THE RELATIVE COST FACTOR: A METHOD OF COMPARING PETROLEUM REFINERY INVESTMENT

John L. Birkler, William H. Micklish, Edward W. Merrow

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The RAND Corporation, 1700 Main Street, P.O. Box 2138, Santa Monica, CA 90406-2138

PREFACE

This paper, which was originally published in *Chemical Engineering*[1] at their request, is a condensation of a previously published RAND Note, N-2389-PSSP, *Comparing Project Investment Costs: A Methodology and Baseline for the Refining Industry*, John L. Birkler and William H. Micklish, February 1986. The paper presents an approach for evaluating capital costs of a broad range of projects.

The approach is easy to use and does not require detailed engineering data. It also establishes a baseline against which costs can be compared.

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[1]Comparing Cost of Oil Refinery Projects, September 29, 1986, Vol. 93, No. 18, McGraw-Hill Publications Company.

THE RELATIVE COST FACTOR: A METHOD OF COMPARING PETROLEUM REFINERY PROJECTS

Because capital cost data on individual petroleum refineries are seldom generally available, a refiner cannot assess its own relative investment efficiency. Therefore, we have attempted to develop, from actual cost data for recent projects, a measure for comparing refinery project costs, and to establish an industry baseline against which investment costs can be matched.[1]

Developing a tool for gauging the investment efficiency of refinery projects is a complex and difficult endeavor, because no two refineries are identical in process units, feedstocks, product slates or locations. Project management philosophies also differ. Therefore, a parametric approach seemed most appropriate for developing such a tool.

The parametric method described here can also be used to obtain rough cost estimates before detailed descriptive information and engineering designs are at hand. With these estimates, a refiner can assess whether a proposed project's costs will be competitive with the industry standard. After a project's development is well under way and higher-resolution estimates are needed, greater accuracy can be achieved by conventional estimating methods.

RESEARCH PROCEDURE

If the proper explanatory variables are used, parametric tools require few inputs, are easy to use, and provide reasonable accuracy. On the basis of prior analytical and engineering experience, we chose relative cost, unit capacity, mechanical completion date, process type, feedstock quality, and product characteristics as possible explanatory variables.

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[1]This research was conducted as part of The RAND Corporation's "Private Sector Sponsors Program, Process Industries Agenda." See John L. Birkler and William H. Micklish, *Comparing Project Investment Costs: A Methodology and Baseline for the Refining Industry*." The RAND Corporation, N-2389-PSSP, February 1986.

Extensive data are needed to quantitatively assess project cost, schedule and performance. Because such data are proprietary, a database encompassing the breadth of information needed was not available.

To create such a database, we first searched through publications to find firms that had completed major refinery projects within the past 15 years. We then contacted over 30 of the domestic firms found, and visited several to explain our objectives. Fifteen firms provided data, under nondisclosure agreements that prohibited the presentation of data in a way that would permit units to be identified. Summary tables, trends and regression lines could be presented.

PROJECT CHARACTERISTICS

Most of the projects in the database were completed within the last decade. These projects could be categorized by such characteristics as process type and technical attributes, nature of project site, geographical location, contract type and management strategy.

The 15 projects in the database involved more than 50 process units, representing all major refinery processes. Each project included from 1 to 12 major units. These units and their capacity ranges are listed in Table 1. Because data were collected from both major and independent refiners, the capacity ranges are broad, in some cases varying by more than an order of magnitude.

The projects ranged from single-unit additions to extensive expansions and "grass root" units. Slightly less than half were adjacent to an existing facility; 36 percent were additions to facilities to which a unit had not been previously added. A smaller percentage were at undeveloped sites.

We collected limited general information on the type of organizational structure and contracts that were used. In more than half the projects, a single prime contractor was involved in both design and construction. In another third, the design was done by a separate contractor or the owner's engineers.

