contract Award** - Every contract award, whether competitive or negotiated, must be documented with a thorough justification memo analyzing the reason for the selection and comparing the relative merits of all contractors considered.
- **Contractors' Performance** - The performance of active contractors must be evaluated and documented periodically.

- **Cost Evaluations** - In addition to the cost reports normally issued by the contractors, independent cost evaluations must be done and documented periodically by the Project Manager. Those evaluations must include analysis of variations and new cost forecasts.

- **Monthly Progress Reports** - Monthly reports must be structured to inform two different levels of management, a summary section addressed to corporate and group management, and a detailed section addressed to CED and division management.

- **Monthly Cost Reports** - Monthly cost reports must provide a clear view of the projected costs compared with AFE estimates plus a brief explanation of the changes from the previous report.

- **Deviations from Standards** - Any deviation from corporate standards and guidelines must be justified and documented.

- **Project Closeout** - The completion of any project must be documented. Documentation should include relevant cost data that would be useful for future projects.

CHAPTER 18
PLANT STARTUP

You can never have too many competent people on startup.

18.1 Introduction

The last, but very important, phase of a construction project is the plant startup. On a major project this is as significant an event as Front End Loading or Design Construction.

On many major projects, startup is put on the back burner and not given the proper amount of planning and resources that are necessary to have a quick, successful demonstration of the operability. Although a well-planned startup will not overcome deficiencies in design and construction, a poorly organized one will seriously mar the completion of a well-designed and well-constructed plant. It is the responsibility of the Venture Manager to avoid this predicament.

The successful startup must begin at the very onset of the project. Its planning must be part of the Project Execution Plan developed during Front End Loading:

- Startup and operating staff requirements must be determined and schedules prepared for their training and integration to the project team at the right moment.
- Piping design leaders must get familiar with startup sequences to incorporate into the piping systems sufficient connections to facilitate

independent flushing of the various systems in an orderly and rational manner.

- Detailed instructions must be written for both the startup and regular operators.
- Contractors and subcontractors must be made contractually aware of the owner's requirements concerning their participation during the startup period.

Although this sounds like common sense, once the required resources for a startup are known, the most common management response is "you don't need that many people." The Venture Manager must be firm in insisting on the required resources and keep reminding management of the "old Irish saying:"

YOU CAN NEVER HAVE TOO MANY PEOPLE ON STARTUP!

18.2 Phases of the Startup

Startup actually should begin during the plant design. For simplicity, activities can be divided into pre-mechanical completion and post-mechanical completion. See Fig. 18.1.

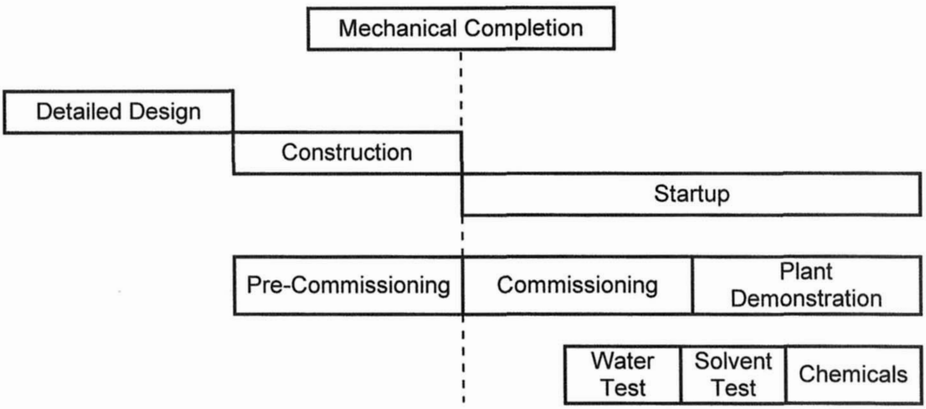


Figure 18.1 Phases of the startup.

- **Pre-Commissioning**. These are construction activities and include the final construction inspections and tests required to ensure that the project has been mechanically installed as per the design. Among the activities are:

  - P&ID confirmation.
  - Electrical/instrument loops checks.
  - Leak tests.
  - Hydraulic pressure tests.
  - Alignment checks.

  The Project Manager is still the lead of the integrated team during this period. All members of the startup team help in this activity under the direction of the Project Manager.

- **Mechanical Completion**. The "sign off" by the Construction Manager and Owner's Project Manager signals that the plant has been assembled mechanically according to the approved plans and drawings. Some call it "the transfer of care, custody, and control" from the contractor to the Owner. It also signals that the contractor has performed its contractual obligation.

- **Commissioning**. This is the functional test, the last test before active chemicals are introduced to the system. Among the activities are:

  - Bumping and rotational tests of all motors.
  - Interlock and action test on all automatic systems.
  - Program check.
  - Water (or other inerts) test.

  The Project Manager maintains the lead of the team during this period.

- **Plant Demonstration**. This is the operation of the plant using actual chemicals. During this period all process conditions, rates, and step synchronization are confirmed. All critical process and mechanical conditions should be documented, e.g., yields, reaction kinetics, separation efficiencies, and motor amperages under various operating conditions. Documentation is important to determine baselines. If troubles occur later, the baseline data can be consulted for troubleshooting clues.

  The lead of the integrated team passes to the Manufacturing Manager and the Startup Manager during this period.

  Depending on the complexity or hazardous nature of the process, this startup period may be subdivided. The test period may involve simulations with water or other inert materials before active chemicals are introduced.

Active, non-hazardous chemicals may be simulated next to ensure process conditions can be achieved. Finally, the actual materials are introduced.

For a more detailed list of activities during Pre-commissioning and Commissioning, see Appendix O.

18.3 Startup Organization

For a small, simple project the startup could be as easy as starting a pump. Obviously, one person could probably handle the startup efficiently. For a "mega project," several hundred operators and engineers may be needed. For this description, let us assume that the project is for a first of a kind operation with 200 pieces of major equipment. Many of the functions will be there no matter what size project. For your project, the size and complexity will determine the total number of people required. The organization chart in Fig. 18.2 shows the startup team and the reporting relationship.

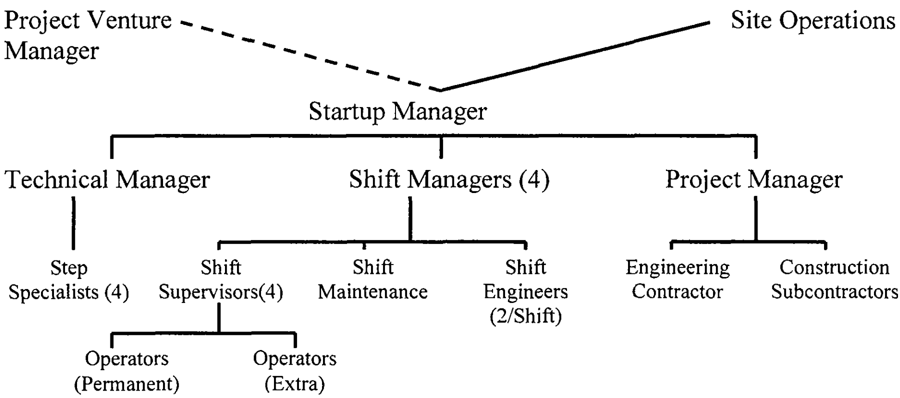


Figure 18.2 Startup team organization.

- The **Project Startup Manager** has total responsibility of the startup. He has a dual reporting relationship. Since the startup is an operating responsibility, the Startup Manager reports (solid line) to the appropriate operating manager within the plant's operating organization. Since the project has not yet been demonstrated, the startup manager also reports (dotted line) to the integrated team's Venture Manager.

  Ideally, the Project Startup Manager should be the integrated team's Manufacturing Manager and has been through the design effort and thus is intimately familiar with the project. This is of great importance during startup. When changes have to be made, an intimate knowledge of what the thought processes and assumptions were during design can improve the startup decisionmaking.

The Project Startup Manager should also be the unit supervisor after the project is completed. This also helps during startup. "Quick fix" solutions at the expense of better, permanent solutions will be minimized. The decision to release the project team will not be a premature one.

- The **Startup Technical Manager** must be the integrated team Technical Manager, and as such is responsible for the technical performance of the project processes. This includes the technical startup plan, writing of the operating manuals, training of the engineers and operators, and providing technical support to the operating personnel during the startup.

  Having gone through the design process, the Technical Manager will be intimately familiar with the design assumptions and why certain decisions were made. As mentioned before, this continuity of design into the startup phase is very important.

- The **Step Specialists** are responsible for the technical performance of a portion of the project. Experience has shown that one specialist can handle about 50 major pieces of equipment (one major processing step) depending on the complexity of the section. The specialists will be responsible for the startup plan, writing their portion of the operating manual, training of the engineers, supervisors, and operators, and direct technical support to the operators during the startup.

- The **Shift Managers** and **Shift Engineers** are positions not commonly found in startups. When a fast startup is imperative and is complex technically, these positions can add considerable value.

REMEMBER THE OLD IRISH SAYING…

Shift Managers are selected from the manufacturing organization and are capable of making complex decisions. Having the Shift Manager does one very important thing. It allows the Startup Manager to go home and get some rest.

RECOMMENDED SAFETY RULE: NO ONE SHOULD BE ALLOWED TO WORK ON THE PLANT MORE THAN 16 CONTINUOUS HOURS. THIS SHOULD BE RIGOROUSLY ENFORCED, ESPECIALLY FOR MANAGERS. TIRED MANAGERS MAKE BAD DECISIONS.

Shift Engineers are usually selected from the manufacturing organization. Depending on the size of the new facility, one to three per shift will be useful. Their prime responsibility is to provide close technical support for the supervisors and operators. They will also assist the Step Specialists by continuing and watching any tests or startup activities begun by the Specialists. This also permits the Step Specialist to go home and rest.

- **Shift Supervisors** - Ideally, this should be the shift supervision team that will run the facility after startup. The shift supervisors are responsible for the safe "hands on" operation during their shifts.

  If the facility is going to be part of an existing operation, using the existing shift supervisors may not be possible. Temporarily filling the permanent shift supervisors positions so they can obtain the best experience with the new plant is extremely valuable.

- **Permanent Operators** – As with the shift supervisors, these should be the operators who will remain after startup. This may also mean temporarily filling their positions to allow them to gain the startup experience. The operators will do the hands on operation during his shift.

- **Additional Operators** – It is recommended that additional operators be assigned during startup for special assignments, e.g., cleanups, watching troublesome equipment. The number should be one third or one fourth of the permanent crew.

- **Shift Maintenance** – Responsible to provide minor repairs or modifications to keep the startup going. Instrument/electrical, millwright, and pipefitter capabilities must be available around the clock. If the existing plant doesn't have the staffing to provide this, contractor support may be used effectively.

- **Project Manager** – Is on standby during this period to provide major repair or modifications. If there is a major correction needed, a formal takeback by the contractor may be done.

- **Contractor** – Must be ready to provide support as needed.

18.4 Punchlisting

As the integrated and Startup Team perform the inspections and tests during pre-commissioning, commissioning, and plant demonstration, deficiencies are uncovered. The system of identifying, designing corrective measures, and implementing corrective actions for these deficiencies is known as punchlisting.

The punchlist is a tracking method that itemizes the activity, identifies the responsible party for correction, and targets the timing for corrective action. There should be only one official punchlist. The Project Manager should take the responsibility for its maintenance and the contractor and its subcontractor must provide a "Snapper Crew" to make the necessary corrections.

Most items on a punchlist would fall under construction error or design error.

- Luckily most will be **construction errors**. The facility wasn't erected per the design. Fortunately, most of these would be considered minor and can be corrected quickly. The Project Manager and appropriate subcontractor can usually clear these items quickly.
- **Design errors** may take longer to correct. First, there has to be agreement that the design will not work as required. Second, a design change must be made. Finally, the new design has to be installed and rechecked. The Technical Manager must take the lead in this area. Often, the engineering contractor has to be involved as well as the construction subcontractor.

Almost all plants have a Management of Change (MOC) procedure. This is a documentation that any change to a design does not have a negative safety impact. If the design of the project had a proper hazards analysis, then any change to the design must be analyzed also.

THE PLANT MOC PROCEDURE MUST BE FOLLOWED FOR ANY CHANGE IN DESIGN.

The Project Manager must beware of insidious scope changes during punchlisting. Often, nice to have items appear, usually provided by personnel who have not been part of the original design team. Screen punchlist items carefully.

- Scope changes add to the cost.
- Scope changes add to the completion time.
- Some scope changes may make sense, but be judicious.

The most effective method of administering this activity is through a daily **punchlist meeting**. During the pre-commissioning and commissioning periods, this should be done late in the afternoon so that new items can be planned for the next day's construction work.

The punchlist meeting must be run efficiently.

IT IS NOT A DESIGN MEETING.

Keep the discussions for each item only long enough to make everyone aware of the problem. If redesign is necessary, the Technical Manager will call a follow-up meeting. Only discuss new items, items with unresolved problems, and announcement of items that have been corrected. The Project Manager is the facilitator.

18.5 Startup Goals

Speed and **Safety** are the most important goals during startup.

Speed

The investment spending has been made, but the project will not earn a penny until the plant produces on-spec product. The quicker the startup the higher the IRR and NPV of the project. The following will help ensure a quick startup.

Enough people

The organization chart shown in Fig. 18.2 was intended for a medium sized project and should be modified to fit different situations.

- If the plant has more than 200 pieces of equipment, increase number of step specialists
- If the plant involves high technical risks, consider adding more technical support specialists in the risk areas

Timing of activities

As mentioned in the introduction, startup planning must begin during Front End Loading.

- Locate resources (by name) and free them to join the integrated team as soon as possible.
- Complete operating manuals and startup plans well before pre-commissioning.
- Complete training before pre-commissioning starts. When pre-commissioning starts there will be too much going on to allow time away from the job site.

Around the clock

Even if a plant is not scheduled to operate around the clock once it has started up, the startup should be three shifts a day, seven days a week. A single shift startup will take 5 to 10 times longer to complete.

Multiple startup

Starting at the beginning of a multi-step process and working sequentially through each step adds weeks or even months to the startup. You have enough people (if you were paying attention earlier). Start up as many sections as possible concurrently, as long as it can be done safely. Importing intermediates from other plants or from pilot facilities is often possible.

Safety

This is the most important criterion for the startup. Nothing takes precedent. Not even speed.

> ALL THE NORMAL RULES OF CHEMICAL PLANT OPERATIONS STILL APPLY. IN FACT, THEY BECOME EVEN MORE IMPORTANT.

Special emphasis must be placed on the particular hazardous conditions associated with startups: confusion, modifications, and fatigue.

Confusion

- Due to the large number of people around the facilities, certain protocols should be enforced.
- No one should be allowed in the facility unless accompanied by a member of the startup team.
- Only operators, through the instructions of their shift supervisors, are to perform any operational functions.
- Don't let the engineers near the control panel.
- Follow the change control procedure. Any changes to the operation must be approved by the appropriate Step Specialist and the Technical Manager. In an emergency, the Shift Manager can give temporary approval.

Repairs and modification

There may be many people involved with modifications while the rest of the plant is operating. Special extra emphasis on equipment preparation, lock out, barricading, confined space entry, etc., is vital.

Fatigue

This is the biggest enemy of a successful startup. Shift managers and shift engineers will allow the non-shift personnel to leave at night. The consecutive working hour rule must be rigorously enforced. Recommend that no more than 16 consecutive hours out of 24 and no more than 80 hours in a seven day week.

CHAPTER 19
SEMI-DETAILED ESTIMATING SYSTEM

Good cost estimates need not require thousands of engineering and estimating hours.

19.1 Procedure

General

The proposed semi-detailed estimating system is consistent with the guidelines presented in Section 10.4 and includes simple procedures and tools that will allow project managers to quickly and accurately:

- Develop order-of-magnitude and conceptual estimates from minimal information.
- Prepare, when necessary, semi-detailed estimates (for small projects) suitable for appropriation and/or further project control.
- Check estimates prepared by others.
- Analyze subcontractors' bids.
- Check the cost of proposed changes.

When applied to Phase 1 designs (complete P&ID's and arrangement drawings), the quality of the resulting estimates could be as good as the conventional detailed estimates normally prepared by contractors at much greater expense.

The system emphasizes:

- The maximum use of equipment counts, rather than factors and ratios, as the prime parameter to determine the cost of commodities.
- The use of easily quantifiable comprehensive units of discrete comprehensible scope.

The system offers the following advantages:

- It offers the flexibility to prepare estimates at almost any level of engineering detail.
- It provides sufficient details to permit scope and cost tracking during the preliminary design stage.
- The details provided can be used directly to develop a progress monitoring system.
- It includes rational guidelines for consistent application of resolution allowances and contingency.
- Most of the procedures could be easily programmed in PC's using simple commercially available programs.

- All the estimating units can easily be adapted to reflect project-specific materials costs and labor rates.

NOTE: ALL THE COSTS PROVIDED ARE BASED ON APPROXIMATELY EQUIVALENT TO END OF YEAR 2000 AND A CE PLANT COST INDEX OF 420.

Order of Magnitude and Conceptual Estimates

- When only the equipment count is available an order-of-magnitude estimate can be prepared in a few minutes, with the aid of the factors included in Section 19.11. See example in Section 5.3.
- When the equipment list with brief description is also available (annotated equipment list), a conceptual estimate broken down by construction disciplines can be developed in a couple of days for a plant with 50 to 100 equipment items.
  - **Equipment Costs** - Use Section 19.2. Add 5% for freight.
  - **Equipment Erection** - Use 20% of equipment cost as per Section 19.2.
  - **Instrumentation** - Based on equipment count as per guidelines in Section 19.7.
  - **Electrical** - Based on motor count as per guidelines in Section 19.6.
  - **Engineering** - Estimate based on equipment list as per Section 19.8.
  - **Piping** - Use a combination of:
    1. Factors in Chapter 10.
    2. Conceptual shortcut in Section 19.11.
    3. Unit prices and unit hours in Section 19.4.
    4. Judgment.
  - **Structural Steel** - Use a combination of:
    1. Factors in Chapter 10.
    2. Judgment to conceptualize the volume of structure required to contain the equipment and the pipe racks.
    3. Section 19.3 to estimate weight and cost.
  - **Labor Costs** - Follow guidelines in Section 19.9.
  - **Other Direct Accounts** - Use factors in Chapter 10.
  - **Field Indirects** - Since all costs and factors are based on subcontractor rates, use 20% of labor and subcontract columns.

- **Resolution Allowance/Contingency** - Follow guidelines in Section 19.10.

- Another simple, and perhaps more relevant way to prepare a conceptual estimate broken down by construction disciplines would be to:
  - Estimate equipment and engineering accounts as shown above.
  - Estimate total field costs with factor in Table 19.35 and break down into construction disciplines with aid of Table 19.36. See example in Table 8.1

Semi-Detailed Estimate

A semi-detailed estimate could be conceptual, preliminary, or definitive, depending on the quality of the information provided. In any case, the following information is required:

- Equipment list with sizes and materials of construction.
- P&ID's.
- Plot plans and equipment arrangements showing at least the outline of the required supporting structures.
- Area of buildings.

If plot plans and equipment arrangements are not available, the estimator should be able to develop preliminary ones with the aid of Section 6.4.

The preparation of a semi-detailed estimate for a medium sized chemical plant with 50 to 100 pieces of equipment should take 5 to 7 working days, including 3-4 days to develop preliminary equipment arrangements and doing all calculations manually. The various accounts are estimated as follows:

- **Equipment** - Most equipment items can be estimated using Section 19.2 plus 5% for freight. Vendors should be contacted for special equipment.
- **Equipment Erection** – 20% of the equipment account is usually a generous allowance and should be used for preliminary estimate. On appropriation or definitive estimate the individual work hours in Table 19.1 should be used.
- **Piping** - Use P&ID's, Plot Plans, and arrangement drawings to develop take-offs as follows:

  a. Identify and account for all lines in a given process area and estimate their length starting from the nearest point in the interconnecting pipe rack. Add around 10% to the shortest route to allow for the fact that it is not always feasible and 20% to hot lines (over 250°F) to allow for expansion loops.

b. Identify and account for all lines in the interconnecting pipe racks including utility supplies from remote areas.

c. Make specific allowances for distribution systems within the process area for the various utilities: cooling water, high/low pressure steam/condensate, service water/air, nitrogen, instrument air, vent collection systems, etc. Lengths and sizes must be determined based on arrangement and flows. Allow at least 30 ft. of pipe from distribution system to each individual user.

d. Count all valves in P&ID's, including control valves. Allow one valve for every utility subheader. Do not count vents, drains, and instrument connections; they are built into the pipe unit costs.

   Note: The control valve count is used only to determine labor costs. The cost of the valve is included with the instrumentation account.

e. Establish the required quantity for each of the miscellaneous piping items mentioned in Section 19.4.
   1. **Heat Tracing** - Linear feet of tracing.
   2. **Utility Stations** - One per every 5,000 ft.^{2} of process area or one per level.
   3. **Safety Stations** - As required (at least one per operating area).
   4. **Instrument Purges** - Per process requirement.
   5. **Equipment Drains** - One per vessel or tank.
   6. **Sump Ejector** - One per sump or diked area.

f. Estimate material costs and labor hours with the aid of Section 19.4.

- **Instrumentation** - Use P&ID's to count balloons, TDC connections, and air hook-ups. Compare count with average given in Section 19.7 and use unit costs.

- **Electrical** - Count motors and other electrical loads and use procedure in Section 19.6 to estimate cost.

Note: For a preliminary estimate, the cost can be calculated in a few minutes with the aid of the charts provided. For definitive estimates intended for appropriation and/or progress monitoring, the cost should be developed with the semi-detailed procedure. Both approaches should result in approximately the same cost.

- **Site Preparation, Sewers, and Fire Protection** - If details are available, make rough take-offs and use prices in Section 19.3. If not, make an allowance consistent with the factors in Chapter 10.
- **Concrete** - Use procedure in Section 19.3 to develop take-offs and cost. Break down as many items as information permits.
  1. Equipment - by item.
  2. Structure Foundations - per structure.
  3. Floor Slabs - per areas.
  4. Dikes - per dike.
- **Structural Steel** - Use procedure in Section 19.3 to develop take-offs and cost. Break down by structures and pipe racks and don't forget to identify and estimate miscellaneous service ladders and platforms related to specific equipment items.
- **Buildings** - Identify and estimate the shelter (roof and siding) requirements for process structures as well as the area of buildings included in the Scope of Work. Use unit prices in Section 19.3 to estimate costs.
- **Insulation** - The take-offs for piping insulation are developed as part of the piping account estimate. The take-offs for equipment insulation are developed by identifying and estimating the outside area of those items requiring insulation. The unit prices in Section 19.5 are used to estimate cost.
- **Painting** - Make allowance consistent with the factors in Chapter 10.
- **Labor Costs** - All accounts estimated on a subcontract basis include the cost of labor and must be listed in the estimate under the "Material and Labor Subcontract" column. The hours included with the estimating units are intended only to determine construction staffing for planning purposes.

  Other accounts are estimated on a material and labor hours basis. The estimated hours must be adjusted, if necessary, for productivity as per the guidelines in Section 19.9. The cost must be estimated on a subcontract basis following the guidelines in Section 19.9 and shown in the estimate under the "Labor" column.
- **Field Indirects** - If the Owner acts as construction manager, the Field Indirects should not exceed 10% of the total labor and subcontract columns. If construction management is done by a contractor, follow guidelines in Section 19.9.
- **Engineering** - Contractor's engineering hours must be estimated with the procedure in Section 19.8. The cost per hour including overheads

and profit varies from \$75/hr on the East Coast and West Coast to \$45/hr in the Midwest and South.

Note: The proposed execution approach will influence the required engineering hours and must be taken into account when preparing the estimate, especially a definitive or appropriation type estimate. Refer to the discussion in Section 15.3.

- **CED Costs** - CED costs will vary with the execution approach. If the project is going to be managed by CED using a full-service contractor, the required man-hours can be estimated with the aid of Section 19.8.
- **Taxes** - Taxes will depend on the specific location.
- **Spare Parts** - An allowance of 10% of equipment cost should be more than adequate.
- **Startup** - An allowance of 7% of the "Labor" column plus the labor fraction of the subcontract column is usually adequate.
- **Escalation** - Apply current inflation rate to the mid-life of the project. Refer to Section 19.10.
- **Resolution Allowance/Contingency** - Follow guidelines in Section 19.10.

Figure 19.1 summarizes the scope and applications of the proposed semi-detailed estimating system.

19.2 Equipment Estimating Procedures

General

The recommended, and most accurate, method of pricing equipment is with the help of vendors or recent purchase orders. However, it frequently occurs that either the purpose of the estimate does not justify the effort or the time constraint does not permit it. In those cases, the following procedures will be of great value to the Project Manager and/or the Estimator.

In the absence of more precise information, they have proved to be very quick and reasonably accurate especially when applied to a substantial number of pieces of equipment such as the entire equipment account of a chemical process plant. They are also useful to determine whether the price quoted for a specific piece of equipment is reasonable.

These procedures are more suitable for detailed or semi-detailed estimates where the various commodities (civil, piping, electrical, etc.) are estimated individually or related to equipment count rather than to equipment cost. These procedures should not be used in factored estimates where an error in the equipment account would be greatly amplified by the time it reaches the bottom line.

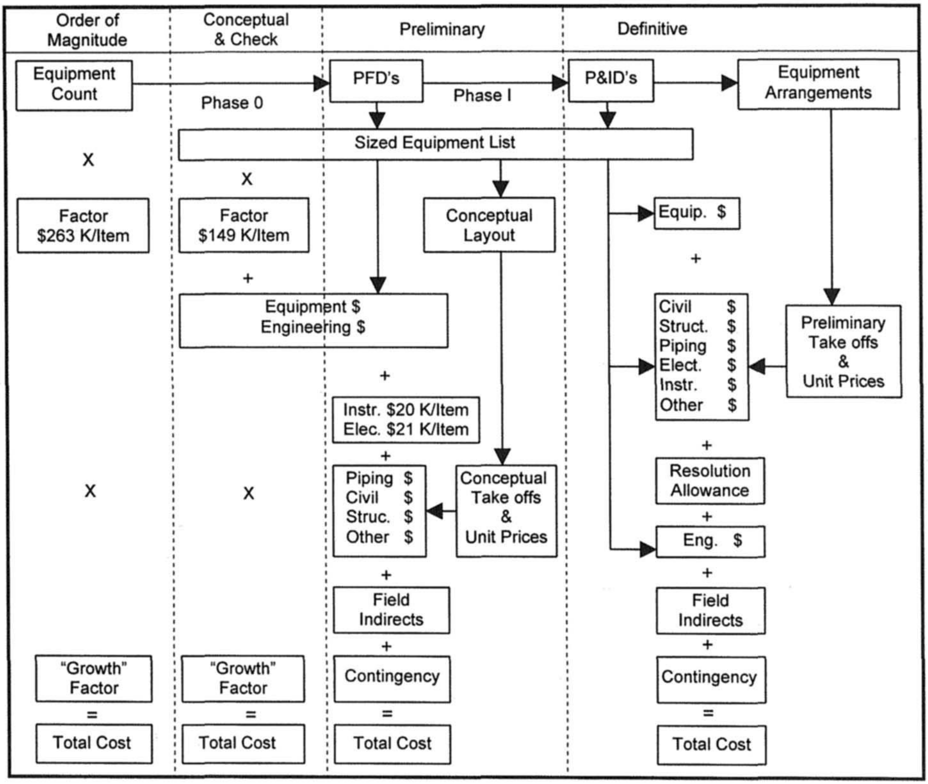


Figure 19.1 Semi-detailed estimating system.

Vessels

Scope

This procedure can be applied to all types of pressure and atmosphere tanks and vessels:

- Reactors, columns, storage tanks, process pots and pans.

It covers a variety of materials of construction:

- Carbon steel, 304 SS, 316 SS, Hastelloy C, glass lined, FRP Furan.

Weight Estimate

Basis of Procedure

The weight is determined with the aid of Figs. 19.2 or 19.3 and Fig. 19.4.

- Fig. 19.2 is used to estimate the thickness of steel vessels and tanks and is merely the graphical representation of the pressure vessel basic design equation.

  The estimated thickness is based on an allowable stress of 15,000 psi and a joint efficiency of 0.85. It includes a corrosion allowance of one-eighth of one inch (1/8 in.).

  When the specified corrosion allowance is less than 1/8 in., the thickness must be adjusted accordingly. It must be noted that on flat bottom atmospheric storage tanks, the bottom and top thickness need not be more than 1/4 in.

- Fig. 19.3 was developed to estimate the thickness of FRP Furan tanks. It is based on 500 psi allowable stress and includes a 1/4-in. liner. The wall thickness in FRP tanks normally tapers down from bottom to top; for estimating purposes, the thickness should be calculated for the pressure at one-third of the tank height.

- Fig 19.4 was developed empirically to adjust the base level weight to allow for nozzles and supports.

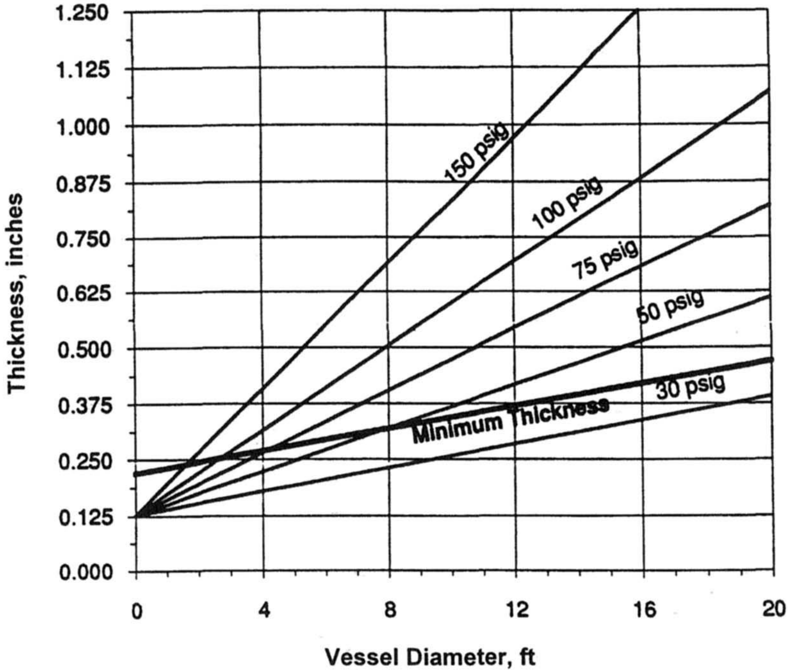


Figure 19.2 Metal vessel thickness.

Procedure

-	Shell Area:	3.14 x Dia x Height
-	Flat Bottom Area:	$(\text{Dia})^2$ x .785
-	Cone Roof Area:	$(\text{Dia})^2$ x 1.1
-	Approx. ASME Head Area	$(\text{Dia})^2$
-	Base Weight (C.S.):	Area x Unit Weight
	1. 1/6-in. plate	2.5 lb/ft.^{2}
	2. 1/8-in. plate	5.0 lb/ft.^{2}
	3. 1/4-in. plate	10.0 lb/ft.^{2}
	4. 1/2-in. plate	20.0 lb/ft.^{2}
	5. 1-in. plate	40.0 lb/ft.^{2}

- Weight Corrections:

1. Full vacuum service	x 1.10
2. Hastelloy C	x 1.15
3. Furan	x 0.20
4. Baffles and Jackets	Calculate
5. Nozzles and Supports	See Fig. 19.4

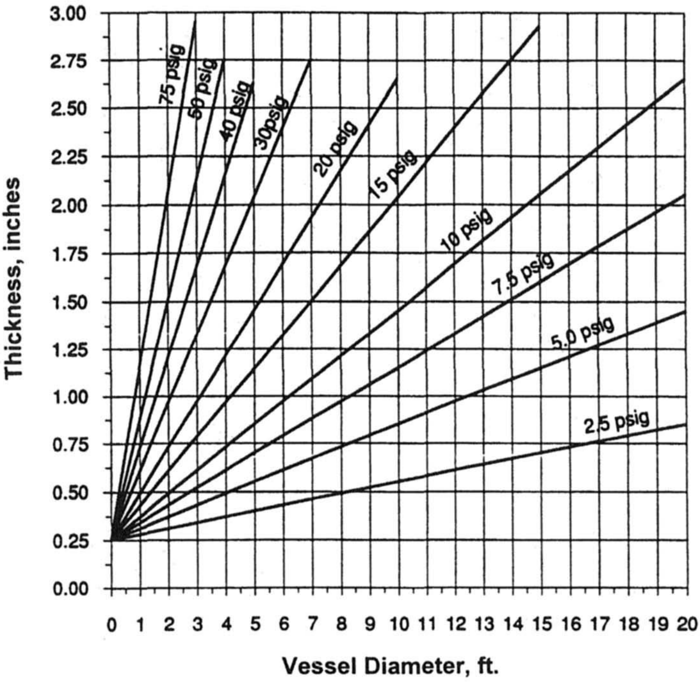


Figure 19.3 FRP (Furan) vessel thickness.

Cost Estimate

Step 1

Calculate cost of basic vessel from the following chart:

Weight lb	Cost $/lb	Weight lb	Cost $/lb
Up to 200	7.40	25000	2.20
500	5.90	30000	2.00
1000	5.20	40000	1.70
2000	4.60	50000	1.60
4000	4.10	70000	1.40
6000	3.80	100000	1.30
10000	3.30	150000	1.20
15000	2.90	200000	1.10
20000	2.50	200000	1.04

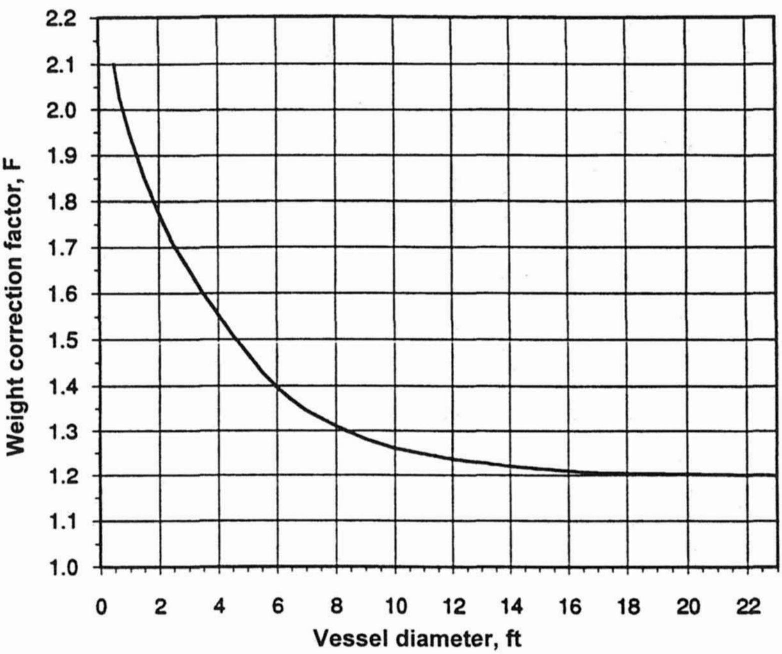


Figure 19.4 Vessel weight correction for nozzles and supports.

Basic Vessel Description

1. Carbon steel.
2. ASME construction (up to 75 psia).
3. Shop fabrication.
4. Simple design.

Step 2

Use correction factors to convert to actual conditions:

Material Correction	Multiplier
304L SS	2.20
316L SS	2.50
Glass lined	2.50
Hastelloy C	12.00
Furan	2.80

Fabrication Correction	Multiplier
Atm. shop fabricated	0.85
Atm. field fabricated, open top	0.90

Complexity Correction	Multiplier
Baffles, panel coils, pipe coils, external agitator supports	1.10 ea.
Full jacket	1.30
Reactors	1.50
Columns	1.50-2.00

Pumps

Fig. 19.5 was developed with cost data provided by a pump manufacturer and should cover the most frequently used pumps in chemical plants up to 100 hp. The base curves represent 316 SS horizontal ANSI pumps with TEFC motors and a single mechanical seal.

The cost of the basic pump (without motor) must be corrected as follows for the various cases covered by the procedure:

Material Correction	Multiplier
Ductile Iron	0.60
Hastelloy C	2.50

Pump Type Correction	**Multiplier**
API Pump	3.2
Dynamic Seal Pump	2.1
Magnetic Drive Pump	2.5

Double Seal Correction

Add $6,000 to account for:

1. Seal.
2. Seal pot and related instruments and interlocks.
3. Nitrogen supply.
4. Related piping and electrical wiring.

Note: Most of the costs associated with the double seal could be estimated with the piping, electrical, and instrument accounts. However, to insure their inclusion in the estimate, they should be included together with the pumps

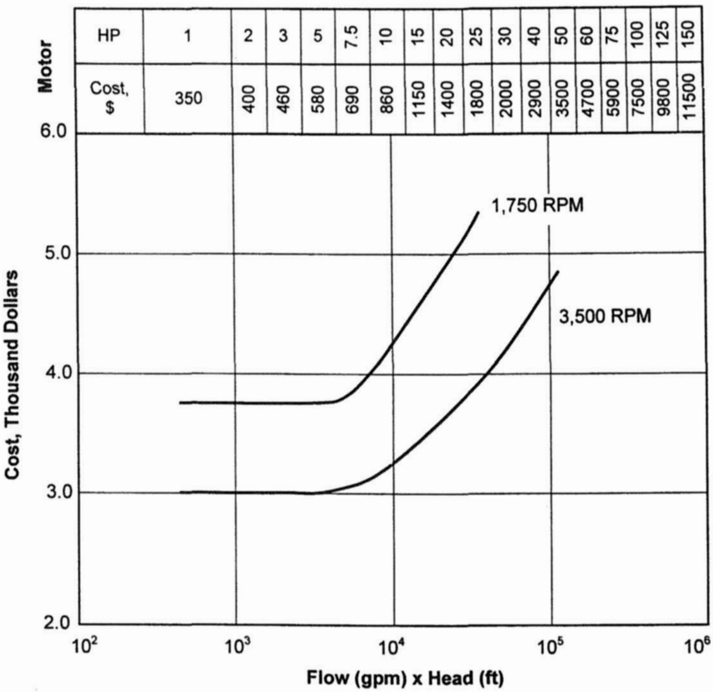


Figure 19.5 Centrifugal pump costs.

Shell and Tube Heat Exchangers

Fig. 19.6 was developed with the aid of the B-JAC computer program to provide approximate cost estimates with minimal available information. The curve is based on the following parameters:

- Shell Material:	Carbon Steel
- Tube Material:	304 SS
- Tube Arrangement:	1-in. Triangular
- Tube Diameter:	3/4-1 in., Welded
- Tube Sheet:	Fixed

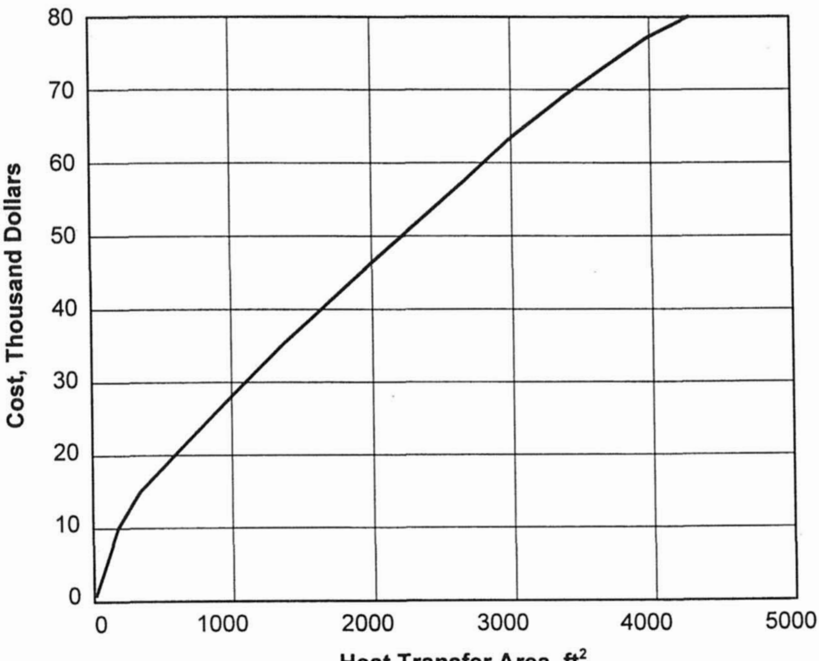


Figure 19.6 Shell-and-tube heat exchange cost.

The following corrections are required for different construction materials:

Material	Shell	Tubes	Tube Ga.
Carbon Steel	0	-30%	16
304 SS	+14%	0	16
316 SS	+20%	+15%	16
Admiralty	+15%	+10%	16
Alloy 20	N.C.	+110%	18
Hastelloy C	N.C.	+400%	18
Titanium	N.C.	+65%	20
Graphite	N.C.	+60%	-

N.C. - Not Considered

The cost of vacuum condensers would be 10% to 20% more than the corresponding heat exchanger depending on vacuum level.

Miscellaneous Equipment

The attached list provides costs of miscellaneous equipment frequently used in chemical plants. They were extracted from a widely used computerized estimating program:

Centrifugal Air Compressors - 50 to 100 psig

1,000 cfm	\$132k to \$140k
5,000 cfm	\$300k to \$320k

Reciprocal Air Compressors - 250 psig

100 cfm	\$53k
250 cfm	\$90k

Centrifugal Turbo Fans - 2 to 20 psig (carbon steel)

500 cfm	\$24k
5,000 cfm	\$72k to \$101k

Rotary Blowers - 2 to 5 psig (carbon steel)

500 cfm	\$18k
1,000 cfm	\$22k

Centrifugal Fans - 6 to 15 in. H_2O (carbon steel)

1,000 cfm	\$2k - \$4k
20,000 cfm	\$6k - \$12k
304 SS	x 1.5
FRP	x 1.3

Air Dryers

250 cfm	\$10k

Baghouses

2,000 cfm	\$14k
20,000 cfm	\$55k
80,000 cfm	\$72k

Rotary Drum Blenders (carbon steel)

50 C.F.	\$48k
200 C.F.	\$143k
304 SS	x 1.5
316 SS	x 2.0

Fixed Propeller Agitators (316 SS)

5 hp	\$14k
10 hp	\$18k
20 hp	\$25k
30 hp	\$29k
50 hp	\$42k
Carbon Steel	x 0.9
Hastelloy C	x 2.5

Continuous Spray Dryers (carbon steel)

1,000 lb/hr Evap. Rate	\$242k
5,000 lb/hr Evap. Rate	\$375k
304 SS	x 1.8

Vacuum Tray Batch Dryers (carbon steel)

40 ft.^{2}	\$10k
200 ft.^{2}	\$26k
304 SS	1.5
316 SS	x 2.0

Batch Bottom Unloading Centrifuges (316 SS)

36 in. Dia.	$104k
56 in. Dia.	$161k

Continuous Solid Bowl Centrifuges (316 SS)

36 in. Dia. x 60 in.L	$322k
54 in. Dia. x 60 in.L	$357k

Open Belt Conveyors - 20 to 40 ft. (carbon steel)

18 in. Wide	$24k to 29k

Screw Conveyors - 10 to 20 ft. (carbon steel)

6 in. Dia.	$4k to $5k
9 in. Dia.	$5k to $6k
304 SS	x 1.5

Continuous Bucket Elevator - 30 to 50 ft. (carbon steel)

10 in. Wide	$18k to $23k
16 in. Wide	$23k to $31k

Pneumatic Conveyor System (carbon steel)

100 ft. x 4 in., 30 hp	$14k

Barometric Condensers (carbon steel)

200 gpm	$4k
2,000 gpm	$22k

Dowtherm Units - gas fired

1.0 MM Btu/hr	$64k
10.0 MM Btu/hr	$182k

Wiped Film Evaporator (316 SS)

27 $ft.^2$	$54k

4-Stage Steam Ejectors - 5.0 to 1.0 mmHg

20 lb/hr	$13k to $24k
50 lb/hr	$20k to $36k

Oil Seal Vacuum Pump (carbon steel)

100 cfm	$7k
500 cfm	$26k

Cartridge Filters (316 SS)

50 gpm	\$4k
200 gpm	\$5k
500 gpm	\$8k

Pressure Leaf Filters (carbon steel)

200 ft.^{2}	\$30k
600 ft.^{2}	\$48k
316 SS	x 2.0

Rotary Drum Filters (carbon steel)

200 ft.^{2}	\$72k
600 ft.^{2}	\$133k
316 SS	x 2.0

Centrifugal Refrigeration Units - + 40 to -40°F

75 tons	\$133k to \$161k
250 tons	\$337k to \$438k

Gas Fired Package Boilers - 250 to 500 psig

30,000 lb/hr	\$184k to \$201k
100,000 lb/hr	\$345k to \$375k

Ion Exchange Water Treatment

150 gpm	\$23k
400 gpm	\$27k

Cooling Towers

1,000 gpm	\$61k
2,000 gpm	\$76k

Electric Generators

200 kW	\$54k
500 kW	\$136k

Stacks - 30 to 200 ft.

