CHEMICAL ENGINEERING ECONOMICS

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PREFACE AND ACKNOWLEDGMENTS

There are many excellent books about economics for the process industries, each containing unique features. However, none of them emphasize the basic economic information that most working engineers will need. When the author started teaching chemical engineering economics some years ago at the University of California, Santa Barbara (UCSB), there were no texts available to provide specific instruction on cost estimating, project evaluation techniques and industry background on economics that related to, or could be profitably used by the engineer. Because of these circumstances a series of notes were assembled that gradually led to this book.

The book is intended primarily for the working engineer who is not a cost estimator, upper level manager, or economics specialist, but who needs economics in his or her daily activities for better job performance and advancement. When practicing engineers are asked in surveys about the subjects they wish they had taken in more detail in school, almost all place economics high on their list. This book is designed to fulfill that wish and to be useful in the chemical engineering curriculum.

Because of the importance of economics, and since it is a required course for accreditation, most engineers will have had some economics instruction in college. This book, whether used in conjunction with a design course or not, can provide the fundamental economic background that can be used in day-to-day engineering problems and assignments. Finally, since most chemical engineering professors are highly skilled technical specialists, this book can offer an easier and more comprehensive basic economic guide for the noneconomics instructor teaching the course.

The author wishes to acknowledge the support and assistance given by the UCSB Chemmical Engineering Department, which has made writing this book and the companion teaching assignment highly interesting, enjoyable, and rewarding activities. The friendship and assistance of Professor Jack Meyers, former UCSB Dean of Engineering, have been of great value. And last, but not least, the author wishes to thank his constantly helpful wife Maggie and his secretary Pat Weimer; the former for her patience, encouragement, and for acting as a sounding-board, and the latter who toiled endlessly, cheerfully, and most competently on the book's preparation.

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1

INTRODUCTION

Economics is a subject that almost everyone deals with on a daily basis, since one of its facets is the study or practice of utilizing, controlling, or budgeting money or wealth. Most people earn money, make spending decisions and budgets, and plans for future income, investments or spending. This truly is the practice of economics, but of course, it is a fairly limited part of the subject. Far more economic detail is required of most chemical engineers in the execution of their jobs, and naturally even more for managers, financial staffs, and so on.

Chemical engineering almost by definition involves the practical and economic blending of science, engineering, and mathematics to solve problems and make engineering decisions in the conduct of the employer's business. Every engineer is expected to have some economic knowledge, and most will use this training (at least as background) frequently. The need for chemical engineering economic familiarity might include, among other things: decision making on equipment, projects, or plants; managing or controlling new or old operations, projects, or plants; cost estimating; budgeting, accounting; understanding reports, balance sheets, operating statements; marketing, market research; foreign sales and currency; personal finances, the stock market, funds and other investments; and economic indicators, inflation, national budgets; and so on.

Economics is far from an exact science, and much of what you may need to know about it will be generalities and procedures rather than exact equations or models. Even though "unscientific" it still will have considerable value, and the skillful and common sense use of economics can constantly improve most chemical engineers' capabilities. Unfortunately, this lack of scientific basis, its general simplicity, and the frequent inexactness of the economic techniques makes some engineers or students feel that it has little value and is too easy and general to be interesting. This is largely unavoidable, so it is urged that if this reaction is encountered, try to rise above it, and attempt to master the subject as well as possible. There is no question that it can be useful in your career and in your personal life.

FREQUENTLY USED ECONOMIC STUDIES

Economics is as much a career tool for chemical engineers as any of the unit operations or other engineering subjects. As with any single facet of an education, most engineers will only make detailed economic studies periodically, and for extensive use considerable additional learning of company methods and new subjects will be required. However, early and throughout the career of most engineers a basic knowledge of the major economic procedures used in financial decisions can provide a much better ability to solve problems, as well as provide a "feel" for the employer's business, and an ability and confidence to better conduct, and then understand the outcome of engineering assignments. Knowledgeably employing economic principles throughout one's career will generally also increase the probability of engineering success and advancement.

Economics is a required subject in all accredited chemical engineering departments, indicative of the general feeling that economics is an integral part of an engineering education and that all engineers should have a "practical" viewpoint, and consider costs and general economics in their decisions and actions. It is also interesting that in most surveys of recent chemical engineering graduates or others concerning what additional courses should have been offered, or which they wished they had taken in their college careers, more economics is always stressed (Basta 1986, 1987; Hughson and Lipowitz 1983; Septenary Committee 1985). The chemical engineering curriculums are over crowded with high priority, new potential subjects, so this is difficult to respond to (*Compressed Air Magazine* 1986; Farrell 1985; Kreiger 1987; Mathis 1986), but it does indicate that a fair percentage of young engineers do find that economics is an important subject in their jobs. This has very much been the author's own experience, not only in his own industrial career, but with most economics courses taught to date, one or more graduating seniors have come back the next year and related how useful the economics course was in their first assignments, and the cudos they had received for their skill with the subject.

Examples of how one might use economics throughout a chemical engineering career are given in Table 1-1. It is seen that for most job categories, preliminary cost estimates, simple profitability analyses, budgets, a general understanding of their industry's activities, corporate operating statements, balance sheets and financial indicators, project management, and personal finances are the economic principles that most chemical engineers will need to know. It is, therefore, this basic information that will be covered in this text. Initial and primary emphasis will be on cost estimation, followed by techniques for making economic decisions and a review of the economics of the chemical industry.

It is usually quite expensive and time consuming to have either an engineering contractor or an in-house engineering department prepare preliminary cost estimates and economic analyses for a small project or a new idea, and consequently it is often not possible to obtain management approval and budgets too early or frequently for such work. Thus, until one is at the authorizing management level an engineer must do most of this estimating himself, if it is to be done at all. In many cases such estimates are very preliminary or for personal information and guidance only, so they do not need to be extremely accurate, but a knowledge of the details in the cost breakdown and factors in reasonably reliable economic analyses is much more useful than an off-the-cuff guess.

It is fairly obvious that medium to upper level management will frequently make economic decisions, and perhaps occasionally use the wide variety of economic analyses covered in advanced economic texts, but this need will be many years in the future for most engineers. The economic fundamentals such as the time value of money taught now will still be valid, but by then all of the financial calculations and procedures will be organized in computers for each company (most large companies are at this point now), and the specific analyses used will be somewhat different from the ones now in vogue. As with most aspects of one's career, there will be a need to constantly learn new and changing technologies, and economics will not be an exception. Consequently, it is felt that to be most useful this book should concentrate on the basic principals of the more widely used economic concepts and knowledge frequently encountered in a working engineer's career, and provide information and techniques that can be used during his advancement period. An attempt will be made to provide such information in the following chapters.

BASIC ECONOMIC SUBJECTS

Priorities

Since economics is such a broad general subject with many specialties and quite divergent detailed areas of interest, even the experts usually do not attempt to master the entire subject. The same general limitations usually apply to engineers, for even within their area of interest there are a rather large array of specialties and fringe economic fields. This text will not attempt to provide the detail that a specialist or highly experienced engineer may need to know, but rather to cover only the more basic components of a wide range of economic subjects that are frequently encountered in engineering assignments. Similarly it is not intended to present a compendium of all of the economic ideas or information that have been presented on each subject, but rather to focus primarily on the most commonly used methods, procedures, and information that are somewhat of a current concensus of opinion.

In this manner it is hoped that the working engineer will be provided with a broad basic economic background which will allow him to better perform and enjoy his work, and assist in his career advancement. Economic knowledge and understanding are highly prized by industry, particularly if they cover a wide range of subjects, such as project evaluation, a knowledge of current industry

Table 1-1
Examples of the Use of Chemical Engineering Economics.*

1. Production or Plant Technical Service
   a. Plant equipment continuously needs repair, replacement, or modernization. The responsible engineer should know roughly what the comparative performance, costs, and payout periods are, even if there is a plant engineering group to do that type of analysis, or later firm price quotations will be obtained.
   b. Plant changes, such as initiated by the ever increasing costs of energy and environmental requirements, necessitates that many energy saving, pollution, and hazardous waste control possibilities must be considered. For the responsible engineer to make intelligent recommendations, he should personally conduct design and cost estimates, pay-back, and economic calculations on the alternatives before making even preliminary recommendations.
   c. Competitors' processing methods, as well as R & D, sales, or management suggested changes must be continuously examined. Supervisors or other groups may be responsible, but the staff engineer can help a great deal by making preliminary cost estimates and economic analyses of the changes to guide his own thinking (and hopefully the group's position).
   d. All engineers should have a feel for their company's business, products, and economics. This requires occasional economic reading, and a basic understanding of company annual reports and general industry economic news.
2. Research and Development
   a. In the process of being creative one thinks of many novel ideas. During the analytical phase of creative thinking many of the ideas will require a quick cost estimation and economic analysis to provide a better idea of their merit. Even though supervisors or others may be assigned to do this work, the chances of conceiving good ideas and having them accepted increases immensely if some economic screening can be done by the originator.
   b. While conducting R & D studies there are always many stumbling points, or alternative directions that may be taken in attempting to solve the problems. Often brief cost estimates and economic analyses will help in deciding which are the most promising directions to pursue.
   c. After an early or intermediate stage of an R & D program has been successful, new funding requests usually are required to continue the study. These requests can always benefit from having potential preliminary economic analyses. Later, in the final stages of a successful project the engineer may be part of a team assigned to provide a more definitive preliminary economic projection and analysis.
   d. In dealing with production, sales, or management personnel one can usually gain more respect, and be considered more practical and less "theoretical" by having a reasonable knowledge of the costs and economics of the projects under study, and general industry economics.
3. Sales
   a. A general knowledge of company costs, profits, and competition are very helpful for more effective salesmanship.
   b. Salesmen often recommend new products, improvements, or pricing ideas to their management. A cost and economic estimate for these ideas should be helpful in the proposal report.
   c. Salesmen sometimes perform market surveys. Again, a general economic knowledge of the industries and companies surveyed may be essential, and is always useful.
   d. Salesmen, as the other chemical engineering occupational categories, may move into management, where economic knowledge is a major part of the job.
4. Engineering
   a. Because of the extreme specialization of most engineering companies and many company engineering departments, cost estimating and economics may not be directly required in many engineering company or department jobs. However, other jobs will deal exclusively with cost estimating and economic analysis, and all will benefit from a good, fluent knowledge of the basic economic procedures. Engineering departments or companies usually have very well-developed in-house methods and data that must be used, but the basics are still applicable.
5. General
   a. All chemical engineers are assumed to know the rudiments of cost estimating, economic evaluation, and the economics of their industry. A high percentage will find this knowledge useful or necessary throughout their careers.
   b. All work situations are more or less competitive, and one means of maintaining the highest advancement potential with most jobs is to convince superiors of your knowledge and interest in management, business, and economics. Associated with this is the demonstration of ability, an interest in accepting responsibility, and ability to communicate. Many companies promote people whom they think can "manage," such as those with MBA (Master of Business Administration) degrees, or with perceived equivalent capabilities ahead of people with a better performance record. Basically, a confidence that you can learn managerial skills as you need them, and a knowledge of economics should make most chemical engineers equal or preferred candidates for advancement.

*(See Table 12-3 for general job classifications).

conditions, and so on. Hopefully the material in this book can provide this base, which will be appreciated by management, directly useful in engineering assignments, and later used as a foundation for further specialization if desired.