None of the projects was a joint venture, and project responsibility was often vested in a single manager. However, half of the projects had more than one project manager. Most were part of a

Table 1

SUMMARY OF PROCESS TYPES AND UNIT CAPACITIES

Process	Number of Units	Capacity (MB/SD) Min.	Max.	Mean
Atmospheric distillation	5	95	263	160
Vacuum distillation	5	16	200	80
Coking (delayed)	4	9	72	31
Alkylation	5	7	19	11
Hydrotreating	7	37	76	51
Hydrodesulfurization	4	45	100	73
Hydrogen production[a]	6	8	95	58
Sulfur recovery[a]	8	40	900	370
Reforming	3	24	60	43
Catalytic cracking[b]	8	3	75	49
Visbreaking	1	..	..	120
Hydrocracking	1	..	..	20

[a]Hydrogen production is given in MMSCF/SD; sulfur recovery, in LT/SD.

[b]Includes resid cracking.

larger construction project, and had a small number of contractors that performed specialized jobs. One firm employed a total of ten different design and construction contractors. However, none of these factors were found to significantly affect costs.

Every effort was made to ensure that the data obtained were complete and comparable. Investment costs (which include all design and construction costs) for the projects in the study ranged from $12 million to $1,000 million. Fortunately, the major investment-cost components in the data supplied were consistent.

Because the data span different time periods, cost comparability was an important concern. The oldest project in the database came online during the early 1970s, and the newest in late 1984. Therefore, after ensuring that all definitional differences were eliminated, we made one major adjustment: We put all investment costs on a fourth-quarter 1983 basis, using both the empirically fitted S-shaped expenditure curve (developed for the process industries by consultant John Hackney) and the *Chemical Engineering Plant* Cost Index.

As part of our analysis, we examined the times required to execute and start up projects. With few exceptions, the projects were completed on, or very close to, schedule. We also examined data on the actual output of projects for each month in the 12-month period following startup.

Performance ranged very broadly, generally improving with time. Mean performance was about 60 percent for the second through the fifth months, and 80 percent for the next six months. However, these data do not reflect several factors that affected production, such as lack of feedstock, seasonal market demand, and scheduled maintenance downtime.

We also collected data on project availability over the same 12-month period. In this case, the range is considerably narrower, and the mean values much higher (about 90 percent). Availability for most projects was higher than 85 percent, but was restricted by lack of feedstock (caused, for example, by low operating rates due to poor market conditions). The project with the lowest availability was at the bottom of the range for more than five months, because of severe design errors and equipment malfunctions. These difficulties were probably compounded by an attempt to conduct the detailed engineering and construction phases concurrently.

In general, however, the projects examined were completed on schedule and performed to expectations. Because most of the units involved standard refinery technology and were built by firms whose personnel had experience with the technology, this result was to be expected.

ANALYTICAL TECHNIQUES

We used ordinary least-squares regression as the basic tool for developing relationships [1], and calculated the usual statistical measures of fit (coefficient of correlation, coefficient of variation, F-value, etc.). In selecting preferred equations, we generally looked for a high coefficient of determination (R^2), a low average standard error of prediction, and a level of significance for all independent variables of at least 90 percent. In addition, we used small-sample statistics, which provide greater insight into the estimation error and stability of relationships [2]. These methods helped us understand the sensitivities of the relationships to particular characteristics of individual projects in the database.

Before applying statistical methods, we established two criteria for selecting the explanatory variables: (1) the variables had to be logically related to cost, and (2) they had to be known fairly accurately.

The search for suitable explanatory variables began with the hypothesis that project cost is a function of:

Project size. Because size affects the amount of raw materials and labor that goes into a project, large projects cost more than small ones.

Project complexity. The number and type of units involved strongly influence investment costs.

Design for lowest-quality feedstock. The lower the quality of the feedstock (higher level of impurities, such as metals and sulfur, and lower API gravity), the more severe, and hence the more costly, processing conditions become.

Product value. The capital investment for a complex process that yields high-value products will be greater than for a simpler process that uses the same feedstock.