24 in. Dia.	\$5k to \$20k

Equipment Erection

The equipment erection hours are rarely more than 7-8% of the total construction hours, and errors in this account will have a very small impact on the total estimated costs. Estimating equipment erection costs as a percentage of the equipment cost is then an acceptable method.

> IN MOST CASES, 20% OF THE EQUIPMENT COST WILL COVER THE COST OF ERECTION LABOR AND RELATED RENTAL EQUIPMENT.

This factor is to be applied only to the equipment listed in the estimate under the "Materials" column that requires minimum or no assembly by the regular construction forces. Equipment that requires field assembly by the vendor, such as large storage tanks, large boilers, materials handling systems, and other complicated packages, should be listed in the estimate under the "Subcontract" column. The cost includes both materials and field costs.

The approximate field work hours (W-H) required for field manpower planning can be estimated as follows:

$$\text{Erection Cost} \div \text{Loaded Labor Rate}$$

Plus

$$(\text{Subcontracts} \times 0.4) \div \text{Loaded Labor Rate}$$

Refer to Section 19.9 for applicable rates.

Knowing the total equipment erection hours is not sufficient for accurate construction progress monitoring; the total must be broken down into discrete portions related to specific equipment items. Table 19.1 provides guidelines for the allocation of hours to each equipment item.

19.3 Civil Work Estimating Procedures

Concrete Work

This is not a foundation design procedure. It is only a tool for preparing quick semi-detailed cost estimates and/or checking contractors' estimates. It is also a good tool for discussing and evaluating design alternatives and field change orders. They can be used either to estimate work done on a direct hire basis (materials plus labor) or work done on a subcontracted basis.

Table 19.1 Typical Equipment Erection Work Hours

Equipment	Unit	W-H
Pumps & drives		
< 1 hp	ea	20
1-10 hp	ea	40
15-25 hp	ea	60
30-60 hp	ea	80
70-125 hp	ea	100
150 and over	ea	120
Process vessels (<12 ft. dia.)		
< 100 gal	ea	80
100-1,000 gal	ea	100
1,100-5,000 gal	ea	120
5,100-20,000 gal	ea	160
Field fabricated vessels/tanks (> 12 ft. dia.)		
< 20,000 gal	ea	240
21,000-50,000 gal	ea	480
51,000-100,000 gal	ea	800
101,000-500,000 gal	ea	1,200
501,000-1,000,000 gal	ea	1,600
Compressors & refrigeration units		
< 50hp	ea	80
50-100 hp	ea	100
100-300 hp	ea	480
400-600 hp	ea	880
700-1,000 hp	ea	1,600
Agitators		
< 10 hp	ea	30
15-50 hp	ea	60
60-100 hp	ea	100

Table 19.1 (Continued)

Equipment	Unit	W-H
Reactors		
< 500 gal	ea	100
750	ea	120
1,000	ea	160
2,000	ea	200
5,000	ea	240
Shell & tube heat exchangers		
Up to 100 ft.^{2}	ea	40
200 ft.^{2}	ea	60
500 ft.^{2}	ea	80
1,000 ft.^{2}	ea	120
2,000 ft.^{2}	ea	160
Columns (typical)		
Up to 2 ft Dia. x 30 ft. height	ea	100
4 ft. Dia. x 50 ft. height	ea	160
6 ft. Dia. x 80 ft. height	ea	240
Columns Internals		
2 ft.–5 ft. Dia. columns	ea	40
6 ft.–8 ft. Dia. columns	ea	60
Demister	ea	20
Material handling equipment		
Field work hours will vary greatly depending on the extent of field assembly required. Check with vendor.		

Unit costs

Table 19.2 includes unit prices and work hours for the various types of concrete normally found in chemical projects. They can be used to estimate work done on a subcontracted basis.

The units costs are comprehensive and include a pro rata of all related components and operations, from excavation to form-stripping, clean-up and grouting. They are consistent with costs obtained from a large civil contractor in the Northeast and based on loaded labor of approximately $45/hr.

Table 19.2 Comprehensive Concrete Unit Costs/W-H

Type	Description	Labor W-H [(1)]	Subcontract $/CY
1	Ground slabs and area paving	6	345
2	Elevated slabs with metal deck	10	520
3	Equipment foundation, pile caps, grade beams	12	630
4	Structures & building footings, dike walls, sumps & pits	20	1,000
5	Structural concrete, columns, and elevated beams	30	1,300
6	Average all types	12	630

Includes excavation, back fill, rebar, forming, stripping, finish, grouting and craft foremen.
Does not include dewatering, purchased backfill, underground obstructions, special concrete treating, or curing.
[(1)] For planning purposes only. Cost of labor is included in subcontract cost.

Labor hours represent the average of several contractors and published data and are based on "Gulf Coast" productivity.

The cost can be easily corrected to specific locations by adjusting the hours to reflect local productivity and the hourly rate to reflect labor rates and contractors' mark-ups.

Table 19.3 lists the unit hours for the individual operations normally involved in concrete work. These units could be very useful to discuss and negotiate field extras.

Material take-offs

Table 19.4 reflects a very rough design based on conservative assumptions and is used to approximate the concrete volume related to steel structures and pipe racks.

Fig. 19.7 relates motor horse power to cubic yards of concrete and is used to estimate the approximate concrete volume for pumps. It assumes that the pumps will be set on individual foundations 4 ft. below ground level.

Table 19.3 Miscellaneous Concrete Unit Work Hours

Description	Unit	W-H
Hand excavation one lift med. soil	yd^3	1.60
Mach. excavation (typical) (1)	yd^3	0.10
Mach./hand excavation (typical) (2)	yd^3	0.30
Back fill and compact (manual)	yd^3	0.80
Form work Fab./Install/Strip	$ft.^2$	0.30
Rebar installation only (3)	lb	0.03
Pour concrete (average)	yd^3	2.50
Concrete finish	$ft.^2$	0.10
Anchor bolts and imbedded items	lb	0.10
Grout	$ft.^2$	0.30

(1) Backhoe medium soil.
(2) Mixed unit used by some contractors.
(3) Fabrication offsite.

Fig. 19.8 relates motor horse power to cubic yards of concrete for both reciprocal and centrifugal compressors. It is based on the rule of thumb that foundation weight should be 5 times the compressor weight.

Fig. 19.9 relates tank diameter to cubic yards of concrete for flat bottom tanks. It includes both concrete pads on top of existing slabs and independent ring foundations four feet deep.

Table 19.5 is used to estimate foundation volumes for tall tanks and towers. They have been derived from published information (Bauman, HC, Fundamentals of Cost Engineering in the Chemical Industry, Reinhold Publishing Co., 1964) and corrected for 125 mph winds.

Table 19.4 Comprehensive Concrete Take-Off Units

Description	CY concrete per 1000 ft.^{3} Structure — Foundation: Open Structure	Sheltered Structure	CY Concrete per 100 ft.^{2} Floor Area: Elev. Slabs 10 inch	Floor Slabs 6 inch	Tie Beams
Heavy structures vibrating load	1.7	2.0	3.0	2.0	1.5
Heavy structures minimum vibration	1.5	1.8	3.0	2.0	1.5
Average structures	1.3	1.6	3.0	2.0	1.2
Light structures	1.1	1.4	3.0	2.0	1.0
Service structures	0.7	0.9	-	-	1.0
One level pipe racks	0.6	-	-	-	-
Two level pipe racks	0.8	-	-	-	-
Three level pipe racks	1.0	-	-	-	-

Dike walls 4 ft. high 0.50 CY/ ft. Dike walls 1 ft. additional height 0.05 CY/ ft.

Table 19.5 Columns Foundations

W/D	Cubic Yards: L/D = 3-8	L/D = 10	L/D = 15	L/D = 20
	W based on empty vessel			
1	-	5	5	5
2	-	12	10	8
3	-	28	25	18
4	-	52	47	30
5	-	90	75	50
6	-	140	110	70
7	-	210	160	100
8	-	-	220	145
	W based on test weight full of water			
10	10	-	-	-
20	28	-	-	-
30	45	-	-	-
40	65	-	-	-
50	85	-	-	-
60	105	-	-	-
70	135	-	-	-

Basis: Soil bearing: 2,000 lb/ft.^{2} W – Weight, thousand pound.
Wind velocity: 125 mph D – Diameter, ft. L – Height, ft.

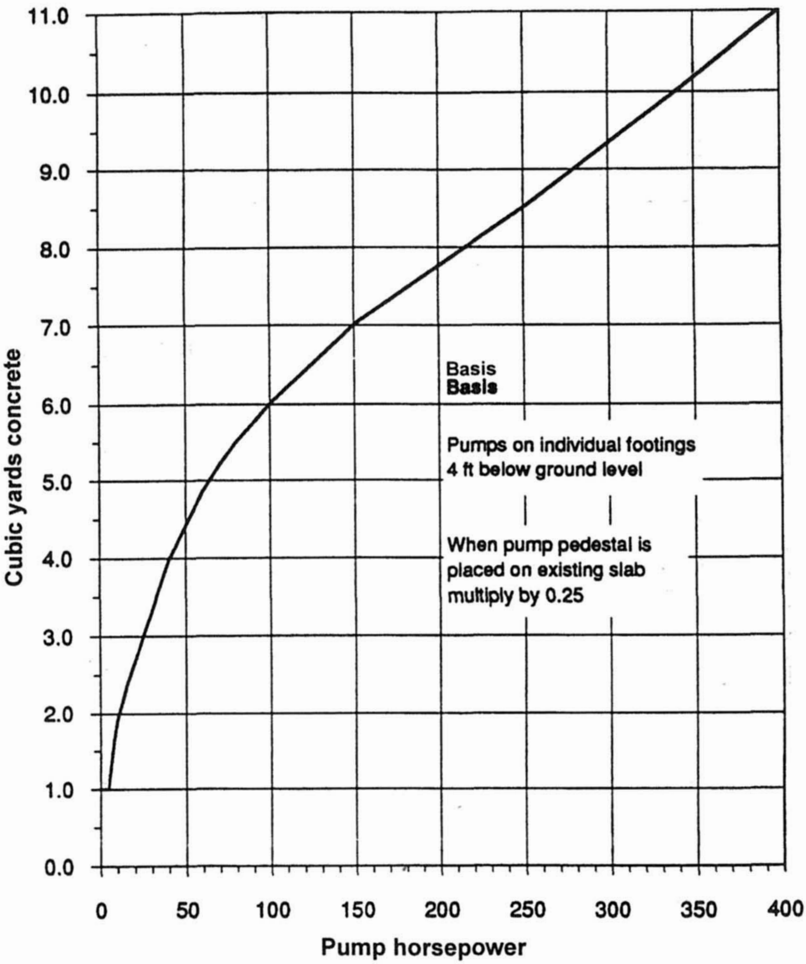
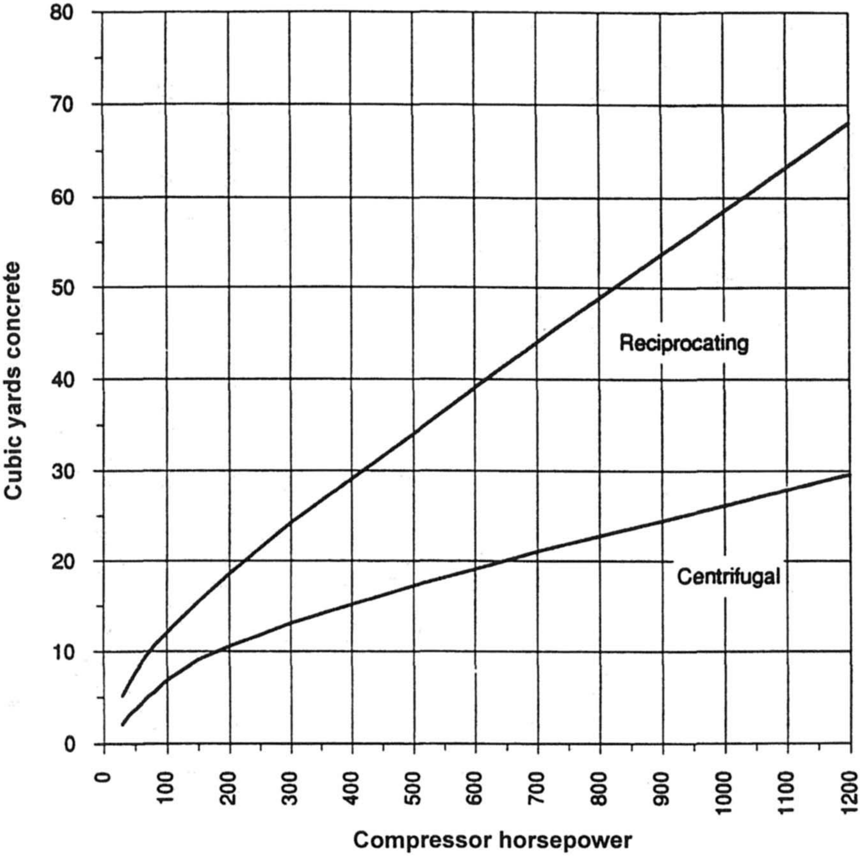


Figure 19.7 Pump foundation.



Basis: Weight of concrete is 5 times weight of compressor.

Figure 19.8 Compressor foundation.

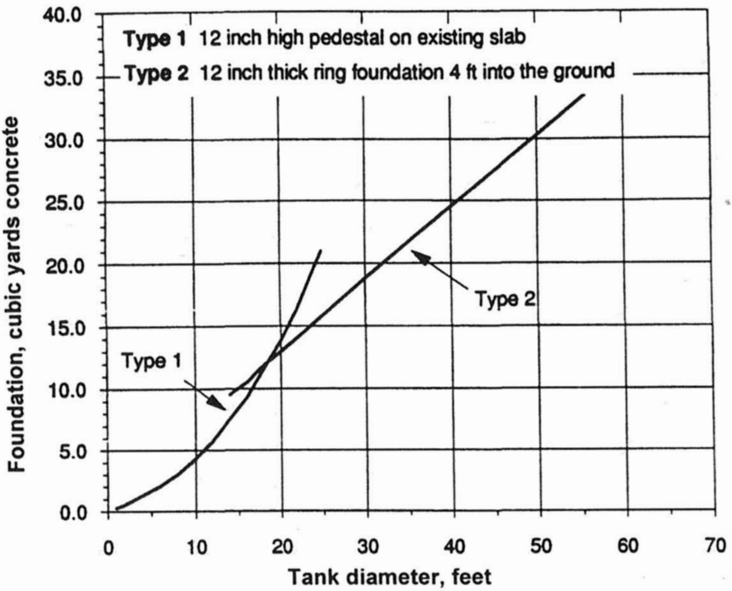


Figure 19.9 Concrete estimating system tank foundations.

Structural Steel

This procedure is used to estimate the weight, fabricated cost, and erection hours of the various types of steel structures required in a chemical plant. It is a very good tool for checking contractors' take-offs and estimates as well as discussing and evaluating field extras.

Bases for estimates

Material costs: Fabricated and delivered to the job site, including one primer and two finish coats of shop applied paint.

Erection hours: Represent the average of the hours used by several contractors and are based on competitive lump sum work basis.

Comprehensive unit weights (lb/ft.^{3}): Represent pondered averages derived from several actual cases.

Comprehensive unit costs: Developed from typical mixes of structural components in complex structures and the basic unit costs in Table 19.6.

Miscellaneous unit weights and costs: From published data and current costs.

Application

Complex structures: Calculate the total volume, including stairwells, to the highest platform and use the applicable units from Table 19.7.

Note: Do not include steel supporting roof and siding.

Table 19.6 Structural Steel Basic Units

Unit	Description		Cost, $ Per Ton	Cost, $ Other	Labor, WH Per Ton	Labor, WH Other
1	Heavy Steel, >40 lb/ft.		1,720	--	8	--
2	Medium Steel, 21-40 lb/ft.		1,890	--	12	--
3	Light Steel, 11-20 lb/ft.		2,360	--	25	--
4	Light Steel, 0-11 lb/ft.		2,950	--	40	--
5	Stairs – 2' 6" side w.o. handrailing		3,000	107.0/ft.	27	1.00/ft.
6	Handrailings	Straight	4,490	29.50/ft.	31	0.20/ft.
	With toe plate	Circular	5,660	36.60/ft.	31	0.20/ft.
7	Ladders with cage		8,400	84.00/ft.	44	0.45/ft.
8	Galvanized floor grating 1 1/4 x 3/16		2,060	9.00/ft.^{2}	32	0.14/ft.^{2}
9	Miscellaneous platforms around tank, vessels, towers, etc., w.o. grating		4,600	46.00/ft.^{2}	64	0.65/ft.^{2}
10	Galvanized floor grating for circular platforms		4,360	19.00/ft.^{2}	41	0.18/ft.^{2}
11	Shop applied paint system included in unit prices		500	--	--	--

Table 19.7 Comprehensive Structural Steel Costs

Unit	Description	Weight, lb/ft.^{3}	Cost, $/Ton	Erect. Labor, W-H/Ton
1	Heavy equipment structures with vibrating loads	3.30	2,570	16
2	Heavy equipment structures with minimal vibration	3.00	2,630	18
3	Average equipment structures	2.60	2,830	21
4	Light equipment structures – some equipment on individual foundations	2.10	2,920	23
5	Service structures – most equipment on individual foundations	1.50	3,810	32
6	1-tier pipe racks	1.00	2,130	15
7	2-tier pipe racks	1.20	1,850	19
8	3-tier pipe racks	1.40	2,130	19
9	Shelter structures – no equipment	1.40	2,130	19
10	Purlin system for corrugated roof and siding	3.00 per ft.^{2}	2,040	13

Units 1 through 5 include handrails, stairs, and ladders. Do not include floor grating since in some cases floors may be concrete.
All costs include one primer and two finish paint coats applied at the shop.

Table 19.8 Miscellaneous Structural Steel Unit Weights

Description	Weight
1 1/4 x 3/16 bar type grating	9.7 lb/ft.^{2}
1 x 3/16 bar type grating	8.0 lb/ft.^{2}
Ladder 1' 6" w.o. cage	10.0 lb/ft.
Ladder 1' 6" with cage	20.0 lb/ft.
2" L handrail with toe plate	14.0 lb/ft.
1 1/2" pipe handrail with toe plate	13.0 lb/ft.
Stairways – 2' 6" wide w.o. handrails	71.0 lb/ft.
Miscellaneous platforms around tanks and columns w.o. railing and grating	20.0 lb/ft.^{2}

Roof and siding: Calculate the volume of the structure supporting the roof and apply Unit 9 in Table 19.7. Calculate roof and wall area and apply Unit 10 in Table 19.7.

Pipe racks: Calculate volume and use applicable unit from Table 19.7.

Floor grating: Calculate area and apply Unit 8 in Table 19.6.

Miscellaneous: Apply units in Tables 19.6 and 1.8 as required.

Note: All-inclusive (loaded) labor rates can be developed for different areas as follows:

Iron worker journeyman base rate	1.00
Direct supervision	0.15
Indirects - PAC's, small tools, overhead, and profit	0.95
Multiplier	2.10

An additional $5/work hour is suggested to cover major construction equipment.

Miscellaneous Civil Work

The following unit costs provide ballpark estimates for civil work frequently encountered in chemical plant projects. Some have been obtained from contractors, others from published cost data, and the rest reflect the author's actual past experience.

Site Work

- Site clearing	$4,900/acre
- Excavation and disposal within 10 miles	$19/cy
- Compacted backfill including materials	$30/cy
- Asphalt roads (6 inch)	$25/sy
- 8-ft link fence	$30/ft.
- 50-ft wood piles	1,300 each
- Additional	$13/ft.
- Metal sheet piling	$37/ft.^{2}
- Railroad siding (including ballast)	$75/ft.
- Railroad switches	$64,000 each

- Culverts (without excavation)

1. 12-inch	$18/ft.
2. 18-inch	$25/ft.
3. 24-inch	$37/ft.
4. 36-inch	$87/ft.

- U.G. PVC sewers (installed)

1. 2-inch	$25/ft.
2. 3-inch	$27/ft.
3. 4-inch	$30/ft.
4. 6-inch	$37/ft.
5. 8-inch	$44/ft.
6. 10-inch	$52/ft.

Fire protection systems

The following units can be used to develop ballpark estimates for the different components of fire protection systems. They include excavation and backfill. When used to estimate grassroots plants, the estimated total should be checked with the factors in Chapter 5.

- U.G. water main

1. 6-inch	$49/ft.
2. 8-inch	$54/ft.
3. 10-inch	$63/ft.
4. 12-inch	$74/ft.

- Post indicator valves

1. 6-inch	$2,900 each
2. 8-inch	$3,100 each
3. 10-inch	$3,700 each
4. 12-inch	$4,400 each

- 6-inch hydrant including post indicator valve monitor and hoses — $6,900 each

- Deluge sprinkler systems

1. Extra hazard area (flammable service)	$7.00/ft.^{2} floor area
2. Regular hazard areas	$6.00/ft.^{2} floor area

- Additional cost items

Insurance companies usually require that a highly reliable secondary water source be provided in-house. This could be in the form of an elevated water tank or a ground level tank or reservoir with a diesel operated pump. The capacity of the reservoir should be at least two hours of the system design flow capacity. The cost of these items can be estimated with the equipment estimating procedure and included with the equipment account.

Buildings

- A small or medium sized grassroots unit in a developed site with main office, main laboratory, maintenance shop, warehouses, etc., will require at least one building including:

	Approximate Area
Transformer switchgear room	600 ft.^{2}
Control room	1,000 ft.^{2}
MCC room	600 ft.^{2}
2-3 production offices	400 ft.^{2}
1 field laboratory	200 ft.^{2}
1 lunch room	300 ft.^{2}
1 change room	500 ft.^{2}
Utility space	400 ft.^{2}
Total	4,000 ft.^{2}
Total Installed Cost (TIC)	Approx. \$600k

- The following units can be used to develop ballpark estimates of different types of buildings frequently associated with chemical plants:

	TIC/ft.^{2} (\$)
- Control room including computer floor 20 ft. x 40 ft. minimum	250
- MCC room including air conditioning 200 ft.^{2} minimum Plus 6 ft.^{2} per motor x 1.5	120
- Transformer switchgear room 20 ft. x 30 ft. minimum	100
- Miscellaneous buildings, maintenance shops, warehouse, guard house	80
- Front office (approx. 250 S.F. per employee)	300
- Field office	180
- Laboratory	350
- Process buildings	160

Other costs

- 8-inch concrete block wall including doors, windows, trims	$10.00/ft.^{2}
- Corrugated 20-ga. galvanized steel siding including doors, windows, trims	$6.00/ft.^{2}
- 2-inch thick galvanized sandwich panel siding including doors, windows, trim, but not the steel frame	$10.00/ft.^{2}
- Pre-engineered metal buildings including foundation, insulation, doors, trim, and lighting	$40/ft.^{2}
- Uninterruptible power supply unit to be added to control room cost	$60,000 each

19.4 Piping Estimating

Comprehensive Unit Prices

Tables 19.9 through 19.12 contain comprehensive unit prices and work hours for the fabrication and erection of process and interconnecting piping systems in carbon steel, 304 stainless steel, 316 stainless steel, and plastic-lined carbon steel pipe.

They are intended for estimating large volumes of mixed diameter piping of the type typically found in chemical process plants. They should not be used to estimate buildings' service piping nor to estimate one single line, even for a chemical plant. However, the basic unit prices and hours in Tables 19.15, 19.16, and 19.17 can be used to develop estimates for any specific case, provided detailed take-offs are available.

These comprehensive units, based on the models illustrated in Tables 19.13 and 19.14, include all the costs related to the fabrication, erection, and testing of piping systems, except the cost of valves, which are priced separately.

Table 19.9 Comprehensive Piping Estimating Units – Carbon Steel

Dia., in.	Sched.	Piping – per foot: Process areas Mat'l,$	Process areas Labor, hr. Fab.	Process areas Labor, hr. Erect.	Interconnecting Mat'l, $	Interconnecting Labor, hr. Fab.	Interconnecting Labor, hr. Erect.	Valves - each Mat'l,$	Valves Labor, hr. Fab.	Valves Labor, hr. Erect.
Up to 1	80	12.50	--	0.63	--	--	--	--	--	1.0
1 1/2	80	15.00	--	0.77	6.70	--	0.37	--	--	1.4
2	40	15.00	0.71	0.45	7.60	0.12	0.40	104.00	2.0	2.2
3	40	17.10	0.73	0.53	10.00	0.14	0.46	127.00	2.6	3.1
4	40	21.10	0.78	0.64	12.90	0.16	0.56	160.00	3.1	3.8
6	40	30.00	0.97	0.85	19.10	0.19	0.75	242.00	4.4	4.8
8	40	40.60	1.05	1.11	27.10	0.22	0.89	426.00	5.4	6.8
10	Std.	55.20	1.08	1.35	38.30	0.26	1.04	715.00	6.6	9.4
12	Std.	71.00	1.09	1.62	53.00	0.27	1.22	1,040.00	7.7	11.0

Material: A106/A53 C.S Rating: 150 lb.
Connections SWD up to 1 1/2 B.W/flg. over 1 1/2.
Service Process – Non-corrosive hydrocarbons and inorg. solutions and utilities.

Materials

- Pipe.
- Fittings.
- Flanges.
- Vents, drains, and instrument connection.
- Non-structural hangers and supports.

The materials cost represent current market prices and are shown in Tables 19.15 and 19.16.

Table 19.10 Comprehensive Piping Estimating Units – 304 SS

Dia., in.	Sched.	Piping – per foot						Valves - each		
		Process areas			Interconnecting					
			Labor, hr.			Labor, hr.			Labor, hr.	
		Mat'l,$	Fab.	Erect.	Mat'l, $	Fab.	Erect.	Mat'l,$	Fab.	Erect.
Up to 1	10	26.50	0.92	0.30	--	--	--	97.00	2.0	1.5
1 1/2	10	27.20	0.97	0.38	14.50	0.14	0.36	99.00	2.3	1.8
2	10	30.00	1.00	0.49	16.80	0.16	0.47	110.00	3.2	2.4
3	10	36.80	1.10	0.59	22.80	0.19	0.53	152.00	4.1	3.1
4	10	45.00	1.22	0.71	29.30	0.22	0.66	198.00	5.0	3.8
6	10	70.50	1.49	0.96	46.00	0.28	0.89	364.00	7.2	4.8
8	10	104.00	1.73	1.31	70.00	0.36	1.10	640.00	9.4	6.8
10	10	147.00	1.90	1.63	102.00	0.43	1.32	1,035.00	11.9	9.4
12	10	182.00	1.98	1.98	135.00	0.51	1.57	1,518.00	15.0	11.0

Material: 304 SS Rating: 150 lb.
Connections Up to 3/4 S.W. 1 in & over B.W. & L.J. flg.
Service Process – Corrosive hydrocarbons & inorg. solutions.

Labor

- Unloading, storing, and bagging.
- Layout and fit up.
- Shop and field welds and joints.
- Valve handling and installation.
- Installation of vents, drains, and instrument connections (trims).
- Installation of hangers and supports.
- Hydrotesting.

The unit hours were derived from the basic units in Table 19.17, which represents the pondered average of nine different sources, contractors as well as published data. They are based on direct hire (reimbursable) work. For work done through a competitive lump sum contract, the figures must be reduced by 15%.

Table 19.11 Comprehensive Piping Estimating Units – 316 SS

Dia., in.	Sched.	Piping – per foot						Valves - each		
		Process areas			Interconnecting					
			Labor, hr.			Labor, hr.			Labor, hr.	
		Mat'l,$	Fab.	Erect.	Mat'l, $	Fab.	Erect.	Mat'l,$	Fab.	Erect.
Up to 1	40	30.60	0.92	0.30	--	--	--	106.00	2.0	1.5
1 1/2	10	31.30	0.97	0.38	17.30	0.14	0.36	108.00	2.3	1.8
2	10	35.10	1.00	0.49	20.80	0.16	0.47	122.00	3.2	2.4
3	10	44.30	1.10	0.59	28.40	0.19	0.53	168.00	4.1	3.1
4	10	53.00	1.22	0.71	34.50	0.22	0.66	219.00	5.0	3.8
6	10	85.00	1.49	0.96	56.00	0.28	0.89	400.00	7.2	4.8
8	10	126.00	1.73	1.31	89.00	0.36	1.10	704.00	9.4	6.8
10	10	184.00	1.90	1.63	130.00	0.43	1.32	1,140.00	11.9	9.4
12	10	226.00	1.98	1.98	169.00	0.51	1.57	1,670.00	17.0	11.0

Material: 316 SS Rating· 150 lb
Connections Up to 3/4 S.W. 1 in & over B.W. & L J flg.
Service Process – Corrosive hydrocarbons & inorg. solutions.

As shown in Tables 19.13 and 19.14, the fitting density varies with line size for the process area piping. The densities reflect actual experience on several projects and coincide with those used by others.

In addition to preparing estimates, these units can be very useful for:

- Checking estimates.
- Analyzing lump sum bids.
- Discussing and evaluating field changes.
- Monitoring field progress.

Note of caution: When checking estimates, it must be remembered that on sizes 2 1/2 in. and above, the process area pipe is usually prefabricated away from the field and some estimates would show pipe fabricated offsite as material cost. In that case, the cost will include:

- Bare materials.
- Cost of procuring material.
- Labor costs at shop rate.
- Shop overhead and profits.

Table 19.12 Comprehensive Piping Estimating Units: Saran/PPL/Kynar/Teflon-Lined Carbon Steel

Dia., in.	Materials - $/ft. Saran 60°C	Polypropylene 100°C	Kynar 140°C	Teflon 200°C	Erection labor, hr/ft.
Process Areas					
1	69.00	74.00	109.00	108.00	0.60
1 1/2	73.00	80.00	96.00	110.00	0.64
2	77.00	84.00	105.00	119.00	0.68
3	91.00	98.00	130.00	144.00	0.77
4	109.00	119.00	166.00	182.00	0.85
6	120.00	176.00	253.00	300.00	1.05
8	224.00	251.00	353.00	437.00	1.24
Interconnecting					
1	22.70	24.20	32.00	40.30	0.30
1 1/2	25.60	28.30	38.90	46.00	0.32
2	28.80	32.60	45.10	52.90	0.37
3	38.30	43.40	63.00	72.00	0.44
4	49.80	56.40	87.00	98.00	0.53
6	80.00	92.00	144.00	175.00	0.69
8	126.00	142.00	212.00	290.00	0.82

Material: Schd. 40 lined CS rating: 150 lb.
Connections: Ductile iron flgs. & fittings.
Service: Corrosive hazardous liquids compatible with liner composition and temperature rating

Should process and/or safety conditions dictate the use of forged steel flanges and fittings cost of materials will increase by:
15% for process areas.
10% for interconnecting.

Table 19.13 Comprehensive Piping Units Model: Carbon Steel/304 SS/316 SS

	Per 100 feet of piping							
					Welds			
Dia., in.	Fittings	Flanges	Trims	Hang.& Supp.	Shop	Field	Joints	Bolt ups
Process Areas								
Up to 1	30	4	3	15	70 (1)	6 (1)	70 (2)	4
1 1/2	27	4	6	10	64 (1)	6 (1)	64 (2)	4
2	24	4	6	10	52	6	-	4
3	20	4	6	8	44	6	-	4
4	18	4	6	8	40	6	-	4
6	16	4	6	8	36	6	-	4
8	14	4	6	8	32	8	-	4
10	12	4	6	8	28	8	-	4
12	10	4	6	8	24	8	-	4
Interconnecting								
All	6	2	2	8	6	8	-	2

(1) Stainless steel pipe only. (2) Carbon steel pipe only.

Table 19.14 Comprehensive Piping Units Model: Plastic Lined Carbon Steel

	Per 100 feet of piping					
		Flanges				
Dia., in.	Fittings	Shop	Field	Trims	Hang. & Supports	Bolt ups
Process Areas						
1	30	47	2	3	12	25
1 1/2	27	42	2	6	10	22
2	24	38	2	6	10	20
3	20	32	2	6	8	17
4	18	29	2	6	8	16
6	16	26	2	6	8	14
8	14	23	2	6	8	13
Interconnecting						
All	6	10	2	2	10	7

Table 19.15 Basic Piping Materials Unit Costs in Dollars
Carbon Steel / 304 SS / 316 SS

	Dia. in.								
	Up to 1	1.5	2	3	4	6	8	10	12
Carbon Steel									
Pipe, ft	0.85	1.38	1.90	3.82	5.45	9.00	13.50	19.10	25.40
Fttg, ea	7.60	17.60	10.40	14.85	22.80	48.70	90.00	161.00	237.00
Flg, ea	19.60	21.00	24.00	29.00	39.00	61.00	90.00	133.00	196.00
Trim, ea	115.00	115.00	115.00	115.00	115.00	115.00	115.00	115.00	115.00
304 SS									
Pipe, ft	5.95	7.00	8.65	13.30	17.30	27.30	42.80	58.00	74.00
Fttg, ea	12.50	12.40	14.30	26.40	43.00	127.00	248.00	442.00	637.00
Flg, ea	37.00	37.00	43.00	54.00	72.00	128.00	213.00	450.00	587.00
Trim, ea	230.00	230.00	230.00	230.00	230.00	230.00	230.00	230.00	230.00
316 SS									
Pipe, ft	7.70	9.00	11.50	17.90	22.00	35.40	56.60	77.40	95.50
Fttg, ea	15.70	15.70	17.60	33.00	55.00	158.00	306.00	553.00	814.00
Flg, ea	41.00	41.00	48.00	60.00	80.00	142.00	245.00	512.00	782.00
Trim, ea	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00

Fitting 2/3 90 L/R. Ell + 1/3 Tee. **All Flanges** Include prorata of gaskets, bolts & nuts.
SS Flanges CS Slip on & SS stub end. **Trims** Include 3/4 in. coup. and 3/4 in. plug valve.

Table 19.16 Basic Piping Materials Unit Costs in Dollars
Plastic-Lined Carbon Steel

	Dia. in.						
	Up to 1	1.5	2	3	4	6	8
Saran Lined CS							
Pipe, ft.	4.30	5.80	6.50	10.70	15.60	27.60	49.00
Fttg, ea	80.00	90.00	106.00	154.00	200.00	376.00	594.00
Flg, ea	26.50	28.80	33.40	48.30	67.00	103.00	162.00
Trim, ea	450.00	470.00	485.00	520.00	565.00	670.00	860.00
PPL Lined CS							
Pipe, ft.	5.00	7.20	8.50	14.20	20.60	38.30	61.00
Fttg, ea	87.00	101.00	123.00	159.00	212.00	382.00	625.00
Flg, ea	28.80	31.10	35.70	51.80	72.00	110.00	176.00
Trim, ea	460.00	490.00	510.00	540.00	590.00	700.00	910.00
Kynar Lined CS							
Pipe, ft.	10.95	15.60	17.90	28.20	41.40	74.00	109.00
Fttg, ea	88.00	107.00	129.00	199.00	248.00	535.00	914.00
Flg, ea	35.70	38.00	46.00	65.00	114.00	138.00	192.00
Trim, ea	490.00	560.00	580.00	620.00	680.00	830.00	1040.00
Teflon Lined CS							
Pipe, ft.	16.10	19.80	24.00	34.50	49.70	97.00	174.00
Fttg, ea	136.00	143.00	164.00	235.00	331.00	683.00	990.00
Flg, ea	38.00	38.00	39.00	46.00	66.00	92.00	143.00
Trim, ea	490.00	560.00	580.00	620.00	680.00	830.00	1040.00

Table 19.17 Basic Piping Labor Units Based on Direct Hire Construction [(1)]

	Dia., in.									
	0.75	1	1.5	2	3	4	6	8	10	12
Handling & Fit-up, hr/100 ft. [(2)]										
Steel Pipe										
Proc.	20	20	20	25	30	35	50	60	75	90
Inter	-	15	15	18	20	25	35	40	45	50
Lined Pipe										
Proc.	-	22	23	27	32	35	50	60	-	-
Inter	-	12	12	14	15	20	30	35	-	-
Plastic Pipe										
Proc.	12	12	14	18	20	25	35	40	45	50
Inter	-	8	10	12	14	16	25	30	35	40
Joints, hr/ea										
Screwed [(3)]										
Shop	0.30	0.35	0.45	0.55	-	-	-	-	-	-
Field	0.35	0.40	0.55	0.70	-	-	-	-	-	-
S.W. Metal										
Shop	0.45	0.50	0.65	1.05	-	-	-	-	-	-
Field	0.50	0.60	0.80	1.30	-	-	-	-	-	-
Plastic Bell Conn										
Shop	0.40	0.40	0.40	0.45	0.55	0.60	0.70	0.80	1.10	1.20
Field	0.50	0.50	0.50	0.55	0.70	0.75	0.90	1.00	1.35	1.50
Butt Welds, hr/ea										
A53 Cs [(4)]										
Schd	80	80	80	40	40	40	40	40	40	40
Shop	0.3	0.8	1.0	1.2	1.5	1.8	2.6	3.2	3.8	4.5
Field	1.0	1.0	1.2	1.5	1.9	2.3	3.2	4.0	4.8	5.6
304/316 [(5)]										
Schd	40	10	10	10	10	10	10	10	10	10
Shop	1.1	1.2	1.4	1.8	2.4	3.0	4.2	5.6	7.1	8.7
Field	1.4	1.5	1.7	2.3	3.0	3.7	5.3	7.0	8.9	10.9
Misc., hr/ea										
Valves [(6)]	0.4	0.4	0.5	0.8	1.2	1.5	2.0	3.0	4.0	5.0
Bolt ups	0.7	0.7	0.8	1.0	1.2	1.5	1.8	2.5	3.5	4.0
Hang.& Supp.	1.0	1.0	1.2	1.5	2.0	2.5	3.0	3.5	4.0	5.0

(1) For competitive lump sum construction multiply by 0.85.
(2) Includes receiving, storing, rigging, aligning, tack welding (when required), and testing of all pipe & fittings.
(3) Includes cutting & threading.
(4) For Cr-Moly Cs add 25%.
(5) Correction for different alloys: Alloy 20/Monel/Aluminum – add 5%.
Nickel/Hasteloy – add 40%.
(6) Handling only: Installation of companion flanges and bolt ups must be added.

Miscellaneous Comprehensive Unit Prices

Some piping items will usually not be shown in the P&ID's and are often missed in the estimates. The items included in Table 19.18 should cover most of these cases. They should be addressed when checking an estimate or preparing one.

Heat Tracing - The heat tracing units, steam and electrical, were developed in the late 1980's with the help of construction contractors and have been escalated to late 2000 (C.E. plant cost index of 420). The models used to prepare the unit prices are shown in Appendix J and can be used to adapt them to different circumstances.

The heat tracing costs could be reduced by 20-30% with judicious design and optimization of the length of pipe that can be traced with the maximum allowable tracer. However, no credit should be taken for optimization until detailed engineering is done.

Utility Stations - Utility stations (steam, air, and water) with 50-ft. hoses are normally required in process areas. A station should be provided for approximately every 5,000 ft.^{2} of process area or at least one per level of structure. This unit includes three 50-ft. runs of 1-in. carbon steel pipe with one service valve each. The hoses, heat tracing, and insulation are not included.

Safety Stations - Most process plants require safety showers and eye wash fountains strategically located in the process area. The number must be determined based on safety requirements and operating areas. This unit includes one safety shower, one eye wash fountain, 50 ft. of 3/4-in. carbon steel pipe and two 3/4-in. valves. Steam tracing, insulation, and lights are not included.

Instrument Purge - On occasion the process requires that some instrument be purged with either air or inert gas. This unit includes 50 ft. of 1/2-in. carbon steel line and one valve.

Equipment Drains - Most equipment items have drains which must be run to nearby collecting systems. The size will vary with the size of the equipment, but 1 1/2-in. is a realistic average size. The units include one 1 1/2-in. valve and 20 ft. of process type pipe.

Sump Ejector - Curbed areas and dikes are usually provided with a sump and a small steam ejector to empty it. This unit requires insulated steam piping, valve, ejector, and condensate traps.

Steam Traps - Steam trap assemblies are usually shown in the P&ID's but no cost has been provided elsewhere. An allowance is included here.

Utility Headers - Allowances should be made to run utility headers (service and instrument air, cooling water supply and return, steam, process water, potable water, etc.) through the longest axis of the process units. Size varies with the plant. Use the interconnecting piping units to estimate utility headers.

Table 19.18 Miscellaneous Piping Estimating Units

Description	Act. Pipe covered by circuit	Unit	Mat'l, $	Labor, WH	S.C, $
A. Heat Tracing					
Electric					
Up to 4" pipe 1-Tracer					
Winterizing Service	260	LF	15.60	0.16	25.70
250° F process service	130	LF	27.50	0.20	40.70
300° F process service	220	LF	34.70	0.16	51.40
6" to 10" Pipe 2-Tracers					
Winterizing Service	160	LF	31.10	0.32	51.40
250° F process service	130	LF	54.80	0.40	81.60
300° F process service	220	LF	69.30	0.32	93.40
12" & Up Pipe 3-Tracers					
Winterizing Service	160	LF	46.70	0.48	77.20
250° F process service	130	LF	82.20	0.60	123.00
300° F process service	220	LF	104.00	0.48	140.00
Steam					
Up to 4" pipe 1-Tracer					
Screwed & welded pipe		LF	26.10	0.80	72.90
Flanged pipe		LF	28.40	1.10	84.60
6" to 10" Pipe 2-Tracers					
Screwed & welded pipe		LF	52.20	1.60	145.80
Flanged pipe		LF	56.80	2.20	218.00
12" & Up Pipe 3-Tracers					
Screwed & welded pipe		LF	78.30	2.40	219.00
Flanged pipe		LF	85.20	3.30	254.00
B. Miscellaneous Composite Units					
Utility station water/air/steam		ea	1,040.00	125	-
Safety station shower/eye wash		ea	730.00	50	-
Instrument purge		ea	260.00	25	-
CS equip. drain		ea	300.00	10	-
304 SS equip. drain		ea	990.00	15	-
Sump ejector		ea	600.00	20	-
Steam traps		ea	1,190.00	20	-

The instrument air distribution system (headers and subheaders) is considered part of the piping account up to the distribution points to the individual users. The lines to the individual instruments and control valves are considered part of the instrumentation account and the cost is included in the instrumentation estimate.

Note: Another item often overlooked is the piping, instrumentation, and electrical costs associated with double seal pumps (seal oil pot, piping, pressure controls, and interlocks). The cost is included in the pump estimation procedure.