The text starts with the basics of making your own cost estimates, first with single pieces of equipment, then with plants, and finally in estimating manufacturing costs. It next uses this information, along with consideration of the time value of money to evaluate the profitability of the equipment, processes, or plants that you have just estimated. These are the basic components of engineering economics. However, the following chapters present somewhat periphery economic information that is just as useful and needed for a complete knowledge and feel for the subject. This starts with a fairly detailed review of the present status of the chemical industry, and the basics of accounting, budgets, and corporate reports. It is followed by the economics of project management, and finally, a brief discussion is given on the more personal aspects of economics—investing and job hunting.

These chapters have been presented in a general sequence of their importance and dependence upon preceding information. Thus, with limited time available, the first six chapters may be considered as the most basic and important. The following chapters examine equally useful economic information, but progress further and further into varied subdivisions of the main or basic engineering economic requirements. Most engineers will profitably use all of this material in their careers, but the first six chapters are absolutely essential, and the others perhaps more optional.

Problems

For each chapter a brief series of questions and problems on the information covered are included in Appendix 4, followed by the answers and often a brief review of how the problem was approached. Hopefully these questions will cover some of the more important information, and provide practice in solving assignments that might be encountered in common engineering situations. The problems were not inserted in the text in order to reduce potential distraction to the reader, but in case there is some uncertainty while reading the text or the calculation methods it may be advisable to turn to Appendix 4 and work through the relevant problems. This practice may also be useful to provide some fluency in the various procedures.

It should be cautioned in considering the problems that in most practical economic situations additional calculations, heat and material balances, and almost always some (or considerable) conversion of units are required to utilize your basic design data in a form that can be applied to the tables and charts or calculation methods. Conversion is one of the constant requirements of engineering problems, and in order to assist in this regard some of the more common conversion factors encountered in these calculations are listed in Appendix 5.

Appendixes

The first three appendixes provide cost estimating charts for chemical engineering equipment, complete processing plants, and manufacturing cost estimates, respectively. Appendix 4 gives questions and answers, while Appendix 5 lists some of the most commonly used chemical engineering conversion factors. The equipment estimating charts of Appendix 1 are intended to allow simple equipment or plant cost estimates of a rough but ballpark accuracy which can be quickly performed when vendor quotations are not available. The complete plant estimating charts provide an estimate of what at least one or a small number of actual plants have cost, thus again allowing a rough estimate of these more complex facilities to produce specific industrial chemicals. The complete plant manufacturing cost data are more limited, but still cover a number of the more common chemicals. In total these charts provide a fairly broad compendium and average of the cost estimating literature in one easy-to-use location.

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2

EQUIPMENT COST ESTIMATING

As indicated in Chapter 1, one of the basic economic skills that chemical engineers often need is the ability to make cost estimates. The foundation of most estimates is the cost of individual pieces of equipment, and developing that estimating skill is the purpose of this chapter. All chemical engineers should know how to do this, as it is fundamental to considering costs and economics for engineering decisions and recommendations, as well as being "practical" and "cost conscience" in one's work. On a direct use basis, equipment cost estimates are frequently required in many types of work, and are the first step in more detailed plant cost estimates.

MANUFACTURERS' QUOTATIONS

When an engineer has the time and authorization to obtain actual price quotations from several vendors on process equipment his cost estimates will be fairly accurate for the direct purchased price over a reasonable time period. He will still have to estimate shipping and installation charges, but again, with adequate time and funds, price quotations and existing company records on previous jobs can lead to accurate estimates for the installed equipment. This is the preferable method of making all cost estimates, but if there is not time or funds for such detail, or one's supervisor does not authorize the extensive outside contact that would be required, vendor quotations should be obtained on at least the major or most expensive equipment, if at all possible. Then, even if installation costs and the minor equipment must be estimated, the final results will still be fairly accurate and well documented.

Several methods may be used to obtain vendor quotations. For fairly widely used equipment the local phone book yellow pages, or those from the nearest large city, will generally supply the names of agents for different equipment manufacturers, and they can be called directly. For less common equipment, or more extensive lists of vendors for all types of each piece of equipment, there are excellent directories readily available, such as the *Chemical Week* (1987), *Chemical Engineering* (1987) and *Chemical Processing* (1987) *Buyers

Guides*, the *Hydrocarbon Processing Catalog* (1987) and many more (*American Laboratory Buyer's Guide* 1987, etc.). These volumes are given free to all subscribers of their corresponding magazines because of their advertising content, and are very useful. Many of the technical or news magazines (some of them also free) also periodically publish lists of all manufacturers of selected equipment, along with notations of the equipment's major characteristics. Other technical journals periodically publish review articles discussing different equipment in detail, providing excellent information to use in deciding which types of equipment you should consider, and what the major design variables are.

When asking the manufacturer or sales agent for prices you generally will be speaking to a technical representative, who sometimes is a chemical engineer himself, and frequently is very knowledgeable and helpful in discussing design and equipment type alternatives. In these cases you end up with a great deal of technical information as well as the equipment prices you want, and the conversation will be both a pleasant and profitable one. Unfortunately, however, most inquiries do not go that well. The salesman will often want to know design details that you have not yet considered, and some in a trade jargon where you have no idea of what they want. Usually anything more than basic design parameters are unimportant for preliminary cost estimates, but some sales people will not give quotations without their special information. In this case a number of calls are required before you learn the correct language and have calculated a few more parameters in order to obtain an answer, and even then you may not be successful because the salesman may not feel that you are a bonafide potential customer, or the proper representative from your company. Thus, obtaining price estimates on equipment can be a lengthy and difficult process, or it can be quick and educational. It is difficult to know which it will be in advance, so patience and an open mind are required.

Professional cost estimators with engineering companies or company engineering departments make their estimates in this manner on essentially all jobs except those on the tightest budgets and with well-announced and acceptable lower accuracy ranges. For the normal preliminary cost estimate (that will hopefully be within 20–35% accuracy) professional estimators might only obtain one cost quotation on each major piece of equipment, and estimate the installed costs from their extensive records. For greater accuracy, however, they will obtain several price quotations on the equipment, actual costs or quotations on any other component possible, and then detail labor and materials, along with overhead, for all of the installation costs.

The cost to make such estimates is very high, and it takes considerable company and contractor labor and time. It is rare that an engineering company will make any cost estimate for less than $50,000 unless they are doing it as a fairly sure inducement of being granted a large construction contract. Generally the final cost estimates are taken from the detailed engineering design for the plant, and would cost from 1 to 5% of the total plant cost. Because of the high possibility for overrun, if a contractor is required to give a firm cost quotation on a new plant he will define the scope of work extremely tightly and still add a 10 to 20% contingency factor. With luck this could make the contractor a very good profit on a fixed cost job, but the risks are so great that many of the largest contractors will not even bid on a fixed cost construction project. This further illustrates the difficulty of making accurate cost estimates.

With the advent of the personal computer as a common engineering tool numerous software packages have been developed to assist with cost estimating. These vary from fairly simple programs such as "Price" from McGraw-Hill to elaborate ones such as "Questinate" from the Icarus Corp. Also, groups such as the Icarus Corp. will perform capital cost estimates on a contract basis. These programs basically work with cost versus size data, as will next be discussed, and probably have about the same accuracy as our estimating charts. They may be somewhat more current and extensive, although this is not certain. It is well to know of these software packages and services, but for most cost estimating work to be discussed in this text they are not necessary or too useful. For more extensive cost estimating requirements they may become much more valuable.

ESTIMATING CHARTS

The factors of high cost and lengthy time requirements to prepare cost estimates require that most estimates needed by working engineers must be made by themselves, and often even vendor quotations are not possible. To cover this situation a large number of estimating charts have been published in the literature over the years and are available for much less accurate, but more quickly prepared preliminary costs estimates. There have been a number of excellent compilations of such charts in books and articles in the past, and new estimating charts, tables, and equations are occasionally published. Unfortunately, however, most of them are based upon old data, and consequently may have further decreased in their accuracy. Inflation factors are always required to attempt to correct the charts to a current date, but because of the variability of changing technology and unequal price inflation for different equipment with time, this may not be a consistent correction. Charts are not available for every type of equipment one may need to estimate, but often there are charts for somewhat similar equipment, and at least a rough approximation may be obtained. Even with these limitations, equipment cost estimating charts serve a very useful purpose for most chemical engineers.

A number of charts of this type have been assembled in Appendix 1, with the individual equipment listed in alphabetical order. Most charts are a compilation of data from a number of sources, combined with some current price

quotations, so they may be considered to represent a somewhat conservative (although generally higher) median price. The range of actual current price quotations from all vendors with widely differing quality, designs, and specifications can often vary by +100%, −50% from these curves. However, the values still should be in the generally correct range, and represent an approximate average of good-to-high quality equipment. By the time a number of pieces of equipment have been estimated and totaled for a complete design package, the overall estimated accuracy should be somewhat improved.

Size Factoring Exponents

A typical equipment cost curve from the Appendix is presented in Figure 2-1 for a centrifugal compressor. Note that most cost versus size curves are plotted on log–log paper, and that the data are depicted as a straight line. This is the most general situation for much of the cost data, and the slope of this line becomes an independent estimating exponent that allows the cost of one size of equipment (which you may know) to predict the cost of another size by the relationship

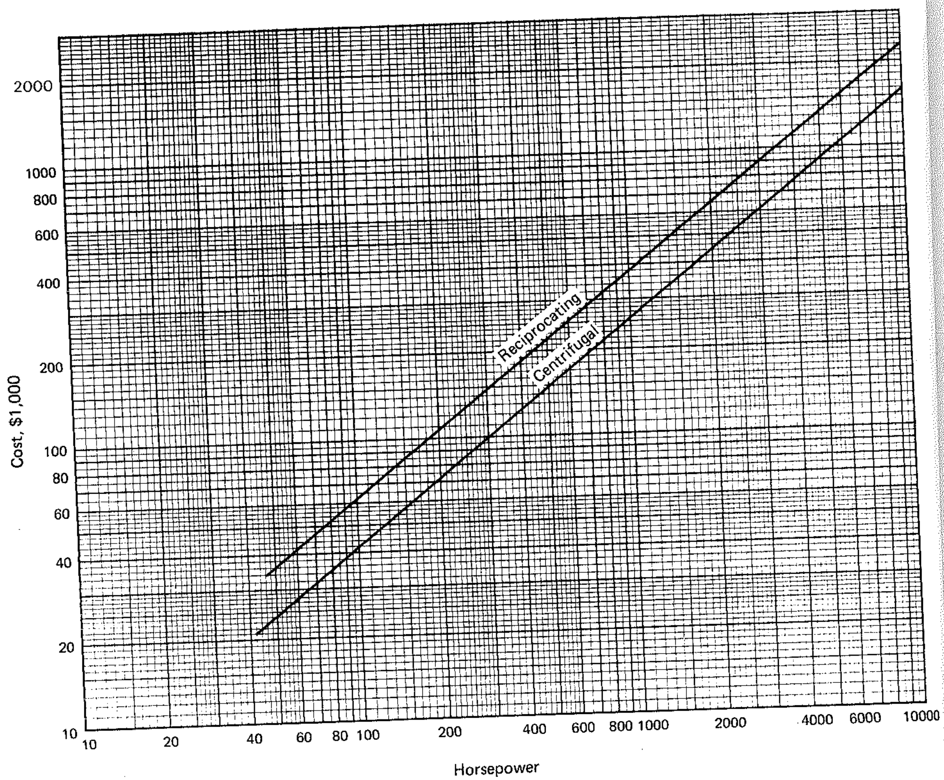
$$\begin{aligned}&\text{cost of second size equipment}\\&\quad= \text{known cost of first size}\left(\frac{\text{size of second}}{\text{size of first}}\right)^{\text{exponent}}\end{aligned}$$

These exponents (the slope of the cost versus size lines) are given under each chart, and in this example is 0.80. Thus, if a 200-HP reciprocating compressor with a motor drive is known to cost $106,000, a 1,000-HP unit should cost

$$\$106{,}000\left(\frac{1000}{200}\right)^{0.80} = \$380{,}000$$

With some log–log graphs the cost data plot as a curve, and if this is the case the slope is constantly changing, and the best that can be realized with sizing exponents is a series of slopes (exponents) that approximate the curve for a short segment. Centrifugal pumps present such a problem, so often three or more exponents are listed for short size ranges. If the cost curve is best represented by a semilog graph or regular coordinates (such as centrifuges), then a sizing exponent has little meaning.