Miscellaneous Valves Costs

Table 19.19 represents the average cost of valves purchased at different times escalated to late 2000. These costs should only be used for conceptual or preliminary estimates when no prices are available. Since the cost variations from one manufacturer to another can be astronomical, definitive estimates should be based on vendors' quotes or, at least, on recent purchases.

19.5 Insulation Estimating

Tables 19.20 through 19.23 can be used either for semi-detailed or detailed estimating of piping and equipment, hot and cold insulation.

The basic piping insulation units in Table 19.20 and the equipment insulation units in Table 19.23 were provided by an Eastern Shore contractor and have been escalated to late 2000 level.

The comprehensive piping units in Tables 19.21 and 19.22 were developed with the basic units in Table 19.20 and the fitting density used for the piping comprehensive units (Table 19.13) applying the linear-feet-per-fitting equivalence normally used in the trade:

- Fittings
  1. Up to 2 in. — 1.3 ft./ftg.
  2. 3 in. — 2.0 ft./ftg.
  3. 4 in. and up. — 3.0 ft./ftg.
- Flanges — 4.0 ft./ftg.

Table 19.19 Approximate Cost of Valves

Conn.	Dia., in.	Ball	Plug	Check	Gate	Globe	Btly
				Carbon Steel			
SWD or SW							
	1	80	70	50	60	70	60
	1.5	90	90	80	110	130	70
Flg.							
	2	220	190	230	270	350	180
	3	390	340	340	370	540	220
	4	590	510	440	450	730	280
	6	1,100	900	630	750	1,100	440
	8	2,000	1,700	1,100	1,100	1,500	620
	10	3,200	2,800	1,700	1,700	2,600	830
	12	4,800	4,100	2,400	2,400	3,900	1,300
				316 Stainless Steel			
SWD or SW							
	1	160	150	230	240	300	120
	1.5	270	260	360	340	430	150
Flg.							
	2	500	430	440	480	550	370
	3	860	740	750	700	960	480
	4	1,300	1,100	1,100	920	1,400	600
	6	3,100	2,700	1,900	1,600	3,500	980
	8	5,800	5,000	3,600	3,100	6,600	1,400
	10	9,300	7,900	5,800	5,200	10,700	1,900
	12	13,100	11,700	8,600	8,000	16,200	2,300
				Teflon Lined Carbon Steel			
Flg.							
	1	140	130	80	110	130	90
	1.5	170	160	150	170	230	130
	2	390	340	400	500	630	300
	3	700	600	600	660	980	400
	4	1,100	920	790	820	1,300	480
	6	1,900	1,700	1,200	1,400	2,100	800
	8	3,700	3,100	2,000	2,000	2,900	1,200
	10	5,900	5,100	3,100	3,100	4,700	1,500
	12	8,700	7,500	4,400	4,400	7,100	1,900

Table 19.20 Basic Piping Insulation Units

Dia., in	Dollars & work hours per L.F.											
	1 in. thk		1.5 in. thk		2 in. thk		2.5 in. thk		3 in. thk		4 in. thk	
	Mat'l	Lab	Mat'l	Lab	Mat'l	Lab	Mat'l	Lab	Mat'l	Lab	Mat'l	Lab
Up to 1	2.80	0.20	4.80	0.21	7.50	0.23	8.50	0.26	11.40	0.31	19.00	0.38
1.5	3.10	0.20	5.40	0.21	8.30	0.23	9.50	0.26	12.20	0.31	19.80	0.38
2	3.30	0.21	5.90	1.22	8.70	0.24	9.70	0.27	12.70	0.32	19.90	0.39
3	4.10	0.22	6.70	0.23	10.00	0.25	11.90	0.28	14.50	0.34	22.30	0.41
4	5.30	0.23	7.60	0.34	11.50	0.26	13.20	0.30	16.90	0.36	24.30	0.44
6	6.50	0.25	8.80	0.27	13.30	0.31	17.60	0.35	20.60	0.42	29.30	0.50
8	9.20	0.29	10.90	0.32	16.60	0.36	21.00	0.42	25.40	0.48	32.50	0.58
10	10.80	0.34	13.70	0.37	19.80	0.42	25.10	0.49	29.30	0.55	39.40	0.68
12	12.30	0.39	15.00	0.43	21.80	0.50	27.40	0.57	32.90	0.66	43.40	0.80
14	14.30	0.45	17.30	0.50	24.60	0.57	30.90	0.66	37.40	0.76	47.10	0.93
16	16.90	0.52	19.50	0.58	27.00	0.66	34.30	0.75	42.30	0.87	52.10	1.05
18	18.20	0.57	22.10	0.66	29.50	0.75	37.40	0.85	46.00	0.98	56.60	1.18
20	20.30	0.64	23.50	0.75	32.60	0.84	40.70	0.96	49.70	1.10	60.50	1.32

Conversion Factors
Foam glass w SS jacket
Mat'l x 1.30
Labor x 1.35
Alum. jacket: Mat'l x 0.90
PVC jacket: Mat'l x 0.85

Material: Fiber glass & SS jacket
Service: Up to 400° F

All units are based on doing the work at an average height of 10 to 30 feet above floor level.

Table 19.21 Comprehensive Piping Insulation Estimating Units: Hot Service

Dia., in.	Thickness, in.	Piping – per L.F.				Valves, Each	
		Process & utility areas		Interconnecting			
		Labor, hr	S.C.,$	Labor, hr	S.C.,$	Labor, hr	S.C.,$
Up to 1	2	0.36	29.50	0.27	21.80	0.30	26.00
1.5	2	0.36	30.40	0.27	22.70	0.50	37.40
2	2 1/2	0.41	34.50	0.32	26.70	2.60	165.00
3	3	0.52	48.30	0.43	39.10	3.40	315.00
4	3	0.61	58.20	0.48	41.00	4.10	390.00
6	3 1/2	0.76	76.30	0.61	61.30	5.10	523.00
8	4	0.92	95.70	0.76	71.80	6.40	680.00
10	4	1.03	110.00	0.90	95.00	7.50	880.00
12	4	1.17	120.00	1.06	109.00	8.80	920.00
14	4	1.33	131.00	1.23	122.00	10.10	1,030.00
16	4	1.47	144.00	1.39	136.00	11.60	1,180.00
18	4	1.62	157.00	1.56	150.00	13.00	1,280.00
20	4	1.81	171.00	1.74	164.00	14.40	1,390.00

Subcontract = Mat'l + work hour @ $45/hr.
Material: Fiber glass & SS jacket.
Service: Up to 400°F.

Table 19.22 Comprehensive Piping Insulation Estimating Units: Cold Service

Dia., in	Thickness, in.	Piping – per L.F.				Valves, Each	
		Process & utility areas		Interconnecting			
		Labor, hr	S.C.,$	Labor, hr	S.C.,$	Labor, hr	S.C.,$
1	2	0.49	39.40	0.36	28.80	0.40	34.30
1.5	2	0.49	40.60	0.36	30.00	0.63	50.70
2	2	0.49	40.70	0.38	31.50	3.50	294.00
3	2.5	0.59	52.60	0.48	42.70	4.60	418.00
4	2.5	0.69	62.60	0.53	47.90	5.50	515.00
6	2.5	0.75	73.70	0.62	60.20	6.80	694.00
8	2.5	0.90	86.50	0.75	72.20	8.60	897.00
10	2.5	1.00	97.90	0.87	85.10	11.10	1,070.00
12	2.5	1.12	103.00	1.01	95.80	11.50	1,220.00
14	3	1.47	140.00	1.35	130.00	15.60	1,300.00
16	3	1.64	156.00	1.55	147.00	15.70	1,550.00
18	3	1.81	170.00	1.74	163.00	17.60	1,690.00
20	3	2.03	130.00	1.96	181.00	19.40	1,830.00

Subcontract = Mat'l + work hour @ $45/hr.
Material: Fiber glass & SS jacket.
Service: Down to 6°F.

Table 19.23 Equipment Insulation Estimating Units

Insulation Material	Thk, in.	Per S.F. Labor, hr	S.C., $
Fiberglass with SS jacket	1 1/2	0.19	13.40
	2	0.19	14.80
	2 1/2	0.20	16.80
	3	0.20	18.70
	3 1/2	0.21	19.80
	4	0.24	22.60
Foam glass with SS jacket	1 1/2	0.25	17.30
	2	0.25	19.00
	2 1/2	0.26	21.50
	3	0.26	23.80
	3 1/2	0.28	25.70
	4	0.32	29.10

19.6 Electrical Work Estimating Procedure

Introduction

Accurate cost estimates for electrical work can be prepared after a reasonable amount of engineering has been completed. This method is time consuming and costly and, if the project is not approved, wasteful.

At the other extreme, electrical work could be estimated as a percent of the equipment costs. However, this method is not only very inaccurate (published information shows a range of 10% to 50% of equipment cost), but also does not provide a means of cost tracking or progress monitoring.

The cost of the electrical account is mainly related to motor count and average horsepower per motor rather than to equipment cost or total horsepower.

- The cost of connecting the motor of a $1,000 pump is the same as for the motor of a $50,000 agitator.
- The cost of connecting one 100-hp motor will probably be less than 20% of the cost of connecting ten 10-hp motors.
- The process areas requiring lighting will normally be directly proportional to the number of motors and average horsepower.

This procedure presents a quick and reasonably accurate system to estimate the electrical account at different levels of engineering design in sufficient detail for subsequent cost tracking and progress monitoring. It can be used for grassroots plants/units as well as for retrofit work.

Scope

The estimating units are intended in general to include all electrical materials and installation costs, except as noted below, for process and utility areas up to and including 480 V substations and associated switchgear.

- Instruments and DCS wiring are considered part of the instrumentation account and the pertinent estimating units have been included in the instrumentation estimating procedure.
- The cost of main substation, high-voltage distribution, and yard lighting must be estimated separately.

The comprehensive materials and work hours charts (Figs. 19.10 and 19.11) were developed from a theoretical model of a plant with one hundred 460 V motors of different sizes, half of them with interlocks, including allowance for lighting, welding receptacles, 110 V outlets, and grounding, directly proportional to the average hp/motor. The material costs and labor hours are based on the composite unit costs in Table 19.24.

The unit prices and unit hours represent composites of all materials and operations required for a finished product; i.e., the motor hook-up units include the breakers, push button, a pro rata of the MCC cabinet conduits or cable trays, power and control wiring, terminators, miscellaneous supports, unloading and storing materials, testing and commissioning, etc.

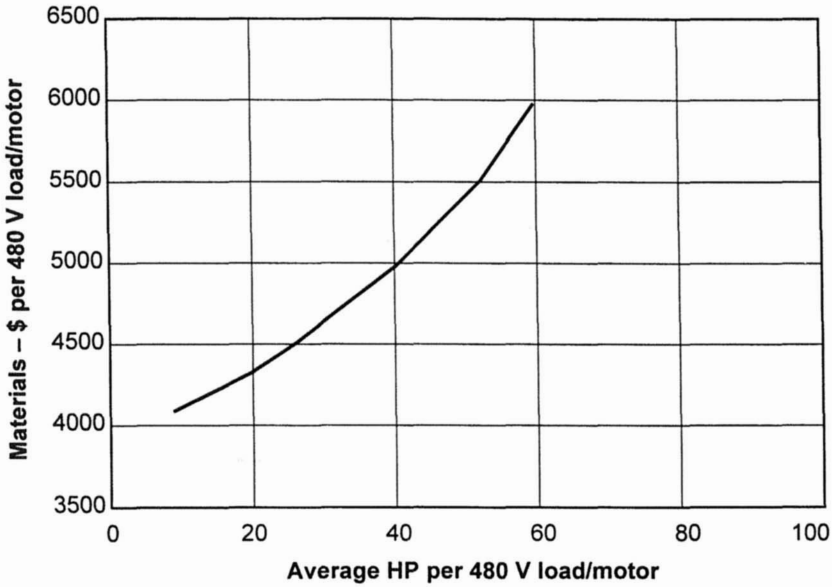
All units are based on Class I, Division 2 service. Occasionally, some sections of a plant are classified as Division 1. In those individual areas, the costs may increase by as much as 50%.

Application

Conceptual estimate

A conceptual estimate can be developed in a few minutes from the preliminary equipment list as follows:

- Identify and count pumps, agitators, compressors, material handling equipment, and other items requiring electric motors.



Includes:
- All 480 V power wiring for both process and non-process service.
- Process area lighting and misc. 110 V loads.
- Hard wire interlocks.
- Grounding.

Excludes:
- Main substation & high volt dist.
- 480V transformer & switch gear.
- High voltage motors wiring.
- Instrumentation wiring.
- Electric heat tracing.
- Non-process buildings lighting.
- Yard lighting.

Figure 19.10 Cost of installation materials per 480 V load/motor.

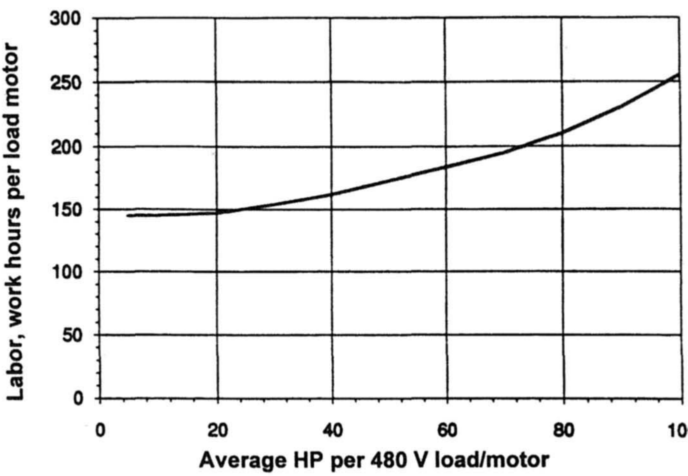
- Identify and count 460 V electric heaters and treat them as motors. Other 460 V and higher loads such as heaters, lighting transformers, service feeders to building, etc., are also treated as motors.
- Make allowance for multiple motors in packages, such as lubricating pumps.
- Make allowance for electric motors not included in equipment list, such as fans, HVAC equipment, motor-operated valves and doors, etc., using 480 V.
- Estimate cost by multiplying total motor count by $21,000; approximately $12,300 for materials and 175 work hours at $48/hr.

Note: This cost is valid only for plants averaging 20 hp/motor or less and does not include the cost of inactive areas (yard) lighting.

Preliminary estimate

A preliminary estimate can be developed in less than two hours with a complete equipment list showing approximate motor horsepower:

- Count 460 V motors and electric loads as before.
- Identify motors operating above 460 V.
- Calculate total 460 V load and average horsepower per motor.
- Use Figs. 19.10 and 19.11 to determine cost of 460 V and 120 V system and Table 19.24 to determine the cost of the substation (1,000 kVA module), the large horsepower motors and the offsite lighting.



Includes:
- All 480 V power wiring for both process and non-process service.
- Process area lighting and misc. 110 V loads.
- Hard wire interlocks.
- Grounding.

Excludes:
- Main substation & high volt dist.
- 480 V transformer & switch gear.
- High voltage motors wiring.
- Instrumentation wiring.
- Electric heat tracing.
- Non-process buildings lighting.
- Yard lighting.

Figure 19.11 Installation labor per 480 V load/motor.

Table 19.24 Comprehensive Electrical Estimating Units

Volts	Description	Unit	Fixed Cost Mat'l, $	Fixed Cost Labor, W-H	Variable Cost per 100 ft Mat'l, $	Variable Cost per 100 ft Labor, W-H
460	1-25 hp	ea	1,300	25	410	25
	50 hp	ea	1,700	40	600	25
	75 hp	ea	2,800	50	800	25
	100 hp	ea	3,000	55	1,400	45
	150 hp	ea	4,800	80	1,600	50
	200 hp	ea	5,200	85	2,700	60
	250 hp	ea	7,400	105	3,400	75
	50 Amp Feeder (25 kVA)	ea	530	25	410	25
	100 Amp Feeder (50 kVA)	ea	790	30	600	25
	200 Amp Feeder (100 kVA)	ea	1,090	45	1,400	45
	300 Amp Feeder (150 kVA)	ea	2,600	55	1,600	60
	Welding Receptacle	ea	1,100	30	410	25
4000	350 hp	ea	12,500	50	1,100	110
	1250 hp	ea	12,800	60	1,800	120
	2500 hp	ea	15,000	75	4,100	140

Description	Unit	Mat'l, $	Labor, W-H
Active areas lighting & 110 V outlets including feeder, transformer, panel, lights and receptacles – process, utilities and tank farm pumps areas	100 ft.^{2}	350	15
Inactive areas lighting, including feeder transformer panel & lights – general yard & tank farms	100 ft.^{2}	120	5
Misc. 110 V identifiable loads, valve operators, solenoids, etc., including feeder, transformer, panel and wiring devices	ea	180	10
Simple interlocks, including one control device, pressure switch or equivalent, one interlock wiring, conduit, etc.	ea	1,400	80
Complex interlocks required for large complex equipment such as large compressors, centrifuges, kilns, etc.	ea	4,100	200
Ground connections including pro rata of ground loop	ea	120	6
13.8 kV/480V 1000 kVA substation including 200 ft. of 13.8 kV feeder and 4-200 ft. 480 V feeders complete with high and low voltage protective switch gear - without building	ea	230,000	1,200
Same as above except for 2000 kVA	ea	290,000	1,500
13.8 kV/4.16kV 3000 kVA substation including 200 ft of 13.8 kV feeder and high and low voltage protecting fused switches - without building	ea	220,000	1,200

Note: Alarm and intercommunication systems must be included in the electrical account. The cost may vary from \$50K to \$200K depending on the size of the plant. Material-labor split would be approximately 50-50. The uninterruptable power supply (UPS) must be included in the cost of the control room at \$60K.

Frequently the distribution system is at 13.8 kV and large motors are run at 4.1 kV. In those cases, the cost of a 13.8 to 4.1 kV substation must be included in the estimate.

Definitive Estimate

Definitive and/or appropriation type estimates can be developed in four or six hours with the information normally provided in a Phase 1 package, i.e., P&ID's, equipment list, plot plans, arrangement drawings, and single line electrical diagram.

- Count all electric loads, 460 V and above, as before, and classify by size.
- Make allowance for electric motors not included in P&ID's such as fans, HVAC equipment, motor operated valves and doors using 460 V, etc.
- Determine distance from each motor to motor control center, follow pipe racks routing and allow at least 10% for miscellaneous turn and deviations from the shortest route. The maximum distance should not exceed 500 ft., otherwise several transformers and/or motor control centers at separate locations may be required.
- Using an average length for the plant or for each area is a valid way to reduce estimating time.
- Calculate the total load as follows:

1 hp	1 kVA
Active areas lighting	5.0 Watt/ft.^{2}
Inactive areas lighting	1.0 Watt/ft.^{2}
Electric heat tracing	15.0 Watt/ft.
Building lights and miscellaneous	50 kVA per building
Add 50% for future and miscellaneous	

Note: The minimum 480 V transformer size should be 1,000 kVA. Reliability considerations may dictate the use of two 1,000 kVA units. The maximum 480 V transformer size should be 2,000 kVA.

- Assume one welding receptacle for every 5,000 ft.^{2} of process area with a minimum of one for each operating floor and utility area.
- Determine area requiring lighting - process and utilities.
- Determine number of interlocks for P&ID's and/or single line diagram.

- Consider one grounding connection for every equipment item and add 20% for grounding of miscellaneous structures.
- Apply the pertinent units from Tables 19.24.

19.7 Instrumentation Estimating Procedure

Introduction

An accurate cost estimate for the instrumentation account requires a substantial engineering effort:

- Reviewed P&ID's.
- Detailed take-offs.
- Current material prices.

It is a time-consuming effort and the cost can be justified only for an approved project.

At the other extreme, the instrumentation account could be estimated as a percentage of the equipment cost. However, this method is very inaccurate; published information shows a range of 15% to 50% of the equipment cost.

The cost of instrumentation is related mainly to equipment type and count rather than to equipment cost.

- Except for the size of the associated control valves, the instrumentation of a small piece of equipment is essentially the same on a large one, in similar service.
- The unit cost of field-mounted instruments varies with the materials of construction; however, the cost of panel-mounted instruments, DCS's, PLC's, etc., does not.
- The cost of handling, calibrating, installing and loop checking depends only on the number of instrument items and is in no way related to the cost of the equipment.

This procedure presents a quick and reasonably accurate method to estimate the cost of the instrumentation account at various levels of engineering development with sufficient details for subsequent cost tracking and project control.

Take-Offs

When reviewed P&ID's and time are available, count:

- DCS points - diamonds and squares.
- DCS wiring connections - some diamonds and squares may have more than one connection.
- Field instruments - balloons only (don't include diamonds and squares).
- Air hookups - zero per self-contained CV; 1.0 per XVC; 1.5 per CV.

See Fig. 19.12 for a typical P&ID representation and take-off guideline.

Note: Different instrument engineers follow different systems to identify field instruments affecting the balloon count. A discussion should be held with the acting instrument engineer to compare the P&ID's with Fig. 19.12 and try to reconcile the take-offs.

When reviewed P&ID's and/or time are not available, reasonably accurate counts can be developed from the equipment list using the following densities, which are representative of organic chemical plants and include both batch and continuous operations.

		No./Equip. Item.
– DCS Points	Batch Process	3.6
	Total Plant	2.0
	Continuous Process	1.7
	Storage Areas	1.0
– DCS Wiring Units	Batch Process	5.4
	Total Plant	3.0
	Continuous Process	2.5
	Storage Areas	1.5
– Field Instruments	Batch Process	12.0
	Total Plant	7.5
	Continuous Process	7.0
	Storage Areas	6.5
– Air Hookups	Batch Process	1.8
	Total Plant	1.0
	Continuous Process	0.9
	Storage Areas	0.5

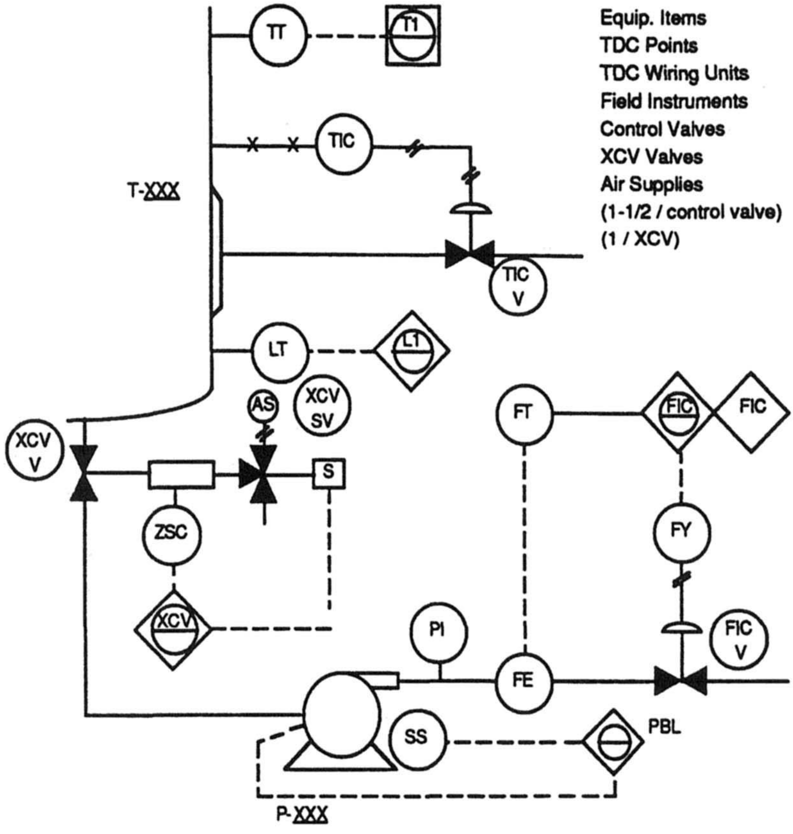


Figure 19.12 Instrumentation estimating procedure take-off guideline.

Pricing

After the take-offs are completed, the material and labor costs are developed with the following units:

Materials

– DCS Hardware Including Computer		\$2,100 per point
– Field Instrumentation	CS equipment	\$750 per balloon
	low alloy equipment	\$980 per balloon
	high alloy equipment	\$1150 per balloon

Installation Subcontract

– Electrical Installation (1)	
1. Includes all installation, materials, conduits, wiring, multiconductor cables, junction boxes, termination panel, miscellaneous supports, etc. 2. Trays for multiconductor cables not included. 3. Includes DCS installation. 4. Material/labor split approximately 30/70. 5. Labor on subcontract basis at \$48/hr.	50% of field instrumentation cost or \$375 and 18 hr per wiring unit.
– Pneumatic Installation (1)	
1. Includes piping, tubing, valves, miscellaneous supports, etc., from instrument air header to instrument. 2. Air header not included. 3. Material/labor split approximately 20/80. 4. Labor on subcontract basis at \$48/hr.	30% of field instrumentation cost or \$260 and 24 hr per air hookup.
– Mechanical Installation and Miscellaneous (1)	
1. Receiving and storage. 2. On-line and off-line installation, including miscellaneous materials. 3. Checkout. 4. Material/labor split approximately 20/80. 5. Labor on subcontract basis at \$48 hr.	30% of field instrumentation cost or 5 WH per instrument.
– Calibration (by Owner)	one WH / instrument

(1) For construction progress monitoring the work hours for these activities may be broken down using the guidelines in Table 15.2.

When the only information available is the equipment list, a good rule of thumb is to use $20,000 per equipment item. This number is based on an average case of:

2.0 DCS points.	per equipment item.
3.0 DCS connections.	
7.5 balloons.	
1.0 air hookup.	

This number is very consistent with the actual cost of several organic chemical plants and several definitive estimates.

It must be noted that in the case of a highly automated 100% batch process plant, the cost could be as high as $30,000-35,000.

19.8 Engineering Hours Estimating System

Introduction

Estimating engineering costs as a percentage of the direct project costs is a very common practice in conceptual and preliminary work. It is very simple but also very risky. The engineering hours related to any piece of equipment have very little relation to its cost.

For instance, the engineering hours related to a small or medium sized carbon steel reactor are essentially equal to those related to a larger Hastelloy C reactor. However, the difference in cost can be a full order of magnitude. Engineering hours relate best to the type of equipment and conditions specific to each project.

The estimating system presented here proposes a relatively simple but accurate method for estimating engineering hours based on the equipment list and a general knowledge of the project particulars. It was developed from published data and a thorough analysis of nine actual projects. The analysis of the data resulted in several adjustment and correction factors - some empirical, some theoretical that recognize, and try to compensate for, the effect of conditions specific to each project, such as:

- New technology/repeat plant.
- New site/retrofit.
- Phase 1 by Owner/by others.
- Plant size and complexity.
- Engineering contractor size.
- Non-process buildings.
- Execution approach.

The system includes procedures for estimating:

- Hours at engineering contractor's office.
- Hours to prepare a Phase 1 package.
- Hours required by the Owner to monitor contractor's work.
- Hours required to do the engineering with in-house resources.

In addition to the nine original study cases, the system has been repeatedly tested, sometimes against final project returns, other times against contractors' estimates. The results, tabulated in Table 19.25, are very good. When tested against final returns, the estimates prepared with the system have invariably been more accurate than the contractors' estimates prepared at the same stage of the project.

> **NOTE OF CAUTION:** ALL THE ORIGINAL STUDY CASES PREDATE THE WIDESPREAD USE OF COMPUTER-AIDED DESIGN PROGRAMS. ALTHOUGH THE AUTHOR EXPECTED TO SEE A DRAMATIC REDUCTION IN ENGINEERING HOURS, THAT DID NOT MATERIALIZE FOR SEVERAL YEARS. HOWEVER, IN THE LAST YEAR OR SO, AS ENGINEERS AND DESIGNERS BECAME PROFICIENT WITH THE SYSTEM, THE 3D CAD IN PARTICULAR, SOME CONTRACTORS APPEAR TO BE SPENDING AS MUCH AS 20-25% FEWER HOURS. IT HAS BECOME VERY IMPORTANT IN THE CONTRACTOR SELECTION PROCESS TO PAY SPECIAL ATTENTION TO THIS AREA OF CONTRACTOR EXPERTISE.

Hours at Engineering Contractor's Office

Summary

The objective of this procedure is to develop a quick and reliable estimate of total contractor home office hours with minimum information.

Information Required

- Equipment list including installed spares:
  1. Preliminary size.
  2. Pressures.
  3. Preliminary horsepower.

Table 19.25 Engineering Hours Estimating System Performance

Type of plant	Contractor size	Actual hr Phase 2	Equip. Count	hr per item	Accuracy Est./Actual
Retrofit	Small	32,570	66	493	0.99
Grassroots	Large	416,600	540	771	1.01
New unit	Small	12,870	21	613	1.02
Grassroots	Small	78,200	118	663	1.02
New unit	Small	76,050	165	461	1.00
Grassroots	Large	262,600	307	855	0.96
Retrofit	Small	27,210	74	368	0.99
Retrofit	Large	172,760	123	1,404	1.03
New unit	Large	10,930	6	1,822	0.86
New unit	Small	19,500	45	433	1.01
Retrofit	Small	11,000	33	333	1.24
New unit	Large	67,300	53	1,270	1.08
New unit	Small	9,520	9	1,058	1.22
Retrofit	Large	18,540	5	3,708	0.92
Grassroots	Large	162,300	273	595	1.05
Grassroots	Large	34,270	52	659	0.94
Estimate	Small	15,950	45	355	1.22
Retrofit	Small	87,470	201	435	1.09
Retrofit	Small	18,600	121	154	1.08
Grassroots	Large	107,200	134	800	1.03
New unit	Small	7,200	21	342	1.00
New unit	Small	22,000	100	220	1.14
Grassroots	Large	159,800	223	717	0.94
Retrofit	Large	22,000	95	232	1.05

- Special conditions:
  1. Continuous/batch process.
  2. Type of instrumentation.
  3. Distribution/collecting systems.
  4. Piling/site preparation.
  5. Non-process buildings.
  6. Retrofit.
- Preliminary Execution Plan:
  1. Phase 0/Phase 1 by others.
  2. Size of contractor.
  3. Direct hire/subcontract.

Procedure

- Computation of base hours - Tables 19.26, 19.27, and 19.28.
- Adjustment of base hours - Tables 19.29 and 19.31.
- Corrections for equipment size, contractor size, and number of equipment items - Tables 19.30 and 19.31.

Basis of estimate

Table 19.26 - Engineering Contractor Hours - Equipment

This table shows the home office hours required by a large contractor to design and procure the different types of equipment normally encountered in a chemical plant. The hours comprise all technical and clerical activities from the start of process design to project closeout. They are intended for a continuous operation, single unit plant with electronic DCS instrumentation built on a direct-hire basis on a clear site and include process-related buildings, such as a motor control center and control room.

The units include hours for activities that are frequently performed either by subcontractor or directly by the Owner. These activities fall into the following areas:

- Process design.
- Estimating, schedule, and cost control.
- Procurement.

Table 19.26 Engineering Contractor Hours - Equipment

Ref.	Equipment Description	Proc. Eng.	Non-Process: Project Mgmt. & Control	Non-Process: Design	Non-Process: Purch. & Exp.	Total
1	– Process furnaces	750	670	2,770	440	4,630
2	– Reactors – Tray towers – Direct fired heaters – Large process incinerators	390	440	1,710	240	2,780
3	– Packed towers – Custom designed press. vessels >4'D – Reboilers – Package boilers – Motor-driven process compressors – Turbine-driven process compressors – Complex multi-unit packages – TDC/PLC and batch controllers – Rotary dryers / filters	270	190	960	140	1,560
4	– Custom designed press. vessels <4'D – Atm. stg. tanks & process vessels – Instrument air package – Emergency generators – Refrigeration packages – Multi-stage ejector systems – Vacuum pumps – Environmental Scrubbers – Belt & screw conveyors – Mills – Thickeners – Vibrating screens	160	110	550	80	900
5	– Shell & tube heat exchangers – Eductors – Single stage ejectors – Wiped film evaporators – Cooling towers – Drum dryers – Elevators – Crushers – Blenders – Kneaders	120	70	350	60	600

Table 19.26 (Continued)

Ref.	Equipment Description	Proc. Eng.	Non-Process: Project Mgmt. & Control	Non-Process: Design	Non-Process: Purch. & Exp.	Total
6	– Turbine driven pumps & blowers – Mixers and agitators – Simple incinerators – Flare stacks – Double pipe heat exchangers – Centrifuges – Dust collectors – Packaging machines – Mechanical feeders & flakers – Hoppers	60	40	240	40	380
7	– Motor driven pumps & blowers	20	50	140	10	220
8	– Fans & extractors – Hoist and trolleys – Rotary valves – In-line filters – Small separators, K.O. pots – Off-the-shelf pressure vessels – Heating coils/plate & bayonet heaters – Sample coolers – Electric heaters – Static mixers – Mobile equipment	10	10	30	10	60
9	– Portable air conditioners – Misc. non-equip. items, tote bins/ buggies/scales/vent filters	5	5	10	5	25

It must also be noted that the base hours include secretarial and clerical work. The author's suggested practice is to consider these hours with the contractor overhead rather than as a reimbursable cost. Table 19.29 includes the recommended adjustment.

In order to simplify the work, the equipment has been classified into nine groups; the hours for each group represent the average of the various items included.

Table 19.27 - Engineering Contractor Hours - Miscellaneous

This table was developed to account for the home office work associated with activities that are required on most projects but are not directly related to equipment.

Table 19.28 - Engineering Contractor Hours - Normal Breakdown

This table shows the normal breakdown of the home office hours by discipline for both liquids and solids handling processes.

Table 19.29 - Engineering Contractor Home Office Adjustments

This table accounts for the deviations from the typical case encountered in practically all cases.

Table 19.30 - Engineering Contractor Hours Overall Correction Factors

This table includes the across-the-board corrections that must be applied to the total hours to account for:

- Complexity as a function of the number of equipment items, including installed spares.
- Size of equipment as a function of the average horsepower of process equipment motors (pumps, agitators, compressors).
- Size and sophistication of the engineering contractor.

Table 19.31 - Engineering Contractor Work Hours Breakdown, Adjustment and Correction Worksheet

This form is suggested to facilitate and document the adjustments and corrections required for each project.

Computation procedure

Step 1 - Compute Base Hours

Base hours are all the home office hours required to perform all the engineering, procurement, subcontracting, project management, estimating, and cost control for a normal case plant. They are computed as follows with the aid of Tables 19.26, 19.27, 19.28, and 19.31.

Table 19.27 Engineering Contractor Hours – Miscellaneous

			Non-Process			
Ref.	Equipment Description	Proc. Eng.	Project Mgmt. & Control	Design	Purch & Exp.	Total
	Subcontract award and administration					
101	Lump sum	-	120 to 240	150 to 300	150 to 300	420 to 840
102	Reimbursable	-	240 to 480	100 to 200	200 to 400	540 to 1080
	Systems shared by multiple unit plants					
103	Steam distribution & condensate system	80 to 160	100 to 160	400 to 600	80 to 120	660 to 1040
104	Vent collection system	60 to 80	50 to 100	240 to 360	60 to 80	410 to 620
105	Cooling water distribution system	40 to 80	50 to 80	200 to 300	40 to 60	330 to 520
106	Waste water collection system	-	40 to 60	200 to 300	40 to 60	280 to 420
107	Fire protection system	-	20 to 40	120 to 200	20 to 40	160 to 280
108	High/medium voltage elect. distribution	-	40 to 60	200 to 300	40 to 60	280 to 420
109	Interconnecting pipes & pipe rack	40 to 80	120 to 200	800 to 1200	80 to 120	1040 to 1600

Table 19.27 (Continued)

Ref	Equipment Description	Proc. Eng.	Non Process: Project Mgmt. & Control	Non Process: Design	Non Process: Purch & Exp.	Total
	Main Substation					
110	Estimated cost not available	-	180	1,000	120	1,300
111	Basic eng. only – detailed eng. by sucontractor – 5% of estimated cost broken down as follows	-	0.25	0.60	0.15	1.00
112	All eng. by contractor – 15% of estimated cost broken down as follows	-	0.2	0.7	0.1	1.00
	Miscellaneous Site Work					
113	Piping, earth movement, access roads, utility, supplies, etc. – 15 % of estimated cost broken down as follows	-	0.2	0.75	0.05	1.00
	Non-Process Buildings					
114	Basic eng. only, details by design/build S.C. - 5% of estimated cost broken down as follows	-	0.25	0.60	0.15	1.00
115	All eng. by contractor – 10% of estimated cost broken down as follows	-	0.20	0.70	0.10	1.00

1. Count and classify the equipment under the categories listed in Table 19.26. Installed spared items must be included in count.

   In retrofit projects, it is very convenient to compute the base hours by groups of equipment that reflect the scope of the retrofit work, such as:

   – New equipment in existing structures.

   – New equipment in new structures.

   – Relocated existing equipment.

   – Existing equipment in-place.
2. Apply the corresponding unit hours and compute the base hours for equipment.
3. Select the applicable units from Table 19.27, apply the corresponding unit hours, and add to the equipment hours for the total base hours.

4. Use Table 19.28 to break down the total hours by discipline and enter in the first column of Table 19.31.

Important note: Occasionally a project involves repetitive steps with identical equipment, instruments, and piping arrangements. Most of the detailed engineering developed for the first unit will be used for all such units with substantial time savings. So the estimator, after estimating the first units, must use judgment to make the proper adjustments to the other units.

Step 2 - Compute Adjusted Hours

Adjusted hours are the home office hours that would be required by a large engineering contractor to perform a specific scope of work for a plant with normal sized equipment. They are derived from the base hours, adjusted to take into consideration the specific situation; e.g., extent of process design required, type of process and instrumentation, special site conditions, extra retrofit work, existing facilities, Owner's participation, etc.

Once the basic hours have been computed and broken down by discipline, the adjusted hours can be computed as follows with the aid of Tables 19.29 and 19.31:

1. From Table 19.29, Items 1 to 15 only, identify the conditions applicable to the project, show the adjustments in the designated column of Fig. 19.31, and compute the adjusted hours for process, design and support, and procurement.
2. Make intermediate adjustment of project and control hours as directed in Item 16, Table 19.29.
3. From Table 19.29, Items 17 to 20, identify the other conditions applicable to the project and compute the adjusted project and control hours.
4. Compute the total adjusted hours.

Note: This step requires engineering judgment and a good understanding of the site conditions and the way in which the project will be executed.

Step 3 - Compute Corrected Hours

Corrected hours are the home office hours that would be required by a given engineering contractor to perform the specific scope of work for a particular plant. They are derived from the adjusted hours, corrected as follows by the factors included in Fig. 19.30, which are based on the equipment count, equipment size, and contractor size.

Table 19.28 Engineering Contractor Hours – Normal Breakdown

Activity	Fraction of Subtotal		"Normal" Percent of Total
Subtotal Process Engineering			11-13 %
Project Management and Control			
Project Management/Engineering	0.45		
Estimating	0.15		
Cost Control	0.25		
Scheduling	0.15		
Subtotal Project Management and Control			15-18%
Detailed Engineering	Fluid [1]	Solid [2]	
Civil/Structural/Architectural	0.15	0.20	
Electrical	0.13	0.16	
Instrumentation	0.13	0.12	
Piping [3]	0.35	0.18	
Equipment/HVAC/Mechanical	0.10	0.20	
Engineering Clerical	0.14	0.14	
Subtotal Detailed Engineering			58-64%
Procurement			
Purchasing	0.65		
Expediting	0.35		
Subtotal Procurement			8-11%
GRAND TOTAL			100%

[1] For fluid handling plants. Based on average of actual cases.
[2] For solid handling plants – best estimate.
[3] Piping work hours breakdown

P&ID drafting	0.07
Layouts	0.05
Model	0.10
Orthographics	0.33
Material take-offs	0.10
Stress analysis	0.05
Isometrics	0.30

1. Determine the total number of pieces of equipment including installed spares.

Note: Non-equipment items in Group 9, Table 19.26 must not be included in the count.

2. From Table 19.30, determine the equipment count factor (F_e).
3. Count electric motors and compute total horsepower.

Note: Count must be limited to major equipment: i.e., pumps, agitators, and compressors. Rotary valves, chemical feed pumps, and the like must not be included.

4. Compute the average horsepower (total hp/number of motors) and determine the correction factor (F_s) from Table 19.30.
5. From Table 19.30, determine the contractor size factor (F_c).
6. Combine the three correction factors into a single factor and use the last column of Table 19.31.

Important note: Experience shows that when a contractor is retained to perform detailed engineering only on specific disciplines, with the Owner retaining the overall responsibility, there is very little sensitivity to the equipment count.

Hours to Prepare Phase 1 Package

The hours required for the preparation of a Phase 1 package are derived from the base man-hours (before adjustments or corrections) in the contractor's hour estimating procedure as follows:

Normal Project

First design of a known process. No previous Phase 1 available.

Discipline	Fraction of Contractor Base Hours
Process	0.60
Instrumentation	0.10
Piping	0.05
Equipment/HVAC/mechanical	0.05
Project and Miscellaneous	Add 20%

Repeat Project

Table 19.29 Engineering Contractor Home Office Adjustments

Items	Adjustments	Comments
1. Phase I design by others	Multiply Process hr x 0.3 Instrumentation hr x 0.9 P&ID drafting hr x 0.4 Piping layout hr x 0.6 Equip./HVAC/Mech. hr x 0.9	
2. Phase 0 design by others	Multiply Process hr x 0.70	
3. Batch process	Multiply Process hr x 0.7 Instrumentation hr x 1.2	Apply only to process units affected.
4. No model required	Multiply Piping model hr x 0.0	
5. Isometrics by subcontractor	Multiply Piping isos hr x 0.0-0.25	Some area isometrics and/or undimensioned isos may be required.
6. Heavy retrofit Removal & installation of equipment in operating areas engineered while existing equipment is in operation & requiring plant shutdown.	Multiply C/A/S hr as required Elec. hr as required Piping orthos hr x 1.8-2.5	Corrections to be applied only to areas requiring the retrofit.

Table 19.29 (Continued)

Items	Adjustments	Comments
7. Light retrofit	Multiply	
Installation of equipment in areas that may be cleared before design	Piping orthos hr x 1.3-1.5	Same as above.
8. Relocate existing equipment	Multiply	
	Mech./HVAC/Eq. hr x 0.25 Procurement hr x 0.2 Adjusted process hr x 0.6	Apply correction only to particular equipment.
9. Existing equipment in place	Multiply	
	Adjusted process hr x 0.6 C/A/S hr x 0-0.25 Mech./HVAC/Eq. hr x 0.25 Procurement hr x 0.2 Piping hr as required Elec. hr as required	Apply correction only to particular equipment. If existing piping, instruments, or electrical are to be reused, adjust accordingly.
10. Existing buildings and/or structures	Multiply	
	C/A/S hr x 0-0.25	Apply only to equipment affected. Check for retrofit & adjust if applicable.
11. Old plant site	Multiply	
	C/A/S hr x 1.1	To cover for potential underground problems.
12. Existing utilities	Multiply	
	Piping orthos hr x 0.8	
13. Non-reimbursable clerical	Multiply	
	Prorated clerical & admin hr x 0.2	Pro rate as follows: $\frac{\text{Adjusted design hr}}{0.86} \times 0.14$

Table 19.29 (Continued)

Items	Adjustments	Comments
14. Procurement by owner and/or subcontractor	Multiply Adjusted procurement hr x 0.2-0.5 Piping MTO hr x 0.2-0.5	
15. Instrument engineering by owner	Take credit based on Owner's involvement	
16. Proj. mgt & controls Proj./Est./Cost Control/Scheduling	Once the process engineering, detailed engineering, & procurement hours have been adjusted, the Project Management and Control hours are adjusted to maintain the same proportion calculated in the base hours total. The adjusted hours are then broken down in the fractions indicated in Table 19.29 and each fraction adjusted as follows:	
17. Initial cost estimate by Owner	Multiply Estimating hr x 0.5	
18. Cost control by Owner and/or subcontractor	Multiply Cost Control hr x 0.2-0.5	
19. Scheduling by Owner and/or subcontractor	Multiply Schd. hr x 0.2-0.5	
20. Project Mgt./Eng. for small projects	Set minimum hr for project mgt./eng. based on project duration & Owner participation in detailed engineering.	Below certain project size a minimum PM/PE attention is required based on project duration.

Table 19.30 Engineering Contractor Hours Overall Correction Factors

Complexity Factor

Equipment Count	Multiplier (F_e)
10	1.80
25	1.50
50	1.30
100	1.05
125-175	1.00
200	1.03
250	1.04
300	1.08
600	1.30

Equipment Size Factor

Avg. Motor hp Process Equipment	Multiplier (F_s)
10	0.90
10-15	0.95
15-50	1.00
50-100	1.05
100	1.10

Contractor Size Factor

Large Contractor	Multiplier (F_c)
Over 300 people, inflexible organization, sophisticated control systems	1.00
Small Contractor	
Flexible, simple control versatile Project Managers	0.80-0.90

Table 19.31 Engineering Contractor Work Hours Breakdown, Adjustment, and Correction Worksheet

Job:______________________________

	Base Hours		Adjustments		Adjusted hrs	Corrected
Process						
Project & Control Proj. Mgt./Eng.			From item 16, Table 13.29			
Estimating						
Cost Control						
Scheduling						
Subtotal						
Design & Support Civil, arch. & struct.						
Electrical						
Instrumentation						
Piping						
Equip./HVAC/Mech.						
Clerical & admin.						
Sub total						
Procurement Purchasing						
Expediting & insp.						
Sub total						
Total						
Correction Factor				±	Equip. cnt. (F_e) ___ Equip. size (F_s) ___ Contr. size (F_c) ___	

Phase 1 design(s) available from previous plant(s).

Discipline	Correction Factor to Normal Project
Process	0.4-0.8
Instrumentation	0.4-0.8
Piping	0.8-1.0
Equipment/HVAC/mechanical	0.6-0.8
Project and Miscellaneous	Add 20%

New Process

Process design developed from pilot and R&D data.

Discipline	Correction Factor to Normal Project
Process	1.5-2.0
Instrumentation	1.2-1.5
Piping	1.0-1.2
Equipment/HVAC/mechanical	1.0-1.2
Project and Miscellaneous	Add 20%

Preparation of a Phase 0 package requires approximately 40% of Phase 1. This must be taken into consideration when the Phase 1 work is based on an existing Phase 0.

Hours to Monitor Contractor's Work

The contractor doing the engineering work requires a certain degree of monitoring and supervision and, in some cases, even direction from the Owner. This is especially true when the contractor performs its work under a cost reimbursable contract.

This procedure proposes a rational method that relates the required Owner's hours to the estimated contractor's man-hours in a consistent and rational manner.

Discipline	Fraction of total contractor hours for each discipline
Process engineering	0.20
Project management/engineering	1.00
Estimate/schedule/control	0.20
Instrumentation	0.20
Electric/mechanical/procurement	0.05
Overhead administration	*

Auditing	*

*Estimate each project based on desired participation.

Hours for In-House Engineering

For a small project of the right complexity, engineering can be most effectively done at the plant level, provided the proper resources are available. The hours required can be derived from the estimating system for contractors' home office hours as follows:

Base Hours

- **Procurement and Clerical** - Unless additional help is specifically required, this work will normally be absorbed by the regular plant staff.
- **Estimating, Cost Control, and Scheduling** - The work in these areas will be the bare minimum and the project engineer would perform it.
- **Adjustments to the Design** - As required in Table 19.29.

Correction Factors

- **Equipment Count Factor** - Experience has shown that in-house engineering is less sensitive to low equipment counts. The following correction factors are suggested:

Equipment Count	Correction Factor
10	1.08
25-50	1.00
75	1.05

- **Equipment Size Factor** - Same as for contractor's man-hours.
- **Contractor Size Factor** - Because of the smaller size of the groups, the less formal communication and documentation procedures and the simple supervision structure, a plant engineering group is able to perform engineering even more effectively than a small contractor.
- A multiplier of 0.6 is warranted.

SECOND EDITION NOTE: THE EVER-INCREASING REGULATIONS AIMED AT INSURING PUBLIC AND

EMPLOYEE SAFETY AS WELL AS A CLEAN ENVIRONMENT WILL REQUIRE MORE SOPHISTICATED CONTROL AND THOROUGH DOCUMENTATION THAT WILL CERTAINLY AFFECT HOME OFFICE HOURS. PROJECT MANAGEMENT HOURS AND CONTROL HOURS AS WELL AS PROCESS AND INSTRUMENTATION WILL BE AFFECTED. AN INCREASE OF 15-20% WOULD BE JUSTIFIED.

19.9 Field Costs

Labor Costs

The labor costs should be estimated in a manner consistent with the planned execution approach.

- If construction is to be executed on a direct-hire basis, the labor costs should include only the basic labor rate. All other labor-related costs (PAC's, fringe benefits, supervision, rental equipment, etc.) should be included with the field indirects.
- When construction is to be subcontracted, some accounts (civil, insulation, and paint) are usually estimated on a total cost basis, combining both materials and labor. Other accounts (piping, electrical, instrumentation, equipment erection) are estimated and shown separately as material and labor. In that case, the labor should be loaded with the subcontractor's field indirects plus overhead and profit. The field indirects would reflect only the cost of construction management.

The Project Manager and/or Cost Engineer reviewing a cost estimate must establish whether the costs in the labor column reflect base rates, loaded costs, or some intermediate value, such as base rate plus fringe benefits. Failing to do so would result in misleading material to labor ratios and incorrect cost analysis.

Table 19.32 indicates the labor rates and fringe benefits that should be used to prepare direct-hire estimates at several U.S. locations. These rates are based on current union rates for pipefitters and represent a conservative average of the various crafts involved in construction.

The following is a typical subcontractor loading:

Table 19.32 Typical Union Labor Rates, Pipefitters, January 1999

Location	Base Rate, $/hr	Fringe, $/hr	Benefits, Frac. of base
Atlanta, GA	20.20	6.24	0.31
Baltimore, MD	22.43	7.45	0.33
Billings, MO	20.50	8.15	0.40
Charleston, WV	24.14	7.45	0.31
Cheyenne, WY	*18.90	-	-
Chicago, IL	30.70	7.02	0.18
Columbus, OH	23.04	8.42	0.37
Denver, CO	22.07	5.12	0.23
Detroit, MI	28.46	9.15	0.32
Houston, TX	20.11	6.00	0.30
Little Rock, AR	17.45	3.56	0.20
Milwaukee, WI	25.86	7.22	0.28
New Orleans, LA	16.80	3.86	0.23
Omaha, NE	21.61	6.28	0.29
Philadelphia, PA	28.07	11.36	0.40
Richmond, VA	19.78	6.12	0.31
Topeka, KS	19.54	5.50	0.28
Wilmington, DE	24.89	10.45	0.42
	Nation Highest		
San Francisco, CA	36.05	21.03	0.58
New York, NY	31.55	20.84	0.66
	Nation Lowest		
Columbia, SC	*15.90	-	-
Fargo, ND	16.10	3.10	0.50
Jackson, MS	12.50	2.35	0.19
Corpus Christi, TX	*15.31	-	-

* Total.

Note: Suggest an additional 2% to escalate to end of 2000.

	Fraction
Base rate	1.00
Fringe benefits*	0.25
Supervision	0.15
Insurance and tax (PAC's)**	0.25
Small tools and consumables**	0.10
Subtotal	**1.75**
Overhead and profit, 20%**	
TOTAL	**2.10**

* Use actual value when available.

** These are typical values. Actual values will change with site, contractor, and business atmosphere.

When time permits, the loaded rate of local subcontractors should be determined prior to estimating.

Subcontractors' loading does not include the cost of the rental construction equipment such as cranes, welding machines, scaffolding, and expensive tools exceeding a predetermined value. These costs are usually reimbursable based on the rental rate submitted by the subcontractor in the proposal.

A simple way to account for the cost of rental equipment used by the subcontractors is to add a discrete amount to the loaded cost. The following amounts are suggested:

- Equipment erection labor $10/hr
- Structural steel erection labor $7/hr
- Piping labor $5/hr
- Electrical/instrumentation labor $3/hr

The rates for non-union labor may be somewhat lower (5-10%) than for union labor but, generally, they are competitive and no credit should be taken in the estimate without an area labor survey.

The potential advantage of using non-union labor is in the lower percentage of time lost because of stringent union work rules. However, this advantage can easily be offset by lower productivity resulting from poor training of the non-union labor pool.

Field Indirects

As discussed in the preceding paragraphs labor costs are defined either as the wages paid directly to the workers in a direct hire situation or the monies paid to the subcontractors to cover all their field expenses (except materials) plus overhead and profit. The field indirects are then all other project-related costs incurred in the field in addition to the labor costs. The scope of the field indirects account in the estimate is naturally in inverse proportion to the scope of the labor costs.

Whether some of them are folded into the labor costs or not, the field indirects include cost items such as:

- Labor fringe benefits.
- Payroll added costs (PAC's).
- Supervision.
- Field offices, storage, and other temporary facilities.
- Rental construction equipment.
- Miscellaneous tools and supplies.
- Lost time.
- Others.

The Field Indirects Checklist and Field Indirects Criteria in Appendix K are intended mainly as control tools to check contractors' detailed estimates and planning as well as to monitor their performance in reimbursable contracts. They can also be used as an estimating tool to develop in-house detailed or semi-detailed estimates. However, for in-house and preliminary estimates, sufficient accuracy can be achieved by ratioing the field indirects to direct labor and subcontracts.

In lump sum contracts and subcontracts, even if all field indirects should be included, the Project Manager must ascertain that they really are and that adequate supervision and support are provided to insure proper execution. Appendix I is also a good tool for that purpose.

When construction is totally subcontracted the field indirects are a mixed bag; some are included in the subcontracts while others must be provided by the construction manager or the general contractor. The field indirects likely to be provided by the construction manager or the general contractor are identified in the Field Indirects Checklist.

The field indirects account for a detailed estimate, specifically in a large project, should be broken down into all its major components to insure that all costs are considered. In semi-detailed and preliminary estimates a breakdown is not required. Sufficient accuracy can be achieved by using the following factors:

- 95-120% of direct labor

  plus

- 15-20% of subcontract labor (loaded)

  plus
- 10-12% of subcontracts (material and labor)

The factors are inversely proportional to the construction hours.

Labor Productivity

General

Labor productivity is always a major concern to the estimator. Variations of up to 100% between two specific sets of circumstances are not unusual. With loaded labor costs running around 40% of total project costs, a 25% variation in productivity could impact total cost by 10%.

The cost impact of the productivity should be shown in the estimates as a line item with the field indirects account. This approach will permit a more consistent analysis of the materials-to-labor ratios and provide better project control by specifically identifying a potentially important source of abnormal project costs.

Factors affecting productivity

The Construction Industry Cost Effectiveness Study (CICE) sponsored by the Business Roundtable in the early 1980's indicated that, to a large extent, poor labor productivity is the result of inadequate management practices. Conversely, the risk of poor productivity can be minimized by effective project management. The purpose of this section is to give project managers a better understanding of the factors affecting productivity and provide guidelines to create, early in the project, an environment conducive to good labor productivity.

Table 19.33 lists the most important factors that affect productivity. Most of them are under control of owners and contractors and can be biased in the right direction by good project management. The Owner can control or at least influence the first eight items by:

- Awarding all construction work on competitive lump sum bases.
- Maximizing the use of design-build contracts.
- Breaking down work, as much as is practical, into discrete portions in order to maximize the use of local contractors using regular employees.
- Setting a realistic schedule to avoid regular overtime and/or excessive staffing.
- Demanding the highest safety standards from all contractors.

- Promoting workers' motivation programs.
- Implementing thorough procedures for screening and qualification of bidders.
- Encouraging the merit shop and site agreement approach to construction.

Table 19.33 Factors Affecting Productivity

	Poor Productivity	Good Productivity
1. Contracting approach	Separate engineering & construction contractors	Design build
	Negotiable	Competitive
	Reimbursable	Lump sum
2. Construction approach	Direct Hire	Subcontract
3. Type of contractor	Large national, general contractor	Small local subcontractors
4. Safety standards	Low	High
5. Contract size	Large	Small
6. Schedule	Fast track/OT	Normal
7. Work rules	Union	Merit shop
8. Labor source	Union hall/open market	Regular employees
9. Labor quality	Poor	Good
10. Supervisor quality	Poor	Good
11. Field organization	Poor	Good
12. Site location	Remote	Accessible
13. Site condition	Clustered	Clear
14. Type of work	Retrofit	New unit
15. Project size	Large	Small
16. Weather	Poor	Good
17. Local economy	Depressed	Booming
18. General area productivity	Poor	Good

The Owner has little or no control over the quality of the contractor's labor, supervision, and organizational capabilities. However, when contractors are selected through a careful and deliberate selection process, the most qualified are likely to be selected.

Neither the Owner nor the contractor can control factors like project size, type, and location; nor can they control local weather or economic environment. However, they can minimize their adverse effects with good project planning and management and, in all cases, by recognizing the dangers and making proper productivity allowances in the estimate.

Basis of construction hours

Labor productivity should be measured against consistent standards. Everybody talks about "Gulf Coast" productivity and of using "Gulf Coast" unit hours in their estimates. Yet everybody seems to have a different set of Gulf Coast unit hours. In real life, many contractors have their own units and modify them periodically to reflect actual experience.

The unit hours used in all the estimating procedures are based on hours used by large contractors to estimate construction work on a direct-hire basis, reduced by 15% to allow for work done on competitive lump sum basis.

The unit hours shown in the concrete and insulation estimating procedures are intended for planning and scheduling only, since the unit costs are based on all inclusive subcontract prices.

Productivity adjustments

Conceptual and preliminary estimates normally would not contain sufficiently detailed information for making any meaningful productivity correction to the labor accounts. Exposure to low productivity should be covered by the judicious evaluation of the contingency allowance.

Definitive and appropriation type estimates should consider project specific conditions with potential effects on productivity and incorporate provisions to minimize their adverse effects and/or cover their cost impact. As mentioned previously, most of the potential adverse effects can be eliminated or, at least, minimized by good project execution planning and management.

Some of the adverse conditions are inherent to the specific sites and/or project and cannot be eliminated through project planning and management. In these cases, the following multipliers should be applied to the estimated hours:

Condition		Multiplier	Comments
Retrofit and/or clustered areas		1.20-1.40	To be applied only to work and areas specifically affected.
Bad weather		1.05	Bad weather has more effect on schedule than on productivity. Apply factor to anticipated bad weather periods.
Second shift		1.10	To be applied only to work on second shift.
Unavoidable extended scheduled overtime:			
50 hr week	Up to 2 weeks	1.05	Even if the overtime is required in only one area and/or for one particular craft, frequently it becomes necessary, to maintain labor peace, to place the entire project on overtime.
	2-4 weeks	1.10	
	Over 4 weeks	1.20	
60 hr week	Up to 2 weeks	1.10	
	2-4 weeks	1.15	
	Over 4 weeks	1.30	

It must be noted that the cost of overtime extends far beyond the productivity loss since the rates of overtime work are at least 1.5 times the regular rate.

19.10 Adjustments

Resolution Allowance Criteria

When an equipment item is priced on in-house information (curves or past experience) and/or budget prices from vendors, the cost is developed without the benefit of a design specification and can either be high or low.

When the price is the result of a formal quote based on specifications developed early in the project, the detailed design, safety reviews, and normal project development will usually result in extra costs:

- Additional recycle streams and instrumentation requires extra nozzles.

- Pumps may require different types of seals.
- Gasket and seal materials may need upgrading.

The same situation occurs when commodities (concrete, structural steel, electrical, etc.) are priced. If they are factored from the equipment account or derived from the actual cost of other projects, they could either be high or low. However, if they are developed through take-offs, from drawings at various stages of completion, the errors will be omissions rather than additions and some growth in quantities is expected. The amount of growth will be inversely proportional to the completion of engineering.

The expected increases in the equipment and commodity accounts should be considered a part of the base estimate rather than contingency. They should be included in the body of the estimate and identified as Resolution Allowances. The purpose of this guideline is to provide rational criteria to determine the appropriate resolution allowance on a consistent basis.

The recommended approach for semi-detailed estimates is to apply the following typical factors used by many contractors in the chemical industry.

Equipment

- 3-5% to equipment costs obtained through formal quotes only.
- 0% to equipment costs obtained from curves or budget quotes.

Commodities

- 20-30% on estimates based on take-offs from preliminary P&ID's and arrangement drawings (typical preliminary estimate).
- 10-20% on estimates based on take-offs from approved-for-design P&ID's and arrangement drawings (typical definitive estimate).
- 5-10% on estimates based on detailed drawings and bill of materials (typical engineering estimate).
- 0% on factored estimates.

Escalation

All estimates must be adjusted for the expected inflation to bring the cost as close as possible to the actual cost at the time of completion.

The simplest approach, quite adequate for small projects, is to apply the current inflation projection to the mid-life of the project; i.e., if the estimated duration is 14 months and the projected annual inflation rate is 6%, the escalation adjustment will be:

$$(14 \text{ months} \div 12 \text{ months/year}) \times 0.5 \times 6\% = 3.5\%$$

On large, extended projects, where the escalation allowance could become a substantial number, it is more appropriate to calculate the escalation for each of the major cost accounts based on the projected inflation rate and the project schedule. By doing so, every cost account will be escalated to the time in which most of the actual expenditure is projected.

Special care must be taken in escalating labor costs since the rates are determined by labor agreements lasting two or three years and it is quite possible that no change in rate occurs during the project or that a step change will occur before construction begins.

Contingency Determination

As in the case of resolution allowance, the required contingency is inversely proportional to the level of engineering completion. The contingency philosophy changes from company to company; it could even change from project to project. Some companies have an unrealistic approach and take an adamant attitude against overruns; they want 90/10 estimates. Other companies are more realistic, are willing to take reasonable risks, and are satisfied with 50/50 estimates. The 90/10 estimates require substantially higher contingencies, as do estimates based on limited engineering.

The following levels of contingency recommended for various stages of engineering completion have been developed by the application of Hackney's definition rating method (Hackney, J. W. Control and Management of Capital Projects. 2nd edition, McGraw Hill, Inc., 1992) to the scope of each engineering stage. They have been successfully tested against the recommendations developed through very sophisticated methods:

		Contingency Probability	
Engineering Level		**50%**	**90%**
Conceptual design	High	60%	137%
	Avg.	47%	107%
	Low	30%	60%
Phase 0 design	High	26%	58%
	Avg.	22%	50%
	Low	17%	39%

Phase 1 design	High	13%	29%
	Avg.	10%	22%
	Low	8%	17%
Basic engineering	High	10%	20%
	Avg.	8%	18%
	Low	6%	12%
Detailed engineering	High	6%	12%
	Avg.	4%	9%
	Low	3%	6%

The above contingencies are to be applied after the base estimate has been corrected with resolution allowances as previously indicated.

> IT IS VERY IMPORTANT TO NOTE THAT THE BASE ESTIMATE IS NOT A FIXED NUMBER. IT MUST BE RE-EVALUATED PERIODICALLY TO REFLECT ACTUAL PROJECT PERFORMANCE AND ANY ADDITIONAL INFORMATION ACQUIRED DURING EXECUTION.

19.11 Quick Estimate Checks/Conceptual Estimating

General

The shortcut techniques included here are very useful for quickly checking estimates as well as developing conceptual estimates. Most have been derived from the analysis of several organic chemical plants, built or estimated; others come from personal observations. Table 19.34 reflects the analysis of nine actual chemical projects and five estimates of the following common characteristics:

- **Materials of Construction** - Mostly low and medium alloy steels.
- **Instrumentation** - Partially automated. DCS with approximately two points per equipment item. Seven or eight P&ID field balloons per equipment item.
- **Piping** - 2.5 to 3 in. average diameter.
- **Structural Steel** - Most process equipment on high bay structures.
- **Construction Labor Rate** - $48 per hr (loaded, and rental equip.).
- **Contracted Engineering Rate** - $75 per hr (loaded).

Table 19.34 Installed Costs Historical Data
(Cost escalated approximately to the end of year 2000. CE plant cost index of 420.)

Project	Actual or Estimate	Equip. count	K$ per equipment item 1 Total Cost	2 Equip. cost only	3 Phase 2 eng. @ $75/hr	4 Commod. & field ins. (1)-(2)-(3)	Instrum. Acct. TDC	K$ / item	Phase 2 eng. hr / item
Organics plant	A	540	243.0	40.4	57.7	144.9	No	15.0	770
Organics plant	A	307	234.5	26.4	54.9	153.2	Yes	19.3	732
Organics plant	A	203	206.1	22.8	34.7	148.6	Yes	17.1	462
Organics plant retrofit	A	15	291.3	99.8	56.3	135.2	No	15.5	750
Organics plant	A	6	359.2	69.1	137.2	152.9	No	N.A.	1,830
Organics plant (1)	A	87	416.5	45.7	106.8	264.0	Yes	31.6	1,424
Organics plant	A	307	248.2	49.1	64.1	135.0	Yes	18.8	855
Organics plant	A	223	301.4	62.0	53.8	185.6	Yes	16.4	717
Organics plant	A	118	220.4	42.5	49.7	128.2	No	16.8	663
Organics plant	E	226	241.1	44.9	51.4	144.8	Yes	22.9	686
Organ./mech. plant	E	57	237.9	54.1	29.0	157.8	Yes	13.9	386
Inorg. plant	E	92	300.0	75.2	60.3	164.5	Yes	N.A.	804
Inorg. plant	E	263	316.3	90.1	51.2	175.0	Yes	17.5	683
Water treat.	E	134	273.1	53.1	55.8	164.2	Yes	18.5	744

(1) This job included lethal chemicals and was built under enormous schedule pressure.

The table is based on the following definitions:

Equipment Count

- All process- and utility-related items, including installed spares and in-line filters are included in the count.

- Items such as conservation vents, service hoists, buggies, and moving equipment are not counted.
- Skid-mounted packages are considered as one item.
- Vendor designed packages broken down and delivered in pieces to be installed and piped in the field are counted based on the number of pieces.

Total Installed Cost (TIC) Scope

The following cost items are not included in the costs:

- Extraordinary site work such as extensive earth movement, piling, retention ponds, utility supplies, access roads, etc.
- Buildings other than sheltering structures, control room, MCC room, and some spares for field offices and maybe a simple field laboratory.
- Main substation and power distribution system.
- Waste treatment plants other than activated carbon absorbers.
- Spare parts, taxes, catalyst, and chemicals.
- Phase 1 engineering and CED monitoring.

Total Installed Cost

Table 19.35 is a derivation of Table 19.34 and provides very valuable historical data.

- In eleven of the fourteen cases analyzed, the TIC was within 20% of $263k per equipment item with six of them within 10%. This number will be referred to as the TICF (TIC Factor).
- After backing out the equipment and engineering accounts, twelve cases were within 20% of $149k per equipment item and 10 of them within 10%. This number will be referred to as the TFCF (Total Field Costs Factor).

This information provides tools for the instant checking of the reasonableness of estimates as well the preparation of order of magnitude, or even conceptual, estimates with minimal information.

Table 19.35 Total Installed Costs (TIC)

	TIC K$/Item	Accuracy TIC/(Avg)	TFCF K$/Item	Accuracy TFCF/(Avg.)
Actual Projects				
Organic Plant	243.0	0.92	144.9	0.97
Organic Plant	234.5	0.89	153.2	1.03
Organic Plant	206.1	0.78	148.6	1.00
Organic Plant Retrofit	291.3	1.11	135.2	0.91
Organic Plant	359.2	1.37	152.9	1.03
Organic Plant	*416.5	1.58	264.0	1.77
Organic Plant	248.2	0.94	135.0	0.91
Organic Plant	301.4	1.15	185.6	1.25
Organic Plant	220.4	0.84	128.2	0.86
Average	**263**	(TICF)	**149**	(TFCF)
• Excluded from avg.				
Estimates				
Organic Plant	241.1	0.92	144.8	0.97
Organic/Mech. Plant	237.9	0.90	157.8	1.06
Inorganic Plant	300.0	1.14	164.5	1.10
Inorganic Plant	316.3	1.20	175.0	1.17
Water Treatment Plant	273.1	1.04	164.2	1.10
Cases within ± 20%		11/14		12/14
Cases within ± 10%		6/14		10/14

- When only the equipment count is known, an order of magnitude estimate can be prepared in seconds with the $263k factor.
- When an annotated equipment list is available, the equipment and engineering account can be estimated with the procedures discussed in this chapter, and a conceptual estimate prepared in one or two days, using the 149 factor.

An allowance must be added in both cases to account for the almost certain growth in equipment count during engineering.

The recommended allowance for first-of-a-kind plants is:

From conceptual design to final	30-40%
From Phase 0 design to final	10-20%
From Phase 1 design to final	5-10%

Duplicate plants should be considered as Phase 0 or Phase 1.

- The effectiveness of these factors, when applied to plants similar to those analyzed has been confirmed with several cases analyzed after publication of the first edition.

  However, it can easily be fathomed that it would be dramatically lower for a lightly instrumented 100% carbon steel or a heavily retrofitted plant.

  Fortunately the scope of effectiveness of the TFCF can be modified and broadened by the judicious analysis of its cost components shown in Table 19.36. For lack of better information this breakdown is based on the typical cost breakdown in Table 10.1 after backing out the equipment and engineering costs

- At the time there were only two cases available that justified modification of the TFCF. Being aware that "one hot day summer does not make" I went ahead with the analysis anyway and was pleasantly surprised by the accuracy of the check estimates.

  Since there were not more cases to confirm these results I decided not to include them in the body of the book but rather present them as points of interest in Appendix M. By doing so I hope to raise the interest of some readers and entice them to further check this approach.

  REMEMBER, PROJECT MANAGERS MUST DO THE BEST THEY CAN WITH THE TOOLS THEY HAVE AT HAND.

Piping Costs

This shortcut technique is suggested for ballpark estimates of the piping account for liquid flow plants. It must be used together with Section 19.4 and confirmed with the factors in Table 10.1.

- **Process Areas**

– Number of lines	Equipment count x 3.5
– Length	50 ft. per line
– Number of valves	1.5 ft. per line
– Average diameter	Estimate based on pump capacity, usually 2 1/2-in. average.
– Material	Pondered average based on plant metallurgy.

Table 19.36 Field Costs Factor Breakdown

	Thousand $			Work Hours	
Field Activity	Total	Mat'l	Labor	$/WH	W-H
Equipment erection	7,250	0	1,250	54.00	134
Piping	58,400	18,000	40,400	48.50	833
Instrumentation	18,200	12,300	5,900	47.50	124
Electrical	11,800	4,400	7,400	47.50	156
Site Preparation	2,200	350	1,850	45.00	41
Fire Protection	3,700	1,850	1,850	45.00	41
Concrete	10,350	1,850	8,500	45.00	189
Structural Steel	12,100	6,900	5,200	51.00	102
Buildings	3,600	2,200	1,400	45.00	31
Insulation	3,600	2,200	1,400	48.50	29
Painting	1,400	350	1,050	45.00	23
Total Directs	132,600	50,400	82,200	48.30	1703
Field Indirects 20% Labor	16,400				
Total	149,000				

- **Interconnecting Pipe and Utility Distribution**
  Estimate based on either flowsheet and plot plans take-offs, or use 50% of the process areas' piping.

Equipment-Related Costs

Instrumentation Account

Based on the Table 19.34 historical data, $20,000 per equipment item is more than adequate.

Electrical Account

An allowance of $21,000 per motor and feeders is usually adequate to cover:

- Unit substation and switchgear.
- Power and control wiring.
- Process area lighting.
- Grounding.

It would not cover:

- Main substation and distribution system.
- Yard lighting.
- Auxiliary buildings lighting usually included with building cost.

Engineering Account

Based on the Table 19.31 historical data, 600-700 hr per item should be adequate for the average project. Loaded engineering costs vary from $75/hr for a large contractor in the East Coast to $50/hr in the South and Southwest.

APPENDIX A
RECOMMENDED READING

- Bent, J. A. *Applied Cost and Schedule Control.* Marcel Dekker, New York, 1982.
- Bierman, H., and Smidt, S. *The Capital Budgeting Decision.* 4th edition. Macmillan Publishing Co. Inc. 1971.
- Cabano, Louis J. *Retrofit Projects-The Ultimate Management Challenge*, Chemical Engineering Progress, April, 1987.
- Cabano, Stephen L., and Michalak, Christopher F., *The Five Step Plan for Project Management*, Chemical Processing, October 1997.
- Clark, Forrest D., and Lorenzoni, A.B., *Applied Cost Engineering*, 3rd Edition, Marcel Dekker Inc., 1997.
- Clough, R. H. *Construction Contracting.* 3rd edition. John Wiley and Sons, New York, 1975.
- Guthrie, K. M. *Process Plant Estimating and Control.* Craftman Book Company of America, 1974.
- Hackney, J. W. *Control and Management of Capital Projects.* 2nd edition. McGraw Hill, Inc., New York, 1992.
- Humphreys, Kenneth K., and English, Lloyd M., Editors, *Project and Cost Engineers Handbook*, 3rd Edition, Marcel Dekker Inc. 1993.
- Kerridge, A. E. *How to Develop a Project Schedule.* Hydrocarbon Processing, January 1984.
- *Manual for Special Project Management.* CII Publication, July 1991.

- *More Construction for the Money.* Summary Report of the Construction Industry Cost Effectiveness Project, a Business Roundtable Publication, Jan. 1983.
- *Project Definition Rating Index*, Industrial Project Implementation (PDRI), A Construction Industry Institute Publication, July 1995.

APPENDIX B
GLOSSARY

AFC Approved for construction.

AFD Approved for design.

AFE Authorization for expenditures.

ANSI American National Standard Institute.

ASME American Society of Mechanical Engineers.

Balloon Symbol for field instrument in a P&ID.

Basic engineering Engineering required to bring a Phase 1 design to the AFD level.

BW Butt welded.

CED Corporate Engineering Department.

CICE (Construction Industry Cost Effectiveness Project) A construction productivity study sponsored by The Business Roundtable.

CII Construction Industry Institute

CF Cubic foot/feet.

CM Construction Manager/Management.

CS Carbon Steel.

CY Cubic Yard.

DCS Distributed control system.

DH (Direct hire) Practice of some general contractors of hiring craftsman directly from the local labor pools rather than subcontracting the work.

EPA Environmental Protection Agency.

EPC (Engineering, procurement, and construction). Consolidation of the responsibility for those activities under a single contract(or).

Fast tracking Overlapping of project activities normally executed in a consecutive manner.

FEL Front End Loading.

Flg. Flanged.

FMEA Failure Modes and Effect Analysis.

Fringe benefits (FB) Contractual adders to the base labor rate: medical and pension plans, vacation, travel pay, holidays, etc.

GC General contractor.

GMP Guaranteed maximum price.

hp Horsepower.

HVAC Heating, ventilating, and air conditioning.

IRR Internal Rate of Return – Project financial value indicator.

Lang Factors Derivations of the estimating technique, originally proposed by H. J. Lang, relating total installed cost to equipment cost.

LF Linear foot/feet.

LJ Lap joint.

Loaded labor rate Base labor rate plus PAC's, fringe benefits, and other subcontractors costs, including overhead and profit.

MCC Motor control center.

MPS Master Project Schedule.

MPy Million pounds per year.

NPDES National Pollutant Discharge Elimination System - Federal water discharge regulation.

NPV Net Present Value.

OH Overhead.

OSHA Occupational Safety and Health Act.

OT Overtime.

PAC's Payroll added costs: Social Security, worker's compensation, insurance, and federal and state taxes.

PDR (Project Definition Rating) Technique to assess contingency.

PDRI Project Definition Rate Index.

PFD Process flow diagram. Process configuration with heat and material balances.

PHA Process Hazard Analysis.

Phase 0 Preliminary process design.

Phase 1 Firm process design.

Phase 2 Detailed engineering design, procurement, and project control.

P&ID Piping and instrumentation diagram. Basics of detailed engineering.

PLC Programmable logic controller.

PO Purchase order.

PM/PE Project Manager/Engineer.

PSM Project Safety Management – OSHA safety program.

QA/QC Quality assurance and quality control.

RMP Risk Management Program.

SC Subcontract/subcontractor.

SF Square foot/feet.

SHE Safety Health and Environmental.

SS Stainless steel.

SW Socket weld.

Swd Screwed.

Sy Square yard.

Take-off Detailed quantity count of work components: cubic yards, tons, feet, etc.

TEFC Totally enclosed fan cooled. Term applied to electric motor.

TFCF Total Field Cost Factor.

TIC Total Installed Cost.

TICF Total Installed Cost Factor.

T-T Tangent to tangent. Straight-side dimension of vessels, columns, reactors.

VIP Value Improved Practice.

VM Venture Manager.

WU Work unit. Standard unit established to value all work components in a rational and consistent manner.

APPENDIX C
TYPICAL COORDINATION PROCEDURE

Introduction

The____________________ Division had approved pre-AFE spending to begin process design for a____________________________ production facility at the ___________________________plant site. Final AFE approval is expected by ___________________ and ____________________ production should start no later than_______________________ in order to meet marketing requirements.

Basic Guidelines

The facility should be designed for a_____________ to _____________ year life. The economics of the product indicate that low capital cost is (is not) more important than low operating costs.

The most cost-effective schedule will be determined during AFE preparation but all schedule improving measures that could have an adverse effect on capital cost must have specific management approval.

In order to minimize cost through the most effective use of in-house personnel, we will follow the small project approach acting as general contractor and subcontract engineering and construction services on a discrete basis as required.

General Responsibilities

____________ *Division*

The _________________ Division (plant) is the project sponsor, owner, and eventual operator of the facility. They provide overall direction as well as design criteria, basic process information and operating experience, and have the ultimate responsibility for the success of the project.

Coordination and overall direction of the project comes from the Division (plant) through the Venture Manager.

Fundamental process data, as well as operating and maintenance experience, come from the plant and/or R&D through the various specialists assigned to the design team.

The plant will provide P&ID drafting, purchasing, and accounting services as well as a field manager to direct construction activities.

Central Engineering Department

CED is responsible for the design and construction of the facility within the scope established in the AFE. The process design (Phase 1) will be done by the CED process section with cooperation from Division R&D and plant engineers.

The task force or team concept prevails. All personnel are responsible to the Project Manager when acting as members of the project team and/or assisting the Project Manager in performing his/her duties with respect to the project.

CED will also do all contracting, obtain prices, and prepare requisitions for the construction materials purchased by the plant.

Corporate Environmental Planning

The Corporate Environmental Planning Department is kept informed of environmental issues and problems. The Project Manager and design team seek advice and assistance from these groups as specific needs arise generally through the plant Environmental Department.

Safety and Industrial Hygiene

The Group Safety and Industrial Hygiene Manager is kept informed of hazards problems by the Venture Manager through the plant safety supervisor. The Project Manager and design team seek advice, recommendations, and assistance from this resource, including coordination of safety audits.

Corporate Health Services

The Health Services group is kept informed of hazards problems by the Venture Manager. The Project Manager and design team seek advice, recommendations, and assistance from this resource.

Individual Responsibilities

Venture Manager (Name)

The Venture Manager reports to (Position) and:

- Represents the business group and is responsible for the establishment of project financial and schedule goals and guidelines.
  - Evaluates developmental engineering efforts coordinating business objectives with realistic execution programs.
  - Reviews business and technological alternatives available and makes a recommendation to business group management.
  - Coordinates venture efforts with corporate groups, marketing, production, purchasing, legal, etc.
  - Assembles the project design team.
- Provides the overall direction and assumes the responsibility of coordinating the efforts of all internal groups and insuring that operable, safe, and economic facilities are designed, built, and started up.
  - Secures all permits, licenses, or other certificates required by governmental agencies.
  - Makes all business arrangements directly associated with the project except those related to contracting engineering and/or construction services.
  - Maintains liaison with Environmental Planning, Health Services, Toxicology, and other corporate staff departments.
  - Ascertains that the Project Team receives adequate and timely input and support form R&D and Operations.
  - Organizes and supervises the startup operations.
  - Keeps Division management informed and secures approvals as required.

Project Manager (Name)

The Project Manager has a dual responsibility to both the Venture Manager and to the CED Director for the execution of the engineering, procurement, and construction.

The Project Manager is the official CED contact with the contractors and has the ultimate responsibility of directing and controlling the scope, budget, and schedule as defined in the AFE. Through the Technical Manager and the Field Manager, the Project Manager manages and coordinates the activities of the design team, plant support, the contractors, other agencies, and the staff specialists assigned to the project. Duties include but are not limited to:

- Support the Venture Manager during the early stage of project development.
  - Develop project execution strategy and conceptual schedules to ascertain the viability of the Venture Manager's objectives.
  - Prepare the preliminary project execution plan.
  - Assume a hands-on participation in the preparation, review, and approval of the AFE estimate.
- Support the Technical Manager during the preparation of Phase 0/1 design packages.
  - Prepare conceptual estimates of the process options being considered to assess their cost impact.
  - Provide project engineering and constructability input to plot plans and equipment arrangement options.
- Monitor, approve, and document all project expenditures, changes, and charges in order to insure proper control.
  - Review and approve, within the established limits of authority, all vendors' and subcontractors' quotations and bid analyses.
  - Review and approve all change orders and claims to confirm their validity, scope, cost, proper approvals, documentation, timeliness, etc.
  - Review and approve all invoices prior to payment.
  - Approve all internal charges to the AFE to ascertain their correctness.
- Direct, supervise, and coordinate the work of all members of the Project Team as well as the various internal supporting groups.
  - Develop the project participants into a team, with a team attitude and focus, so that all participants are free to contribute and participate to the fullest and most beneficial extent.
  - Insure that the owner's reviews and approvals are conducted in a timely manner.

  - Insure the timely participation of the staff specialists.
  - Keep the various support groups informed so that they can provide their input in a timely manner.
  - Review and approve Phase 0/1 packages for completeness before transfer to the engineering contractor.

- Assume the responsibility for the mechanical design and construction of the AFE scope assigned to CED to achieve the quality cost and schedule objectives stated in the AFE.
  - Prepare the project execution plan.
  - Prepare the technical bid package, develop bidders qualifications, and contractor evaluation criteria. Lead the technical evaluation effort.
  - Direct and supervise the work of the engineering contractor, monitoring its procedures, staffing, and performance to insure that the quality, cost, and schedule objectives are met without unnecessary expense and within timing constraints.
  - Review and approve contractors' schedules and cost estimates.
  - Review, on a routine basis, the contractors' progress and establish control systems to make independent evaluations.
- Maintain proper project records and documentation.
  - Organize and maintain proper project files.
  - Keep up-to-date records of all changes and extras.
  - Keep up-to-date records of all commitments and expenditures.
  - Ascertain that all important project decisions are formally documented through minutes of meetings, memos and/or formal change notices.
  - Insure that contractors submit all the required documentation, schedules, reports, insurance policies, etc., on a timely basis.
- Keep the Venture Manager and CED management informed of all significant developments, particularly those concerning changes, cost, and completion dates.
  - Issue monthly status and cost reports.
  - Make monthly schedule and cost forecasts.
  - Prepare close-out report.

Technical Manager (Name)

During the process design stage, the Technical Manager is responsible to the Venture Manager, and during the execution stage, to the Project Manager. Duties include:

- Assume the responsibility for the technical contents of the design.
  - Develop an adequate and economical process design (Phase 0) that is consistent with the design, operating, and maintenance criteria established by the Venture Manager.
  - Develop the detailed process and engineering specifications and P&ID's (Phase 1) required to implement the approved scope.
  - Work closely with the Venture Manager, R&D, plant process engineers, and, if required, outside consultants to achieve consensus on best process choices and insure that proper and sufficient design data are developed on a timely basis to support the Phase 2 engineering.
  - Direct the work of the Process Engineers assigned to the Project Team.
  - Conduct hazards and safety reviews in cooperation with the appropriate personnel and, if required, outside consultants to insure a safe, efficient plant startup and operation.
- Insure contractors' compliance with approved design specification and scope.
  - Transmit all technical information to the contractor.
  - Review and approve contractors' technical work, process calculations, equipment layouts, project specifications, and, above all, any changes to the P&ID's.
  - Review and approve technical content of vendors' quotations and bid summaries.
  - Document all technical decisions and/or changes made by the owner and/or the contractor.
  - Interface with internal and contractors' specialists to obtain their input when required.
  - Prepare design manuals.

Construction Manager (Name)

The Construction Manager has a dual responsibility to both the Project Manager and the plant engineer. The Construction Manager represents the Project Manager in the field and is the official contact with construction contractors in all field-related matters. Generally, the CM is responsible for all field activities including those performed directly by the Owner's personnel. The duties include but are not limited to:

- Direct and/or coordinate both contractors' and plant's field work to insure smooth interfacing.
- Monitor, through the field inspectors, all work to insure conformance to specifications, schedule, safety, and plant regulations.
- Direct and supervise the field inspectors and the project safety engineer.
- Assure proper plant security and safety in all areas related to the AFE work.
- Review and approve all field extras within limits of authorization.
- Coordinate contract work with other plant activities.
- Review and approve detailed schedules of any construction work affecting plant operations.
- Make independent progress evaluations and projections.
- Write field progress reports to keep Project and Venture Managers informed.
- Monitor the work performed by the plant to ascertain whether it is done on a timely basis, and advise contractor and Project Manager of any schedule deviations.

Process Engineers (Names)

Process Engineers have a dual responsibility to both the Technical Manager and their line supervisors. Their responsibilities are to:

- Develop an adequate and economical process design and control criteria consistent with safety, operating efficiency, and maintenance economy.
- Develop, review, and approve process flowsheets and P&ID's.
- Review the instrument engineer's work to ascertain compliance with the established control criteria.

- Document all important technical decisions.
- Conduct operating and hazards reviews.
- Prepare operating procedures.
- Conduct final checkout and assist the production group during plant startup.

Production Engineer (Name)

The Production Engineer is in charge of the startup and operation of the facility. In that capacity, the PE has a dual responsibility to both the Venture Manager and the unit production manager.

CED / Division Specialists as required (Names)

Specialists have a dual responsibility to both the Project Manager and their line supervisors and will support the project work in their discipline areas as required by the Project Manager. These areas include:

- Auditor
- Contract
- Cost
- Electrical
- Hazards
- Instrumentation
- Mechanical
- Procurement

Limits of Authority

Purchasing and Subcontracting

All commitments and expenditures, including work performed by the plant, will be covered by purchase order and/or plant work orders which must be authorized by the Project Manager or a designate. Unauthorized charges will not be honored.

Approval levels for purchase orders and subcontracts within budget are as follows:

Up to	$_______	Project Manager
$______	to $______	Venture Manager
Over	$_______	Venture Manager CED Director

Design / Scope Changes

After approval of the AFE, deviations from the scope as defined in the AFE and/or an approved design shall be handled in a formal manner and subject to the following levels of approval:

Up to	$_______	Project Manager
$_______	to $_______	Venture Manager
$_______	to $_______	CED Director
$_______	to $_______	Manufacturing Director
$_______	to $_______	Group Vice President
$_______	and over	President

Field Changes / Extras

After award of each contract, all field changes and extras shall be documented in a timely manner according to the procedure set up in the contracts.

The authorization levels required have been set as follows:

up to	$_______	Construction Manager
$_______	to $______	Project Manager Venture Manager
$_______	and over	To be handled as Scope Changes

APPENDIX D
ESTIMATE CHECKLIST

Purpose

To call to mind various items required in the preparation of an estimate that should be considered for inclusion.