With all of the cost curves there are obviously more than one variable that affect the cost. Because of this some authors have chosen one parameter, such as cubic feet of gas per minute for compressors, while others have chosen another, such as horse power, to act as the primary variable. In general in this



Size exponent 0.80	Installation factor: 1.30-87, avg. 1.49	Factors:
Equation:		Turbine drive 1.13
(Isothermal compression)		Gas engine 1.41
HP = $0.0044 P_1 Q_1 \ln P_2/P_1$	Module factor: 2.15-3.1, avg. 2.6	Pressure $\left(\frac{P}{1{,}000}\right)^{0.18}$
P_1 = inlet pressure, psi		Stainless steel 2.5
P_2 = outlet pressure, psi		Nickle alloy 5.0
Q_1 = inlet flow rate, cfm	CE index 320	

a. Average of Guthrie (1974); Hall et al. (1982); Happel and Jordan (1975); Peters and Timmerhaus (1980); Pikulik and Diaz (1977)

Figure 2-1. Compressors, high capacity and/or pressure[a].
(1,000 psi; electric motor drive; gear reducer; steel)

book, an attempt has been made to choose the more dominant variable, or a combination such as gallons per minute times the head (as pounds per square inch) for pumps. Whenever simple variables exist that can be plotted as a companion graphs (in Figure 2-1, with reciprocating or centrifugal types of compressors) this was done, or if multiplication factors could be used with the charts such as for different materials of construction or higher pressure, this was added as a brief table below the graph.

Inflation Cost Indexes

Another item of information that is needed for each graph is the *Chemical Engineering* Plant Cost Index (CE Index—see Figure 2-2) that existed at the time the graphs were constructed; 320 for early 1987. This is an inflation indicator made specifically for the chemical industry to correct the cost of each piece of equipment to the date of your estimate, by the relationship

$$\text{equipment cost at your date} = \text{chart cost} \times \frac{\text{CE Index, your date}}{\text{CE Index, chart } (=320)}$$

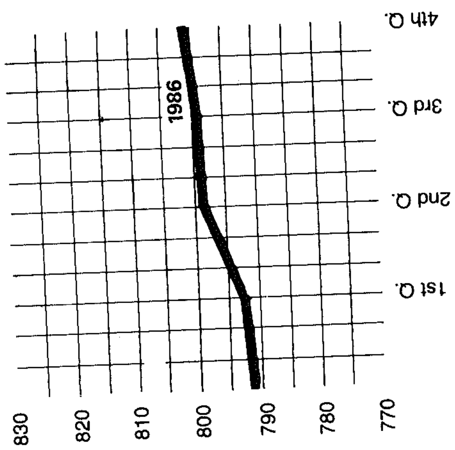
For example, the chart indicates a pump to cost $1,000 at the time when the CE Index was 320, but it is 345 when you make your estimate. You would show the pump as costing

$$\$1{,}000 \times \frac{345}{320} = \$1{,}078, \text{ or } \$1{,}100 \text{ based on the probable accuracy}$$

There are a fairly wide variety of inflation cost indicators that could be used to provide a measure of how the costs of labor, material, supplies, and equipment increase each year. Any one of the factors could be used to update the equipment cost charts, but the oldest and perhaps the best known of these indicators for engineers is the Marshall and Swift Equipment (M & S) Cost Index (Figure 2-2 and Table 2-2). Many chemical engineers prefer to use it, but the one specifically designed for chemical plants is the *Chemical Engineering* Plant Cost Index, called the CE Index. Both are listed each month, along with a 10-year notation of past yearly indexes, in the magazine *Chemical Engineering*, as shown in Figure 2-2. Added to this page are CE Index values back to 1956 (Table 2-1). The CE Index is composed of four components, weighted as follows: equipment, machinery, and supports, 61%; erection and installation labor, 22%; buildings, material, and labor, 7%; and engineering and supervision, 10%. A survey is taken each month of selected manufacturers and contractors in the industry, and the price increases averaged and tabulated to form the index. The yearly figure is established as the average value for that year.

It would be expected that technological improvement, competition, the price of raw materials, labor contracts, and so on would require each manufacturer, product, and cost component to have quite distinct rates of cost escalation, but for the entire industry and larger assemblages of equipment the index should provide a reasonable means of expressing the average escalation of costs.

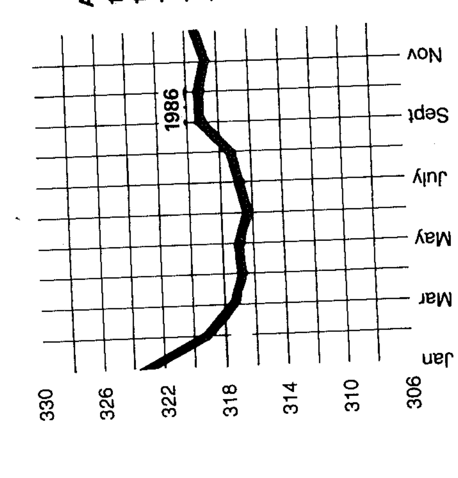
The curves of Figure 2-3 compare the Engineering News-Record (ENR) Construction Cost Inflation Index with the M & S and CE Plant Indexes, and



Annual index
1976 = 472.1
1977 = 505.4
1978 = 545.3
1979 = 599.4
1980 = 659.6
1981 = 721.3
1982 = 745.6
1983 = 760.8
1984 = 780.4
1985 = 789.6
1986 = 797.6

M&S equipment cost index

(1926 = 100)	4th Q. 1987	3rd Q. 1987	2nd Q. 1987
	827.0	**814.8**	**808.8**
Process industries, average	843.6	831.3	825.1
Cement	844.1	832.5	827.8
Chemical	832.5	820.4	813.9
Clay products	831.9	820.5	814.8
Glass	781.9	768.9	761.7
Paint	842.1	829.1	821.9
Paper	795.3	784.3	777.4
Petroleum products	879.1	866.0	861.2
Rubber	900.1	886.6	880.6
Related industries,			
Electrical power	792.4	773.0	763.2
Mining, milling	844.6	836.8	834.1
Refrigerating	978.4	963.8	955.6
Steam power	825.6	810.6	803.7



Annual index
1976 = 192.1†
1977 = 204.1†
1978 = 218.8†
1979 = 238.7†
1980 = 261.2†
1981 = 297.0†
1982 = 314.0*
1983 = 316.9*
1984 = 322.7*
1985 = 325.3*
1986 = 318.4*

CE plant cost index

(1957-59 = 100)	Dec. '87 Prelim	Nov. '87 Final	Oct. '87 Final	Nov '86 Final
	332.8	**330.7**	**329.8**	**318.7**
Equipment, machinery, supports	357.2	353.8	352.2	335.6
Construction labor	264.9	265.3	265.6	264.9
Buildings	316.1	315.3	314.2	304.9
Engineering & supervision	344.9	345.0	345.1	343.5
Fabricated equipment	336.1	333.1	332.3	312.0
Process machinery	337.9	337.6	337.0	329.2
Pipe, valves & fittings	412.5	405.4	401.1	373.6
Process instruments	341.5	336.7	333.4	324.5
Pumps & compressors	435.2	432.4	433.0	424.5
Electrical equipment	261.2	260.2	259.4	251.7
Structural supports & misc	355.8	353.5	352.2	343.4

*Revised; productivity factor = 1.75.
†Unrevised; productivity factor = 2.50

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Table 2-1.
Trend of Plant Costs Since 1956 (Base period: 1957–1959 = 100).

	1956	*1957*	*1958*	*1959*	*1960*	*1961*	*1962*	*1963*	*1964*
Chemical Engineering Plant Cost Index	93.9	98.5	99.7	101.8	102.0	101.5	102.0	102.4	103.3
Equipment, machinery and supports	92.7	98.5	99.6	101.9	101.7	100.2	100.6	100.5	101.2
Construction labor	95.8	98.6	100.0	101.4	103.7	105.1	105.6	107.2	108.5
Buildings	98.0	99.1	99.5	101.4	101.5	100.8	101.4	102.1	103.3
Engineering and manpower	94.2	98.2	99.3	102.5	101.3	101.7	102.6	103.4	104.2

Year *1965*	*1966*	*1967*	*1968*	*1969*	*1970*	*1971*	*1972*	*1973*	*1974*	*1975*	*1976*	*1977*
104.2	107.2	109.7	113.6	119.0	125.7	132.3	137.2	144.1	165.4	182.4	192.1	204.1
102.1	105.3	107.7	111.5	116.6	123.8	130.4	135.4	141.9	171.2	194.7	205.8	220.9
109.5	112.5	115.8	120.9	128.3	137.4	146.2	152.2	157.9	163.3	168.6	174.2	178.2
104.5	107.9	110.3	115.7	122.5	127.2	135.5	142.0	150.6	165.8	177.0	187.3	199.1
105.6	106.9	107.9	108.6	110.9	110.6	111.4	111.9	122.8	134.4	141.8	150.8	162.1

Source: Kohn 1978.

Trend of Equipment Costs Since 1956 (History of the Equipment Component and Major Subcomponents of CE Plant Cost Index. Base period: 1957–1959 = 100).