- General:
  - Contract type:
    1. Lump sum.
    2. Cost plus with/without incentives.
  - Environmental:
    1. Permits - associated delays.
    2. Special pollution control requirements.
    3. Environmental Impact Statement.
  - Weather conditions - seasonal effects:
    1. Winterization.
    2. Rain.
  - Job conditions
    1. Congested work area accessibility.
    2. New technology.
    3. Special safety requirements.
    4. Complex process - highly instrumented?
    5. Revamp of existing facilities.
    6. Utility tie-ins.
    7. Interferences due to operation? Productivity?
    8. Scope well defined? Offsites?
    9. Plot plan, flow sheets.

10. Schedule - manpower loading, availability.
11. Local construction climate - overtime required?
12. Union/non-union.
13. Special fabrication requirements:
    a. Stress relief, X-ray.
    b. Hydrostatic testing.
    c. Pneumatic testing.
14. Special paints.
15. Insulation.

- Site Development:
  - Land purchase.
  - Drainage, dewatering.
  - Cut and fill.
  - Removal of excavated material - contaminated wastes, spoils.
  - Soil stability.
  - Landscaping, seeding, topsoil, fertilizer.
  - Clearing and grubbing.
  - Spillways.
  - Signs.
  - Bridges.
  - Roadways - concrete, asphalt, gravel, other.
  - Walkways - concrete, asphalt, gravel, other.
  - Fencing - property, security chain link, other.
  - Railroads - siding, switching, bumpers.
  - Sewers - storm, sanitary, acid, other.
  - Area lighting.
  - Tank dikes - earth, concrete, other.
  - Special transportation to remote sites.
  - Labor camps, community facilities.
  - Underground obstructions.
  - Existing pipe racks adequate?
  - Piling - bearing, sheet.
  - Parking facilities.
  - Guard service.
  - Housing accommodations.

- Equipment:
  - Spare equipment - in place, warehouse spares.
  - Truck and/or rail scales.
  - Firewater storage tank, firewater pump, emergency power - diesel, electric.
  - Truck loading/unloading facilities.
  - Rail loading/unloading facilities.
  - Barge loading/unloading facilities, docks.
  - Forklift trucks.
  - Hauling vehicles, trains, trucks, tractor.
  - Ambulance.
  - Firetrucks.
  - Vendor representatives, field service startup assistance.
  - Startup.
  - Grouting, setting, acid brick.
  - Safety equipment.
  - Freight - domestic, overseas, air.
- Utilities:
  - Water - city, wells, seawater.
  - Water treatment.
  - Process water treatment.
  - Process waste water treatment.
  - Process waste treatment - outfall treatment or monitoring.
  - Boiler - cogeneration.
  - Boiler - single fuel, multifuel.
  - Boiler - feed water treatment.
  - Boiler - high and low pressure steam and condensate return lines.
  - Compressors - plant air.
  - Compressors - instrument air, receiver, dryer, and main header.
  - Compressors - process gas.
  - Emergency power - electric/diesel generators, inert gas.
  - Firewater systems - tanks, pumps, underground pipe.
  - Sprinkler systems - wet/dry, heads, hose cabinets.
  - Cooling tower, cooling tower pumps, header piping.

- Air venting systems - blower, duct, connections supports.
- Environmental - air purifying, water, dust collecting.
- Metering systems.
- Stacks.

• Buildings - type, style, finish, openings:
  - Process building.
  - Warehouse.
  - Shop, shop crane/hoist.
  - Administration and office buildings, office furniture, equipment.
  - Laboratory, lab equipment computer, analyzers, other equipment.
  - Change house, restrooms, shower, lockers (male and female), lunch room.
  - Control building - blastproof, computer system.
  - Motor control center.
  - Substation.
  - Compressor building.
  - Garage.
  - Pump house.
  - Guard house.
  - Structures - open, closed.
  - Partially enclosed storage areas.

• Miscellaneous:
  - Pipe racks - bents, supports, hangers, sleepers, t-supports.
  - Piping.
  - Instrumentation, instrument pipe, electronic, digital, pneumatic.
  - Automation - process controllers, host computers, robotics.
  - Electrical - power wiring, MCC, substation, X-former, instrument wiring, grounding poles, pole lines, lightning arrestors.
  - Concrete.
  - Steel.
  - Fireproofing.
  - Painting.
  - Insulation.
  - Field costs:

1. Base rate - journeyman.
2. Fringes - vacation, union dues, pension fund, medical coverage, travel, other.
3. Payroll taxes.
4. Payroll insurance.
5. Consumable supplies.
6. Petty tools.
7. Temporary facilities - trailers, water, toilets, change house, parking.
8. Unallocated labor.
9. Construction equipment rental.
10. Overhead.
11. Profit.

- Contract home office and fee.
- Consultants.
- Taxes - federal, state, local.
- Duct work, supports, stiffeners, louvers, diffusers.
- Heating, ventilating, and air conditioning.
- Elevators - freight, passenger.
- Handicapped facilities.
- Protective equipment.
- Expense items - dismantling, repair, rework, removal.
- Taxes - special taxes, duties, imports.
- Spare parts.
- Startup.
- Escalation.
- Restricted reserve.
- Contingency.

APPENDIX E
EXECUTION PLAN/MPS FOR CASE STUDY

E.1 Background

During the initial project analysis and the preparation of the Initial Plan of Action several important facts became evident.

- Some fast tracking would be required to meet the mandated 18 months project duration.
- The estimated hours for both engineering and construction exceed the limits of the definition of small project in Section 1.2. The project had to be handled through an EPC contract.
- Since, ideally, the engineering contractor staff should be 2-4 times the anticipated peak, the bidders list was limited to small to mid-size firms (80 to 160 employees).
- The number of engineers required to complete Phase 1 in time to meet the schedule exceeded the in-house capabilities and had to be supplemented with contractor's personnel. Consequently the selection of the EPC contractor was expedited in order to have personnel available for Phase 1 work.
- Long delivery equipment had to be placed on order before approval of the AFE in order to meet the schedule.
- The estimated construction hours and anticipated peak staff suggested that the work could be beyond the reach of the local contractors. Consideration had to be given to attracting large national contractors or splitting the work into several small subcontractors.

- Additional funding was required to purchase long delivery equipment and start detailed engineering prior to AFE approval.

Additional funds were approved and the work proceeded according to the Initial Plan of Action (see Fig. 5.3).

The EPC contract was awarded on competitive basis to a small (75 employees) contractor with an excellent group of process engineers, a very lean organization, and a very good record of handling subcontractors in construction management situations.

Five or six weeks later, when the process configuration was finalized and an annotated equipment list was available (Phase 0), the Project Manager prepared a quick conceptual estimate using the procedures in Chapter 19 in order to validate the assumptions of the Initial Plan of Action (see Table 9.1).

The validity check (Section 9.4) showed an increase in construction hours with a corresponding schedule extension of one month.

Several expediting measures were planned but held in abeyance waiting for completion of Phase 1 design to find out whether the appropriation estimate and MPS confirmed the potential delay.

In the meantime the Project Manager can use the construction hours breakdown by disciplines to prepare a preliminary execution plan to refine the field staffing requirements and prepare a meaningful, tentative plan to subcontract construction work.

E.2 Preliminary Execution Plan (PEP)

Preamble

The Preliminary Execution Plan is essentially a continuation of the Initial Plan of Action. The construction hours from the validation estimate are used to prepare a "loaded" bar chart schedule which in term will serve as the basis for a tentative contracting plan.

Labor Loading and Construction Progress Curve

- The estimated duration for each construction discipline is laid out in bar chart form over the estimated 10 months total duration. This is done as per the guideline in Fig. 9.1 and is illustrated in the top chart of Fig. 9.2.
- The estimated hours (converted to months) for each discipline are then distributed over the corresponding duration and totalized to develop the labor loading diagram and the construction progress curve illustrated in the bottom chart or Fig. 9.2.

Note: Remember that work activities, unless they are very short, seldom start at full blast, but do so with a minimum staff and gradually build up to a peak that tapers off rather quickly at the end.

Fig. 9.2 shows that the field staff would peak at 115 workers instead of the anticipated 133 estimated with the validity check. It also shows the peak staffing for each discipline thus providing an excellent tool for an intelligent survey of local labor availability and contractors' capabilities.

Field Survey

The field survey should always be conducted by the Project Team in cooperation with plant representatives. When an EPC contractor is on board, like in this case, its construction manager most definitely also participates.

The survey team made the following determinations:

- The area is essentially non-union and most of the qualified craftsmen are controlled by the local contractors.
- There is a large labor pool in the area, many unemployed during the anticipated construction period.
- There are several qualified civil contractors with capability of handling 25 plus workers. Two of them are experienced on design-build contracts.
- There is a small contractor who also owns a construction equipment rental business and specializes in equipment and structural steel erection. He is highly regarded by the plant and has a permanent crew of 25-30 riggers, iron workers, and millwrights.
- There are three mid-sized mechanical contractors, qualified to do industrial piping and equipment erection, with demonstrated capability of handling projects requiring more than seventy workers. Two of them also have piping fabrication shops and asked to be considered for the prefabricated piping purchase. All of them asked to bid for the structural steel erection.
- There are two large electrical contractors well qualified to handle the job. Neither has instrument installers but both have connections, and have worked with well-reputed national firms specialized in instrumentation and would use them as subcontractors.
- There are two qualified insulator contractors.
- Finally, there is a well-known national general contractor, with an important office in the area, who is very interested in taking over the entire construction on cost-reimbursable basis

They have a nationwide labor pool and can mobilize enough craftsmen to staff a project several times the size of this one. When told that management would not entertain that option they still showed great interest to bid all packages as they come out for bids.

Tentative Contracting Plan

After discussing the survey findings among the Project Team, the Venture Manager, and the Engineering Contractor, it was decided to instruct the contractor's engineering group to schedule the design work so that the bid packages could be released in the following sequence.

Week 31 Buildings. Design/build.

Week 32 Civil work including concrete, site work, sewers, underground piping, and fire protection.

Week 35 Structural steel erection.

Week 35 Offsite pipe fabrication.

Week 35 Piping and equipment erection with option to split.

Week 43 Electrical and instrumentation.

Week 51 Insulation.

Bidding

- Try to limit **bidder slate** to three bidders.
- Allow **national contractor** to bid all packages.
- **Civil work**. Include the two most promising local contractors.
- **Buildings**. Include the two with design-build experience.
- **Structural steel**. Try to award the steel fabrication contract including erection. If not possible, include the contractor with the equipment rental business as well as one of the mechanical contractors
- **Piping**. Include the three mechanical contractors.
- **Electrical / Instrumentation.** Include both electrical contractors.
- **Insulation**. Include both contractors.

It is always a good practice to also use the labor survey to investigate, with both contractors and users, the current unit prices of the most important construction components, i.e., cubic yards of concrete, tons of structural steel (erection), craftsman hours (loaded), etc.

E.3 Firm Execution Plan

Reality Check

The construction schedule for the Preliminary Execution Plan (PEP) is based on activity durations that represent an average for "normal" project execution and must be adjusted to reflect the realities of the specific project conditions.

The PEP does not only serve as the basis on the field survey and construction contracting plan; it's also a thought provoker and a lighting rod to attract the (constructive) criticism necessary to develop a realistic firm execution plan.

The specific project conditions requiring schedule adjustments are almost invariably of two types.

- Bad **weather** will always have a negative impact on both schedule and labor productivity, especially on civil work and outdoor structural steel and piping work; allowances **must** be made when that type of work must be done in the winter and/or rainy season.
- Invariably any construction work in an existing site will be subject to **operating restrictions,** i.e.:
  - Welding restrictions.
  - Work in crowded areas.
  - Work around operating equipment.
  - Work requiring plant shutdowns.

All these restrictions impact both cost and schedule and must be addressed before the appropriation estimate and the MPS are issued for management approval.

Appropriation Estimate

Preamble

Most owners require that AFE's (authorizations for expenditure) for important projects be accompanied by at least a preliminary quality estimate and a Master Project Schedule (MPS) with a firm project execution plan. These should always be in-house activities prepared by the project team with direct participation of the Project Manager.

In cases like this case study, when an EPC contractor was involved early in the project, the Project Manager could be very tempted to delegate those activities to the contractor. To do so would be a grave mistake for two important reasons.

- Contractors are notoriously reluctant to respond quickly to requests for estimates and schedules. It would be very unrealistic to ask the EPC contractor to do so in the two or three weeks allowed by the fast track schedule.
- Preparing the appropriation estimate and MPS offers the Project Manager and the entire project team an excellent opportunity to get a firm grip on the project and gives them the best tools to monitor and evaluate contractors' performance. As an experienced project manager said once

KNOWLEDGE IS POWER!

Estimate

The Phase 1 design package is the basis for a very good quality semi-detailed preliminary cost estimate that can be prepared quickly using the procedures in Chapter 19. Appendix L illustrates the preparation of the estimate for the case study

Master Project Schedule (MPS)

- An **engineering schedule** prepared with the guidelines in Fig. 9.1 provides sufficient information for the appropriation request. It also gives the Owner's Project Manager an excellent tool to review the contractor's own schedule and, if necessary, discuss it with a degree of authority (see Figs. E.1 and E.2).

  In small projects the Owner may opt to have the engineering done in-house with regular and/or contracted personnel. In those cases the Project Manager assuming the detailed engineering responsibility must enhance the MPS by breaking down the engineering activities and giving them value based on work hours. The information given in Chapters 12,15, and 19 should enable the curious Project Manager to do so.
- The preparation of the MPS for **Construction** illustrated in Figs. E.3 through E.8 requires some field experience and a basic knowledge of how the various activities are accomplished

Normally one member of the Project Team has construction experience. If the Project Manager does not have it, it is imperative that somebody in the team does.

The starting point to prepare the MPS must be a semi-detailed estimate broken down in discrete portions that relate directly to well-defined construction activities. Some cost items in the estimate need further breakdown to make them more manageable. This could always be done with help from Table 15.2.

The breakdown of activities is shown in Section E.4. The activities are laid out in bar chart fashion in a logical sequence, i.e.,

- Site preparation and underground piping first.
- Foundations before steel structure.
- Pipe racks before process structure to start early erection of the easy to install interconnecting piping.
- Equipment after structure based on deliveries.
- And so on.

Durations to every activity are assigned consistent with the estimated work hours and the number of workers that could work effectively in the particular area.

When all activities have been scheduled they are "loaded" with the estimated hours and totaled to develop the construction progress and labor loading curves shown in Fig. E.9 Since the schedule time grid is based on weeks the work hours must be converted to work weeks so that each unit is equivalent to one worker.

The new curves now show a peak staff of 115 (including supervision and contingency) and a duration of 8 months. However, when the staff is level over a three month period the peak would be 97-105 workers. The 8 month duration assumes perfect field conditions and must be adjusted to meet weather considerations and site restrictions.

Hopefully after the adjustments are completed the construction can be completed in the required nine months. If not, plans must be made to expedite construction through overstaffing, double shifting, or scheduled overtime.

The estimate must be corrected to reflect the situation and management duly informed in the request for funds.

Figure 9.3 in Chapter 9 illustrates the executive version of the Execution Plan to be attached to the request for funds.

E.4 Activity Breakdown and Loading

As mentioned in the previous section the schedule activities closely parallel the cost items in the appropriation cost estimate. The value assigned to each activity (loading) is also based on the estimated labor expressed in units consistent with the schedule time grid.

Since the time grid is based on weeks, the work hours (WH) in the estimate have been converted to work weeks (WW).

- The work hours for the **Site Work and Fire Protection** activities have been lifted directly from the estimate – Appendix L, Sections L.7 and L.8.
- The hours for the Civil Work activities, **Concrete, Structural Steel, and Buildings** have also been lifted directly from Appendix L, Sections L.9, L.10, and L.11. On larger projects deeper activity breakdowns can be prepared with Table 15.2.
- The **Equipment Erection** cost in Appendix L was estimated, following the quick and conservative approach, as 20% of the equipment cost. The work hours were back-calculated at $55/hr. However, this approach does not provide sufficient detail for progress monitoring and control.

  The work hours used for "loading" the MPS have been taken from Table 19.1 The observant reader will note that both approaches yielded, in this case, almost identical results. Deeper activity breakdown, should it be required, can be prepared with the aid of Table 15.2.
- In the absence of P&ID's the **Piping** take-offs were developed with the quick procedure discussed in Section 19.11 and the work hours for this exercise were lifted directly from Appendix L, Section L.4.

  In real life an appropriation estimate should be based at least on preliminary P&ID's and line by line take-offs would be available. The activities can then be broken down, at the Project Manager's discretion, by:

  - Process Areas,
  - Process Steps,
  - Type of Service (Process/Utilities),
  - Type of Activity as per Table 15.2, or
  - A combination of any of the above.

  It is important to note that the hours involved in the prefabrication of pipe in offsite shops are not included in the field construction activities.

  Note: The quick procedure outlined in Section 19.11 has proved to be very reliable on the conservative side on the cases analyzed by the author. Table M.4 in Appendix M illustrates one such case.

- The hours for the **Electrical Work** have been lifted from Appendix L, Section L.5, and broken down by process areas and offsites. The 440 V power distribution was also broken down as follows, as per the guidelines in Table 15.2.

	%
– Receiving materials	5
– Setting MCC	5
– Installing trays and junction boxes	35
– Laying wire on trays	20
– Making connections on both the motor and MCC sides	30
– "Ringing" out system	5
	100%

- Since P&ID's are not available at this point the **Instrumentation** take-offs have been developed with the procedure discussed in Section 19.7. The work hours have been lifted from Section L.5 of Appendix L and broken down by process areas and offsites. The hours for instrument installation and DCS wiring were also broken down as follows as per the guidelines in Table 15.2.

Instrument Installation	%
– Material receipt.	5
– Install.	75
– Activate (loop check).	20
DCS Wiring	
– Install hardware.	5
– Install conduit, wiring, and junction boxes.	60
– Instrument and JB connections.	15
– Install multi-conductor cable to termination panel.	10
– Terminal panel and TDC control connection.	10

- The **Insulation** account in Appendix L was factored to the equipment cost. However, as mentioned in Chapter 10, factored estimates are not suitable for construction progress tracking.

  For the purpose of this exercise the activity breakdown reflects a rough proration based on equipment count and feet of pipe for each area.

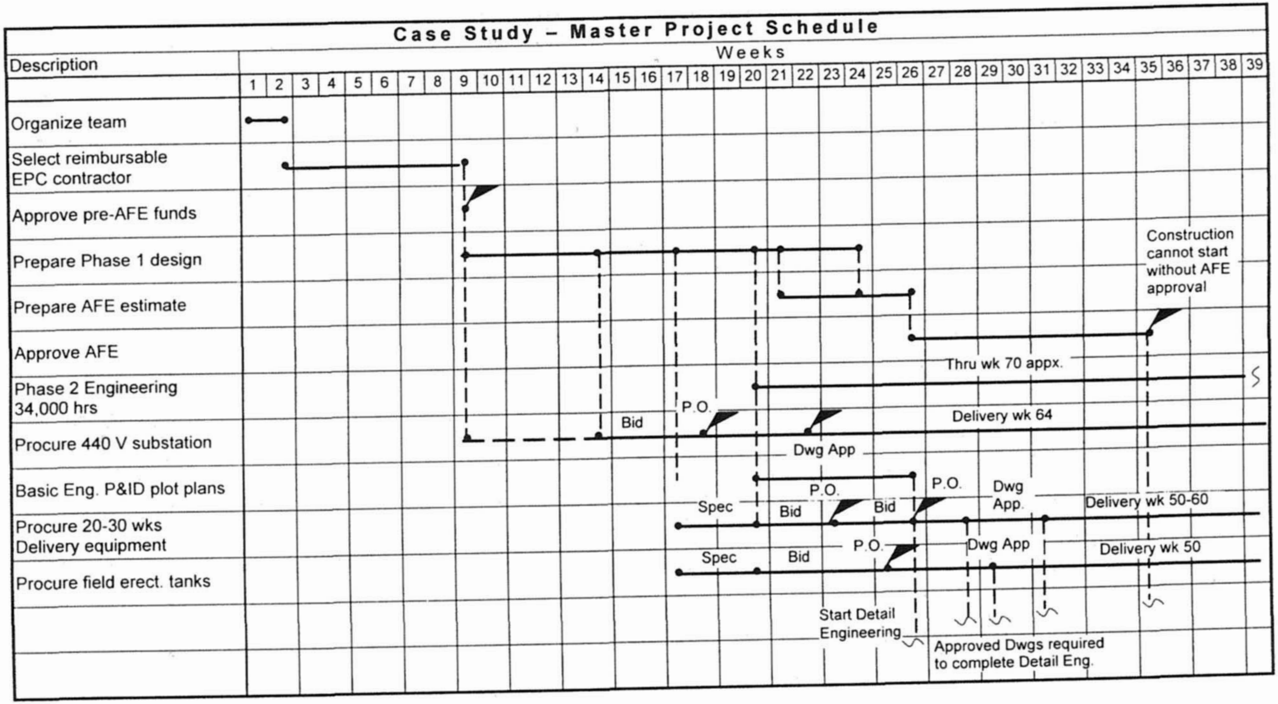


Figure E.1 Case study – engineering MPS, 1 of 2.

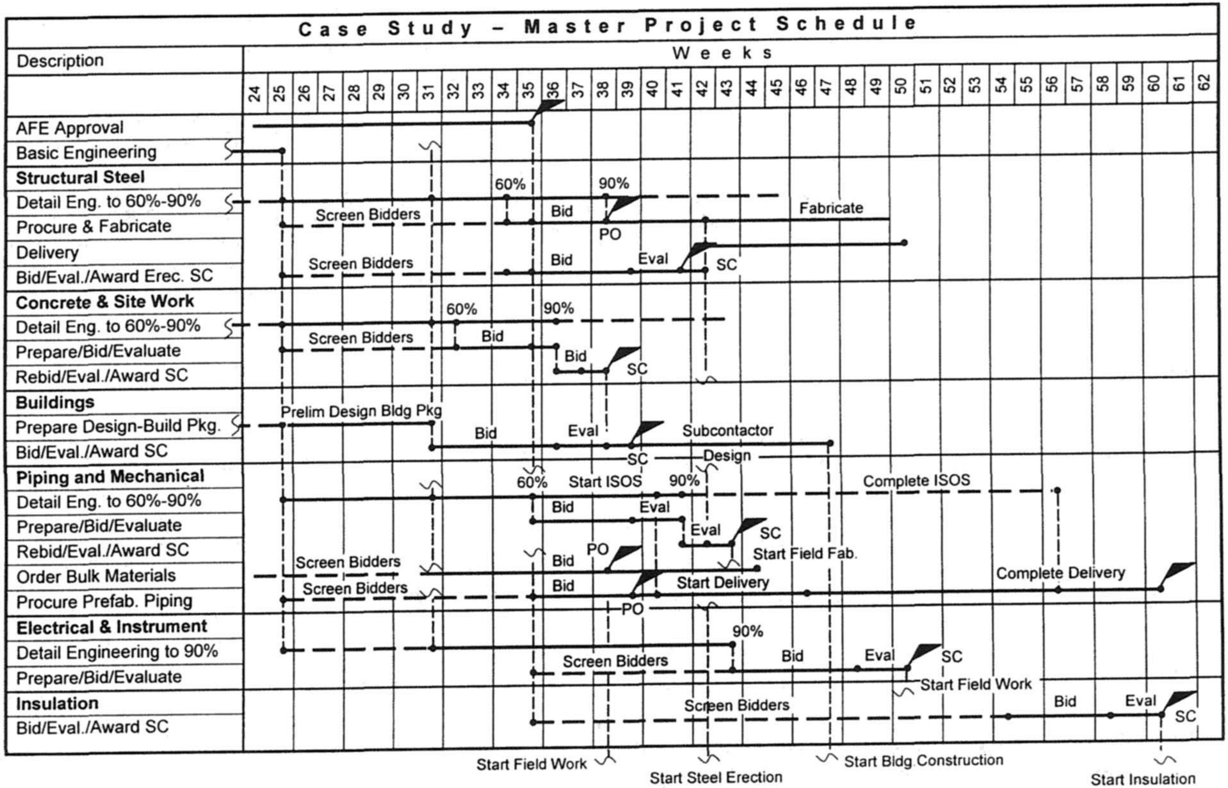


Figure E.2 Case study – engineering MPS, 2 of 2.

Case Study - Construction MPS (Loaded)

Elapsed Weeks

		38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	58	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
	MW	Civil S.C. Award																																					
Site work																																							
Clearing	2		2																																				
Sewers	13			2	4	4	3																																
Paving	11																																	3	5	3		
Transformer fence	1																																	1				
U.G fire water valve/hyd	26			2	4	4	4	4	4	2	2																												
Sprinklers/valve house	12																											2	4	4	2								
Grounding loop	6				2	2	2																																
Total site work	**71**		**2**	**4**	**10**	**10**	**9**	**4**	**4**	**2**	**2**																	**2**	**4**	**4**	**2**				**4**	**5**	**3**		
Concrete																																							
Piperack foundation	35		4	8	8	8	5	2																															
T.F. dike & equip found.	72						4	10	10	10	10	10	10	6	2																								
Loading/unload. area	11													4	6	1																							
Proc. struc. found./slab	63			4	10	10	10	10	10	8	1																												
Scrubber struct. found.	18									3	6	6	3																										
Elevated slabs	29													6	10	10	3																						
F.W. tank & pump found.	9										2	3	3	1																									
Misc. concrete	13																																	2	3	3	3	2	
																Erect tanks																							
Total Concrete	**250**		**2**	**12**	**18**	**18**	**19**	**22**	**20**	**21**	**19**	**19**	**16**	**17**	**18**	**11**	**3**																	**2**	**3**	**3**	**3**	**2**	

Start Struct. Complete struct.

Figure E.3 Case study – construction MPS (loaded), 1 of 6.

Case Study - Construction MPS (Loaded)

Elapsed Weeks

	MW	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Field erected tanks deliv.																																							
20-30 wk deliv. equipment																																							
Structural steel																																							
Pipe racks	22								3	8	8	3																											
Process structure	46									6	10	10	10	10																									
Proc. structure trims	5													2	2	1																							
Scrubber structure	10												2	4	4																								
Scrub. structure trim	3														2	1																							
Misc. equip. platforms	13																			2	2	2	2	2	2	1													
Total structural steel	**99**								**3**	**14**	**18**	**13**	**12**	**16**	**8**	**2**				**2**	**2**	**2**	**2**	**2**	**2**	**1**													
Equipment																																							
Field erected tanks	70																	4	12	12	12	12	12	6															
Pumps																																							
Process area	18														2	6	6	4																					
Scrubber area	5																	2	2	1																			
Tank farm	10																		2	4	4																		
F.W. pump	3																				2	1																	
Vessels/Exchange/Other																																							
Process area	72															4	4	6	6	6	6	6	6	8	8	8	4												
Scrubber area	19																2	4	4	4	3	2																	
Tank farm	11																						4	4	3														
Total equipment	**208**														**2**	**10**	**12**	**20**	**26**	**27**	**27**	**21**	**22**	**28**	**11**	**8**	**4**												

Compl. Foundation

Start Pipe Erection

Start Wiring

Complete Piping

Figure E.4 Case study – construction MPS (loaded), 2 of 6.

Case Study - Construction MPS (Loaded)

Elapsed Weeks

	MW	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
Piping					90%							Complete ISOS								
Detail engineering			P.O.			Start delivery														
Prefabricated piping																				
Bulk materials		P.O.			Delivery															
Subcontract award																				
Receive/sort materials	30				2	2	2	2	1	1	1	1	2	2	2	2	2	2	1	1
Field fabrication	184							4	6	6	10	10	10	10	10	10	10	12	12	12
Erection																				-Test--
Interconnecting	82												10	15	15	15	15	6	2	2
Process area	120																	8	10	10
Scrubber area	30																			3
Tank farm	57																			
Heat tracing	35																		Can start insulation	
Total piping	**538**				2	2	2	6	7	7	11	11	22	27	27	27	27	28	25	28
Electrical														After Pump Erect.						
Grounding loop			With site work																	
Award subcontract																				
Receive Materials	5														1	1	1			
Install trays & JB	30														4	6	6	6	6	2
440 V wiring																				
Process area (23)	8																			2
Scrubber area (11)	4																			
T.F. & offsite (20)	6																			

	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Piping					Last equip. deliv.														
Detail engineering	Complete delivery																		
Prefabricated piping																			
Bulk materials																			
Subcontract award																			
Receive/sort materials	1	1	1	1															
Field fabrication	12	12	12	12	8	6													
Erection																			
Interconnecting	2									--Test--									
Process area	10	10	10	12	12	12	12	8	2	2	2								
Scrubber area	6	6	6	6					1	1	1								
Tank farm			3	4	12	12	12	8	2	2	2								
Heat tracing										2	6	6	6	6	6	3			
Total piping	31	29	32	35	32	30	24	16	5	7	11	6	6	6	6	3			
Electrical																			
Grounding loop																			
Award subcontract																			
Receive Materials	1	1																	
Install trays & JB																			
440 V wiring																			
Process area (23)	2	2				1	1												
Scrubber area (11)			2	2															
T.F. & offsite (20)					2	2	1	1											

Start Piperack Insulation

Insulate all Pipe

Figure E.5 Case study – construction MPS (loaded), 3 of 6.

Case Study - Construction MPS (Loaded)																																							
		Elapsed Weeks																																					
Electrical (continued)		38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
440 V Conn. (both ends)																																							
Process area (23)	11																					4	4	2	1														
Scrubber area (11)	4																							2	2														
T.F. & offsites (20)	10																							4	4	2													
120 V loads																																							
Process area (64)	16																														2	4	4	4	2				
Scrubber area (10)	3																										2	1											
T.F. & offsites (20)	2																											2											
Lighting																																							
Process area	21																								4	4	4	4	4	1									
Scrubber area	5																													3	2								
Tank farm	11																											4	4	3									
Area lighting	50														2	4	4	4	4	4	4	4	4	4	4	4	4												
Set MCC	4																			3	1																		
Install substation	38																											4	8	8	8	8	2						
Grounding – all areas	6																														2	2	2						
Alarm & Comm. System	13																								1	2	2	2	2	2	2								
Ring out	4																																	2	2				
Total electrical	**251**														**7**	**11**	**11**	**10**	**10**	**11**	**8**	**11**	**10**	**14**	**18**	**15**	**14**	**18**	**18**	**17**	**16**	**14**	**8**	**6**	**4**				
Buildings																																							
MCC/Control room	83											4	10	10	10	10	10	10	10	6	3																		
Switch gear/F.W. pump	20																			4	6	6	4																
Total buildings	**103**											**4**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**9**	**6**	**4**																

Complete Bldg. Design

Deliver Substation

Set Control Hardware

Figure E.6 Case study – construction MPS (loaded), 4 of 6.

	Case Study – Construction MPS (Loaded)																																						
		Elapsed Weeks																																					
	MW	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Instrumentation																						Complete Control Room																	
Award subcontract																																							
Receive & calibrate	15			Calibration by Owner																																			
Install instruments																																							
Process area	38																							2	2	2	2	2	4	4	4	4	4	4	4				
Scrubber area	8																						2	2	2	2													
T.F. & offsites	10																									2	2	2	2	2									
Control room																																							
Install termination panel & TDC hardware	3																					2	1																
Make all terminations	13																														3	3	3	2	2				
Wiring to T.P.																																							
Process area	70																							4	6	6	6	6	6	8	8	8	8	4					
Scrubber area	12																						2	4	4	2													
T.F. & offsites	9																										3	3	3										
Control air hookups																																							
Process area	37																							4	4	4	4	4	4	4	4	4	1						
Scrubber area	7																						2	2	2	1													
T.F. & offsites	5																						2	2	1														
Checkout (loop check)	18																																2	4	4	4	4		
Total Instrumentation	**230**																					**2**	**9**	**20**	**21**	**19**	**17**	**17**	**19**	**18**	**19**	**19**	**18**	**14**	**10**	**4**	**4**		

Figure E.7 Case study – construction MPS (loaded), 5 of 6.

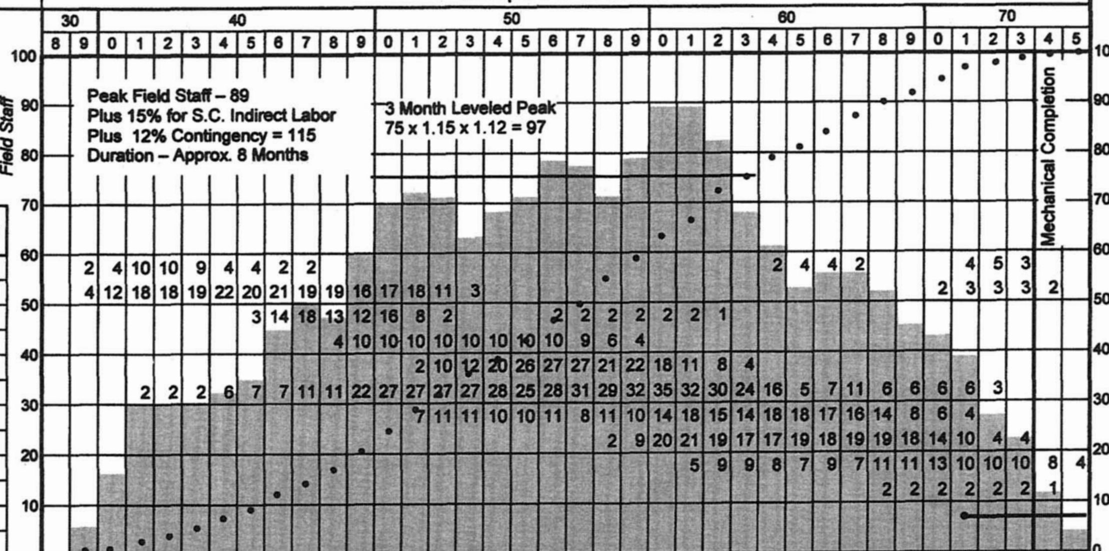
Case Study - Construction MPS

Elapsed Weeks

	MW	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
																		Water test Piperack pipe							Insul. S.C.							Finish water test							
Insulation																																							
Process area																																							
Equipment	21																								5	5	5	4	2										
Piping	46																															6	6	6	6	6	6	6	4
Scrubber area																																							
Equipment	4																												1	3									
Piping	9																															3	3	3					
Tank farm																																							
Equipment	5																													2	3								
Piping	22																															2	2	4	4	4	4	2	
Interconnecting piping	24																									4	4	4	4	4	4								
Total insulation	**131**																								**5**	**9**	**9**	**8**	**7**	**9**	**7**	**11**	**11**	**13**	**10**	**10**	**10**	**8**	**4**
Total painting	**13**																														**2**	**2**	**2**	**2**	**2**	**2**	**1**		

Figure E.8 Case study – construction MPS (loaded), 6 of 6.

Construction MPS – Progress Curve & Staffing



Work Wks	Const. Activity	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
71	Site Work		2	4	10	10	9	4	4	2	2									
250	Concrete		4	12	18	18	19	22	20	21	19	19	16	17	18	11	3			
99	Struct. Steel								3	14	18	13	12	16	8	2				2
103	Buildings											4	10	10	10	10	10	10	10	10
208	Equip. Erect.														2	10	12	20	26	27
538	Piping				2	2	2	6	7	7	11	11	22	27	27	27	27	28	25	28
251	Electrical														7	11	11	10	10	11
230	Instrumentation																			
131	Insulation																			
13	Painting																			
	Startup Support																			
	Total / Week		6	16	30	30	30	32	34	44	50	47	60	70	72	71	63	68	71	78
1894	Cumulative		6	22	52	82	112	144	178	222	272	319	379	449	521	592	655	723	794	872
	% Completion		.3	1.2	3	4	6	8	9	12	14	17	20	24	28	31	35	38	42	46

Work Wks	Const. Activity	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
71	Site Work								2	4	4	2				4	5	3		
250	Concrete														2	3	3	3	2	
99	Struct. Steel	2	2	2	2	2	1													
103	Buildings	9	6	4																
208	Equip. Erect.	27	21	22	18	11	8	4												
538	Piping	31	29	32	35	32	30	24	16	5	7	11	6	6	6	6	3			
251	Electrical	8	11	10	14	18	15	14	18	18	17	16	14	8	6	4				
230	Instrumentation		2	9	20	21	19	17	17	19	18	19	19	18	14	10	4	4		
131	Insulation					5	9	9	8	7	9	7	11	11	13	10	10	10	8	4
13	Painting												2	2	2	2	2	2	1	
	Startup Support																			
	Total / Week	77	71	79	89	89	82	68	61	53	55	55	52	45	43	39	27	22	11	4
1894	Cumulative	949	1020	1099	1188	1277	1359	1427	1488	1541	1596	1651	1703	1748	1791	1830	1857	1879	1890	1894
	% Completion	50	54	58	63	67	72	75	79	81	84	87	90	92	95	97	98	99	99.5	100

Figure E.9 Construction progress curve and staffing.

APPENDIX F

TECHNICAL EVALUATION CRITERIA EXAMPLE

The following example has been taken from the file of an actual project. It illustrates the procedure followed for the final selection of a contractor from a list of bidders who had been qualified previously.

The evaluation criteria and guidelines presented in Tables F.1 and F.2 were prepared by the Project Manager with input from process and cost engineering.

General Guidelines

- At this point, all bidders are technically acceptable and we are only trying to compare them with each other.
- Rate each criteria item from 1 to 10.
- The best should be rated 10.
- If possible, avoid ties. If two or three are considered to be very close to each other, use a narrow spread, e.g., 10.0, 9.8, 9.5.
- For some of the criteria, it could be practical to have each evaluator do an independent rating before comparing the results. In other cases, it could be more practical to do the rating jointly.
- In all cases, the final result must reflect the consensus of the evaluation team.
- If we are required to come up with a preliminary rating based on the proposal only (before visits), the rating must identify those criteria items when the rating could change as a result of the visit. The impact of the potential changes in the final rating must be evaluated.

Table F.1 Evaluation Criteria

Criteria	Points	
General		
Project approach	6	
Construction approach	5	
Controls	5	
Management commitment	4	
Flexibility	3	
Procurement	3	
Size of projects	2	
Size of company	1	
Stability	1	
Subtotal		**30**
Specific to Project		
Process		
Relevant experience of proposed team	7	
Experience with first-of-a-kind process	5	
Availability and use of computer design area	5	
Availability of qualified personnel	5	
Process management commitment	3	
Key personnel		
Project manager	5	
Experience together	5	
Process leader	4	
Construction Manager	4	
Cost engineer (planner)	3	
Subcontract administrator	2	
Instrument engineer	2	
Instrumentation and control	5	
Other disciplines	5	
Understanding of work	5	
Experience in the plant area	5	
Subtotal		**70**
GRAND TOTAL		**100**

Table F.2 Evaluation Criteria Guideline

Criteria	Positive	Negative
General		
Project approach 6 points	Full & real responsibility of P.M. throughout project Task force (modified) approach Understanding that S.C. work requires different planning than D.H. work	Split of responsibility from eng. to const. Matrix approach Trying to prove that D.H. is the best approach to projects
Approach to construction 5 points	Proven capability to perform both in S.C. and D.H. situation Objectivity in discussing D.H. vs S.C.	Usually works on D.H. basis Can't do D.H. Proposes very heavy field staff, > 5% craft labor
Controls planning/ estimating costs 5 points	Prominent position in organization Separate line of reporting Hands-on participation Conduct regular audits (H.O./ field) Computerized systems Regular cost tracking mtgs.	System so elaborate & detailed that reporting is delayed
Management commitment 4 points	Personal interest shown by high executive Personal relationships	Company has substantial backlog Very large jobs going
Flexibility 3 points	P.M. has management support to "bend" rules Client's P.M. has access to "raw data" Direct communication at working levels	Many managerial & approval levels Emphasis on formal communications
Procurement 3 points	Have separate inspection/expediting Will have dedicated coordinator in task force Willingness to be flexible	Tech personnel have negative attitudes towards purchasing department

Table F.2 (Continued)

Criteria	Positive	Negative
Size of projects 2 points	20-50 M	
Size of office 1 point	150-300 people	Our job less than 5% of capacity
Stability 1 point	High average seniority	Recent layoff Frequent reshuffling of personnel
Specific to Project		
Process		
• Relevant experience of proposed team 7 points	Depth of experience in liquid phase stirred reactions, liquid-liquid extraction & non-ideal distillation	Out-of-date with latest technology
	Avg. experience, 5-15 years	Less than 3 years experience
	Familiarity with computer design aids available in firm	
• Experience with first-of-a-kind designs 5 points	Company has experience Individuals have experience	
• Availability & use of computer design aids 5 points	ASPEN, in-house non-ideal distillation programs, etc., available & regularly used	
• Availability of qualified personnel 5 points	6-8 experienced process engineers	
• Process management commitment 3 points	Have special unit for developmental work Manager of process eng. will have active involvement in project	

Table F.2 (Continued)

Criteria	Positive	Negative
Key Personnel		
• Project manager 5 points	Several projects of similar nature	First or second project with firm
	Subcontract experience	> 20 yrs with same company
	Field experience	Specialization in any discipline
	General engineering experience	Relies too much on discipline managers
	Strong commitment to project/client	
	Planning experience	
• Experience together 5 points	Have successfully worked together in previous job	
• Process leader 4 points	Has first-of-a-kind process experience	First or second project with firm
	Previous experience as process leader	
	Has expertise in areas specific to our project	
• Construction manager	Engineering degree	Previous involvement with government work
4 points	Planning experience	First or second project with firm
	Experience with subcontractors	
	Understands role of planning & cost control & uses them	
• Control engineer (planner)	Project engineering experience	First or second project with firm
4 points	Field experience	
	Previous experience as lead man in other jobs	
• Subcontract administrator	Engineering/purchasing &/or legal background	
3 points	Familiar with area subcontractors	

Table F.2 (Continued)

Criteria	Positive	Negative
• Instrument engineer 2 points	Field experience with subcontractors Experience with computer interfaced projects Experience with PC's Experience with similar projects – organic/first-of-a-kind	
Instrumentation & control 5 points	Familiarity with distributed digital controls, computer interfacing, program batch controllers	Any indication of potential conflicts between instrument & electrical groups
Other design disciplines 5 points	Good breadth, have specialists in all disciplines Good depth, have more than one specialist in the various groups	MANDATORY: participation of certain specialties in ALL WORK
Understanding of the work 5 points	Viable plan & schedule submitted with proposal	
Experience in the plant area 5 points	Recent process jobs in area Familiarity with local subcontractors	

APPENDIX G

IN-HOUSE CONSTRUCTION PROGRESS MONITORING SYSTEM EXAMPLE

Scope

A project estimated at $1.0M and 10,000 construction hours with the following major cost components:

Site Work

Estimated at $250k and roughly 1,000 hr. Must be done during the rainy season and includes cleaning up an old chemical waste dump. The cost and schedule overrun risks are very high and no other work can proceed until all site work is completed.

Foundations

Estimated at $100k and 3,000 hr. Suspected presence of underground boulders and some old foundations. High potential for overrun. Building and mechanical work can start but cannot be completed before all foundations.

Building

Estimated at $150k and 1,500 hr. Pre-engineered building with metal siding. No problems anticipated. Mechanical work can start but not be completed before building is completed.

Mechanical Work

Estimated at $500k and 4,500 hr. Installation of a few pumps and tanks and approximately 4,000 feet of mostly straight alloy pipe. Minimal overrun potential.

Relative Values

The relative value assigned to each of the above components could be based on the dollar cost, estimated hours, or on a pondered basis that considers both as well as the potential cost and schedule exposure.

	Cost Basis		Hr Basis			Pondered Basis
	$k	**Fraction**	**Hr**	**Fraction**	**Exposure**	**Fraction**
Site work	250	0.25	1000	0.10	Very high	0.25
Concrete	100	0.10	3000	0.30	High	0.25
Building	150	0.15	1500	0.15	Normal	0.15
Electr./mech.	500	0.50	4500	0.45	Low	0.35
TOTAL	1000	1.00	10000	1.00		1.00

Note: The pondered basis fraction is obtained based on a personal judgment considering the dollar cost, man-hours involved, and risk exposure. When these factors are considered for each major component a pondered basis fraction is assigned.