	1956	*1957*	*1958*	*1959*	*1960*	*1961*	*1962*	*1963*	*1964*
Equipment, machinery and supports	92.7	98.5	99.6	101.9	101.7	100.2	100.6	100.5	101.2
Fabricated equipment	92.5	99.5	99.6	100.9	101.2	100.1	101.0	101.7	102.7
Process machinery	92.2	98.1	100.1	101.8	101.8	101.1	101.9	102.0	102.5
Pipe, valves and fittings	94.8	97.9	98.8	103.3	104.1	101.1	100.6	100.7	101.6
Process instruments and controls	91.2	96.7	100.4	102.9	105.4	105.9	105.9	105.7	105.8
Pumps and compressors	90.0	97.5	100.0	102.5	101.7	100.8	101.1	100.1	101.0
Electrical equipment and materials	93.5	98.4	100.6	101.0	95.7	92.3	89.4	87.6	85.5
Structural supports and miscellaneous	92.5	98.0	100.4	101.6	101.9	99.8	99.2	97.3	98.3

Year *1965*	*1966*	*1967*	*1968*	*1969*	*1970*	*1971*	*1972*	*1973*	*1974*	*1975*	*1976*	*1977*
102.1	105.3	107.7	111.5	116.6	123.8	130.4	135.4	141.9	171.2	194.7	205.8	220.9
103.4	104.8	106.2	109.9	115.1	122.7	130.3	136.2	142.5	170.1	192.2	200.8	216.6
103.6	106.1	108.7	112.1	116.8	122.9	127.1	132.1	137.8	160.0	184.7	197.5	211.6
103.0	109.6	113.0	117.4	123.1	132.0	137.3	142.9	151.5	192.3	217.0	232.5	247.7
106.5	110.0	115.2	120.9	126.1	132.1	139.9	143.8	147.1	164.7	181.4	193.1	203.3
103.4	107.7	111.3	115.2	119.6	125.6	133.2	135.9	139.8	175.7	208.3	220.9	240.2
84.1	86.4	90.1	91.4	92.8	99.8	98.7	99.1	104.2	126.4	142.1	148.9	159.0
98.8	101.0	102.1	105.7	112.6	117.9	126.6	133.6	140.9	171.6	198.6	209.7	226.0

Source: Kohn 1978. Excerpted by special permission from *Chemical Engineering*, May 8, 1978. Copyright © 1978, by McGraw-Hill, Inc., New York.

Table 2-2.
Marshall & Swift Annual Indexes of Comparative Equipment Costs Since 1956 (Base Period: 1926 = 100).

	1956	1957	1958	1959	1960	1961	1962	1963	1964
Equipment Cost Index	208.8	225.1	229.2	234.5	237.7	237.2	238.5	239.2	231.8
Process industries									
Cement	199.4	216.4	222.8	228.7	232.1	231.1	231.8	232.5	235.9
Chemical	209.1	226.5	232.3	236.5	239.2	237.7	238.0	238.7	241.1
Clay products	193.8	210.2	216.8	222.2	225.7	224.6	225.5	225.8	229.2
Glass	197.5	213.8	219.3	223.2	225.3	224.4	224.7	225.4	227.6
Paint	201.2	217.6	223.2	226.9	229.5	230.0	231.5	232.1	235.0
Paper	210.5	218.2	223.8	227.8	229.9	229.0	229.3	229.9	232.3
Petroleum Products	205.4	222.2	228.0	231.8	234.3	235.0	238.2	238.8	241.8
Rubber	207.9	224.9	230.8	234.6	237.3	237.9	239.2	240.0	243.0
Related Industries									
Electrical power	211.0	229.2	235.2	239.0	241.0	236.3	235.6	234.7	236.8
Mining, milling	210.4	227.9	233.8	237.1	240.6	239.2	239.5	240.1	242.6
Refrigerating	234.3	254.2	260.8	265.1	268.2	268.8	270.4	271.2	274.6
Steam power	197.0	213.0	218.6	222.9	224.7	225.3	226.6	227.2	230.1

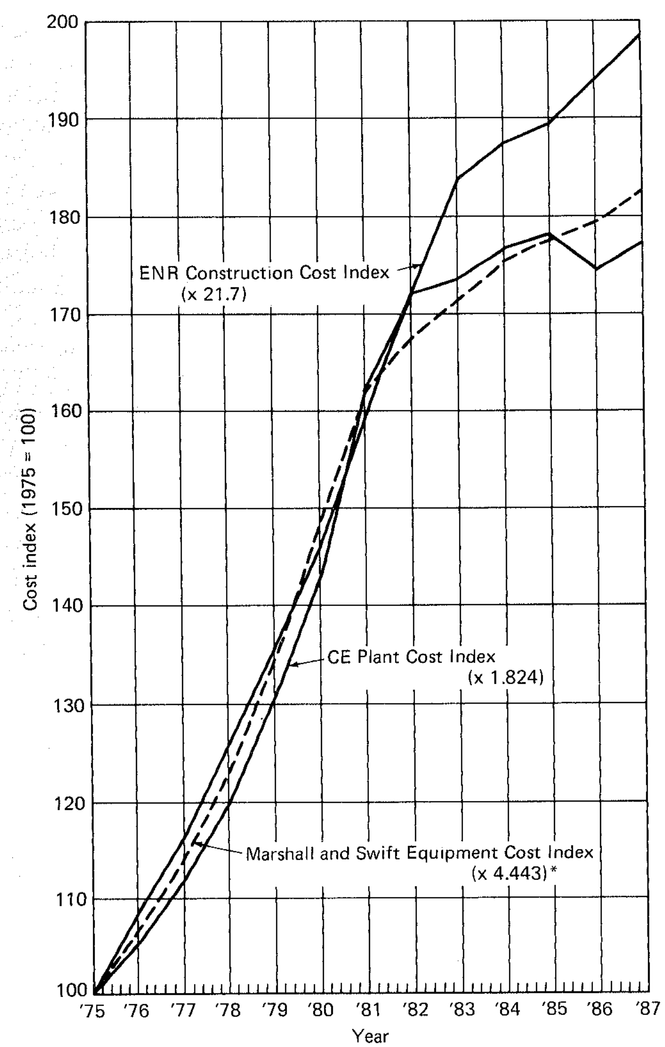
Year	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	197[illegible]
Equipment Cost Index	244.9	252.5	262.9	273.1	285.0	303.3	321.3	332.0	344.1	398.4	444.3	472.1	505
Process industries													
Cement	239.3	249.6	258.1	268.3	280.1	298.3	317.3	328.5	340.1	398.1	454.3	482.2	518
Chemical	243.8	246.1	261.8	271.6	282.8	300.8	319.1	329.7	341.0	400.5	447.6	473.2	507
Clay products	232.6	239.0	250.7	260.7	272.2	289.9	308.4	319.3	330.3	384.5	437.2	466.9	504
Glass	230.1	240.6	271.1	256.3	266.9	283.9	301.2	311.3	322.0	375.4	425.3	451.3	483
Paint	238.1	243.9	255.7	267.4	280.3	300.1	320.7	333.3	345.9	406.0	455.0	481.2	515
Paper	234.8	247.5	252.1	261.6	272.4	289.7	307.5	317.7	328.4	381.7	430.1	457.6	491
Petroleum Products	244.9	253.9	263.4	275.2	288.4	308.8	330.6	343.0	356.0	419.3	470.9	497.7	535
Rubber	236.2	251.2	264.7	276.5	289.9	310.3	331.6	344.7	357.8	415.2	468.5	497.3	532
Related Industries													
Electrical power	239.4	246.5	257.3	264.9	274.8	290.3	307.4	316.4	327.2	391.7	438.5	465.1	494
Mining, milling	245.3	253.0	263.5	273.2	284.5	302.6	321.1	331.8	342.9	394.3	451.2	482.9	520
Refrigerating	278.2	287.1	299.1	312.5	327.5	350.6	374.7	389.5	404.6	472.4	528.1	558.4	595
Steam power	233.0	240.4	250.6	261.8	274.3	293.8	313.9	326.3	338.8	400.8	448.2	475.7	507

Source: Kohn 1978. Excerpted by special permission from *Chemical Engineering*, May 8, 1978. Copyright © 1978, McGraw-Hill, Inc., New York.

show that they do not exactly follow each other, nor maintain the same ratios. However, they are roughly comparable, and since the CE Index applies specifically to chemical plants, it shall be assumed to be more accurate and used as the reference for comparison in this text. The CE Index existing at the time the data in each chart were assembled was 320, corresponding approximately to April, 1987.

Installation Factor

An additional factor shown on many of the charts is an installation factor. In some cost estimates one will be considering only one piece of equipment, or a



Source: Matley and Hick (1988). Excerpted by special permission from *Chemical Engineering*, Apr. 11, 1988. Copyright © 1988, by McGraw-Hill, Inc., New York.
*To convert to actual index

Figure 2-3. Comparison of inflation indexes.

very small number of pieces, and it is desired to know not only the cost of the equipment itself, but also the total cost to purchase the equipment, have it shipped, received, installed, and ready to run. Obviously this adds a large number of additional factors, and no single installation number will be very accurate or authoritative for each particular case. However, a rather general, average figure can perhaps be quoted for a new installation in an existing plant that will give a rough, ballpark estimate, and these are listed below the charts whenever available. As an example, a rotary dryer installation factor is listed at 1.25–96, with the average 1.64. Thus, if the dryer cost is $50,000, the installed cost would usually vary from $63,000 to $98,000, with the average $82,000. This would include freight, crane service, foundations and supports, all labor, electrical, switch gear and controls, gas or oil piping connections, mounting (including the necessary extra material—rollers, bolts, motor couplings, chain drives, etc.), inlet and outlet chutes and hoods, painting, safety guards, and so on. It would not include the burner air compressor (if needed), the conveyor feed and discharge systems, dust collector, fan, ducting, and so on. In other words, this factor would only cover the actual mounting of the equipment itself, ready to run in an existing plant with all of the utilities and services nearby, but without any of its support or auxiliary equipment. The factor is mainly composed of labor, although there are always periphery equipment such as foundations, electrical switch gear, crane service, and so on required. These factors are not meant to be used for anything but single equipment estimates, and not complete plants. Their accuracy is a further step reduced from that of the equipment itself, but again should be in the correct general cost range for very preliminary estimates.

Module Factor

A similar factor to the installation cost is the "module factor" which is defined to include not only the installation cost of the equipment in question, but also the purchase and installation cost of all of the supporting equipment and connections. For the rotary dryers example, it now *would* include the feed and discharge conveyors, the dust collection equipment, the fan, ducting, and everything required to make the entire rotary dryer section of the plant operational. Its primary usefulness is in estimating costs when one major piece of equipment (alone) is to be installed as a new addition to an existing plant, and all of its periphery and support equipment must also be purchased and installed. The smaller "installation factor" is employed more frequently, since replacing or modernizing an existing piece of equipment only requires the installation of the new equipment alone, since all of the support equipment is already in place. Module factors are listed on the estimating charts when available, again with a range as given by various authors, and an average value.

Other additions may be made to the equipment cost estimating charts, such as when an equation has been proposed that describes the cost–size relationship, or pertains to the estimate, it is also given under the chart. The equation may not exactly follow the plotted line. Alternate material, pressure, size, and other variable factors are also included when available.

Estimating Accuracy

The rather poor accuracy of estimating charts has previously been discussed, but it must be remembered on the positive side that just as in purchasing any article of food or clothing, there will be price variations between different manufacturers of equipment that cover the range noted above based upon different features, quality, unusual competition, regional increases, and each manufacturer's costs and profit. Because of this, each chart should actually show a broad band, rather than a line, to indicate the true anticipated price differences. However, a single value is more useful to the estimator, and assuming that the charts try to show an average or typical cost, the user must be even more cautious in stating the accuracy obtainable in his final analysis. As noted earlier, actual vendor price quotations should be obtained whenever possible, but for preliminary estimates, and when actual prices can not be gathered, these charts can still provide excellent information when properly used. In practice this is a very useful function, for in much of an engineer's work approximate estimates are all that is needed.

It is recommended that any engineer interested in economic analysis or ultimate advancement into management keep a notebook of new cost estimating articles encountered in professional reading, and actual price quotations when obtained. In this manner cost estimates can become progressively more accurate, and one will constantly maintain a good general knowledge and feel for costs.

ESTIMATING EXAMPLE

With most of the cost estimating that an engineer may wish to do the problem that actually needs to be answered is somewhat different, and considerably more complex than just looking at the estimating charts. One will often have to go through at least a rough design procedure to establish the size parameter, sometimes convert units from one system to another, and in many cases make an estimate based upon judgment (or a guess) on some of the factors involved. All of this tends to be discouraging as the engineer thinks of the further inaccuracy or uncertainty involved, especially if there is not time or information to adequately study the problem and feel confident of the judgments. However, the point to remember in these very preliminary estimates is that they generally are for guidance and direction only, and that high accuracy is neither possible nor necessary. The engineer needs to be in the generally correct range with the answer, and if reasonable care is taken this will usually be the case. The results will be both useful and quite educational throughout the various steps of the study. One will have learned more about the equipment, its design, and the costs involved. And if the results look promising and management concurs, there will be adequate time later to do the detailed engineering, cost estimating, and prepare the final proposal much more accurately.

An example of a problem that an engineer might encounter in a production department where energy costs are high is as follows:

PROBLEM. You are a junior production engineer in a Green River, Wyoming natural soda ash plant and have been instructed to search for ways to reduce energy costs. The plant produces 1,000,000 t/yr Na_2CO_3, and now consumes 4.0 MM Btu (as steam)/ton Na_2CO_3 in the monohydrate, triple effect evaporator step. It has a 2.4/1 lb water evaporated/lb steam efficiency. You have heard that one of your competitors now uses only 0.8 MM Btu/ton Na_2CO_3 for this step after converting to vapor recompression. Would this be practical for your company? The CE Index is now at 400.

ANSWER. First find an approximate cost for the necessary new vapor recompressors. This requires a rough estimate of the cfm of steam to be "recompressed," which would be (assuming all evaporated water compressed twofold)

$$1{,}000{,}000\ \text{t/yr}\ Na_2CO_3 \times \frac{70\%\ H_2O\ \text{in sat. soln.}}{30\%\ \text{solids}}$$

$$\times \frac{2{,}000\ \text{lb/ton}}{365\ \text{d/yr} \times 0.95\ \text{on stream efficiency} \times 24\ \text{hr/d} \times 60\ \text{min/hr}}$$

$$\times \frac{359\ \text{cf/lb mole}}{18\ \text{lb/lb mole}} \times \frac{14.7\ \text{psa std. pres.}}{29.4\ \text{psa final pres.}} \times \frac{672°\text{R actual temp.}}{460°\text{R std. temp.}}$$

$$= 1.36 \cdot 10^5\ \text{cfm}$$

Using the horsepower equation, HP $= 1.36 \cdot 10^5 \cdot 4.4 \cdot 10^{-3} \times 14.7 \cdot \ln 2 = 4710$ HP (see Figure 2-1). However, it would be easiest to use a separate compressor on each of the three evaporator effects, making the vapor flow from each effect $3.5 \cdot 10^4$ cfm. Using the horsepower equation, HP $= 3.5 \cdot 10^4 \cdot 4.4 \cdot 10^{-3} \times 14.7 \cdot \ln 2 = 1570$ HP

From Figure 2-1 this would indicate a cost of about $0.36 million per centrifugal unit and $0.41 with a turbine drive. When installed (1.49 factor) this would be $0.41 × 1.49 × 400/320 = 0.76 MM for each unit, or $2.3 MM for the total cost of the three compressors. This estimate assumes installing the compressors to a well-prepared existing plant with all of the support equipment in place. However, this is a case where a totally new set of equipment (the compressors and their support equipment) is to be installed, so the module factor would be more appropriate for the complete installation. Also, since rather extensive new steam lines and controls will be required, perhaps the higher end of the module factor range should be used. On this basis the three new compressors might cost $0.41 million × 3 × 3.1 × 400/320 = 4.77 million. If constructed of stainless steel the cost would be $11.93 MM.

The potential profitability, assuming the competitor's steam consumption and a cost of $4/MM Btu steam in the existing coal fired boilers would then be 1 MM t/yr × (4.0 − 0.8) MM Btu/ton savings × $4/MM Btu = $12.8 MM savings for a $11.93 MM investment, or 11.93 × 12/12.8 = 11 month payout for the capital investment.

Obviously the situation will be much more complex than these simple calculations, and in reality when all factors are considered, such as the plant's steam-power balance, the downtime for the change over, and other costs that may be required or desirable, the savings may be much less. Later cost estimates based upon complete heat and material balances, equipment designs, and the cost of lost production for the change could be quite different. However, it would appear conclusively from this very quick preliminary economic analysis that the potential for considerable savings exists with such a change, and that the project should be highly recommended for further study.

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3

PLANT COST ESTIMATES

Once individual equipment costs are known from either manufacturers' price quotations or estimating charts as discussed in the previous chapter, they can be utilized to form preliminary total plant cost estimates. A suggested sequence for obtaining such estimates is as follows:

1. Prepare a flow sheet for the process or operation to be estimated, showing all of the major equipment and whatever of the basic auxiliary or general plant facilities that directly affect the process (i.e., boilers for steam; cooling towers; special electric requirements, unusual storage facilities, transportation equipment, etc.).
2. Prepare heat and material balances around each piece of equipment to the degree of accuracy and detail required to size the equipment.
3. Size all of the equipment with the precision required to obtain the parameters needed for manufacturers' cost quotations or to estimate costs from charts.
4. Analyze the process carefully to determine what "plant cost factors" should be used, and then prepare a detailed breakdown of the total plant cost package. This will be discussed in the following sections.

ACCURACY AND COSTS OF ESTIMATES

The American Association of Cost Engineers (AACE) has published a listing of different types of cost estimates, and the accuracy that such estimates theoretically have when estimated by professionals. It is shown in Table 3-1, along with perhaps a more realistic prediction of the accuracy range of a working engineer or contractor's estimates, and what management might actually count on for all estimates. A graph showing the possible spread in the accuracy of these estimates is shown in Figure 3-1. If it is assumed that what has just been done on equipment cost estimating, and will soon be done for plant costs is the AACE first item, order of magnitude or very preliminary estimates, then the AACE (professional) accuracy figure would appear to be totally beyond the confidence

Table 3-1
Characteristics and Possible Accuracy of Chemical Plant Capital Estimates

Type of Estimate (AACE Name)	Common Names	Usual Basis	Usually Prepared by	Basis for Estimate	Result; Possible Approval for	Possible Accuracy[b]: AACE 1974	Possible Accuracy[b]: More Realistic Estimate
Order of magnitude	Very preliminary estimate	Estimating charts; previous cost information	Individual engineer	Basic idea	Inexpensive study	40	40–100
Study	Detailed preliminary, or factored estimate	Some vendor quotations; estimating charts, etc.	Project group	Following initial study	Expensive study	25	30–50
Preliminary	Initial budget, scope estimate	Vendor quotes on all major equipment	Contractor[a] (professional estimating)	Following final study	Detailed design; market research	12	20–35
Definitive	Project control estimate	Detailed quotes, labor, material estimates; not complete drawings	Contractor[a]	Complete design drawings	Construct plant	6	10–15
Detailed	Firm estimate, contractor's estimate	Competitive vendor quotes, complete drawings and specifications	Contractor[a]	Most equipment purchased	Continue construction	3	5–10

[a] Or company engineering department.
[b] $\pm$% of total cost.

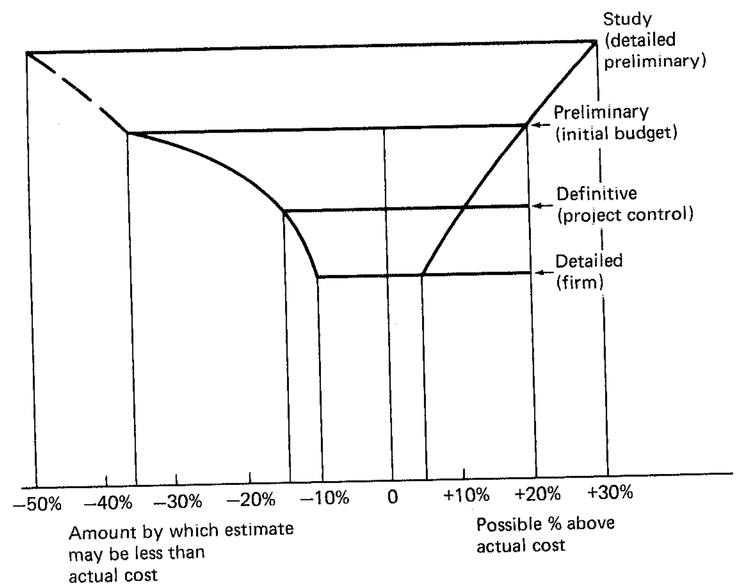


Figure 3-1. Most likely accuracy range of plant cost estimates.

factor of the average engineering estimate. As one looks down the table, this would also appear to be the case for each of their predicted accuracies.

The explanation of this claim for such high accuracy probably comes from several factors: first when these numbers were prepared (apparently in the 1960s) world economics were much more stable. Inflation and interest rates had been historically much lower and less subject to change, labor costs and work rules were simpler, more reliable, and stable, energy costs were much lower, safety rules and environmental permits and pressures were much less, and so on. All of these factors, along with equipment shortages, changed dramatically in the 1970s. Secondly, professional cost estimators may not take responsibility for changes such as the above, or other unforeseen "acts of governments, environmentalists, unions, or God," and claim that their accuracy is only based upon more normal changes and things they can control. Finally, it is extremely rare that a professional estimator would perform the first two types of studies. Their work is too expensive and slow for most companies to be able to afford their services for such early estimating purposes. Usually these estimates are left to the individual engineer or group, and they do not have the experience, exhaustive records, or time to make the estimates with such accuracy.

It is more likely that the initial very preliminary estimate has a range of up to 100% error, hopefully much better, but one cannot be sure that the error is not somewhere between 40 and 100%. This estimate will be made primarily with cost estimating charts or other plant estimating factors at early stages of a project evaluation by the engineer or group involved.

Table 3-2
Possible Cost of Chemical Plant Cost Estimates

Type of Estimate	*Possible Cost, $*
Very preliminary	$2,000–5,000
Detailed preliminary	10,000–50,0000
Initial budget	50,000–200,000
Definitive	150,000–700,000
Detailed	1–5%[a]

[a]Percent of total plant cost. The range expands or contracts for small (<$2 million) or large (>$100 million) plants.

The detailed preliminary estimate is usually performed when a project is partly completed, or finished with its development stage. As such the estimate will often be made by a group, or an individual with much more time. Manufacturer's (vendor's) or subcontractor cost quotations will be used whenever possible, but many factors, charts, and estimating methods will still be employed. The estimate's accuracy should be in the 30–50% error range.

The initial budget estimate is usually the first one performed by a contractor or the company's engineering department—professional estimators. For this estimate they will use single vendor quotations on major equipment, and some charts and factors, but theirs will be based upon much more recent experience and far more detailed estimating information, and should be more correct. A 20–35% accuracy might be expected.