Considering the schedule importance and potential risk involved in the site preparation work and the simplicity of the mechanical work, the pondered relative values would provide a more meaningful parameter to gauge progress.

The total value of the work is now unity and will remain unchanged regardless of scope addition or subtraction. The major components as well as the comprised related construction activities are expressed as fractions.

Each of the major components must be broken down into discrete activities consistent with the cost estimate breakdown, the execution plan, and the nature of the activity. The relative value of each activity within a given major component must be assigned on the basis of either cost, man-hours, and/or physical units (yd^3 ton, ft., $ft.^2$, etc.) and prorated to the component fraction.

Site Work (Fraction: 0.250)

Since the activities involved are very diverse and the estimated hours are not a true reflection of their real values, the assigned fractions are based on the pondered assessment of cost and man-hours.

Activity	Qty	Cost Basis		Mhr Basis		Pondered Basis	
		$K	Frac.	Mhr	Frac.	Site Frac.	Total Frac.
Excavation	500 yd^3	10	0.04	100	0.10	0.10	0.025
Disposal	300 yd^3	150	0.60	100	0.10	0.30	0.075
Backfill	200 yd^3	40	0.16	200	0.20	0.20	0.050
Sewers	500 LF	20	0.08	300	0.30	0.20	0.050
Paving	1000 yd^2	30	0.12	300	0.30	0.20	0.050
TOTAL	N.A.	250	1.00	1000	1.00	1.00	0.250

The progress of each activity can be gauged in the most practical manner for each one.

- Excavation, disposal, and backfill by cubic yard and/or truck load.
- Sewers by line and/or linear feet.
- Paving by square yards.

Concrete Work (Fraction: 0.250)

The activities involved are straightforward and their value can be related to work hours:

Activity	Yd^3	Hr	Concr. Frac.	Total Frac.
Building foundations	100	1500	0.50	0.125
Building grade beams	20	450	0.15	0.038
Building floor slab	50	300	0.10	0.025
Area paving	45	300	0.10	0.025
Pump pads	10	150	0.05	0.012
5 tank foundations	25	300	0.10	0.025
TOTAL	250	3000	1.00	0.250

Note: If so desired, the building foundations could be broken down in several sections.

The progress of each activity can be gauged with a milestone system.

Building (Fraction: 0.150)

If the estimate does not include an activity breakdown, the project manager uses experience and/or imagination to break the work into the conventional building construction activities

Activity	Bldg. Frac.	Total Frac.	Progress Gauging
Main structure	0.10	0.015	Eyeballing
Roofing	0.15	0.022	$ft.^2$
Siding	0.15	0.023	$ft.^2$
Doors & windows	0.10	0.015	Unit
Lighting	0.20	0.030	Milestones
HVAC	0.20	0.030	See note
Finish	0.10	0.015	Eyeballing
TOTAL	1.00	0.150	

Note: HVAC work could be broken down by power supply, equipment installation, or ducts installation.

Electrical/Mechanical Work (Fraction: 0.350)

The activities involved are very diverse:

- Equipment erection.
- Miscellaneous structures.
- Piping fabrication and erection.
- Power wiring and lighting.
- Instrument wiring.
- Insulation.

Most of these could be dissected into small components, all of which are related to work hours and can be gauged with a milestone system. The hours are easily prorated to the 0.350 total fraction.

IMPORTANT NOTE - TO AVOID POTENTIAL MISTAKES WITH THE USE OF DECIMAL FRACTIONS, THEY SHOULD BE MULTIPLIED BY 1000.

APPENDIX H
CONSTRUCTION PROGRESS MONITORING – CASE STUDY

H.1 General

Appendix G deals with various ways to assign value to and track the progress of field activities. This appendix illustrates the preparation and application of a tracking system specifically tailored to the case study.

- The **activities' breakdown** parallels the preliminary semi-detailed cost estimate in Appendix L and the Master Project Schedule illustrated in Appendix E.
- The **relative values** of activities are based on the work hours taken from the semi-detailed estimate.
- The **progress measurements** are based on the typical construction activity breakdown and milestones shown in Table 15.2

On a project the size of the case study, the system could be implemented manually by the project team and should not require more than one, two at the most, work days every two weeks. Larger projects could justify a dedicated full time person who could also collect data and develop correlations for future use as well as prepare the regular project reports.

The "S" curve in Fig. H.1 is a graphic display of the progress of the total construction activities. It is prepared from the "loaded" MPS shown in Appendix E. It is superimposed on the bar chart type illustrations of the scheduled progress of the main construction subcontracts:

- Site work and concrete.

- Structural steel erection.
- Buildings.
- Mechanical work – equipment erection / piping.
- Electrical and instrumentation.
- Insulation/paint.

Tables H.1 through H.8 are used to calculate and track the progress and productivity of the various subcontracts. They are self-explanatory.

The "S" curve submitted with the AFE becomes the baseline for judging the project schedule performance and must never be changed.

> CONSTRUCTION IS NOT COMPLETE UNTIL ALL ACTIVITIES HAVE BEEN PERFORMED, NO MATTER HOW MANY HAVE BEEN ADDED OR DELETED.

Additions and deletions must be handled by adjusting the number of work hours. In the case of additional work this can be done either with overtime or increasing the work force. If it becomes apparent that these measures cannot keep the project on the right track at a reasonable cost (within the contingency allowance) it is time to bite the bullet and inform management of the schedule delay and the cost impact and risks of trying to maintain schedule at all costs.

H.2 Activity Breakdown

As mentioned in Section H.1 the activity breakdown for this example is based on the preliminary estimate in Appendix L that was prepared without the benefit of P&ID's and arrangement drawings. This breakdown would be barely adequate for tracking the civil work – site, concrete, and steel erection. However, it is not detailed enough for use for tracking electromechanical work – equipment erection, piping, electrical, and instrumentation.

For an adequate tracking in those areas the breakdown must go down to the level of:

- Equipment items.
- Pipe runs.
- Motors.
- Instruments.
- Control loops.

Table H.1 Construction Progress Monitoring Summary

Total estimated work units – 1894.

Wk #	Work Units				Percent Completion		Productivity
	Current Total	Earned to Date		Worked to Date			
		Estm.	Actual		Estm.	Actual	
39	1894	6			.3		
40	1894	22	20	23	1.2	1	0.87
41	1894	52			3		
42	1894	82	79	85	4	4	0.93
43	1894	112			6		
44	1894	144	146	148	8	8	0.99
45	1894	178			9		
46	1894	222	235	240	12	12	0.98
47	1894	272			14		
48	1894	319	329	334	17	17	0.99
49	1916	379	364	381	20	19	0.96
50	1916	449	402	433	24	21	0.93
51	1916	521	460	499	28	24	0.92
52	1916	592	546	582	31	28	0.94
53	1916	655	629	665	35	33	0.95
54	1916	723	720	717	38	38	1.00
55	1916	794	807	842	42	42	0.96
56	1916	872	905	929	46	47	0.97
57	1916	949			50		
58	1916	1020	1071	1083	54	56	0.99
59	1916	1099			58		
60		1188			63		
61		1277			67		
62		1359			72		
63		1421			75		
64		1498			79		
65		1541			81		
66		1596			84		
67		1651			87		
68		1703			90		
69		1748			92		
70		1791			95		
71		1830			97		
72		1857			98		
73		1879			99		

Table H.2 Construction Progress Monitoring:
Civil Contract – Site / Concrete

Total estimated work units – 321.

Wk #	Work Units				Percent Completion		Productivity
	Current Total	Earned to Date		Worked to Date			
		Estm.	Actual		Estm.	Actual	
39	321	6			2		
40	321	22	20	23	7	6	0.87
41	321	50			16		
42	321	78	75	81	24	23	0.93
43	321	106			33		
44	321	132	130	133	41	40	0.98
45	321	156			49		
46	321	179	181	185	56	56	0.98
47	321	200			62		
48	321	219	230	235	68	72	0.98
49	321	235	241	251	73	75	0.96
50	321	252	256	270	79	80	0.95
51	321	270	270	290	84	84	0.93
52	321	281	282	305	88	88	0.92
53	321	284	284	310	88	88	0.92
54	321	284	284	310	88	88	0.92
55	321	284			88		
56	321	284	284	310	88	88	.092
57	321	284			88		
58	321	284	284	310	88	88	0.92
59		284			88		
60		284			88		
61		284			88		
62		284			88		
63		284			88		
64		286			89		
65		290			90		
66		294			91		
67		296			92		
68		296			92		
69		296			92		
70		298			95		
71		305			95		
72		313			98		
73		319			99		

Table H.3 Construction Progress Monitoring:
Steel Erection Contract

Total estimated work units – 99.

Wk #	Work Units				Percent Completion		Productivity
	Current Total	Earned to Date		Worked to Date			
		Estm.	Actual		Estm.	Actual	
39	99						
40	99						
41	99						
42	99						
43	99						
44	99		2	3		2	0.67
45	99	3			3		
46	99	17	20	25	17	20	0.80
47	99	35			35		
48	99	48	35	46	48	35	0.76
49	109	60	53	68	61	40	0.78
50	109	76	71	90	77	65	0.79
51		84	81	103	85	74	0.79
52		86	90	106	87	83	0.85
53		86	94	112	87	86	0.84
54		86	96	116	87	88	0.83
55		86	96	116	87	88	0.83
56		88	98	119	87	90	0.82
57		90			91		
58		92	102	124	93	94	0.82
59		94			95		
60		96			97		
61		98			99		
62		99			100		
63							
64							
65							
66							
67							
68							
69							
70							
71							
72							
73							

Table H.4 Construction Progress Monitoring: Buildings Contract

Total estimated work units – 103.

Wk #	Work Units				Percent Completion		Productivity
	Current Total	Earned to Date		Worked to Date			
		Estm.	Actual		Estm.	Actual	
39	103						
40	103						
41	103						
42	103						
43	103						
44	103						
45	103						
46	103						
47	103						
48	103	4	0	0	4	0	
49	103	14			14		
50	103	24	0	0	25	0	
51	103	34	10	15	33	15	0.67
52	103	44	32	33	43	31	0.97
53	103	54	46	45	52	45	1.02
54	103	64	64	60	62	62	1.07
55	103	74	78	72	72	76	
56	103	84	88	80	82	85	1.10
57	103	93			90		
58	103	99	98	89	96	95	1.10
59	103	103			100		
60							
61							
62							
63							
64							
65							
66							
67							
68							
69							
70							
71							
72							
73							

Table H.5 Construction Progress Monitoring:
Mechanical Contract – Equipment Erection

Total estimated work units – 208.

Wk #	Work Units				Percent Completion		Productivity
	Current Total	Earned to Date		Worked to Date	Estm.	Actual	
		Estm.	Actual				
39							
40							
41							
42							
43							
44							
45							
46							
47							
48							
49							
50							
51	208	2			1		
52	208	12	2	4	6	1	0.50
53	208	24	14	17	12	7	0.82
54	208	44	34	37	21	16	0.92
55	208	70	60	66	34	29	0.91
56	208	97	90	100	47	43	0.90
57	208	124			60		
58	208	145	135	142	68	65	0.95
59	208	167			80		
60	208	185			89		
61		196			94		
62		204			98		
63		208			100		
64							
65							
66							
67							
68							
69							
70							
71							
72							
73							

Table H.6 Construction Progress Monitoring: Mechanical Contract - Piping

Total estimated work units – 538.

Wk #	Work Units				Percent Completion		Productivity
	Current Total	Earned to Date		Worked to Date			
		Estm.	Actual		Estm.	Actual	
39							
40							
41	538	2			0.4		
42	538	4	4	4	0.7	0.7	1.00
43	538	6			1		
44	538	12	14	12	2	3	1.16
45	538	19			4		
46	538	26	34	30	5	6	1.13
47	538	37			7		
48	538	48	60	53	9	11	1.13
49	550	70	69	63	13	13	1.09
50	550	97	79	73	18	14	1.08
51		124	89	91	23	18	1.09
52		151	134	126	28	24	1.06
53		178	174	161	33	32	1.08
54		206	214	196	38	37	1.09
55		231	254	230	43	46	1.10
56		259	294	266	48	53	1.10
57		290			54		
58		319	374	336	59	68	1.11
59		351			65		
60		386			72		
61		418			78		
62		448			83		
63		472			88		
64		488			91		
65		490			92		
66		500			93		
67		511			95		
68		517			96		
69		523			97		
70		529			98		
71		535			99		
72		538			100		
73							

Table H.7 Construction Progress Monitoring:
Electrical and Instrumentation Contract

Total estimated work units – 481.

Wk #	Work Units				Percent Completion		Productivity
	Current Total	Earned to Date		Worked to Date			
		Estm.	Actual		Estm.	Actual	
39							
40							
41							
42							
43							
44							
45							
46							
47							
48							
49							
50							
51	481	7			1		
52	481	18	6	8	4	1	0.75
53	481	29	16	20	6	3	0.80
54	481	39	28	32	8	6	0.88
55	481	49	38	42	10	8	0.90
56	481	60	51	54	12	11	0.94
57	481	68			14		
58	481	81	78	82	17	16	0.95
59		100			21		
60		134			28		
61		173			36		
62		207			43		
63		238			49		
64		273			57		
65		310			64		
66		345			72		
67		380			79		
68		413			86		
69		439			91		
70		459			95		
71		473			98		
72		477			99		
73		481			100		

Table H.8 Construction Progress Monitoring: Insulation and Paint

Total estimated work units – 144.

Wk #	Work Units				Percent Completion		Productivity
	Current Total	Earned to Date		Worked to Date			
		Estm.	Actual		Estm.	Actual	
39							
40							
41							
42							
43							
44							
45							
46							
47							
48							
49							
50							
51							
52							
53							
54							
55							
56							
57							
58							
59							
60							
61		5			3		
62		14			10		
63		23			16		
64		31			22		
65		38			26		
66		47			33		
67		54			38		
68		67			47		
69		80			56		
70		95			64		
71		107			74		
72		119			83		
73		131			91		

Such details are only available when the estimate is based on P&ID's and arrangement drawings, in other words, on definitive type-cost estimates.

Definitive estimates are normally prepared by engineering contractors at considerable cost, in a rather long time. However, with the semi-detailed system propounded in this book, owners could prepare, at a much lower cost and in a much shorter time, in-house estimates of equivalent accuracy.

H.3 Relative Values

In this case the dollar value, direct labor, and risks involved in all construction activities are pretty well balanced. It is then logical to base the relative value system on work hours, better yet, on **work weeks** (WW's).

For example a construction activity estimated at 200 WH is given a value of

$200 \div 40 = 5$ work units (WU)

and could be executed by 1 man in 5 weeks or 5 men in 1 week or any equivalent combination.

If the actual work weeks required to perform the activity are more or less than five, then the productivity is either lower or higher than that assumed in the estimate.

H.4 Progress Measurements

Calculating percent completion could appear to be a boring, tedious operation. However, as mentioned in Chapter 15 it is not so if you use the milestone approach shown in Table 15.2.

- At any given moment, many activities have not been started and others have been completed. Those are credited with zero or one hundred percent of their assigned value.
- The majority of those in progress will be covered by the milestones in Table 15.2 and are credited accordingly.
- The remaining few must by eyeballed. Of those, many will either be in the early stages or essentially complete; eyeballing them should present no problem.
- The potential error of eyeballing the remaining activities should have minimum effect on the overall evaluation.

Tables H.9 and H.10 illustrate some of the forms that can be developed from Table 15.2 and be very helpful for calculating percent completion.

Table H.9 Concrete Work Progress Control

Project______________________________ Report Date_____________________

Section Piperack/Process area

Description	Take off		Value		Percent Progress										Earned Units	% Completion
	Qty	Unit	W-H	Work Unit Man wk	Excavate & Place Forms						Rebar		Pour	Strip & Fin		
					10	20	30	40	50	60	70	80	90	100		
Utility piperack	24	cy	480	12	×	×	×	×	×	×	×	×	×	×	12	
Main piperack	24	cy	480	12	×	×	×	×	×	×	×	×	×	×	12	
Scrubber piperack	8	cy	160	4	×	×	×	×	×	×	×	×			3.2	
N-S piperack	11	cy	88	2	×	×	×	×	×	×					1.2	
Tank farm piperack	3	cy	60	1.5	×	×	×	×	×	×					0.9	
Total piperacks	70	cy		31.5											29.3	93%
Proc. Structure Foundation	98	cy	1960	49	×	×	×	×	×	×	×	×	×	×	49	
Proc. Structure Tie Beams	15	cy	180	4.5	×	×	×	×	×	×	×	×	×	×	4.5	
Proc. Structure Floor Slab	47	cy	282	7	×	×	×	×	×	×	×				4.9	
Proc. Structure Elevated Slab	116	cy	1160	29											0	
Total Proc. Structure	206	cy		895											58.4	65%

Table H.10 Major Equipment Erection Progress Control

Project______________________________ Report Date_____________________

Section Process area

Description	Take off		Value		Percent Progress										Earned Units	% Completion
	Qty	Unit	W-H	Work Unit Man wk	Receive	Rough Setting						Shim & Plumb		Cleanup		
					10	20	30	40	50	60	70	80	90	100		
R-101 A/B 3K gal. reactors	2	ea.	480	12	×	×	×	×							4.8	
C-110 A/B 5'x60' dist column	2	ea.	560	14	×										1.4	
H-105 A/B 1500 SF reboiler	2	ea.	320	2												
H-111 A/B 1000 SF condens.	2	ea.	240	6												
T-130 A/B 9K gal. tanks	2	ea.	320	8												
V-135 A/B 2K gal. vessels	2	ea.	240	6	×	×	×	×	×	×	×				4.2	
V-140 A/B 2K gal. vessels	2	ea.	240	6	×	×	×	×	×	×	×				4.2	
Total Proc. Area			2400	60											14.6	24%

The following forms can be prepared from Table 15.2:

- Concrete work.
- Structural steel erection.
- Major equipment erection.
- Rotating equipment installation.

- Building.
- Piping fabrication and erection.
- Instrument calibration and installation.
- Instrument wiring and loop check.
- Instrument air hook-up.
- Electrical power feeders.
- Lighting.
- Equipment insulation.
- Piping insulation.

In most projects these would cover at least 90% of the field work.

The evaluation of piping, electrical, and instrumentation work could be enhanced by marking up the P&ID's with a color code to show progress on every line, every motor, and every instrument and control loop.

H.5 Project Control Application

Conducting regular periodic evaluation of actual work performed (earned units) and comparing them with the estimate and the contractors daily force reports the project team can keep close tabs on:

- Percent completion,
- Schedule compliance,
- Contractor's productivity,

in order to:

- Forecast final cost (in cost-reimbursable contracts).
- Anticipate contractors' extras (in lump sum contracts).
- Forecast project completion (in all cases).

Monitoring the overall progress curve is not sufficient for good control. Progress in every major construction discipline and/or subcontract as well as compliance with the MPS must also be scrutinized regularly for deviations. Even if the overall progress appears to be on track, major trouble could be developing if a critical activity is falling behind and the fact is obscured by the faster progress in an irrelevant (at the moment) activity.

A case in point is illustrated in Fig. H.1. The construction work started on schedule on week 39 and proceeded right on track for several weeks. On week 48, although the overall progress was right on track, a closer inspection revealed a serious variation in the steel erection contract. This variation could have had disastrous repercussions since steel erection falls on the critical path and the delay would affect equipment and piping erection and jeopardize the project completion date.

An investigation revealed that the delay was the result of several factors beyond the control of the contractor:

- Delays in delivery of the fabricated structure.
- Several rainy days in weeks 47 and 48.
- An unexpected change in scope that increased the contractor's work by 10%.

Corrective action was initiated immediately:

- The steel fabricator was instructed to put the shop on regular overtime until fabrication was 100% completed.
- The erection contractor was instructed to increase its field staff and work 6 ten hour days until the progress was back on track.
- Progress evaluations were conducted on a weekly basis until the progress was back on track.

The corrective actions were successful and construction was back on track in week 54.

This example illustrates the value of:

- Having in place an effective **In-house Progress Monitoring System** to allow the project team to detect almost immediately any potential trouble spots.
- Taking corrective action at the **first sign of trouble**. Unattended "blips" in the progress curve more often than not have the nasty habit of rapidly becoming major, and some times irreversible, deviations.

Total Work Units – Orig. Estimate 1894
Total Work Units – Last Period 1916
Total Work Units – This Period 1916

Estimated Construction Start – 39th week.
Actual Construction Start – 39th week.

Construction Progress Monitoring - Summary

Elapsed Weeks

Description		Cumm % Compl.	30		40										50						
			8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
Site Work & Conc.	Sch	100		2	7	16	24	33	41	49	56	62	68	73	79	84	88	88	88	88	88
Contract	Act				6		23		40		56		72		80		88		88		88
		90																			
Steel Erection	Sch									3	17	35	48	61	77	85	87	87	87	87	89
Contract	Act	80							2		20		35		65		83		88		88
Buildings	Sch	70											4	14	23	33	43	52	62	72	82
Contract	Act												0		0		31		62		85
		60																			
Mech. Contract	Sch															1	6	12	21	34	47
Equip. Erect.	Act	50															1		16		43
Mech. Contract	Sch	40				.4	.7	1	2	4	55	7	9	13	18	23	28	33	38	43	48
Piping	Act						.7		3		6		1		14		24		37		47
		30																			
Elect./Instrument.	Sch															1	4	6	8	10	12
Contract	Act	20															1			6	
Insulation	Sch	10																			
& Paint	Act																				
Projected Estm.		%		.3	1.2	3	4	6	8	9	12	14	17	20	24	28	31	35	38	42	46
Actual		%			1		4		8		12		17		21		28		38		47
Cum. Productivity		%			.87		.93		.99		.98		.99		.93		.94		1.00		.97

Description		Cumm % Compl.	50			60										70					
			7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
Site Work & Conc.	Sch	100	88	88	88	88	88	88	88	89	90	92	92	92	92	93	95	98	99		
Contract	Act			88																	
		90																			
Steel Erection	Sch		91	93	95	97	99														
Contract	Act	80			94																
Buildings	Sch	70	90	96	100																
Contract	Act			95																	
		60																			
Mech. Contract	Sch		60	68	80	89	94	98	100												
Equip. Erect.	Act	50		65																	
Mech. Contract	Sch	40	54	59	65	72	78	83	88	91	92	93	95	96	97	98	99	100			
Piping	Act			68																	
		30																			
Elect./Instrument.	Sch		14	17	21	28	36	43	49	57	64	72	79	86	91	95	98	99	100		
Contract	Act	20	11																		
Insulation	Sch	10					3	10	16	22	26	33	38	47	56	64	74	83	91	97	100
& Paint	Act																				
Projected Estm.		%	50	54	58	63	67	72	75	79	81	84	87	90	92	95	97	98	99	100	
Actual		%		56																	
Cum. Productivity		%		.99																	

Projected Estm. x
Actual o

Figure H.1 Construction progress monitoring summary.

APPENDIX I

FORECASTING FINAL SUBCONTRACT COST

Introduction

When a project is executed through a competitive lump sum subcontract, the Project Manager must frequently take a calculated risk in order to maintain the schedule and start awarding subcontracts with partially complete detailed engineering. The result is an almost certain increase in cost between subcontract award and completion.

The increase in cost must be anticipated by adding, upon award, an adequate resolution allowance to the base subcontract cost. This resolution allowance must be reevaluated periodically as the work progresses and new information becomes available.

The following tools are required in order to exercise project cost control and provide accurate forecasts:

- Consistent definitions of the various subcontract-related costs.
- A method to evaluate and assign, in a rational manner, the resolution allowance required for each subcontract.
- A method to re-evaluate and update the resolution allowance as work progresses.

This guideline addresses all three requirements and is intended mainly for electromechanical work.

Subcontract Cost Definitions

Base Scope

This includes work covered by the bid drawings and specifications agreed upon at the time of subcontract award. The award cost must be treated as "committed." Items on "hold," even if related to the initial scope, are not considered part of the initial scope. However, they must be identified and treated as "uncommitted" at their current estimated cost and included in the cost forecast.

Additional Scope

Work resulting from the resolution of "holds" and/or major design changes in the initial scope is considered additional scope. When defined and added to the subcontract, they must be considered as "committed" at the subcontractor firm price or best estimate, as applicable. Changes in take-off quantities arbitrarily fixed for bidding purposes will fall in this category. The "committed" quantity must be adjusted based on unit prices as soon as the real quantities are known.

Correction of oversights and miscellaneous changes resulting from detailed design are not considered additional scope. They must be considered subcontract changes, as indicated below.

New Scope

Work unrelated to the initial scope that is added to the subcontract is considered new scope. When incorporated into the subcontract, it must be treated as "committed" at the subcontractor's firm price or best estimate, as applicable.

New scope to a subcontract could be either work already identified in the AFE estimate or work resulting from scope changes.

Base Subcontract Cost (BSCC)

The BSCC is the baseline for cost tracking and determination of the resolution allowance. It is the cost of the base scope plus any additional scope and/or new scope as applicable. It does not include changes. The BSCC could be:

- A lump sum developed by the bidders (subcontractors) based on the bidding documents.
- A cost derived from unit price developed by the bidders applied to approximate materials take-offs provided by the client.

Subcontract Changes (Growth)

Generally, subcontract changes would come from:

- Engineering (home office) design changes:
  1. Changes developed through detailed engineering.
  2. Minor P&ID revisions.
  3. Scope-related items not identified at subcontract award.
  4. Correction of errors and oversights, regardless of size, in the original subcontract documents.
- Field changes:
  1. Corrections of errors made by engineering and/or vendors.
  2. Additional work and or changes requested by client in the field.
  3. Cost variances in items incorporated in the subcontract on an estimated rather than lump sum basis.
  4. Shortages of materials or services that were to be supplied by others.
  5. Extra cost resulting from unreasonable delays in delivery or materials and/or engineering information.
  6. Extra costs resulting from delays related to plant operation needs not covered in the bid package.
- Punchout / precommissioning:
  1. Miscellaneous last-minute work not covered by subcontract scope and/or changes required for startup of the facility.

Resolution Allowance

The resolution allowance is intended to cover the "normal growth" of the BSCC that reflects subcontract changes as defined above. Since the resolution allowance represents an expected cost, it is not treated as contingency but must be included in the cost forecast and shown initially as "uncommitted" and gradually transferred to "committed" as the changes materialize. Major design changes are covered by the contingency (refer to Section 19.10 for a better understanding of contingency and resolution allowance).

Resolution Allowance Criteria

The "normal growth" occurs gradually through three well-defined execution phases and is due to:

- Design changes (engineering phase).
- Field changes (construction phase).
- Punchout items (commissioning phase).

The extent of each depends on the circumstances particular to each project:

- Schedule: normal/fast track.
- Type of plant: Grassroots/retrofit.
- Subcontractor size.
- Depth of client's review.

All the preceding factors must be taken into consideration when the resolution allowance is set for each subcontract. Table I. 1 proposes a criteria to do so.

Monitoring Subcontract Growth and Updating Resolution Allowance

- As the work progresses, the subcontract cost will grow as a result of design and field changes.

  For good cost forecasting, the growth must be monitored and projections made to ascertain that the final growth will be consistent with the resolution allowance. If not, the resolution allowance must be adjusted as required.

  The correlation in Figure I.1 was developed from three subcontracts, two piping/mechanical, and one electrical/instrumentation. The BSCC of each one was approximately $1 million. Even if the growth factor were different in each case, the rate of growth followed a very consistent pattern. This correlation should provide a good tool for monitoring growth and adjusting the resolution allowance when so required.

- This correlation should be most effective when:

  - Both design and field changes are recognized and incorporated in the cost on a timely manner, even if based on preliminary estimates. In this case, a poor estimate is much better than no estimate.
  - The field supervision has established an accurate progress measurement system independent from the subcontractors'. If this is not available, subcontractors' progress reports can be used. In this case, it must be remembered that most subcontractors will over-evaluate progress by 5-10%.

The portion of the resolution allowance allocated to punchout / precommissioning (see Table I. 1) should be left intact until the work is at least 95 % complete.

Table I.1 Initial Resolution Allowance Criteria

		Resolution, % of BSCC		
Type of Change	Criteria for Minimum Changes	Min.	Normal	Max.
Engineering Design Changes	• Minimum schedule pressure • AFC basic drawings – P&ID's – Arrangement dwgs – Piping dwgs • Detailed engineering – Isometrics / schematics – Steam tracing details – Piping supports	2	2-4	6
Field Changes	• Minimum schedule pressure – Complete bid package – Intelligent bids – Thorough negotiations • Grassroots facility – New equipment • Extensive review/approvals • Model • Plant commitment • Subcontractor – Sophisticated – Conservative	4	7	12
Punchout / Precommissioning	• Extensive reviews/approvals • Model • Plant commitment/V.M.	2	4	7
TOTAL		8	15	25

Type of work	BSCC, K$	Growth, K$	Final Cost, K$	% Growth
Equip./pipe	1,100	330	1,430	30.0
Equip./pipe	1,085	165	1,250	15.2
Elec./Inst.	1,072	168	1,240	15.7

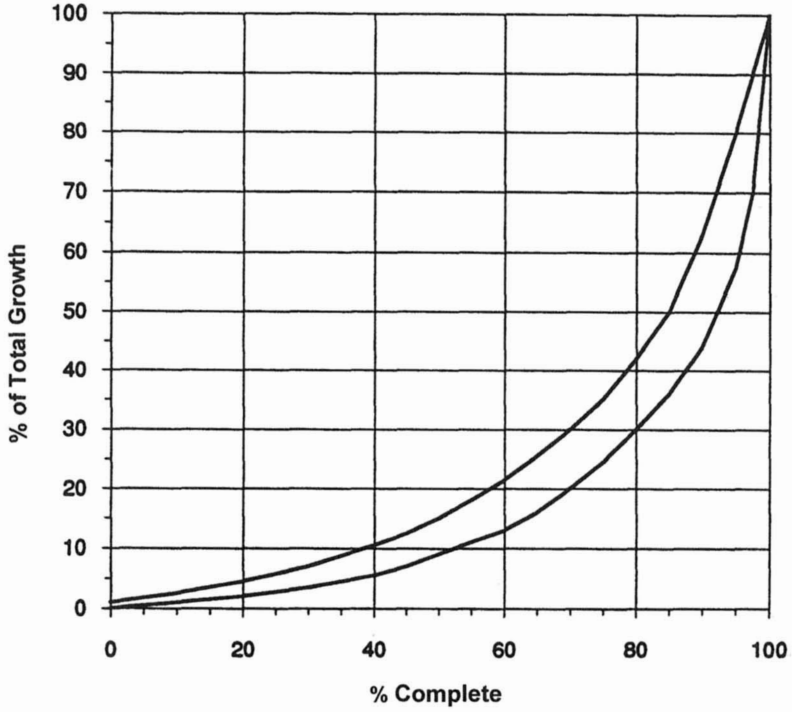


Figure I. 1 Rate of subcontract growth.

APPENDIX **J**

HEAT TRACING MODELS

Electric Tracing

Winterizing Service

- One 250-ft. 50-amp, 480 V feeder.
- One 480/120 V 15-kVA transformer.
- One distribution panel with ten 20-amp 120 V switches, 8 active and 2 spares.
- Eight 40-ft. 120 V lead wires.
- Eight 200-ft. runs of 5 BTV 1-ct heater tape, complete with thermostat, power connection kit, end seals, and contactor.

  Average actual pipe coverage 160 ft.

250 °F Process Service

- One 250-ft. 100-amp 480 V feeder.
- One 480/120 V 40-kVA transformer.
- One distribution panel with ten 40-amp 120 V switches, 8 active and 2 spares.
- Eight 40-ft. 120 V lead wires.
- Eight 160-ft. runs of 15 XTV 1-ct heater tape, complete with thermostat, power connection kit, end seals, and contactors.

Average actual pipe coverage 130 ft.

300 °F Process Service

- One 250-ft. 200-amp 480 V feeder.
- One 480/240 V 75-kVA transformer.
- One distribution panel with ten 50-amp 240 V switches, 8 active and 2 spares.
- Eight 40-ft. 240 V lead wires.
- Eight 280-ft. runs of 20 KTV 1-ct heater tape, complete with thermostat, power connection kit, end seals, and contactors.

Average actual pipe coverage 220 ft.

Steam Tracing

- One 30-ft. long 2-inch diameter insulated steam feeder with filter and self-contained ambiant temperature control valve.
- One 2-inch diameter insulated steam manifold complete with filter and trap assembly. Six 1/2-inch valved connections and two capped spaces.
- Six 40-ft. runs of pre-insulated 1/2-inch steam tubing.
- Six 75-ft. runs of 1/2-inch copper tubing.

Average actual pipe coverage 60 ft.

- Six 40-ft. runs of pre-insulated 1/2-inch condensate tubing.
- One 2-inch diameter insulated condensate manifold with six 1/2-inch connections, each with a filter and trap assembly and two capped spaces.
- One 20-ft. 2-inch diameter insulated, valved condensate line.

APPENDIX **K**

FIELD INDIRECTS CHECKLIST

Total Cost

The total cost of the field indirects is 100-130% of direct labor costs (direct hire) plus 15-20% of subcontracts and inversely proportional to project size. In the following breakdown, an asterisk denotes services usually supplied by Construction Manager or General Contractor.

	Percent of Direct Hired Labor Costs
Labor	
Indirect Craft Labor	*15-20*

1. General foremen
2. Temporary facilities builders*
3. Temporary facilities maintenance*
4. Chainmen on layout crew*
5. Janitors*
6. General cleanup crews*
7. Drivers (non-construction)
8. Tool room attendants
9. Warehouse helpers*
10. Fire watch
11. Equipment and weather protection
12. Show time
13. Evacuation alarms and tests*
14. Sign-up/termination time
15. Standby time
16. Craft
17. Safety meetings
18. Security checks

Indirect Non-Craft Labor	*5-6*

1. Secretaries
2. Clerical/accounting/cost/engineering
3. Timekeepers
4. Guards/watchmen
5. Nurses
6. Storeroom attendants
7. Draftsmen

Labor PAC's Craft and Non-Craft	*20-25*

1. FICA
2. Workmen's Compensation
3. Federal/state unemployment taxes

Craft Fringe Benefits	*20-25*

1. Medical/pension plans
2. Holidays/vacations
3. Travel/subsistence pay

Materials

Temporary Facilities (Build and Maintain)	*5-7*

1. Offices*
2. Warehouses*
3. Tool rooms
4. Change rooms
5. Sanitary facilities*
6. First aid room*
7. Fabrication shops
8. Instrument calibration shop
9. Guard house/brass alley*
10. Roads/fences/parking/drainage/signs/lighting*
11. Equipment and weather protection shelters
12. Office furniture/computers*
13. Temporary utilities*
14. Laydown and storage areas*
15. Repair plant roads*

*Supplies**	*2-4*

1. Office supplies
2. Reproduction
3. Communications
4. Medical supplies
5. Janitorial supplies

Consumables	*4-5*
Small Tools	*4-5*

Equipment Rentals

Equipment	*8-12*
Fuels and Lubricants	*3-5*

Home Office Supervision*

Direct Field Supervision	*5-7*
Administrative Support	*2-4*
Travel Expenses	*per contract*

Other

Contractor's Field Overhead	*per contract*
Premium Pay	*4-6*

APPENDIX L
SEMI-DETAILED ESTIMATE EXAMPLE - CASE STUDY

L.1 Introduction

The Case Study initiated with the initial Plan of Action in Section 5.3 has evolved into a Phase 0 Design Package and now a **Preliminary Cost Estimate** is required to confirm the viability of the project and, if required, request funds for the preparation of a Detailed Process Design and Engineering Specification (Phase 1) and an appropriation quality estimate.

The following information, developed during Phase 0 is available to the Estimator and is sufficient for the preparation of a preliminary type Semi-Detailed Cost Estimate:

- An annotated Equipment list with sizes, materials of construction, and, when applicable, motor horsepower (hp).
- General Plot Plan showing the size and location of all process structures and site requirements including piperacks, buildings, roads, tank farms, underground piping, fire protection system, etc. (See Figs. L.1 through L.5.)
- Since P&ID's and Equipment Arrangement drawings are not available yet, piping and instrumentation information must be estimated with the preliminary procedures in Chapter 19. Painting and insulation can be estimated using a "Lang Factor."
- The equipment account and all civil accounts, as well as the Electrical Account and the Contract Engineering man-hours can be estimated with the respective semi-detailed procedures in Chapter 19.

- All costs have been escalated to approximately the first quarter of 2001 using a chemical engineering Plant Cost Index of 420.
- If approved, the Project would be executed by a small contractor.

Calculate labor cost using the following "loaded" rates which include rental construction equipment.

Account	$/Hour
Equipment	$55.00
Piping	$49.00
Civil, insulation, and fire protection	$45.00
Structural steel	$52.00
Electrical	$48.00
Instrumentation	$48.00
Engineering	$75.00

This estimate has been prepared using the techniques and guidelines in Chapter 19.

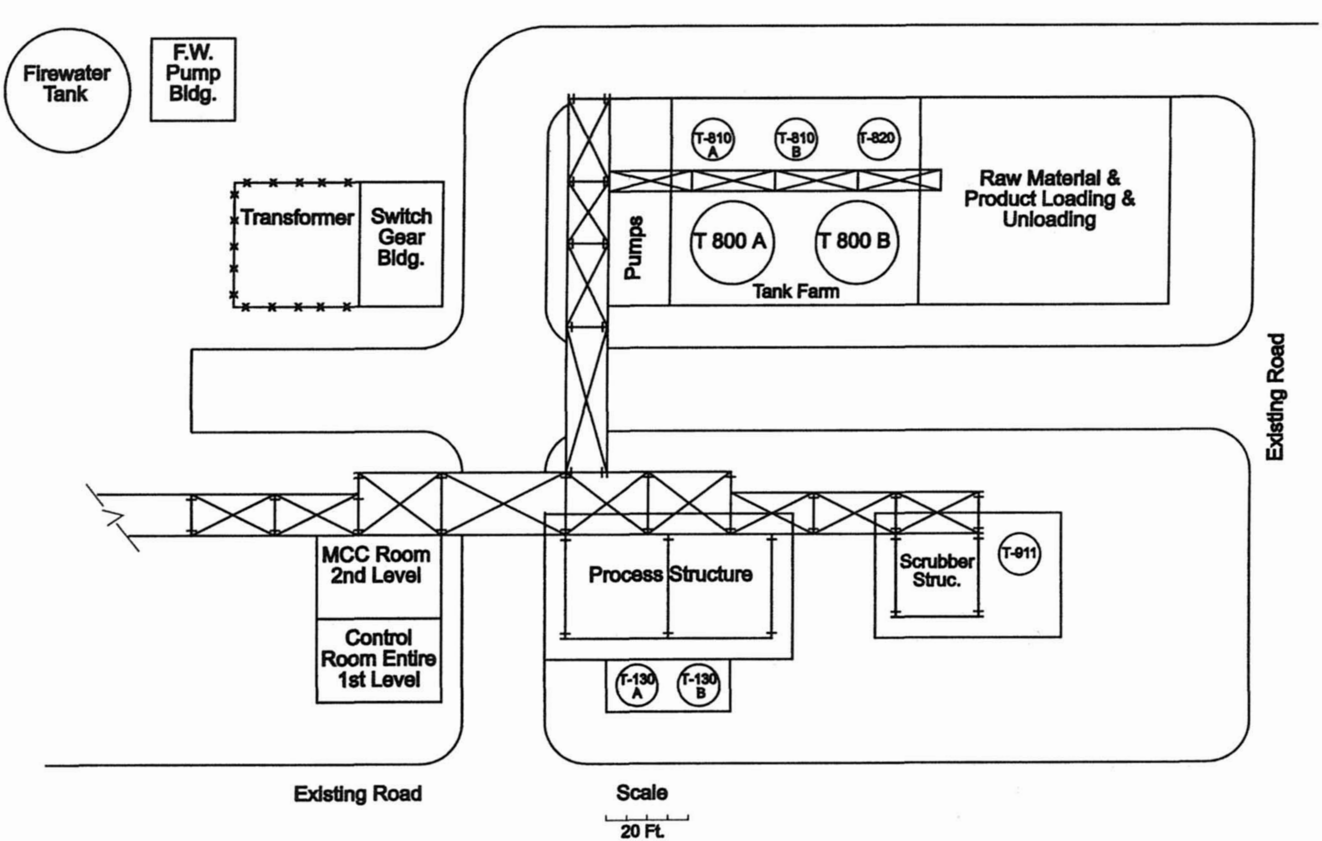


Figure L.1 Plot plan.

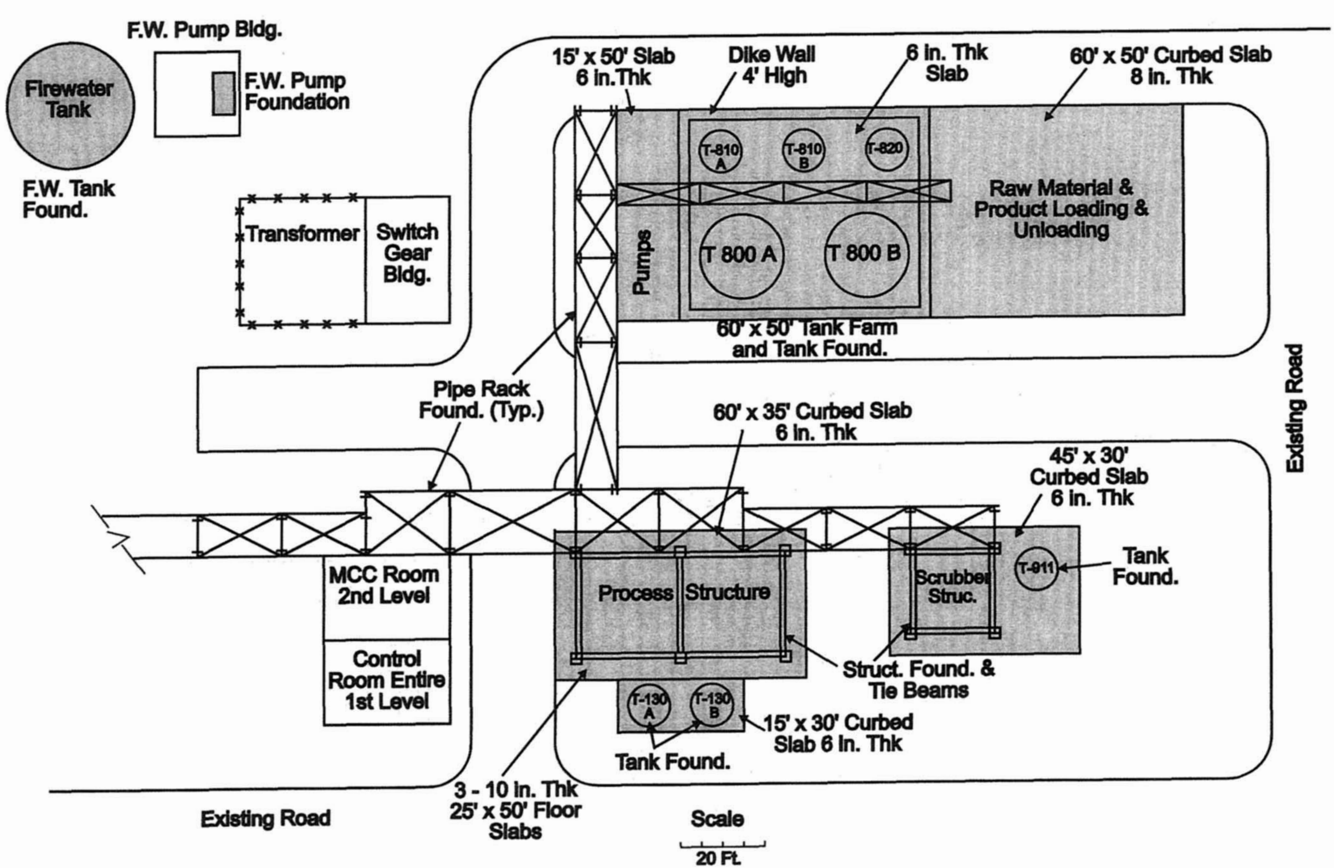


Figure L.2 Concrete work.

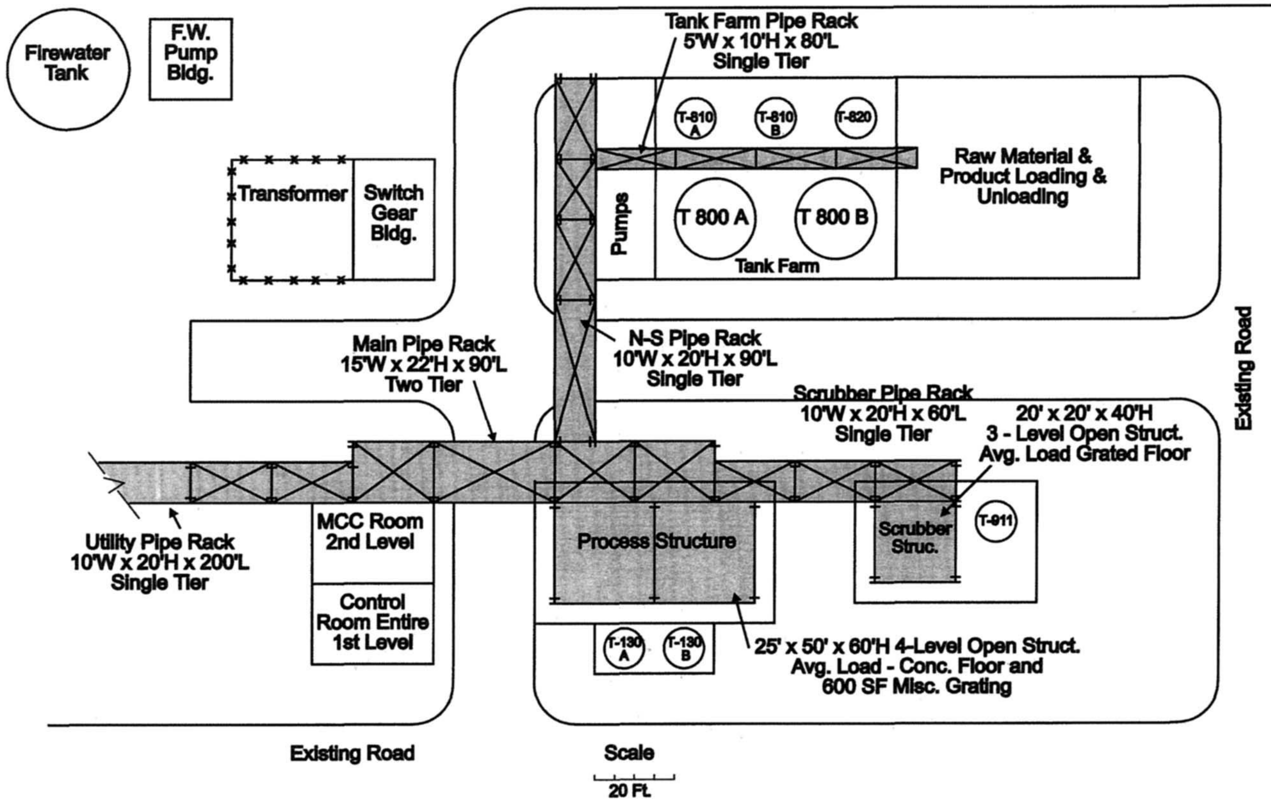


Figure L.3 Structural steel.

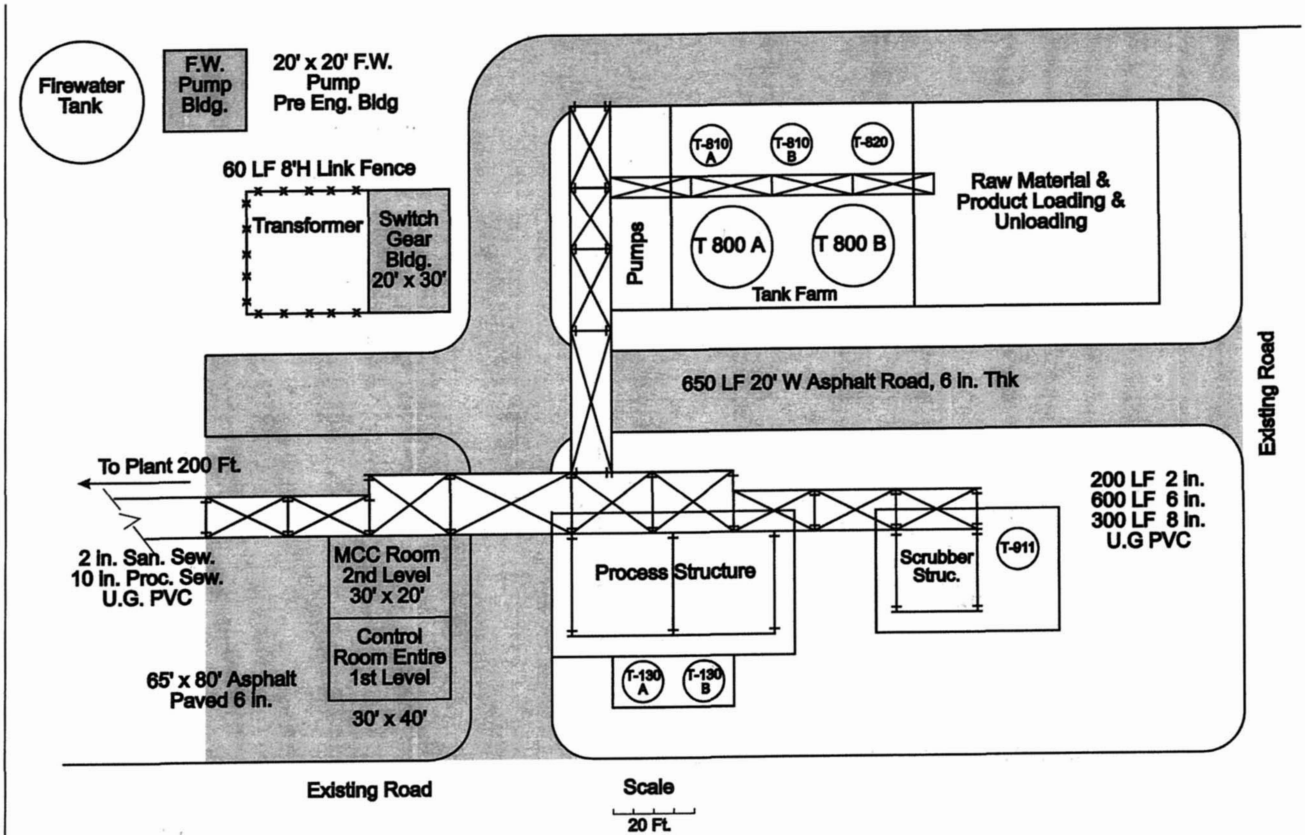


Figure L.4 Miscellaneous civil work.

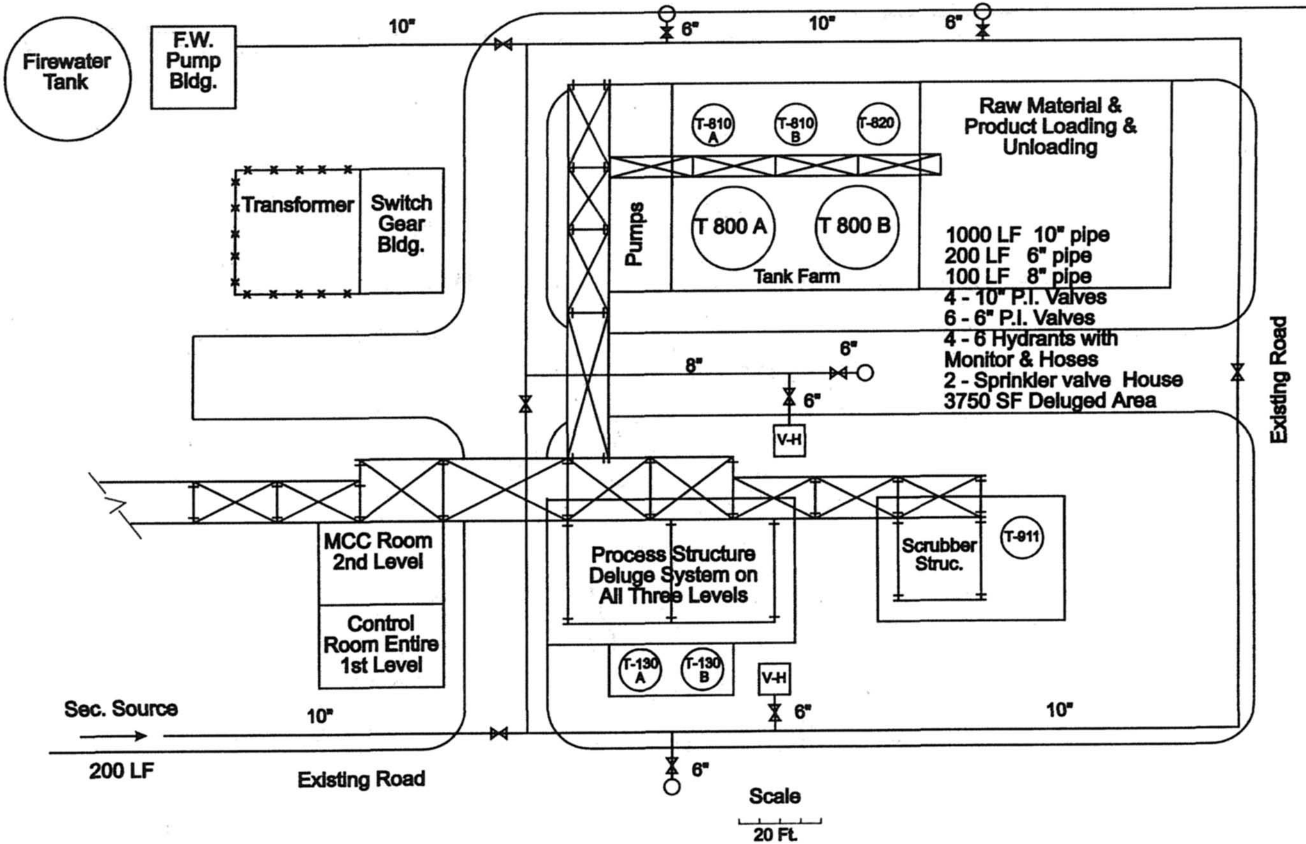


Figure L.5 Fire protection system.

L.2 Annotated Equipment List

Qty.	Item #	Description	Total K$	HP
Process Area				
2	R-101A/B	8' Dia. x 8' TT 316ss Full Jacket 25 psig/FV Reactor – 1/32" Corrosion Allowance	196.0	N/A
2	G-101A/B	316ss 25hp Agitator for R-101A/B	52.0	2 x 25
2	C-110A/B	5' Dia. 60' TT Packed Column, 316ss 25 psig/FV – 1/32" Corrosion Allowance	354.0	N/A
2	J-120A/B	4 Stage Steam Ejector – 316ss 2mm 30lb/hr	46.0	N/A
2	H-105A/B	1500 SF S&T Reboilers, CS Shell 316ss Tubes	84.8	N/A
2	H-111A/B	1000 SF S&T Condensers, CS Shell 316ss Tubes	74.0	N/A
12	Misc. Pumps	100 gpm x 150" Head 316ss Centrifugal Pumps 1,750 rpm	68.4	12 x 15
2	T-130A/B	10'Dia x 15' high Atmospheric Tank-Cone Roof Corrosion Allowance 1/32"	115.6	N/A
2	V-135 A/B	6' Dia x 8' TT 316ss 25 psig Pressure Vessel Corrosion Allowance 1/32"	67.0	N/A
2	V-140 A/B	6' Dia x 8' TT 316ss 25 psig Pressure Vessel Corrosion Allowance 1/32"	67.0	N/A
2	F-121 A/B	100 gpm Dual Cartridge Filter – 316ss	9.0	N/A
2	H-115 A/B	250 SF S&T Heat Exchangers, 316ss Shell & Tubes	21.6	N/A
Scrubber Area				
1	B-911	5000cfm FRP Blower 6" H_2O 5 hp	5.2	1 x 5
1	C-910	3' Dia x 40' Packed Atmospheric FRP Scrubb	100.0	N/A
2	G-921 A/B	316ss Agitators for T-920A/B – 5hp	28.0	2x5
2	P-922 A/B	100 gpm X 150' Head 316ss Centrifugal Pumps 1750 rpm	11.0	2 x 15
2	P-913 A/B	50 gpm x 75' Head Hastelloy C Centrifugal Pumps 1750 rpm	20.0	2 x 5
2	T-920 A/B	8' Dia x 10' high 316ss Atmospheric Tank Open Top-Corrosion Allowance 1/32"	73.0	N/A
1	T-911	12' Dia x 16' high FRP Atmospheric Tank, Cone Roof	67.6	N/A
1	H-915	200 SF S&T Heat Exchanger CS Shell, Hastelloy C Tubes	34.5	N/A
Tank Farm Area				
2	T-800 A/B	20' Dia x 24' high CS Atmospheric Tank, Cone Roof – Corrosion Allowance 1/8" Field erected	133.0	N/A
2	T-810 A/B	10' Dia x 15' high 316ss Atmospheric Tank, Cone-roof - Corrosion Allowance 1/32"	120.0	N/A
1	T-820	10' Dia x 15' high CS Atmospheric Tank, Cone-roof - Corrosion Allowance 1/8"	24.0	N/A
2	F-812 A/B	100 gpm Dual Cartridge Filters – 316ss	9.0	N/A
2	P-801 A/B	100 gpm x 150'H 316ss Double Seal Centrifugal Pump 1750 rpm	23.0	2 x 15
2	P810 A/B	100 gpm x 150'H 316ss Single Seal Centrifugal Pump 1750 rpm	11.0	2 x 15
2	P821 A/B	100 gpm x 150'H Ductile Iron (D.I.) Single Seal Centrifugal Pump 1750 rpm	7.6	2 x 15
1	No Tag #	Fire Water Tank – 30' Dia x 30' High CS Open Top, Field erected	109.0	N/A
1	No Tag #	1000 gpm Diesel Driven Fire Water Pump 150 psig	46.0	N/A
1	No Tag #	Fire Water Jockey Pump	3.8	1 x 3
		Total	1981.1	338

L.3 Equipment Account

Cost Estimate – Process Area		
R-101 A/B	8' Dia. x 8' TT Reactor with full jacket & agitator 25 psig/FV design – 1/32" corrosion allowance Thickness (Fig. 19.2) =1/4" Area = (8 x 3.14 x 8) + (2 x 8^2) = 329 SF Weight: Body = 329 x 10 x 1.1[1] = 3610 lb Baffles (1/2" Thick Baffle) = 4 x 8 x 20 = 640 lb Jacket = (1/8 Thick) [(8 x 3.14 x 8) + 64] x 5 = 1320 lb 5600 lb 5600 lb x 1.3[2] = 7250 lb Cost = 7250 x 3.60 x 2.5 x 1.5 = [1] F.V. [2] Fig. 19.4 x 2 units =	 98,000 $196,000
G-101	316ss 25 hp Agitator From Miscellaneous equipment = x 2 units =	 26,000 $52,000
C-110A/B	5' Dia x 60 TT – Packed Column 316ss 25 psig/FV Thickness (Fig. 19.2) = 1/4" Area = (5 x 3.14 x 60) + (2 x 5^2) = 992 SF Weight = 992 x 10 x 1.45 (Fig. 19.4) =14,400 lb Cost = 14,400 x 2.90 x 2.5 x 1.5 = Plus Packing (say) = Subtotal = x 2 units =	 156,600 20,400 177,000 $354,000
J-120 A/B	4 Stage Ejector – 316ss 2m 30 lb/hr From Miscellaneous equipment = x 2 units =	 23,000 $46,000
H-105A/B	1500 SF S&T Reboiler CS Shell & 316ss Tubes Basic cost from Fig. 19.6 = 316ss Tubes = + 15% = Subtotal = x 2 units =	 37,000 5,600 42,400 $84,800
H-111A/B	1000 SF S&T Heat Condenser CS Shell & 316ss Tubes Basic cost from Fig. 19.6 = 316ss Tubes = + 15% = Subtotal = Condenser (Med. Vacuum) x 1.15 = x 2 units =	 28,000 4,200 32,200 37,000 $74,000
Pumps	316ss Pumps 1750 rpm 100 gpm x 150' Head, Single Seal, gpm x Head = 15,000 hp = 15, From Fig. 19.5 Pump = Motor = Subtotal = x 12 Pumps =	 4,300 1,200 5,700 $68,400
T-130A/B	10'Dia x 15' H – 316ss Atmospheric Cone Roof F.B. Thickness (Fig. 19.2) = 1/4" Shell Bottom Cone roof Area = (10 x 3.14 x 15) + (10^2 x .785) + (10^2 x .785 x 1.1) = 635 SF Weight = 635 x 10 x 1.26 (Fig. 19.4) = 8000 lb Cost = 8000 x 3.4 x 2.5 x 0.85 = x 2 units =	 57,800 $115,600

V-135 A/B	6' Dia x 8'TT – 316ss, 25 psig – 1/32" corrosion allowance Thickness = 1/4" Area = (6 x 3.14 x 8) + (2 x 6^2) = 223 SF Weight = 223 x 10 x 1.4 = 3120 lb Cost 3120 x 4.30 x 2.5 = x 2 units =	 33,500 $67,000
V-140 A/B	6' Dia x 8'TT – 316ss, 25 psig – 1/32" corrosion allowance Thickness = 1/4" Area = (6 x 3.14 x 8) + (2 x 6^2) = 223 SF Weight = 223 x 10 x 1.4 = 3120 lb Cost 3120 x 4.30 x 2.5 = x 2 units =	 33,500 $67,000
F-121 A/B	100 gpm Dual Cartridge Filters, 316ss Cost from Miscellaneous equipment = x 2 units =	 4,500 $9,000
H-115 A/B	250 SF S&T Heat Exchanger 316ss Shell & Tubes Basic cost from Fig. 19.6 = 316ss Tubes = +15% = 316ss Shell = + 20% = Subtotal = x 2 units =	 8,000 1,200 1,600 10,800 $21,600

Cost Estimate – Scrubber Account		
B-911	5000 cfm FRP Blower 6" H_2O 5 hp Basic cost from Miscellaneous Equipment 1000 cfm 6" H_2O CS = $2,000 20,000 cfm 6" H_2O CS = $6,000 5,000 cfm 6" H_2O CS = FRP x 1.3 =	 4,000 $5,200
C-910	3' Dia x 40' Packed Atmospheric F.R.P. Scrubber TT Dimension = 40' + 10' (Assumed) = 50' Design Pressure = 50 / 2.3 lb./FT H_2O x 0.67 (@1/3 H) = 14.5 psig Avg. Thickness (Fig. 19.3) = 3/4" Area = (3 x 3.14 x 50) + (2 x 3^2) = 489 SF Weight = 489 x 30 x 0.20 x 1.65 = 4840 lb Cost = 4840 x 4.1 x 2.8 x 1.5 = Packing (say) = Total =	 $83,000 17,000 100,000
G-921 A/B	316ss Agitators for T-920 A/B 5 hp From Miscellaneous equipment = x 2 units =	 14,000 $28,000
P-922 A/B	316ss Pumps 1750 rpm 100 gpm x 150' Head gpm x Head = 15,000 hp = 15 From Fig. 19.5 Pump = Motor = Subtotal = x 2 Pumps =	 4,300 1,200 5,500 $11,000

P-913 A/B	Hastelloy C Pumps 1750 rpm 50 gpm x 75 ' Head gpm x Head = 3750 hp = 7.5 From Fig. 19.5 316ss Pump = \$3,700 Hastelloy C x 2.5 = Motor = Subtotal = x 2 Pumps =	 9,300 700 10,000 \$20,000
T-920 A/B	8' Dia x 10' High 316ss ATM Tank, Open top, flat bottom, Corrosion allowance 1/32 Thickness = 1/4" Area (8 x 3.14 x 10) + (10^2 x .785) = 330 SF Weight = 330 x 10 x 1.3 (Fig. 19.5) = 4,300 lb. Cost = 4,300 x 4.00 x 2.5 x .85 = x 2 units	 36,500 \$73,000
T-911	12' Dia x 16' High F.R.P. Tank – Cone roof F.B. Design pressure = 16 / 2.3 lb/ft H_2O x 0.67 = 4.7 psig Avg Wall thickness (Fig. 19.3) = 1" Roof & bottom thickness (judgement) = 3/4" Area (shell) = (12 x 3.14 x 16) = 603 SF Area (bottom & roof) = 12^2 x 0.785 + 12^2 x 0.785 x 1.1 = 237 SF Weight = 603 x 40 x 0.20 x 1.23 (Fig. 19.4) = 5930 lb. = 237 x 30 x 0.20 x 1.23 (Fig. 19.4) = 1750 lb. 7680 lb. Cost 7680 x 3.7 x 2.8 x 0.85 =	 \$67,600
H-915	200 SF S&T Heat Exchanger C.S. Shell, Hastelloy C Tubes Basic cost from Fig. 19.5 = Hastelloy C Tubes = + 400% =	 6,900 27,600 \$34,500

Cost Estimate – Tank Farm Area		
T-800 A/B	20' Dia x 20' high Atmospheric C.S. Tank F.B. Cone roof Wall Thickness = 1/2" Bottom & roof thickness = 1/4" Area (wall) = (20 x 3.14 x 20) = 1256 SF Area (bott/roof) = (20^2 x 0.785 + 20^2 x 0.785 x 1.1) = 659 SF Weight (walls) = 1256 x 20 x 1.2 (Fig. 19.4) = 30,100 lb. Weight (bott/roof) = 659 x 10 x 1.2 (Fig. 19.4) = 7,910 lb. 38,000 lb. Cost 38,000 x 1.75 = x 2 units =	 66,500 \$133,000
T-810 A/B	10' Dia x 15' high 316ss ATM Tank F.B. Cone roof Corr. allow. = 1/32" Thickness = 1/4" Area = (10 x 3.14 x 15) + (10^2 x 0.785 x 2.1) = 640 SF Weight = 640 x 10 x 1.26 (Fig. 19.5) = 8,100 lb. Cost = 8100 x 3.50 x 2.5 x .85 = x 2 units	 60,000 \$120,000
T-820	10' Dia x 15' high CS ATM Tank F.B. Cone roof ,Corr. allow. = 1/8" Thickness = 1/4" Area = (10 x 3.14 x 15) + (10^2 x 0.785 x 2.1) = 640 SF Weight = 640 x 10 x 1.26 (Fig. 19.4) = 8,100 lb. Cost = 8100 x 3.50 x .85 =	 \$24,000
F-812 A/B	100 gpm Dual Cartridge Filter 316ss Cost from Miscellaneous Equipment = x 2 units =	 4,500 \$9,000

P-801 A/B	100 gpm x 150' Head 316ss Double seal, Centrif. Pump 1750 rpm gpm x Head = 15,000 From Fig. 19.5 hp = 15 Pump cost = Motor cost = Double seal = Subtotal = x 2 units =	 4,300 1,200 6,000 11,500 $23,000
P-810 A/B	100 gpm x 150' Head 316ss Single seal, Centrif. Pump 1750 rpm gpm x Head = 15,000 From Fig. 19.5 hp = 15 Pump cost = Motor cost = Subtotal = x 2 units =	 4,300 1,200 5,500 $11,000
P821 A/B	100 gpm x 150' Head Ductile Iron, Single seal, Centrifugal Pump 1750 rpm From Fig. 19.5 hp = 15 Pump cost = 4,300 Ductile Iron x 0.60 = Motor cost = Subtotal = x 2 units =	 2,600 1,200 3,800 $7,600
Fire Water Tank	30' Dia x 30' CS Tank, Open top Wall thickness = 5/8" Bottom thickness = 1/4" Area (wall) = (30 x 3.14 x 30) = 2824 SF Area (bottom) = (30^2 x 0.785) = 706 SF Weight (walls) = 2824 x 25 x 1.2 (Fig. 19.4) = 84,700 lb Weight (bottom) = 706 x 10 x 1.2 (Fig. 19.4) = 8,500 lb 93,200 lb Cost = 93,200 x 1.3 x 0.9 =	 $109,000
Fire Water Pump	2000 gpm – 150 psig – Diesel Driven gpm x Head = 2000 x 150 x 2.3 = 69,000 hp = (Approx. from Fig. 19.5) = 100 hp Educated guess on cost derived from cost of a 200 KW Generator from Miscellaneous Equipment	 $46,000
Jockey Pump	50 gpm x 300' Head Ductile Iron, Centrif. pump 350 gpm gpm x Head = 15,000 From Fig. 19.5 hp = 15 Pump cost = 4,300 D.I. x 0.6 = Motor cost =	 2,600 1,200 $3,800
	Total Equipment Cost = **Freight** = 5% of equipment =	$1,981.0 K $ 100.0 K

Cost Estimate - Equipment Erection			
1	Total Equipment Cost	($K) =	1,981.0
2	Less Field Erected Tanks (F.W. Tank = $109.0 K) (T-800 A/B = $133.0 K)	($K) =	242.0
3	Net	($K) =	1,739.0
4	**Erection cost (Line 3 x 0.2)**	**($K) =**	**348.0**

5	Approximate Hours (Line 4 / $55/Hour)	Man-hours =	6,340
6	Approximate Field Erected Tank Hours ($242K x 0.40 / $50*/Hour	Man-hours =	1,940
7	Approximate Total Man-Hours	Man-hours =	8,280

Note: Table 19.1 must be used to estimate erection hours for "Earned Value System" used for monitoring construction progress. See Appendix E.

L.4 Piping Account

Basic Assumptions (Section 19.11)	
Process and Storage Areas	
Lines per Equipment Item	3.5
Valves per Line	1.5
Average Length of Line (Based on dimensions of each area) Process Area Scrubber Area Tank Farm	 50 ft. 30 ft. 50 ft.
Average Diameter (Based on capacity of pumps) 50% = 2" 50% = 3"	
Materials of Construction (Based on equipment metallurgy) 20% = Carbon Steel (C.S.) 80% = 316 Stainless Steel (ss)	
Interconnecting Pipe	
50% of Process and Storage areas	

Take-Offs	
Process Area 34 pieces of equipment	
Carbon Steel Pipe 2" 34 x 3.5 x 50 x 0.5 x 0.2 3" 34 x 3.5 x 50 x 0.5 x 0.2	 600 ft. 600 ft.
Carbon Steel Valves (Ball Valves) 2" 34 x 3.5 x 1.5 x 0.5 x 0.2 3" 34 x 3.5 x 1.5 x 0.5 x 0.2	 18 Valves 18 Valves
316ss Pipe 2" 34 x 3.5 x 50 x 0.5 x 0.8 3" 34 x 3.5 x 50 x 0.5 x 0.8	 2,380 ft. 2,380 ft.
316ss Valves (Ball Valves) 2" 34 x 3.5 x 1.5 x 0.5 x 0.8 3" 34 x 3.5 x 1.5 x 0.5 x 0.8	 72 Valves 72 Valves
Scrubber Area 12 pieces of equipment	
Carbon Steel Pipe 2" 12 x 3.5 x 30 x 0.5 x 0.2 3" 12 x 3.5 x 30 x 0.5 x 0.2	 130 ft. 130 ft.
Carbon Steel Valves (Ball Valves) 2" 12 x 3.5 x 1.5 x 0.5 x 0.2 3" 12 x 3.5 x 1.5 x 0.5 x 0.2	 6 Valves 6 Valves

316ss Pipe		
2"	12 x 3.5 x 30 x 0.5 x 0.8	510 ft.
3"	12 x 3.5 x 30 x 0.5 x 0.8	510 ft.
316ss Valves (Ball Valves)		
2"	12 x 3.5 x 1.5 x 0.5 x 0.8	26 Valves
3"	12 x 3.5 x 1.5 x 0.5 x 0.8	26 Valves
Tank Farm Area 16 pieces of equipment		
Carbon Steel Pipe		
2"	16 x 3.5 x 50 x 0.5 x 0.2	280 ft.
3"	16 x 3.5 x 50 x 0.5 x 0.2	280 ft.
Carbon Steel Valves (Ball Valves)		
2"	16 x 3.5 x 1.5 x 0.5 x 0.2	8 Valves
3"	16 x 3.5 x 1.5 x 0.5 x 0.2	8 Valves
316ss Pipe		
2"	16 x 3.5 x 50 x 0.5 x 0.8	1120 ft.
3"	16 x 3.5 x 50 x 0.5 x 0.8	1120 ft.
316ss Valves (Ball Valves)		
2"	16 x 3.5 x 1.5 x 0.5 x 0.8	34 Valves
3"	16 x 3.5 x 1.5 x 0.5 x 0.8	34 Valves
Interconnecting Pipe		
Carbon Steel Pipe		
2"	(600 + 130 + 280) x 0.5	510 ft.
3"	(600 + 130 + 280) x 0.5	510 ft.
316ss Pipe		
2"	(2380 + 510 + 1120) x 0.5	2010 ft.
3"	(2380 + 510 + 1120) x 0.5	2010 ft.

Piping Take-Off Summary		
Carbon Steel Piping		
Process Type		
2"	600 + 130 + 280	1010 ft.
3"	600 + 130 + 280	1010 ft.
Interconnecting Type		
2"	50% of Process Piping length	510 ft.
3"	50% of Process Piping length	510 ft.
316ss Piping		
Process Type		
2"	2380 + 510 + 1120	4010 ft.
3"	2380 + 510 + 1120	4010 ft.
Interconnecting Type		
2"	50% of Process Piping length	2010 ft.
3"	50% of Process Piping length	2010 ft.
Valves (Ball Valves)		
Carbon Steel Valves		
2"	18 + 6 + 8	32 Each
3"	18 + 6 + 8	32 Each
316ss Valves		
2"	72 + 26 + 34	132 Each
3"	72 + 26 + 34	132 Each

Cost Estimate										
Material	Dia.	Feet	Unit				Extension			
			Mat'l $/Unit	Labor WH/Unit			Mat'l K$	Labor W-H		
				Field		Offsite		Field		Offsite
				Erect.	Fab.	Fab.		Erect.	Fab.	Fab.
Process Type Piping										
CS	2	1010	15.00	0.45	0.71		15.2	455	715	
CS	3	1010	17.10	0.53		0.73	17.3	535		735
316ss	2	4010	35.10	0.49	1.00		140.7	1970	4010	
316ss	3	4010	44.30	0.59		1.10	177.6	2370		4410
Interconnecting Piping										
CS	2	510	7.60	0.40	0.12		3.9	206	62	
CS	3	510	10.00	0.46		0.14	5.1	236		72
316ss	2	2010	20.80	0.47	0.16		41.8	945	325	
316ss	3	2010	28.40	0.53		0.19	57.1	1065		385
Valves										
CS	2	32	220	2.4	2.0		7.0	76	64	
CS	3	32	390	3.1		2.6	12.5	99		81
316ss	2	132	500	2.4	3.0		66.0	315	385	
316ss	3	132	860	3.1		4.2	113.5	410		555
Totals		15,080 328	feet of pipe valves				$657.8K	8582	5571	6238
Adjustments										
Specialty Items (Steam Traps, Strainers, etc. x 1.05)							$690.7K	9060	5880	6590
Total Hours									21,530 WH	
Labor Cost for Piping @ $50.00							**$1,076.3K**			
Total Piping							**$1,767.0K**			

Heat Tracing

For a Conceptual Estimate where P&ID's and Arrangement Drawings are not available, heat tracing must be estimated as an allowance based on the available process and site information.

In this case the judgment is that 40% of the piping will be traced. Of this amount, 50% will be for process and 50% will be for winterizing.

From Table 19.18	M & L S.C.	Labor
Type	$/LF	WH/LF
Process	40.70	0.20
Winterizing	25.70	0.16
Average	33.20	0.18
So: 15,080 x 0.4 = 6,030 Linear feet of tracing Subcontract = 6,030 x 33.20 = $200K Labor = 6,030 x 0.18 = 1100 work hours		

	Work Hours	Material	S/C Labor	S/C Material & Labor	Total
Piping	21,500	$690.7K	$1076.3K		$1,767.0K
Tracing	1,100			$200.0	$ 200.0K
Total	22,600	$690.7K	$1076.3K	$200.0	$1,967.0K

Note: For estimates based on take-offs from P&ID's and Arrangement Drawings, a resolution allowance would be warranted at this stage. Resolution allowances would be from 5% to 30%, based on the design status. (See also Section 19.10 "Adjustments.")

However, since we are dealing with an estimate based on the "quick" procedure, we can only refer back to the "Lang Factors" in Table 5.1.

Low 1.20 E or 1981 x 1.2 = $2,380
Average 1.60 E or 1981 x 1.6 = $3,170
High 2.00 E or 1981 x 2.0 = $3,960

The Piping Account should be increased to **at least** the minimum.

Experience in recent organic projects of similar size and scope has shown the Piping Account to be approximately 1.30 of the Equipment Cost.

We will use 1.35.

So: Piping Account = 1981(Equip. Acct.) x 1.35 = $2,670.0K

Prorating the results of the "quick" estimate we have:

Man hours(1)	Materials (K$)	Labor (K$)	Subcontract (K$)	Total (K$)
31,000	$930.0	$1,470.0	$270.0	$2,670.0

Note 1: Approximately 8,900 WH (6590 x 1.35) will be executed in offsite fabrication shops under controlled conditions, higher productivity and lower labor rate. The potential cost saving could be as high as $150K.

Note 2: More accurate estimates (appropriation and definitive) can be prepared as the project evolves and P&ID's and equipment arrangement drawings are completed. Line per line take-offs can then be prepared using the P&ID's to count valves and arrangement drawings to estimate line lengths only since all fittings, supports and trimmings are folded into the unit prices in the book. This type of estimate would justify a resolution allowance as indicated in Section 19.10.

L.5 Instrumentation Account

Take-Offs Based on Typical Instrument Densities (see Section 19.7)				
Main Process Area (Batch Process) Equipment Count = 34				
DCS Points	34 x	3.6	=	123
DCS Wirings	34 x	5.4	=	184
Field Instruments	34 x	12.0	=	408
Air Hook-Ups	34 x	1.8	=	62
Scrubber Area (Continuous Process) Equipment Count = 12				
DCS Points	12 x	1.7	=	21
DCS Wirings	12 x	2.5	=	30
Field Instruments	12 x	7.0	=	84
Air Hook-Ups	12 x	0.9	=	11
Storage Areas and Offsites Equipment Count = 16				
DCS Points	16 x	1.0	=	16
DCS Wirings	16 x	1.5	=	24
Field Instruments	16 x	6.5	=	104
Air Hook-Ups	16 x	0.5	=	0
Total Project Equipment Count = 62				
DCS Points				160
DCS Wirings				238
Field Instruments				596
Air Hook-Ups				81

Note: When P&ID's are available the take-off should be made by actual count following the guideline from Fig. 19.12. In that case a resolution allowance must be added for hidden items. An Instrument Engineer should be consulted.

Cost Estimate			Unit		Mat'l ($K)	Subcontract	
			$ Each	WH. Each		Mat'l ($K)	Work Hours
DCS Hardware	160	Points @	2,100	-	336.0	N/A	N/A
DCS Wiring	238	@	375	18	N/A	89.0	4,280
Field Instruments	596	@	1,000	-	596.0	N/A	N/A
Field Instrument Installation – Installation and Check-Out – (@ 0.3 of Material $)							
Materials	596.0	x 0.3 x 0.2			N/A	35.0	N/A
Labor	596.0	x 0.3 x 0.8 / $48.00			N/A	N/A	2,980
Air Hook-Ups	81	@	260	24	N/A	21.0	1,940
Subtotals					932.0	145.0	9,200
Subcontract Labor Cost (@ $48.00 / hr)						441.6	
Total Subcontract Cost (S.C. Mat'l + S.C. Labor)						586.6	
Total Account (Mat'l + Subcontracts)					**$1,518.6K**		

Quick Checks

Cost / Equipment Item

Actual 1519K/62 = \$24.5 K

Check (Sect. 19.11) = \$20.0 K

Ratio to Equipment

Actual 1519K/1981K = 0.76

Check (Table 10.1) = 0.25 – 0.75

Comments

The estimate seems to be on the high side which is preferable at this stage of projects. No adjustment is necessary.

L.6 Electrical Account

Take-Offs (Section 19.6)			
Power Distribution			
Average Run = (Based on Plot Plan)			150 ft.
Process Motors 25 hp or less			
– Process Area			
– Scrubber Area		14	
– Tank Farm		7	
Miscellaneous Motors 25 hp or Less		7	
– Process Area			
– Scrubber Area		3	
– Tank Farm		2	
	Total Motors	1	34
460 V Feeders to Bldgs. (100 Amps/50 kVA)			3
Welding Receptacles (Based on Plot Plan Area)			
– Process Structure		6	
– Scrubber Structure		2	
– Tank Farm, Offsite, and Miscellaneous		9	
	Total Welding Receptacles		17
Grounding Connections			
62 Items x 1.2	Total =	75	
Lighted Areas			
Total (Scaled from Plot Plan) = 250 x 200 =		50,000	SF
Active Areas			
Process Structure = (50 x 25 x 4) =		5,000	SF
Scrubber Structure = (20 x 20 x 3) =		1,200	SF
Tank Farm Pumps = (15 x 60) =		900	SF
Loading/Unloading = (60 x 30) =		1,800	SF
	Subtotal =	8,900	SF
	Call it	9,000	SF
Inactive Areas			
(50,000 – 9,000)		41,000	SF
Misc. 120 V Loads (From Inst. Acct. Air Hook-Ups) =		80	

Total Load			
Process Area Motors (from Equip. Acct.) 383 hp		Approx. 383	kVA
Miscellaneous Motors		Approx. 30	kVA
100 amp Feeders		150	kVA
Heat Tracing (6,000 LF @ 15W/ft)		90	kVA
Welding Receptacles (Educated Guess)		50	kVA
Active Area Lighting @ 5W/SF		50	kVA
Inactive Area Lightning @ 1W/SF		40	kVA
Miscellaneous 120 V Loads (with Lighting)	N/A		
	Subtotal =	793	
	Subtotal x 1.5 =	1,189	
Result = One 2,000 kVA Transformer			

Note: 2 – 1000 kVA transformers would provide a more reliable system at approximately $200K additional cost. This would be a management decision.