The next two estimates come after all competitive equipment bids have been received, and should be quite close; 10–15% before all of the drawings, engineering, and purchasing are complete, and 5–10% afterward. Even with the professional estimator's know-how and experience, however, environmental problems, permit hang-ups, labor trouble, supply problems, unusual weather, and so on can make each of these professional estimates have many fold the anticipated error. Such problems have become more the rule than the exception.

The cost to prepare economic estimates is even harder to predict, but might be somewhat in the range shown in Table 3-2. These figures are based upon typical time and material spent in preparing the estimate, with the actual cost dependent upon the detail desired and the complexity of the plant. Even an engineer's own early estimates are expensive if rigorously accounted for, but many will be done on one's own time for his or her own knowledge, and only an occasional estimate may be authorized or requested by the company.

Cost Overruns

The previous section has dealt with the generalities of cost estimating accuracy. It is interesting to compare this with actual studies on the cost of very large projects. A mid-1987 study (Parkinson 1987) concluded that most large projects were underestimated, and that the principal cause of cost escalation for megaprojects ($500 million to $10 billion) resulted from conflicts between the plant owner and governmental agencies. It is very likely that a similar situation exists for most medium-to-large projects. For the 52 mega projects studied the average cost overrun was 82% from that estimated at the beginning of detailed engineering; only four projects were under their budgets. (An earlier study for projects under $500 million averaged 31% escalation). The average time slippage was 18%. The study found that the owners and contractors went into the projects expecting to experience problems with logistics, labor, equipment, and materials, but in reality the problems were with environmental regulations, opposition from institutions and the public, worker health safety rules, labor practices, and procurement controls.

The study recommended that if costs were to be controlled, project managers and estimators must:

1. Explore the regulations of all concerned governmental agencies with respect to each aspects of a project as an absolutely essential part of project definition. Environmental impact statements (or their equivalent) may not be demanded, but usually are, and should generally be completed in comprehensive detail.
2. Frequent meetings are necessary with the regulators, politicians, and community groups.
3. Laws and regulations must be seen as legitimate by project managers, even if they are privately considered distasteful or wasteful.
4. The government makes the rules; they can change them at anytime—and often do (such as late in the permit stage, or during construction suddenly demanding environmental impact or other studies).
5. A project may provoke changes in rules by generating problems or opposition that politicians will seek to resolve or benefit from.
6. Politicians consider getting elected and staying in office more important than the success of any project.
7. Do not expect bureaucrats anywhere to be more reasonable, understanding, flexible, or quick about their (your) business than they are locally.

PLANT COST ESTIMATING FACTORS

There are many components in a total chemical plant besides the processing equipment itself. The plant occupies space, so there must be land or a platform. Each piece of equipment must be supported by foundations or structural members, and interconnected by piping, conveyors, electrical lines and switch gear, instruments, and so on. There must be buildings for labs, offices,

warehouses, maintenance, and perhaps to enclose some or all of the plant. The so-called off-site facilities include boilers, generators, roads, utility service and transportation equipment. Finally, to build a plant requires engineering, construction labor, supervision and contractor's profit. Later there will need to be start-up expenses and working capital. A partial list of some of these plant components and costs are given in Table 3-3.

A large number of these items and many more are included in the cost of a totally new, or "grass roots" plant, while only some of them are required with simpler plant expansions or modernizations. The cost of each component can of course be estimated individually and in detail for the greatest accuracy, but it has been found that simplified estimating factors may also be used to provide a quick and reasonably reliable plant cost estimate.

Table 3-3
Partial List of Components in a Plant Cost Estimate

On-site Facilities	
Process equipment, such as:	
Towers, columns	Dryers
Heat exchangers	Pumps
Filters, centrifuges	Evaporators
Reactors	Tanks
Installation costs:	
Labor to install equipment	Insulation
Piping	Utilities
Electrical	Yard improvements
Instruments	(grade, pave, fence)
Foundations	Painting
Platforms	Railing, catwalks
Buildings	Safety equipment
Fireproofing	Inventory, supplies, catalyst
Product storage, handling	Environmental facilities
Construction expense:	
Engineering, design	Tools, temporary facilities
Model; computers, software	
Supervision, overhead	Changes, additions
Construction equipment	Licenses, fees
Accounting; scheduling; planning	Environmental, safety, etc. studies, reports
Company Costs:	
Design, drafting	Research and development
Engineering	Licensing fees
Owner's inspection	Feasibility studies
	Market research
Off-site Facilities	
(See Table 3-6)	
Start-up; Working Capital	

In its simplest form, the total purchased price of all of the equipment included in the plant can be added and then multiplied by a single factor to estimate the total plant cost. Single multipliers of the equipment cost, used directly and alone have been called "Lang" (1947) factors, and currently vary from about 3.4 to 5.2, depending upon whether the plant processes primarily solids or liquids, and its complexity. Other estimating methods may ultimately come down to such single numbers, but the potential accuracy is much better when using smaller individual factors for the major plant components, such as piping, electrical, and so on. This also allows a more detailed understanding of where the costs are in a total plant cost estimate so that they may hopefully be reduced, and much better controlled.

In considering individual plant component (piping, etc.) factors, different authors have used many different breakdowns and estimating methods. Chilton (1960) used equipment multiplying factors which changed according to the variables most important to that type of plant, such as hazardous, complex and new. Guthrie (1974) used "modules" which encompassed all of the plant cost components related to one major piece of equipment or portion of the plant. Most others, however, have used the simplified "solids" (a small multiplying factor) or "fluids" (a large factor) handling basis, with more or less of the total plant components included. Some have based these multipliers upon the *installed* cost of the basic major equipment, but since this requires an extra conversion calculation to change the purchased cost to installed costs, it is far simpler to use purchased cost directly, so this will be done in this book.

Table 3-4 lists some of the more important components of a plant, and the multiplying factors suggested to be used with the purchase price of all of the equipment. As might be expected, over the years there have been literally hundreds of different, but similar, charts of this type suggested, with an even greater number of multiplying factors (Holland et al. 1974; Klumpar and Slavsky 1985a; Ward 1986). This table represents a reasonable consensus among them, and an attempted simplification. Greater complexity to perhaps provide better accuracy would not appear to be warranted because of the chart's intrinsically limited accuracy (Cran 1981; Viola 1981). The major cost components will be discussed separately below:

Equipment Installation

Equipment installation costs have been mentioned in the previous chapter and are given in various of the equipment cost charts. It is seen that each piece of equipment requires quite a different multiple of its purchased price to pay for its installation. Generally the costs are fairly specific for, and based upon special characteristics of the equipment, with some influence of the local installation conditions for the equipment mounting, and the process, location, and size also helping to determine this cost. The installation cost consists of the freight from

Table 3-4
Plant Cost Estimating Factors

Component	*Plant Cost Factor, Fraction of Total Purchased Equipment Cost*	
Purchased equipment	1.00	
Piping	0.15–0.70	
Electrical	0.10–0.15	
Instrumentation	0.10–0.35	
Utilities	0.30–0.75	
Foundations	0.07–0.12	
Insulation	0.02–0.08	
Painting, fireproofing, safety	0.02–0.10	
Yard improvements	0.05–0.15	Optional Estimating
Environmental	0.10–0.30	Factors, Fraction
Buildings	0.05–1.00	of (Subtotal)
Land	0–0.10	Plant Costs
	Subtotal	1.96–4.80
Construction, engineering	0.30–0.75	0.10–0.40
Contractors fee	0.10–0.45	0.03–0.10
Contingency	0.15–0.80	0.05–0.20
Total	2.51–6.80	2.31–8.16
Usual limits for total factor		*Lang Factor*
Minimum (solids processing)	3.00	3.4
Average (mixed processing)	4.00	
Maximum (fluid processing)	5.50	5.2
	Additional Factor, % of Total Plant Cost	
Other capital requirements		
Off-site facilities	0–30	
Plant start-up	5–10	
Working capital	10–20, or 10–35% of mfg. cost	

the factory, the unloading and handling costs, foundations or supports, physically putting the equipment in place and securing it, and connecting it so that it will run (electric switch gear, etc.) and function (connect piping, etc.). A knowledge of this installation cost is necessary if one is considering single pieces of equipment only, or small process additions. Otherwise, however, for complete plant estimates, installation is *not* considered separately and is included indirectly in other items such as the electrical hookup and switch gear, instrumentation, piping or conveyor attachment, and so on, all of which are necessary for the equipment in a new plant to function. The installation cost ranges and averages listed on the equipment charts were taken from many authors, often with a somewhat different basis. The average installation cost for all of the equipment in the charts of Appendix 1 is 63%.

Instrumentation

This factor has traditionally been about 2–18% of the total purchased equipment cost for chemical plants, but rising labor charges and the rapidly increasing use of computer and more complex instrument control has significantly increased its value. It may be more typically 10–35% now, and will continue to increase in the future. Figure 3-2 shows generalized relationships of instrument cost versus equipment cost and the total plant cost. The values on this chart have been corrected to a CE Index of 320.

Piping

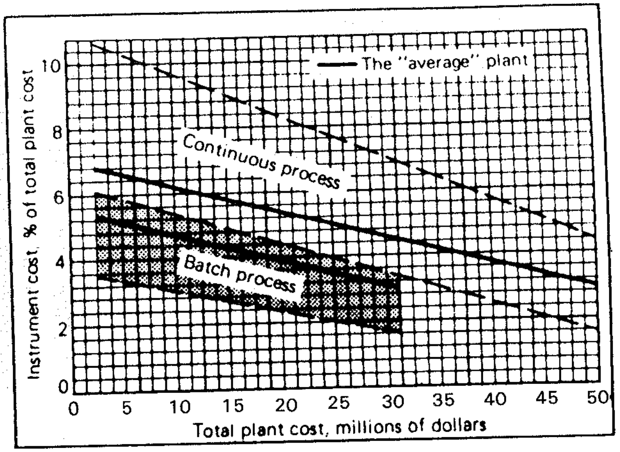
Process piping has always represented a major cost in chemical plants. Computer-assisted design and scale-size models are helping to optimize piping runs and plant design (Brooks 1988), but the need for energy saving (larger pipe sizes) and attempts to reduce maintenance with better corrosion and erosion resistant materials is tending to offset this gain and increase piping costs. It varies widely, but a 15–70% factor usually covers the range for most plants. Operations where there is considerable solids handling and conveying equipment would cause the piping to be at the lower end of the range, while plants handling only fluids with considerable recycling and heat exchange would have the highest factors. Some piping component costs (i.e., pipe, valves, etc.) are also given in Appendix 1, if specific pipe cost estimates are needed.

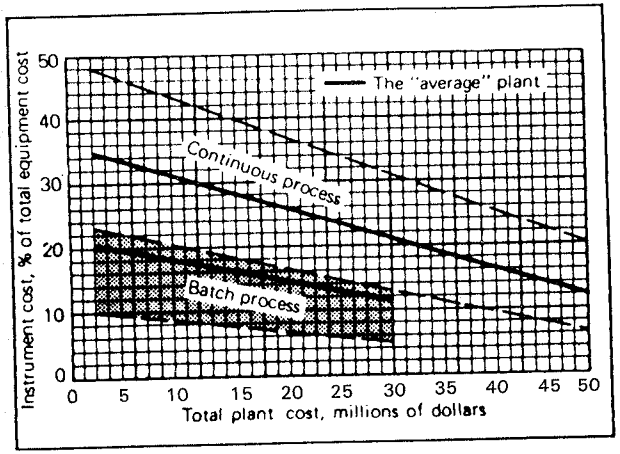
Insulation

As with piping sizes, the need to conserve energy by insulating much more thoroughly is a rapidly increasing factor for both old and new plants. The processing temperatures and heat duty determine the amount of insulation required, but equipment cost multiples of 2–8% may be fairly typical at present. Limited general and piping insulation costs are given in Appendix 1.