Cost Estimate					
	Quantity	Unit (Table 19.24)		Extension	
		$ Each	WH Each	($K)	Work Hours
Motors ≤ 25 hp					
Fixed	34	1,300	25.0	44.2	850
Variable x 1.5	34	410	37.5	20.9	1,275
100 amp Feeders					
Fixed	3	790	30.0	2.4	90
Variable x 1.5	3	600	37.5	2.7	113
Welding Receptacles					
Fixed	17	1,100	30.0	18.7	510
Variable x 1.5	17	410	37.5	10.5	638
Miscellaneous 120 V Loads	80	180	10	14.4	800
Active Lighting Area (9,000 SF / 100)	100	350	15	31.50	1,350
Inactive Lighting Area (41,000 SF / 100)	400	120	5	49.2	2,050
Grounding Connections	75	120	6	9.0	450
Alarms & Intercom	1	30.0	500	30.0	500
2,000 kVA Transformer	1	290	1,500	290.0	1,500
			Subtotal	523.5	10,126
		Total (10,126 @ $48.00/Hr)		523.5	486.0
Account Total				**1,009.5**	

Power Wiring Summary (use in Appendix E)				
		Work Hours		
		Fixed	Variable	Total
Motors	34	850	1275	2125
Feeders	3	90	113	203
Welding	17	510	638	1148
Total	54	1450	2026	3476
Average WH per load 3476 ÷ 54 = 64				

Electrical Account Check Estimate (Preliminary, for information only)					
				Material ($K)	Work Hours
Average hp per 480 V Load Process Motors Misc. Motors Feeders Totals Average	 28 6 3 37	 383 hp 30 hp 150 hp 563 hp 15 hp			
480 V and 120 V Systems Cost (from Fig. 19.10)	37	@	4,200	155.4	
Work hr (from Fig. 19.11)	37	@	145		5,365
Inactive Area Lighting 41,000 / 100 =	$410	@	$120/5 WH	49.2	2,050
2,000 kVA Transformer				290	1,500
			Subtotal	494.6	8,915
			Labor @ 48.00/hr =		428.0
			Grand Total	**920.0**	

Quick Checks

Ratio to Equipment

Actual 1010/1981 = 0.51

Typical (Table 10.1) 0.20-0.50

Cost per Motor Load

Cost without inactive areas

1010 K - (49.2 K + 2,050 WH @ $48/hr) = $862 K

Number of Motors/Loads

34 Equip. Motors
6 Misc. Motors
3 Bldg. Feeders
3 Lighting Feeders (Guess)
40

Actual Cost 862K/40 = 21.6 K

Check $21.0 K (Section 19.11)

L.7 Site Work Account

Sitework Take-Offs		
Take-offs from SK 4 and 5 Unit prices from Section 19.3 – Miscellaneous Units Assume that 40% of the Subcontract (S/C) cost is "loaded" labor @ $40.00/Hour		
	S/C $	Approx W-hours
Clearing and Grubbing		
Area = 250' x 200' = 50,000 SF, call it 1.5 acre		
@ $4900.00 / acre =	7,400	
$7,400 x 0.4 (Labor Fraction) /$45.00/hr =		70
Asphalt Pavement		
Roads – (650' x 20') / 9 = 1450 SY Parking – (65' x 80') / 9 = 580 SY 2030 SY		
@ $25.00/SY =	50,800	
$50,800 x 0.4 (Labor Fraction) /$40.00/hr =		450
Transformer Fence		
Fence 100 LF @ $30.00/LF = $3,000 Gate $1,000 $4,000 Total Fence =	4,000	
$4,000 x 0.4 (Labor Fraction) /$40.00/hr =		40
Sewers		
10" 200 LF @ $52.00/ LF = 10,400 8" 300 LF @ $44.00/ LF = 13,200 6" 600 LF @ $37.00/ LF = 22,200 2" 400 LF @ $25.00/ LF = 10,000 $55,800 Total Sewers =	55,800	
@ $55,800 x 0.4 (Labor Fraction) /$45.00/hr =		500
Total Account	**$118,000**	**1,060**

Quick check

Ratio to Equipment

Actual 118/1981 = 0.06

Typical = 0.04-0.08

L.8 Fire Protection Account

Cost Estimate					
			S.C.$/ft	Total	WH
10" Pipe	1,000 ft	@	63.00	63.0	560
8" Pipe	100 ft	@	54.00	5.4	50
6" Pipe	200 ft	@	49.00	9.8	90
10" P.I.V. Valves	4 ea	@	3,700	14.8	130
6" P.I.V. Valves	6 ea	@	2,900	17.4	150
6" Hydrants	4 ea	@	6,900	27.6	240
Valve Houses	2 ea	@	3,000	7.5	70
Deluge Area	4,000 SF	@	7.00	28.0	250
Total Account				**173.5**	**1,540**
Approx. W-Hours = $173.5 x 0.40 / $45/hr = 1,540 Work Hours					
Notes: Valve House Cost is an "educated guess" Take-offs are from SK-5 Unit Prices are from Section 19.3					

Quick Check

Ratio to Equipment

Actual = 173.5/1981 = 0.09

Typical = 0.05-0.15

L.9 Concrete Account

Take-Offs	
Process Structure Foundation (Table 19.5 and SK-3) [(25' x 50' x 60') / 1,000 CF] x 1.3 CY/1,000 CF	98 CY
Process Structure Tie Beams (Table 19.5 and SK-3) [(25' x 50') / 100 SF] x 1.2 CY/100SF	15 CY
Process Structure Elevated Slabs (SK3) [3 x (25' x 50' x 10"/12")] / 27 CF/CY	116 CY
Process Structure Floor Slab (SK-2) [(60' x 35') + (15' x 30')*] x 0.5 / 27 * T-130A/B Slab	47 CY
Scrubber Structure Foundations (Table 19.5 & SK-3) [(20' x 20' x 40') / 1,000 CF] x 1.3 CY / 1,000 CF	21 CY
Scrubber Structure Tie Beams (Table 19.5 & SK-3) [(20' x 20') / 100 SF] x 1.2 CY/100 SF	5 CY
Scrubber Structure Floor Slab (SK-2) (45' x 30' x 0.5) / 27	25 CY
Tank Farm Dike Wall (Table 19.5 & SK-2) (50' + 60') x 2 x 0.5 CY/LF	110 CY
Tank Farm Floor Slab [{(50' x 60') – (20^2 x 0.785 x 2) – (10^2 x 0.785 x 3)}x 0.5] / 27	40 CY
Loading and Unloading Slab (SK-2) (60' x 50' x 0.67) / 27	75 CY
Utility Piperack Foundations (Table 19.5 & SK-3) [(10' x 20' x 200') / 1,000] x 0.6 CY / 1000 CF	24 CY
Main Piperack Foundations (Table 19.5 & SK-3) [(15' x 22' x 90') / 1000] x 0.8 CY / 1000 CF	24 CY
Scrubber Piperack Foundations (Table 19.5 & SK-3) [(10' x 20' x 60') / 1000 CF] x 0.6 CY / 1000 CF	8 CY
N-S Piperack Foundations (Table 19.5 & SK-3) [(10' x 20' x 90') / 1000] x 0.6 CY / 1000 CF	11 CY
Tank Farm Piperack Foundations (Table 19.5 & SK-3) [(5' x 10' x 80') / 1000] x 0.6 CY / 1000 CF	3 CY
T-800A/B Foundations (Equipment List and Fig. 19.9)	25 CY
T-810A/B & 820 Foundations (Equipment List and Fig. 19.9)	15 CY
T-130A/B Foundations (Equipment List and Fig. 19.9)	10 CY
T-711A/B Foundation (Equipment List and Fig. 19.9)	6 CY
Fire Water Tank Foundation (Equipment List and Fig. 19.9)	20 CY
Fire Water Pump Foundation (Equipment List and Fig. 19.9)	10 CY
Miscellaneous Yard Concrete	42 CY
Total	**750 CY**

Take-Offs Summary	CY	CY
Type 1 Concrete (Table 19.2)		
Process Structure Floor Slab	47	
Scrubber Structure Floor Slab	25	
Tank Farm Floor Slab	40	
Loading/Unloading Floor Slab	75	
Subtotal		187
Type 2 Concrete		
Elevated Slabs		116
Type 3 Concrete		
Process Structure Tie-Beams	15	
Scrubber Structure Tie-Beams	5	
T-800A/B Foundations	25	
T-810A/B Foundations	15	
T-130A/B Foundations	10	
T-911A/B Foundation	6	
Fire Water Tank Foundation	20	
Fire Water Pump Foundation	10	
Subtotal		106
Type 4 Concrete		
Process Structure Foundations	98	
Scrubber Structure Foundations	21	
Tank Farm Dike Wall	110	
Utility Piperack Foundations	24	
Main Piperack Foundations	24	
Scrubber Piperack Foundations	8	
N-S Piperack Foundations	11	
Tank Farm Piperack Foundations	3	
Subtotal		299
Type 6 Concrete		
Miscellaneous Yard Concrete		42
Total		**750 CY**

Cost Estimate

		Unit		Extension	
Type	CY	S.C. $	Labor	$K	WH
1	187	345	6 WH	64.5	1,120
2	116	520	10 WH	60.3	1,160
3	106	630	12 WH	66.8	1,270
4	299	1,000	20 WH	299.0	5,980
6	42	630	12 WH	26.5	510
			Total Work Hours		10,040
			Total Account	**$517.1K**	

Quick Check

Ratio to Equipment

Actual 517 / 1981 = 0.26

Typical (Table 10.1) = 0.10-0.50

L.10 Structural Steel Account

Take-Offs			
1	Process Structure (Avg. Service) [(25' x 50' x 60') / 2,000 lb] x 2.60 lb/ ft^3	(Note 1)	97.5 Tons
2	Scrubber Structure (Light Service) [(20' x 20' x 40') / 2,000 lb] x 2.10 lb/ ft^3	(Note 1)	16.8 Tons
3	Utility Piperack [(10' x 20' x 200') / 2,000 lb] x 1.0 lb/ ft^3	(Note 1)	20.0 Tons
4	Main Piperack [(15' x 22' x 90') / 2,000 lb] x 1.2 lb/ ft^3	(Note 1)	17.8 Tons
5	Scrubber Piperack [(10' x 20' x 60') / 2,000 lb] x 1.0 lb/ ft^3	(Note 1)	6.0 Tons
6	N-S Piperack [(10' x 20' x 90') / 2,000 lb] x 1.0 lb/ ft^3	(Note 1)	9.0 Tons
7	Tank Farm Piperack [(5' x 10' x 80') / 2,000 lb] x 1.0 lb/ ft^3	(Note 1)	2.0 Tons
8	Floor Grating – Scrubber Structure [(20' x 20') x 2 Floors] x 9.7 lb/ ft^2 / 2,000	(Note 2)	3.9 Tons
9	Miscellaneous Tank Platforms (6' x 10' x 8 Tanks) x 20 lb/ ft^2 / 2,000 LB	(Note 2)	4.8 Tons
10	Miscellaneous Tank Gratings (6' x 10' x 8 Tanks) x 9.7 lb/ ft^2 / 2,000	(Note 2)	2.3 Tons
11	Miscellaneous Tank Railings (6' x 10' x 8 Tanks) x 14.0 lb/ ft^2 / 2,000	(Note 2)	1.8 Tons
12	Miscellaneous Tank Ladders (20' x 8 Tanks)x 20.0 lb/ ft / 2,000	(Note 2)	1.6 Tons
	Total		**183.5 Tons**
	Note 1: From Table 19.7 Note 2: From Table 19.8		

Cost Estimate			Units		Extension	
Item	Tons		Mat'l \$/Ton	Lab WH/Ton	K \$	WH
1	97.5	(1)	2,830	21	274.5	2,050
2	16.8	(1)	2,920	23	49.1	386
3	20.0	(1)	2,130	15	42.6	300
4	17.8	(1)	2,130	19	37.9	338
5	6.0	(1)	2,130	15	12.8	90
6	9.0	(1)	2,130	15	19.2	135
7	2.0	(1)	2,130	15	4.3	30
8	3.9	(2)	2,060	32	8.0	125
9	4.8	(2)	4,600	64	22.1	307
10	2.3	(2)	2,060	32	4.7	74
11	1.8	(2)	4,490	31	8.1	56
12	1.6	-	8,400	44	13.4	70
Total	**183.5**				**496.7**	**3,959**
Note:			3,959 WH @ 52.00/hr =		205.8	
(1) From Table 19.7 (2) From Table 19.6				**Total**	**\$702.5 K**	

Quick Check

Ratio to Equipment

Actual 703 / 1981 = 0.35

Typical (Table 10.1) = 0.20-0.45

L.11 Building Account

Cost Summary	SC K$	Approx W-Hrs
Control Room 40' x 30' = 1200' SF @ $250.00 SF =	[1]300.0	
$300,000 x 0.40 / $45.00/hr =		2670
MCC Room 20' x 30' = 600' SF @ $120.00 SF =	72.0	
$72,000 x 0.40 / $45.00/hr =		640
Switchgear Building 20' x 30' = 600' SF @ $100.00 SF =	60.0	
$60,000 x 0.40 / $45.00 hr =		540
Fire Water Pump Bldg. 20' x 20' = 400 SF @ 80.00 SF =	32.0	
32,000 x 0.40 / $45.00/hr		280
Take-Offs from SK-4 Unit Prices from Section 19.13 (Buildings)		
Total	**464 K**	**4,130**

[1] Including computer floor.

Quick Check

Ratio to Equipment

Actual 464 / 1981 = 0.23

Typical (Table 10.1) = 0.01-0.15

Comment: This account is too high for the type of plant. An alert Project Manager would review the buildings' dimensions and endeavor, during detailed design, to reduce sizes and minimize cost.

L.12 Insulation and Painting Account

A semi-detailed estimate of the **Insulation Account** can be prepared when P&ID's and equipment arrangement drawings are available to develop take-offs and apply the unit prices in Section 19.5

In this case we must factor to the equipment account following the guidelines in Table 10.1.

The analysis of the equipment list (reactors, columns, condensers, reboilers) indicates a heavily insulated plant so we are using the high-end of the 0.05–0.30 range.

The **Painting Account** in this case must be low; the cost of structural steel includes painting and a high portion of equipment and piping is covered with insulation. We are using the low-end on the 0.02–0.08 range.

Insulation

Subcontract = 1981 x 0.3 = **$600.0 K**
Work Hours = 600K x 0.4 / $/Hr = 5,300 WH

Painting

Subcontract = 1981 x 0.03 = **$60.0 K**
Work Hours = 60K x 0.4 / $45 = 530 WH

L.13 Field Indirects Account

According to guidelines in Section 19.9 the Field Indirects can be prorated to labor cost as follows:

15-20% of loaded subcontracted labor
Plus
10-12% Mat'l and Labor Subcontract

This estimate is based on the mid-range.

$2,522K x 0.175 = 441
$3,013K x 0.11 = 331
Total $ 772 K

L.14 Engineering Account

Base Hours Estimate									
		Process		Project Mgmt & Control		Design & Support		Procurement	
Ref. [1]	Qty.	Unit	Extension	Unit	Extension	Unit	Extension	Unit	Extension
2	2	390	780	440	880	1,710	3,420	240	480
3	8	270	2,160	190	1,520	960	7,680	140	1120
4	13	160	2,080	110	1,430	550	7,150	80	1040
5	5	120	600	70	350	350	1,750	60	300
6	4	60	240	40	160	240	960	40	160
7	26	20	520	50	1,300	140	3,640	10	260
8	4	10	40	10	40	30	120	10	40
	62								
101	4	-	-	180	720	220	880	220	880
103	1	120	120	130	130	500	500	100	100
104	1	70	70	70	70	300	300	70	70
105	1	60	60	60	60	250	250	50	50
107	1	-	-	30	30	160	160	30	30
119	1	60	60	160	160	1,000	1,000	100	100
			6,730		6,850		27,810		4,630
[1] See Tables 19.26 and 19.27								Base Hours =	46,020

Breakdown & Adjustment of Base Hours

	Base Hours		Adjustments		Adjusted Hours	
Process	0.15	6,730	Phase I by Owner x 0.30		Note 1	2,020
Proj. Mgmt & Cont.			From item #16 Table 19.29			
Proj. Mgmt & Engr.	0.45	3,080	2,030			2,030
Estimating	0.15	1,030	680	Some by SC x 0.50		340
Cost Control	0.25	1,710	1,110	Some by SC x 0.50		560
Scheduling	0.15	1,030	680	Some by SC x 0.50	Note 18, 19	340
Subtotal	0.15	6,850	4,500	[(2020 + 20890 + 3110)/0.85] x 0.15	Note 16	3,270
Design & Support						
Civil/Arch/Struct.	0.15	4,170				4,170
Electrical	0.13	3,620				3,620
Instrumentation	0.13	3,620	Phase I by Others x 0.90		Note 1	3,260
Piping	0.35	9,730	See Adj. Piping Hrs next page.			6,200
Equip/HVAC/Mech.	0.10	2,780	Phase I by Others x 0.90		Note 1	2,500
					Subtotal	19,750
Clerical & Admin.	0.14	3,890	(Adj. Des. Hrs x 0.14 x 0.20) / 0.86		Note 13	640
			$\frac{19,750}{1.00-.14}$ x .14 x .20			
Subtotal	0.60	27,810				20,390
Procurement						
Purchasing	0.65	3,010	Bulks by SC x 0.6			1,810
Expediting & Inspect.	0.35	1,620	Equipment by Eng. x 0.8			1,300
Subtotal	0.10	4,630				3,110
Total	**1.00**	**46,020**				**28,790**

Notes refer to Adjustments in Table 19.29.
Isometrics by Mechanical Subcontractor.
All construction Subcontracted.
Clerical Non-reimbursable.

Breakdown & Adjustment of Piping Hours

	Base Hours		Adjustments	Adjusted Hours	
P&ID Drafting	0.07	680	Phase I by Others x 0.40	Note 1	270
Layouts	0.05	490	Phase I by Others x 0.60	Note 1	290
Model	0.10	970			970
Orthographics	0.33	3,210			3,210
Material Take-Offs	0.10	970	Mostly by SC x 0.4	Note 14	390
Stress Analysis	0.05	490			490
Isometrics	0.30	2,920	Mostly by SC x 0.2	Note 5	580
	1.00	**9,730**			**6,200**

Notes refer to Adjustments in Table 19.29.

Correction of Adjusted Hours		
	Owner Estimate	
	Adjusted	Corrected
Process	2,020	1,960
Project Mgmt. & Control	2,030	1,970
Project Mgmt & Engr.	340	330
Estimating	560	540
Scheduling	340	330
Subtotal	3,270	3,170
Design & Support		
Civil/Arch/Structural	4,170	4,020
Electrical	3,620	3,510
Instrumentation	3,260	3,160
Piping	6,200	6,020
Equip/HVAC/Mech.	2,500	2,420
Home Office Construction	-	-
Clerical & Admin.	640	620
Subtotal	20,390	19,750
Procurement		
Purchasing	1,810	1,760
Expediting & Inspect.	1,300	1,260
Subtotal	3,110	3,020
Total	**28,790**	**27,900**

Correction Factors from Table 19.30. Equipment Count (Fc) 1.20
Factor (1.20 x 0.85 x 0.95) = 0.97. Equipment Size (Fs) 0.95[1]
Contractor Size (Fc) 0.85

[1]Avg. Motor Size (from Equipment List) 338/26 = 12hp

Account Total = 27,900 @ \$75.00/Hr = \$2,090K

L.15 Other Costs

Spare Parts

Normally 10% of Equipment
1981 x .10 = **\$200K**

Startup Costs

Contractor's support and miscellaneous maintenance materials are usually covered by 7% of total labor costs.

[\$2,510K + (\$3,015 x 0.4)] x 0.07 = **\$260K**

Table L.1 Case Study – Preliminary Cost Estimate, Cost Summary

		Thousand Dollars			
	Work		Subcontracts		
Direct Costs	Hours	Material	Labor	M & L	Total
Equipment	-	1,739	-	242	1,981
Equipment erection	8,300	-	346	-	346
Freight + 5% equip		90	-	-	90
Piping	31,000	930	1,470	270	2,670
Instrumentation	9,200	932		587	1,519
Electrical	10,100	524	486	-	1,010
Site preparation	1,100	-	-	118	118
Fire protection	1,500	-	-	174	174
Concrete	10,000	-	-	517	517
Structural steel	4,000	497	206	-	703
Buildings	4,100	-	-	464	464
Insulation	5,300	-	-	600	600
Paint	500	-	-	60	60
Total Directs	85,100	4,712	2,508	3,032	**10,252**
Indirect Costs					
Field indirects	.175 x S.C. Labor + .11 x M & L S.C.				770
Contract engineering	27,900 hr @ $75/hr				2,090
CED costs	Not Included				-
Taxes	Not Included				-
Spare parts	10% Equipment				200
Startup	7% (2,510 + 0.40 x 3,015)				260
Total Indirects					**3,320**
Directs + Indirects					**13,572**
Escalation		Not included			-
Target Estimate					**13,572**
Contingency 22%					2,985
Total Installed Cost					**16,557**
					Call it 16,600

L.16 Contingency

From guidelines in Section 19.10, a 50% probability estimate based on Phase 0 information would need 22% contingency.

Total Directs + Indirects = $13,572 K
Contingency x 0.22 = **$2,985 K**

Quick Checks	
Equipment count	62
Design stage	Phase 0
Growth factor	10-20%
Call it	15%
Equipment cost	$1,981K
Engineering cost	$2,090K
Total Installed Cost	
***Based on TICF**	
62 x $263/item x 1.15 =	$18,750K
***Based on TFCF**	
[(62 x 149) + 1,981 + 2,090] x 1.15	$15,300K
Preliminary Semi-Detailed Estimate	$16,600K

* **Note**: From Chapter 19, Table 19.35.

APPENDIX M
ACCURACY OF THE MODIFIED TFCF FOR CONCEPTUAL AND CHECK ESTIMATES

As mentioned in section 19.11 the total field cost factor (TFCF) can be modified and adapted to facilities that differ from those in the original study. The modified factor is developed by adjusting each of its cost components (see Table 19.36) to meet the requirements of specific cases. This approach can be very useful for conceptual estimating as well as for the quick checking of estimates prepared by others.

This Appendix illustrates the use of this technique in two actual cases. Since they were the only ones available that justified the modification of the TFCF, the results must be confirmed with more cases. However, the results were so good that I don't hesitate to recommend that all project engineers/managers include the procedure in their "tool box." I pray that some readers will be interested enough to dig into their files and check the procedure against their completed projects to confirm these results.

Case 1

Small 100% carbon steel plant handling simple non-toxic hydrocarbons with minimal instrumentation and by pressurizing vessels rather that pumping.

- The modified TFCF was $82K rather than $149K (see Table M.1).
- The check estimate was 8% higher that the final cost (see Table M.2).

Case 2

Medium size, 100% automated, computerized, organic chemical plant, handling hazardous and highly toxic materials in 316SS, Hastelloy, and glass lined equipment and complex piping. Built onsite of abandoned unit making maximum use of existing foundations, structures, buildings, and electrical systems.

- The modified TFCF was \$139K rather than \$149K (see Table M.3).

The final cost was distorted and rendered meaningless by several major scope changes, so the procedure was evaluated against each of the three key estimates of the project: preliminary, appropriation, and definite.

The first two were prepared in-house with minimal engineering and very few estimating hours using the techniques proposed in this book. The definitive estimate was prepared by the contractor after several months of engineering (12,000+ hours) using the usual detailed take-off method.

> IN ALL CASES THE CHECK ESTIMATES WERE WITHIN 2% OF THE FORMAL ESTIMATE AND THE IN-HOUSE, PRELIMINARY ESTIMATE WAS WITHIN 1% OF THE DEFINITIVE ESTIMATE! (See Table M.4.)

Author's Note: Checks like these would be the exception rather than the rule. Anybody would be very happy with ± 10% results.

This case also illustrates the value of the quick and semi-detailed estimating techniques proposed in this book. The 1.01 accuracy of the quick estimate versus the contractor's definitive estimate can only be considered a stroke of luck. However, the authors can attest to repeated instances of 0.90-1.10 accuracy of the semi-detailed method recommended for appropriation estimates.

	Basic TFCF			Correction Factor		Modified TFCF	
Description	Mat'l $	Labor WH	Comments	Mat'l	Labor	Mat'l $	Labor WH
Equip. erection	-	134		1.00	1.00	-	134
Site preparation	350	41		1.00	1.00	350	41
Concrete	1,850	189		1.00	1.00	1,850	189
Structural Steel	6,900	102		1.00	1.00	6,900	102
Buildings	2,200	31		1.00	1.00	2,200	31
Piping	18,000	833	100% C.S. 2 in. max Dia [1]	0.35	0.65	6,300	541
Electrical	4,400	156	No pumps / exist. substation	0.50	0.50	2,200	78
Instruments	12,300	124	Less than 50% normal instru. density, existing TDC	0.40	0.40	4,900	50
Insulation	2,200	29		1.00	1.00	2,200	29
Paint	350	23		1.00	1.00	350	23
Fire protection	1,850	41	Existing infrastructure	0.60	0.60	1,100	20
Total Directs	**50,400**	**1,703**				**28,350**	**1,238**
Avg. Labor Rate $/H		48.25	Lower rate / non-Union				36.00
Total Labor $	**82,200**					**44,600**	
Field Indirects 20%	**16,400**					**9,000**	
Total TFCF	**149,00**					**82,000**	

[1] Base cost of 3 in. 316 SS vs. 1 in. C.S.

Table M.2 Case 1 Final Cost Check

Modified TFCF $83K
Equipment Count 80

	Thousand Dollars	
	Actual	Check
Equipment	900	900
Engineering	1,250	1,250
Other	5,950	82 x 80 = 6,650
Total	8,100	8,710
Accuracy	**1.08**	

Description	Basic TFCF		Comments	Correction Factor		Modified TFCF	
	Mat'l $	Labor WH		Mat'l	Labor	Mat'l $	Labor WH
Equip. erection	7	134		1.00	1.00	-	134
Site preparation	350	41	Some demolition.	0.25	0.25	90	10
Concrete	1,850	189	Appx 60% of plant on existing foundation slab.	0.50	0.50	930	95
Structural Steel	6,900	102	Appx 60% on exist. structures & piperacks	0.50	0.50	3,450	51
Buildings	2,200	31	Expand existing bldg.	0.60	0.60	1,300	20
Piping	18,000	833		1.00	1.00	1,800	833
Electrical	4,400	156	Appx 50% of substations & MCC capacity available.	0.80	0.80	3,520	125
Instrumentation	12,300	124	Heavy density 100% automated.	1.50	1.50	18,450	186
Insulation/paint	2,550	52		1.00	1.00	2,550	52
Fire protection	1,850	41	Existing infrastructure.	0.75	0.75	1,390	31
Total Directs	**50,400**	**1,703**				**49,680**	**1,537**
Avg. Labor Rate $ / H		48.25					48.25
Total Labor $	**82,200**					**74,160**	
Field Indirects 20%	**16,400**					**14,830**	
Total	**149,000**					**139,000**	

Table M.4 Case 2 Estimate Check

Type	In-House Prelim. & Appropriation				Contractor Definitive	
Eng. Status	Good Phase 0		Phase 1		Basic Engineering	
Equip. Count	330		329		347	
Elapsed Time	1 Month		4 Months		8 Months	
Estimating Hours	32	16	300	16	12,000	16
Estimating Method	Quick	Check	Semi-Detailed	Check	Detailed	Check
Equipment	14,150	14,150	14,950	14,950	17,650	17,650
Freight	430		460		460	
Equip. erection	1,440		1,150		1,100	
Site preparation	300		1,610		1,380	
Conc./steel/bldg	4,340		6,790		6,900	
Piping	15,280		12,080		14,720	
Elect./Instrument.	11,940		13,920		14,490	
Insulation/Paint	2,650		2,880		2,650	
Fire protection	520		1,150		2,650	
Total Directs	**51,050**		**54,990**		**62,000**	
Engineering & Fee	12,770	12,770	11,320	11,320	13,450	13,450
Field Indirect	3,150		2,560		4,400	
Total Field Cost / Modif. TFCF x Count	330 x 139 = 45,870		329 x 139 = 45,730		347 x 139 = 48,250	
Subtotal	**66,970**	**72,790**	**68,870**	**72,000**	**79,850**	**79,350**
Escalation x	1.05	1.05	1.03	1.03	Incl.	1.05
Contingency x	1.25	N.A.	1.15	1.15	1.11	N.A.
Growth Factor x	N.A.	1.12	N.A.	1.08	N.A.	1.05
Subtotal	**87,900**	**85,600**	**81,600**	**80,100**	**88,600**	**87,500**
Laboratory	Incl.	500	Incl.	750	Incl.	750
Piling	0	0	Incl.	750	Incl.	750
Grand Total	**87,900**	**86,100**	**81,600**	**81,600**	**88,600**	**89,000**
TFCF Accuracy	0.98		1.00		1.00	
Proposed Estimating Systems Accuracy	1.01		1.09			

APPENDIX N
OFFSHORE ESTIMATING

N.1 Introduction

This Appendix illustrates the conversion of the U.S. basis estimate for the case study (see Appendix L) to an offshore location. The new location is in a Southeast Asia country that we have named "Jauja" after an old Spanish children's storybook.

The "Jauja" data were obtained from the local offices of two U.S. contractors with an active presence in "Jauja." The data were sorted out and the most conservative in each category were used for the conversion.

	Thousand Dollars	
	U.S.	"Jauja"
Equipment cost	1,981	1,788
Import duty and freight (1)	90	551
Other materials (2)	3,218	(2) 4,068
M & L subcontracts	1,933	483
Labor only subcontracts	3,032	790
Field indirects/C.M.	770	350
Engineering	2,090	420
Spare parts	200	350
Startup assistance	230	120
Subtotal	13,544	8,920
Contingency 22%-30%	2,956	2,680
Grand Total	**16,500**	**11,600**
Construction hours	**85,100**	**170,200**
Engineering hours	**27,900**	**35,000**

Notes: (1) Equipment only. (2) Duty & freight included.

Table N.1 (Same as Table L.1 – See Note) Preliminary Cost Estimate, Cost Summary, U.S. Basis

		Thousand Dollars			
	Work		Subcontracts		
Direct Costs	Hours	Material	Labor	M & L	Total
Equipment	-	1,739	-	242	1,981
Equipment erection	8,300	-	346	-	346
Freight + 5% equip		90	-	-	90
Piping	31,000	1,120	1,550	-	2,670
Instrumentation	9,200	1,077	442	-	1,519
Electrical	10,100	524	486	-	1,010
Site preparation	1,100	-	-	118	118
Fire protection	1,500	-	-	174	174
Concrete	10,000	-	-	517	517
Structural steel	4,000	497	206	-	703
Buildings	4,100	-	-	464	464
Insulation	5,300	-	-	600	600
Paint	500	-	-	60	60
Total Directs	85,100	5,047	3,030	2,175	**10,252**
Indirect Costs					
Field indirects	.175 x S.C. Labor + .11 x M & L S.C.				770
Contract engineering	27,900 hr @ $75/hr				2,090
CED costs					Not Incl.
Taxes					Not Incl.
Spare parts	10% Equipment				200
Startup	7% Labor				260
Total Indirects					**3,320**
Directs + Indirects					**13,572**
Escalation					Not Incl.
Target Estimate					**13,572**
Contingency 22%					3,028
Total Installed Cost					**16,600**

Note: The estimate in Table L.1 has been restructured to facilitate the conversion calculations.

N.2 Cost Conversion Questionnaire and Summary of Answers

A. Cost Basis – late 2000

B. Rate of Exchange – per dollar

C. Conceptual Scope

1. *Site* – Industrial park with basic utilities
2. *Equipment*

Equipment	No.
– Reactors, 3-5 k gal.	2
– Columns, 3' x 40'	3
– Pres. Vessels, 1-3 k gal	4
– ATM Tanks, 5-10 k gal	8
– Field FAB, Tanks	3
– Pumps & Blowers	25
– Exchangers	7
– Agitators	4
– Inline Filters	4
– Steam Ejectors	2
TOTAL	62

Note: Please provide estimate of Home Office man-hours design, procurement, project management and controls for above plant.

D. Relative Costs – U.S.= 1.0

Note: If you are not familiar with US prices but can provide copies of recent purchase orders, we would price them on US basis.

1. *Equipment* – FOB site

	"Jauja"
a. Pressure Vessels, 30 psig, 2-6k gal.	
– CS	0.70
– 316	Imported
b. Atmospheric Tanks, 30,000-100,000 gal.	
– CS	0.70
– 316	Imported
c. S & T Exchanger, 100 psig, 50-300 SF	
– CS shell/316SS tubes	0.80
– CS shell/Hastelloy tubes	Imported

d. Centrifugal Pumps, 10-200 gpm, 100 ft. head
   - CS 0.60
   - 316SS 0.90

e. Agitators, 5-50 HP
   - CS 0.80
   - 316SS Imported

2. *Materials*

a. Piping
   - CS-40S 0.80
   - 316 – 10S Imported

b. Flanged Valves
   - CS plug 1.40
   - FEP-lined plugs Imported

c. Electrical
   - Switch Gear 1.25
   - Conduit & Wire 1.25

d. Instruments Imported

e. Civil Materials, Material only
   - Concrete 0.50
   - Structural Steel 0.40

f. Labor Productivity, Man-hour basis
   - Construction 0.50
   - Engineering 0.80

E. Subcontract Unit Prices

a. Concrete (foundation) $175/cy
   including excavation, forming, rebar Appx. 0.25 US
   pouring, stripping, labor indirects, and
   contractor's overhead and profit

b. Structural Steel – Medium weight $920/Ton
   including fabrication, erection, rentals, Appx. 0.25 US
   and contractor's overhead & profit

c. Labor Costs
   including payroll costs, fringe benefits,
   insurance & contractor's overhead &
   profit without equipment rental
   - Pipefitter/Welder $1.50/W-H *
   - Design Engineer $12.00/W-H

   *Plus equipment rentals – see Note 1

d. Mechanical Erection

– Equipment	N.A. M-Hr/MetricTon
– Piping	N.A. M-Hr/MetricTon
– Structural Steel	N.A. M-Hr/MetricTon

F. Availability of Materials

a. National supply	List
b. Import duties & freight	40% + 10%

G. Permitting

a. Requirements	Explain
b. Duration	4 - 6 Months

Note 1: Major construction equipment rentals are assumed to be the same as in U.S. as shown in Section 19.9, corrected for labor productivity.

Equipment erection	10.00 x 0.5 = 5.00 \$/Hr
Structural steel	7.00 x 0.5 = 3.50 \$/Hr
Piping	5.00 x 0.5 = 2.50 \$/Hr
Elec/Instr	2.00 x 0.5 = 1.00 \$/Hr

N.3 Equipment

	Thousand Dollars		
National	US	Factor	"Jauja"
316SS ATM Vessels	309	0.80	247
CS ATM Vessels	266	0.70	186
316SS Pumps	113	0.90	102
CS Pumps	11	0.60	7
CS/316SS Exchangers	180	0.80	144
Subtotal	879		686K
Imported			
316SS Pres. Vessels	684		684
Hast. Pumps	20		20
FRP Equipment	173		173
316SS Agitators	80		80
CS/Hast. Exchangers	35		35
Misc. Equipment	110		110
	1,102		1,102
Subtotal	**1,981**		**1,788**

Duty and Freight		
US Freight 5% total Equip	90	
"Jauja" Duty & Freight 50% imports		551
Total Equipment	**$2,071**	**$2,339**

N.4 Other Materials

	Thousand Dollars		
National	U.S.	Factor	"Jauja"
C.S. Piping	60	0.80	48
C.S. Valves	30	1.40	42
Struct. Steel	497	0.40	199
Instrument. Misc. Mat'ls	145	1.25	181
Electrical Materials	524	1.25	655
Subtotal	1,256		1,125
Imported			
316SS Piping & Valves	850	*1.50	1,275
Heat Tracing Mat'l	180	*1.50	270
DCS & Field Instruments	932	*1.50	1,398
Subtotal	1,962		2,943
Total other materials	**3,218**		**4,068**

* Duty and freight included

N.5 Materials and Labor Subcontracts

	Thousand Dollars		
	U.S.	Factor	"Jauja"
C.S. Field Erected Tanks	(1)	0.70	(1)
Concrete	517	0.25	129
Site preparation	118	(2) 0.25	30
Fire protection	174	(2) 0.25	43
Buildings	464	(2) 0.25	116
Insulation	600	(2) 0.25	150
Paint	60	(2) 0.25	15
Total M & L subcontracts	**1,933**		**483**

Notes

(1) With equipment.

(2) Assumed cost ratio same as concrete.

N.6 Labor Subcontracts

	U.S.			"Jauja"		
	Hours	\$/Hr	K \$	Hours	\$/Hr	K \$
Equip erection	6,300	55.0	346	12,600	11.5	145
Field erect. tanks	2,000		(1)	4,000	6.50	(1)
Piping	31,000	50.0	1,550	62,000	6.50	403
Instrumentation	9,200	48.0	442	18,400	4.50	83
Electrical	10,100	48.0	486	20,200	4.50	91
Site preparation	1,100		(1)	2,200	1.50	(1)
Fire protection	1,500		(1)	3,000	1.50	(1)
Concrete	10,000		(1)	20,000	1.50	(1)
Structural steel	4,000	52.0	208	8,000	8.50	68
Buildings	4,100		(1)	8,200	1.50	(1)
Insulation	5,300		(1)	10,600	1.50	(1)
Paint	500		(1)	1,000	1.50	(1)
Total Labor Subcont.	**85,100**		**3,032**	**172,000**		**790**

Note

(1) Cost of labor included in subcontract in N.5.

N.7 Indirect Costs

	Thousand Dollars		
Engineering	U.S.	Factor	"Jauja"
Work Hours	27,900	1.25	35,000
@ \$/hr	75.00		12.00
Total Engineering K \$	**2,090**		**420**
Field Indirects	**770**		***350**
*Appx. 25% of subcontracts			
Spare Parts	**200**		***350**
* 15% of equip. plus freight & duty			

Startup Assistance		**260**		***120**
*Local – 10% of construct. labor 17,000 hr @ 1.20 = $ 20K Expatriate: 5 men for 2 months @ $10K / mo. = $100K				
Subtotal		**13,572**		**8,920**
Contingency	22%	3,028	30%	2,680
		16,600		**11,600**

APPENDIX O
PLANT TESTING ACCEPTANCE AND COMMISSIONING INSTRUCTIONS

1.0 INTRODUCTION

1.1 At the end of construction, Contractor has completed its scope of work in accordance with all the Owner's requirements and wants the Owner to accept the plant and assume the responsibility for operations.

1.2 The Owner also wants to accept the plant and start operations as soon as possible, but first it must verify that the plant will perform mechanically as per design and specifications.

1.3 Before the plant is ready for acceptance by the Owner, all plant completion tests and pre-commissioning activities shall be successfully completed.

1.4 The purpose of these instructions is to establish the minimum acceptance requirements and serve as the basis for a Plant Completion Program and Acceptance Procedure that will satisfy the common objective of prompt plant acceptance and startup.

1.5 The plant completion program and the acceptance procedure must be agreed upon and approved by both the Owner and Contractor.

2.0 GENERAL

2.1 The Owner reserves the right to witness all tests and shall be given adequate notice to exercise that right.

2.2 In all cases, Contractor shall issue reports, signed by its authorized representatives, certifying the tests and their results.

2.3 Staged acceptance is not only an acceptable practice, but one recommended to expedite plant startup.

2.4 Testing shall be done as requested by the various Owner General Specifications and applicable industry and local code and standards.

2.5 After contractor has completed all construction as per 3.0, he shall notify the Owner that the plant is "ready for inspection." The Owner will then perform final inspection and provide Contractor with "punch lists" for corrections.

3.0 CONSTRUCTION COMPLETION

Before the plant or any part of it can be considered complete and ready for final inspection by the Owner, Contractor shall complete the following as a minimum:

3.1 Inspection of the plant to check that erected facilities conform to flow diagrams, construction drawings, vendor drawings, and the specifications.

3.2 Non-operating field leak tests or field pressure tests on piping and field fabricated equipment as required by the specifications. Disposing of test media in accordance with the Owner's instructions. Removal of test blinds.

3.3 Removal of all temporary supports, bracing, or other foreign objects that were installed in vessels, transformers, rotating machinery, or other equipment to prevent damage during shipping, storage, and erection.

3.4 Unheading vessels after erection and inspecting in place all internals. Opening both internal and external manways for inspection of vessel by Owner. Closing manways after inspection.

3.5 Field inspection of all shop fabricated equipment.

3.6 Checking that no foreign objects (i.e., tools, loose bolts/nuts, trash, etc.) are left inside equipment and piping.

3.7 Checking to ensure that all base plates and soleplates are level and properly grouted.

3.8 Checking pipehangers, supports, guides, and pipe specialities, and the removal of all shipping and erection stops for the correct cold settings for the design service.

3.9 Checking of alignment of all piping fitup to equipment and removal of excessive stresses.

3.10 Insulating and/or painting flanges, threaded joints, or field welds after the specified testing of each item has been completed.

3.11 Re-installing all components such as safety valves, control valves, orifices, and meters removed for pressure testing.

3.12 Installing mechanical seals, permanent packing, and accessories in rotating equipment.

3.13 Checking rotating machinery for correct direction of rotation and for freedom of moving parts before connecting driver.

3.14 Making cold alignments to the manufacturer's tolerances.

3.15 Providing, installing, and removing all blinds required for flushing or operation.

3.16 Providing and installing all required temporary strainers.

3.17 Installing purge and vent connections.

3.18 Performing all non-operating pre-firing checks on boilers and fired heaters in accordance with the manufacturer's instructions.

3.19 Manually checking materials handling equipment for freedom and direction of movement.

3.20 Providing the services of factory representatives for equipment or other items as required for construction supervision and final check-out.

3.21 For all instrument systems within the defined battery limits performing the following operations:

- 3.21.1 Any non-operating checks that will ensure instrument operability (i.e., remove all shipping stops, check pointer travel, and verify instrument capability to measure, operate, and stroke in the direction and manner required by the process application).
- 3.21.2 Cleaning all transmission and control tubing by blowing with plant instrument air before connecting to instrument components.
- 3.21.3 Cleaning all air supply headers by blowing with plant instrument air and checking them for tightness.
- 3.21.4 Leak testing pneumatic control circuits in accordance with ISA Recommended Practice RP 7.1: Pneumatic Control Circuit Pressure Test, latest revision.
- 3.21.5 Checking piping from instruments to process piping for tightness.
- 3.21.6 Installing and connecting all system components and verifying their conformance to specifications and design criteria for function and range, using dummy transmission signals as needed.
- 3.21.7 Checking all electrical signals and alarm wiring for continuity, correct source of power, and polarity.
- 3.21.8 Checking thermocouples for proper joining wires, position of elements in wells, proper polarity, and continuity of receiving instruments.

3.21.9 Checking boiler and heater dampers for proper positioning and travel.
3.21.10 Checking control valves for proper travel.
3.21.11 Simulating operation of closed loops.
3.21.12 Calibrating instrumentation with standard test equipment and making all required adjustments and control point settings. Bench calibration of instruments at jobsite (Owner witnessed and approved) prior to installation is acceptable.

3.22 Testing and adjusting all safety devices and sealing wherever necessary or desirable.
3.23 Installing all safety devices (including pressure relief valves) after testing and adjustment.
3.24 Performing all electrical testing in accordance with the requirements of Owner General Specification.
3.25 Providing continuous clean-up of the construction area. Removing excess materials, temporary facilities, and scaffolding.
3.26 Blowing fuel lines, checking them for cleanliness, and connecting burner piping.
3.27 Sterilizing the potable water system and connected equipment.
3.28 Marking all piping to show fluid and direction of flow as per established procedure.
3.29 Performing all pressure and other mechanical testing required by the specifications.

4.0 PRE-COMMISSIONING ACTIVITIES

These activities shall be completed in their entirety before the plant is considered ready for acceptance and the introduction of feedstock.

		Responsibility
4.1	Internally inspecting, cleaning, flushing, draining, blowing out, drying, and purging of equipment, tanks, vessels and their linings and piping systems, and the installation and removal of temporary blinds, strainers, screens, etc., as necessary.	Contractor
4.2	Chemical cleaning BFW system, boilers, transfer line, exchangers, and high pressure steam system, and other specified parts of the plant including compressor suction piping and lube and seal oil systems. Providing chemicals and disposing of wastes as directed by Owner.	Contractor
4.3	Chemical cleaning and passivation, including chemicals and disposing of wastes as directed by the Owner.	Contractor

4.4	Removing and replacing control valves, relief valves, orifice plates, etc., removed for cleaning operations.	Contractor
4.5	Calibrating, testing, and adjustment of instruments and control equipment, including safety devices, and installing orifice plates and other sensing devices insofar as these can be done before initial operations of the plant.	Contractor
4.6	Cleaning strainers, screens, and filters; replacing and adjusting packings and seals; and tightening flanges.	Contractor
4.7	Checking out electrical systems, including substations and switchgear; checking all interlocks and setting all relays. Energizing all substations after completion of all tests as directed by the Owner.	Contractor
4.8	Amperage checking of motors and removal of temporary screens.	Contractor
4.9	Installing lubricants and fuels.	Owner
4.10	Boiling out of steam generation plant, including bringing up to pressure and performing all required operating tests, including those of relief valves, high and low level alarms, etc.	Owner
4.11	Drying out of refractory and linings of stacks, heaters, etc., in accordance with manufacturers' instructions.	Owner
4.12	Completing checkout of fuel gas, fuel oil, steam and air systems, including conducting light-off and making associated checks and adjustments for all fired equipment.	Owner
4.13	Charging the lube oil, seal oil, and oil cooling systems with flushing oil and circulating for cleaning purposes. Disposing of flushing oil in accordance with the Owner's instructions.	Contractor
4.14	Charging the lube oil, seal oil, and cooling systems with the operating oil recommended by the manufacturer.	Owner
4.15	Providing the assistance of manufacturers' or vendors' representatives as required, for technical assistance during run-in for informational and operating purposes.	Contractor
4.16	Arranging with vendors or manufacturers to provide training required by operators.	Owner
4.17	Setting turbine governors.	Owner
4.18	Coupling turbines, hot checking, cleaning, and removal of temporary screens.	Contractor
4.19	Test running of compressors and drivers, making vibration trip, governor, and safety device checks, and any other operating tests and adjustments as required.	Owner
4.20	Making hot alignment and any doweling required.	Contractor

4.21	Circulating and operating systems including cooling and potable water, effluent and drainage, fire protection, steam distribution, instrument air, plant air, and inert gas, relief, and blowdown and interconnecting lines. Making all final adjustments and conducting all performance tests on these systems.	Owner
4.22	Setting up of circulations and running in of pumps on water, methanol, naphtha, feedstocks, and products, as appropriate.	Owner
4.23	Adjusting pipehangers, supports, guides and pipe specialties for hot settings.	Contractor
4.24	Installing packing, catalyst supports, catalysts, desiccants, and chemicals. (a) Inspecting vessel interior before, during, and after loading to ensure proper installation.	Contractor
4.25	All running tests necessary to ensure that the section and components of the plant are ready for operation and safe commissioning.	Owner
4.26	Hot bolting and hot alignment to the extent possible prior to introduction of feedstocks.	Contractor
4.27	Completion of all outstanding mechanical work such as insulation and painting and removal of scaffolds, etc., that cannot be completed during operation.	Contractor
4.28	Installing lock and car seals where necessary.	Owner
4.29	Removal of all rust preventives and oils used to protect equipment during the construction period.	Contractor
4.30	Completing clean-up of area.	Contractor
4.31	Marking all controls to show desired or anticipated control points.	Owner
4.32	Setting all control functions; e.g., reset proportional band, etc., of instruments at values expected to be required for operation of the plant.	Owner
4.33	Performing all such further work as in the reasonable opinion of the Owner is necessary to bring the various sections and components of the plant to a state of readiness for the introduction of feedstocks and for safe initial operation.	Contractor

5.0 ABSOLUTE COMPLETION

5.1 Acceptance for operations does not mean that the plant is totally complete and fully accepted by the Owner.

5.2 Before the plant is fully accepted Contractor shall:

5.2.1 Finish all outstanding construction work and punch list items.

5.2.2 Correct all defects and deviations from specifications encountered during pre-commissioning and commissioning activities.
5.2.3 Remove all temporary facilities and restore the site to its original condition or as called for in the "Job Specification."
5.2.4 Complete successfully the post-construction noise survey.
5.2.5 Complete "as-built" drawings and submit them to the Owner.
5.2.6 Submit to the Owner copies of all engineering calculations and vendors' information.
5.2.7 Fulfill all its contractual obligations.

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