Electrical

Electrical hookups, conduits, wiring, switch gear, control panels, transformers, and distribution panels and vaults or centers are all part of the electrical cost factor. This has stayed constant at about 10–15% of the equipment cost. Some direct electrical installation costs are listed in Appendix 1.





Correction Factors to Reflect Instrumentation Philosophy

Features	*Factor, F**
Localized control	−0.20
Pneumatic instrumentation	0.00
Centralized control	0.00
Sample analysis performed in laboratory	0.00
General-purpose process area	0.00
Explosion-proof process area	+0.10
Graphic panel display	+0.10
Special alloys required for pipeline items	+0.15
Sample analysis by online analyzers	+0.20
Electronic instrumentation	+0.20
Limited-scope optimizer computer included	+0.25
All loops on computer control	+0.45

*Fraction change in total cost.
Source: Liptak 1970. Excerpted by special permission from *Chemical Engineering*, Sept. 1970. Copyright © 1970, by McGraw-Hill, Inc., New York.

Figure 3-2. Instrumentation costs.

Buildings

A certain number of buildings are required for any plant, such as control rooms; offices; shops; laboratory; employee lunch, change rooms, and lavatories; and so on. However, the really important cost of buildings arises when there are large product or raw material storage warehouses or silos required, and when some or all of the plant must be housed in buildings for reasons of weather, safety or environmental control. Although varying widely with the specific circumstances, the building factor may range from 5 to 100% of the initial equipment purchase price. Various direct building estimating costs are listed in Appendix 1.

Environmental Control

Over the past few years environmental control has become a major cost in most new plants. Many governmental jurisdictions are requiring essentially a zero discharge of any contaminant into the air, water, or land, and more will in the future. Other agencies are requiring a close monitoring and control of hazards and hazardous wastes. This usually means extensive pollution control and treating facilities, groundwater monitoring wells, leak detectors and soil sampling surveys, air pollution monitoring, controls and alarms, hazardous waste handling, storage and shipping facilities, and very costly to prepare permits. At present this might total from 10 to 30% of the basic plant equipment, but the figure will be steadily rising. Some direct wastewater treatment costs and air pollution control facilities are listed in Appendix 1.

Painting, Fire Protection, Safety, Miscellaneous

This is a small factor, but an important one to the appearance and safety of the plant. It might average 2–10% of the equipment cost, but with increasing insurance costs and public scrutiny it is increasing.

Yard Improvements

This item includes grading, drainage, roads, rail facilities, parking, fences, landscaping, concrete slabs and walkways, sumps, lighting, as well as all other required nonprocess components of the site or yard in the plant area. It might vary from 5 to 15% of the equipment cost. Some of the yard improvement costs often are considered as part of the off-site facilities.

Utilities

Utilities include the general services required to operate the plant, such as telephone, water, gas, other fuel, steam, compressed air, inert gas, sewage, and

bringing electricity into the plant. These items usually represent a major plant cost, as exemplified by the electrical hookup. It may only require bringing in one outside power supply, or hopefully two, or a standby emergency generator, and installing the necessary high voltage transformers and substations throughout the plant. However, it may also require, in addition, installing a power plant or a cogeneration power plant-steam generator facility. Obviously these items would be expensive, but they may save considerably on energy costs and emergency shutdowns, and many plants are now installing them. In a similar manner, large plants often have a complex water system, with drinking water, boiler makeup water, process water, cooling water, sanitary and landscaping water, fire water, and so on. Depending upon the water source (your own wells, river, sea, city, recycled, etc.), its scarcity, and discharge requirements, some or all of these (or more) may be needed.

The other utilities are usually not so complex, but they still can be quite involved and expensive. Costs may range from 30 to 75% of the purchased equipment cost for the total utility package. Some direct utility costs are listed in Appendix 1.

Land

This may not be involved in the plant costs, but if new land is to be purchased it may run from 3 to 10% of the equipment cost.

Construction and Engineering Expense, Contractor's Fee, Contingency

These contractor factors can be quite variable, and each may be in the range of 3 to 40% of the total plant cost (Mendel 1985). Construction and engineering expense is for the detailed engineering required for the plant design, drawings, permits, and managing and supervising construction. These charges are over and above the construction cost itemized in the previous factors. Engineering and supervision is generally charged on a cost plus expenses and overhead basis, so it is quite variable, but it may be about 30–75% of the purchased equipment cost, or 10–40% of the total plant cost. The contractor's profit (fee) is usually negotiable, but usually runs from 10 to 45% of the equipment cost, or 3 to 10% of the total plant cost. The contingency can be set by the owner at any number desired, but is almost always a necessity between 15 and 80% of the equipment cost, or 5 and 20% of the total plant costs to cover the many uncertainties of design, permits, purchasing, and construction. The variability with these items depends mainly on plant size, but also on its complexity and uniqueness. For a simple or standard plant or type that the owner and/or contractor has considerable experience with, the fees and costs can be on the low side of the ranges.

Total Multiplier

By the time all of the factors are added a total is reached which can be used to multiply the total purchased equipment cost, just like the Lang factor. In Table 3-4 the normal variation of these numbers is usually not the sum of each of the maximum and minimums in the columns above, but a more realistic somewhat tempered range as indicated by the "usual limits for total factor" table. For every cost estimate the final multiplier should be compared to these values to double check its reasonableness. Many estimates can have higher or lower values, but they are unusual, and if the estimate is beyond this range there should be a good reason for it.

Each of the total factors is large, showing that there is considerable capital required for a plant besides the basic equipment. In deciding upon these estimating factors in preparing a very preliminary plant cost estimate, an engineer may feel that he does not have the experience or knowledge to estimate the factors meaningfully because of the lack of data available, and that an overall total might be just as accurate. This may very well be the case, but for most estimates, even at an early stage, the itemization and best judgment on each factor will be of value in better understanding the total cost, and as guidance for later development or more detailed estimates. Furthermore, many times the engineer himself later, or a reviewer of the cost estimate may wish to know the value assigned to certain cost components, and suggest changes. With the detailed cost breakdown this can be easily done.

COMPLETE PLANT ESTIMATING CHARTS

Just as there are estimating charts for process equipment as a function of size, there are similar charts for the average cost of complete plants. Typical of this are the extensive charts of Guthrie (1970), *Chemical Engineering* (1974) and the nomographs of Kharbanda (1979). This data have been factored to a CE Index of 320, averaged, and new data added to produce the charts of Appendix 2. They are especially useful for providing a general idea of the cost of these complex, highly evolved basic commodity plants whenever the same product or a very similar operation is needed. Many of these plants are so complex that reasonable estimates can only be obtained from complete plant charts such as these, or by comparison with a similar plant where data are available. However, since most of the charts are fairly old or based upon only one reported plant, and because of rapidly changing technology, new design requirements (environmental controls, more costly fuel or energy, etc.), and the specific designs of each licensor, contractor, or site, many of these estimates have a fairly high potential error. Also, many of the original source charts covered a size range that is somewhat smaller than is now standard installation practice. For example, it would be very rare for any new ammonia plant to be built smaller than with

a 1,000 t/d capacity, and 1,500 t/d is a more frequently employed size. The original charts ended at the smaller of these capacities.

Cost per Ton of Product

Plant cost estimates are sometimes made in a very approximate manner by using a ratio of the capital cost of a new plant per annual ton of product. This type of estimate can be used for rough predictions when data are available on exactly designed and sized plants compared to the ratio data, but intrinsically this is an erroneous method. Plant costs usually vary as some exponent of size, so using a linear relationship such as this can be many fold in error. Some numbers of this type are listed in Table 3-5, but it is cautioned that they are at best only accurate for the listed plant size. They were taken from plant cost data of Appendix 2. A typical example of their variability is with polyvinyl chloride, where at 200,000 t/yr capacity the factor is \$370 per annual ton, while at 20,000 t/yr the cost is \$930 per ton.

Capital Ratio (Turnover Ratio)

A similar type of generalization is based upon the ratio of the yearly value of the product sold to the initial plant capital cost, and is called the capital or turnover ratio. This method may not be quite as inaccurate for approximating the capital cost of a plant as the cost per ton method, and is sometimes quite useful for an entire plant or a totally unknown design. It divides a number into the yearly product value to estimate the original capital requirement. Examples of this ratio are also listed in Table 3-5, again estimated from the plant costs in the charts and the product sales value listed in the *Chemical Marketing Reporter* (CMR). For many products the ratios vary from 0.4 to 3, although it actually can vary between the range of 0.2 to 5.0 and greater. It is interesting to note, however, that for the chemical industry as a whole their plants' asset value is about equal to the yearly value of the product sold (see Table 7-4). Since the average plant is about 50% depreciated, this implies that the original plant cost averaged about two times the yearly product sales value, or a turnover ratio of 0.5. Table 3-4 would not indicate anywhere near this low an average product turnover ratio, which demonstrates that: (a) the plants are not operating at capacity; (b) the CMR product sales prices probably are higher than actually realized; and (c) the plant costs of Appendix 2 do not include start-up, auxiliaries, and working capital, which are a significant part of the total investment. Because of this industry-wide consistent ratio of 0.5, however, it becomes a reasonable number to use if no other information is known about a plant's cost.

A number of other simplified plant cost estimating methods have been proposed over the years (Cran 1981; Ward 1986), such as "functional or operating steps" (Viola 1981) where plant capacity and the number of major

Table 3-5

Plant Cost per Annual Ton of Product, and Turnover Ratio (Annual Sales Value per Original Plant Cost) Numbers
(Estimated from Appendix 2 and Mid-1987 CMR Prices)

Compound	*Capacity, M t/yr*	*$ Sales/$ Plant*	*$ Plant/annual ton*
Acetalehyde	50	1.8	410
Acetic acid	20	1.7	440
Acetone	200	3.4	140
Acrylonitrile	300	1.4	560
Alumina	100	1.9	430
Aluminum sulfate	25	1.5	130
Ammonia	330	0.63	130
Ammonium nitrate	300	4.6	28
Ammonium phosphate	250	2.9	48
Ammonium sulfate	300	3.7	22
Benzene	260	8.1	51
Butadiene	250	1.8	140
Butanol	100	1.4	480
Caprolactam	45	1.6	1,100
Carbon tetrachloride	30	1.1	420
Chlorine	300	1.0	190
Citric acid	3.3	0.50	4,800
Cyclohexane	100	9.0	61
Diphenylamine	10	2.0	1,250
Ethanol	30	0.14	2,500
Ethanolamine	25	6.1	360
Ethylbenzene/paraxylene	20	0.63	700
	8.5	0.35	1,000
Ethyl chloride	15	0.51	940
Ethyl ether	35	5.7	160
Ethylene dichloride	25	0.57	600
Ethylene oxide	200	1.0	700
Glycerine	35	2.2	810
Hydrogen peroxide	200	2.5	180
Isopropyl alcohol	150	2.5	240
Maleic anhydride	50	5.4	200
Methanol	330	0.93	110
Melamine	70	0.94	810
Methyl chloride	10	2.2	230
Methyl isobutyl ketone	2.5	1.8	400
Methyl isobutyl carbonyl	10	2.1	530
Nitric acid	200	4.1	46
Para xylene	20	0.24	1,500
Phenol	200	2.1	280
Phosphorous	100	1.7	1,100
Phosphoric acid	20	2.2	270
Phathalic anhydride	200	2.7	200
Polyethylene	20	0.38	1,800

Table 3-5 (*Continued*)

Compound	*Capacity, M t/yr*	*$ Sales/$ Plant*	*$ Plant/annual ton*
Polypropylene	20	0.32	2,800
Polyvinyl chloride	200	2.7	370
Propylene	20	1.9	180
Sodium carbonate (Mine)	500	0.40	210
Sodium carbonate (Brine)	400	0.18	460
Sodium metal	20	1.10	1,170
Styrene	500	5.0	110
Sulfur	15	0.24	490
Sulfuric acid	330	0.60	83
Titanium dioxide	50	0.58	2,800
Tolune disocyanate	12.5	0.69	2,900
Urea	200	2.40	84
Vinyl acetate	200	1.9	420
Vinyl chloride	500	3.3	320

processing component steps are considered the basis of plant cost. Most of these methods are not too easy to use and may require additional arbitrary judgments. Some can increase the accuracy of preliminary estimates, but with much additional complexity. This provides no significant advantage, so they shall not be considered further in this book.

Factoring Exponents

Both individual pieces of equipment (as noted before) and entire plants may be roughly cost estimated by knowing the cost of one size and an exponent that relates cost with size. Since most of the complete plant cost versus size charts are straight lines, or can be approximated by a series of straight lines on log–log plots, a sizing exponent for a limited range (the slope of this line) can reasonably factor the costs. These exponents are listed in Appendix 2 under each plant cost chart. However, the likelihood of having accurate data on one plant size, or the sizing exponent, and the high probability of technical or process changes, coupled with each owner having quite different specifications for the plant, make such estimates still of only marginal usefulness. One of the most frequent uses for the sizing exponents, however, is to examine the effect of plant size on profitability, and to examine plant costs as part of the "sensitivity analysis." This will be considered in Chapter 6. If not specifically available, an exponent of 0.6 is considered to be a good general average for most chemical or related plants and equipment, although the average actual exponent for the 40 plants listed by Guthrie in Appendix 2 was 0.64.

PLANT MODIFICATIONS

The preceding discussions primarily concern cost estimates for complete plants. The same principles apply to the perhaps more common objective of plant modification. Because of environmental obstacles in siting a totally new grass roots chemical plant, and the general public's fear of unknown "toxics" from chemicals in general and their plants in particular, for many locations in the United States it is far easier to expand or modify an existing facility than it is to build a totally new plant. Also, there is the normal need to modernize and make older plants more efficient and environmentally acceptable if they are to remain competitive. Modification often becomes the most cost effective and practical procedure, and this, along with the difficulty of obtaining permits for totally new plants make additions or modifications the most common estimating need for the average engineer.

The procedures for estimating capital costs for plant modifications are exactly the same as previously discussed, except that some of the cost factors are either eliminated or greatly reduced. Land costs, for instance, are eliminated, and utility costs greatly reduced. Sometimes demolition, facility removal, and tie-ins require major additional expenses. Lost production from the old facility and arrangements to cause the minimum disruption to the plant often can also result in considerable scheduling problems and extra cost.

OTHER COMPONENTS OF TOTAL CAPITAL INVESTMENT

The total capital investment for any project is usually far greater than the cost of the "battery limits," or direct processing plant alone, and may include any of the following items.

Off-Site Facilities

A typical condensed checklist for off-site or additional facilities to be considered with any new plant estimate is given in Table 3-6. Some of these items relating to auxiliary, "off-site" or nonprocessing or production facilities may have been included in the previous capital cost estimate. If the auxiliary equipment will only be used by the production plant being cost estimated, then their cost should be itemized in the detailed battery limits estimate. However, if the plant is to share these facilities with other plants, or the facilities are quite general and removed from the new plant, then they will probably have to be considered separately. This might include assuming some (or all) of the cost of headquarters buildings; research and development facilities; engineering and plant technical service departments; safety, security; environmental control or hazardous waste facilities; power plants, utilities and sewage facilities; shipping facilities; and so on. The list of possible off-site requirements can be quite extensive, and should always be carefully reviewed to see which, if any, is

Table 3-6
Partial List of Possible Auxiliary Facilities

Typical Utilities
- Boilers; condensate and makeup water systems
- Generators (including cogeneration)
- Standby generators or battery assemblies
- Main power transformer stations
- Fuel storage and distribution facilities (oil, coal, gas, etc.)
- Plant-wide air conditioning facilities
- Plant-wide paging, emergency communication system
- Sewage collection (and treatment)
- Inert gas systems
- Fire fighting equipment and systems
- Flares, stacks, waste gas treatment
- Compressed, instrument air
- Cooling towers, distribution systems
- Refrigeration; hot oil systems

Service Buildings and Related Facilities
- Employee lockers, showers, time-card, lunch, restrooms
- Office building (management, sales, accounting, administration)
- Engineering, technical service facilities
- Laboratory (analytical), R & D, environmental
- Shipping, receiving office; supply warehouse
- Inventory (raw materials, products, supplies) storage
- Maintenance buildings, shops

Product Sales
- Packaging facilities
- Loading, unloading rail spurs, docks, forklifts, loaders, etc.
- Warehouses
- Shipping equipment (trucks, railcars, ships, barges, etc.)
- Distant storage, reshipping facilities

Environment
- Air, water, and ground monitoring equipment and controls
- Water treating and reuse facilities
- Incineration equipment
- Solid or liquid waste processing, handling equipment
- Solid or liquid waste shipping facilities

applicable, or perhaps not included in other sections of the cost estimate before totaling the capital investment. The cost for these facilities may be estimated directly (see Appendix 1), or they may be factored, usually as 0–30% (see Table 3-4) of the total plant cost.

Distribution Facilities

For some products the only way that they can be sold is for the company to install some, or extensive packaging and distribution facilities. This might include warehouses; branch offices; cars, trucks, ships, barges, rail cars;

shipping, receiving, or reshipping (i.e., rail to truck, etc.) facilities; packaging machinery; and so on. Such capital items may not be involved in a particular estimate, or if they are, perhaps they can be shared with many other products, but some new plants cannot be considered complete until these facilities have been included as part of the total capital investment. In some cases this investment may be optional and/or evaluated on its own separate merits with its own value-added economics, but for all estimates it should be investigated and itemized if appropriate. For this equipment the costs must be estimated separately and not merely factored from the plant costs because of the unusual and unique demands of the products or plants under consideration.

Research and Development, Engineering, Licensing

For many plants there is a sizable capital cost that must be added to a new project for the prior expense of research and development that was done for it, licensing if a lump sum payment (with or without royalties) is required, and for preliminary engineering design, review, and analysis before the new plant was approved for detailed engineering and construction. As will be seen in later chapters, the long time period that may be required for the research and development and engineering before the project is approved can have a considerable impact upon the ultimate profitability of the operation. The government tax laws do not allow these expenses to be considered part of the prior operating cost, and if a plant is built they must be "capitalized" and added to the plant capital.

Working Capital

Every plant has a requirement for a certain amount of capital to be available to pay the bills and sustain the operation before product is sold and payment is received. Some of this capital is needed prior to the first months' operation, and all of it is needed throughout the plant's life. It should be totally recovered at the end of the operating period when the plant is finally shut down. Its value generally consists of:

1. Operating capital equal to the operating expense for:
   a. the average length of time the product is being manufactured and in storage in the plant, plus shipping and storage time in other locations (if any) before it is sent to the customer, and
   b. the average length of time that it takes to collect for the merchandise sold (accounts receivables). This later figure generally averages about 60 days, although for very efficient companies it may be as low as 30 days, and companies selling to seasonal markets (i.e., agriculture) may run 120–180 days or longer.

2. Cash for wages, fringe benefits, local taxes, and other current obligations.
3. Inventories of raw materials, maintenance, and operating supplies.

Raw materials often require about a one month's supply, and maintenance and operating supplies about 2–4% of the total plant cost. However, for remote locations this must be much larger, and for urban areas it may be smaller. The current "just-in-time" supply and raw materials policy of some manufacturers (auto industry, etc.) is an attempt to greatly reduce this supply inventory (and warehousing) cost by precisely scheduling these materials to arrive exactly as needed. It would be very difficult to schedule in such a manner for the chemical industry and in fact, chemical companies servicing the just-in-time plants generally have to increase their inventory in proportion to the customer's decrease.

Working capital is often 10–20% of the plant's total cost (see Table 3-4), or perhaps 50% of the installed equipment costs. Such values may be acceptable for very rough estimates, but calculating a more precise figure by means of itemizing the manufacturing cost components is generally simple, and should be done if possible. A fraction of the yearly manufacturing cost is a much more relevant method of establishing working capital than using a factor times the installed plant cost, and might typically be 10–35% of the yearly operating cost.

Start-up Expenses

The final item of possible extra capital expense that should be considered is the cost of starting the plant and bringing it to full production. Usually there is little saleable, good quality, product generated during this period, so the start-up expense represents an additional increment of capital cost. Labor, materials, and overhead expenses during start-up time would be required, plus often extra engineering and considerable minor equipment, piping, controls, and so forth, modification. There is no way to precisely estimate this capital, or the start-up time, but for many plants the costs might run from 5 to 10% of the total plant cost. (See Table 3-4.)

FOREIGN LOCATIONS

The cost estimates in this text are based upon average U. S. prices and locations. It can be readily visualized that the same plant built in a foreign location would cost a somewhat different amount because of the difference in local labor costs, governmental requirements and taxes, varying transportation costs and availability of services. Often some of the construction costs will be cheaper, and some more expensive, but usually an overall factor can be applied to the U. S. costs to provide a first approximation of the costs in a foreign location. Table 3-7 gives an estimate of such factors. As with all the other estimating methods

Table 3-7
Foreign Location Factors

Australia		1.3	Malaysia		0.8
Austria		1.0	Middle East		1.1
Belgium		1.0	Newfoundland		1.2
Canada		1.15	New Zealand		1.3
Central Africa		~2.0	North Africa	(imported element)	1.1
Central America		1.0		(indigenous element)	0.75
China	(imported element)	1.1	Norway		1.1
	(indigenous element)	0.55	Portugal		0.75
Denmark		1.0	South Africa		1.15
Eire		0.8	South America (North)		1.35
Finland		1.2	South America (South)		2.25
France		0.95	Spain	(imported element)	1.2
Germany (West)		1.0		(indigenous element)	0.75
Greece		0.9	Sweden		1.1
Holland		1.0	Switzerland		1.1
India	(imported element)	1.8	Turkey		1.0
	(indigenous element)	0.65	U.K.		0.9
Italy		0.9	U.S.		1.0
Japan		0.9	Yugoslavia		0.9

Notes:
1. Increase a factor by 10% for each 1,000 miles, or part of 1,000 miles, that the new plant location is distant from a major manufacturing or import center, or both.

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this is perhaps an oversimplification of the problem and not too accurate, but it should nevertheless provide a somewhat more realistic estimate of plant costs in other countries.

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