Of course, technical characteristics alone cannot explain all the variability in project costs. However, a cost model based on data from a wide assortment of projects includes the assumption that every project will have its share of technical planning and managerial problems.

DEVELOPMENT OF THE MODEL

After describing a method for characterizing and quantifying oil refinery projects, we will apply the method to the projects in our database. The resulting analysis yields a methodology that will enable engineers to compare project performance against an industry baseline.

We began with a multiple regression approach that uses process variables to explain project costs. These variables include capacity, feedstock quality (percent sulfur, percent metals, Conradson carbon and API gravity), and product slate. However, we found that our sample was neither sufficiently homogeneous nor large enough to support this approach. Although process capacity, feedstock quality, and the transportation fuel produced as a percentage of output appear to help explain investment costs, no combination of variables yielded the required goodness-of-fit. Therefore, we adopted an approach first proposed by Wilbur Nelson, which uses relative cost as an independent variable [3].

Estimates of refinery complexity by the Nelson method are based on the investment cost of the capacity needed to distill a barrel of crude oil in an average-size U.S. refinery. Complexity values for the major refining processes are obtained by dividing the unit capacity cost for an average-size process by the unit capacity cost for crude distillation. For example, using 1973 investment data for cokers ($570/bbl of capacity, and 15,300-bbl/stream-day average size) and crude distillation ($104/bbl of capacity; and 56,500-bbl/stream-day average size), the coker complexity factor is 570/104, or 5.5. Complexity factors for many processes can be calculated in this way.

The complexity value for a process in a particular refinery is the product of the process complexity factor and the ratio of process capacity to crude capacity. Thus, for Nelson's "average" refinery, the coker complexity factor is 1.5--i.e., 5.5 x 15.3/56.5. Summing the complexity values for each process yields a complexity number for an entire refinery.

As Nelson pointed out, this method suffers from dependence on an average size to represent the wide capacity ranges of refinery units. For example, within recent years, delayed-coking units have been built in capacities ranging from less than 10,000 to over 70,000 bbl/stream-day. Due to economies of scale, unit capacity costs for these cokers have varied from $717/bbl to $370/bbl, and complexity factors (based on average-crude-distillation capacity), from 6.9 to 3.6, respectively. Obviously, neglecting such a variation can lead to significant errors in complexity calculations [4].

THE RELATIVE-COST-FACTOR METHOD

To lessen the foregoing deficiency, we used data published by Nelson and others to relate cost as a function of process capacity for typical refinery facilities to a standard cost. The ratio of the cost of a process unit to the standard cost forms the basis of this method, which we call the relative-cost-factor (RCF) method.

In this approach, it is assumed that, barring major advances in technology, actual costs may vary with time but the RCF ratio will remain essentially constant. The standard used--$8.4 million, in 1973 dollars--is the investment cost for an atmospheric pipestill having a capacity of 100,000-bbl/stream-day [5]. The distillation process was chosen because its technology has been well worked out and is well understood. Because developments that will drastically affect distillation costs are unlikely to occur, this process forms a firm foundation on which the methodology can be based.

The ratio of the investment cost for a particular process to the investment cost for the standard pipestill yields the RCF value at a certain capacity. Using published information and inhouse data, we developed RCF-vs.-capacity relationships for the major refinery processes. Processes, RCF-vs.-capacity relationships, and capacity ranges are listed in Table 2. To calculate RCF, we need to know only the types of major process units that make up the project, and their capacities. RCF values for particular units are calculated by means of the equations. These are then summed to arrive at total RCF. Offsite processes are not included in the calculation. Their contribution to RCF is difficult to determine because they are very specific to project and site. (Offsites include all facilities not directly related to refining operations--e.g., utilities, tank farm, shipping docks.)

Listed in Table 3 are RCF values calculated via the Table 2 equations for a hypothetical "grass roots" oil refinery. Note that when more than one unit of a particular type are part of a project (sulfur recovery is a common example), RCF values for each unit are calculated, based on the capacity of each.

Table II — RCF-vs.-capacity relationships for major oil refinery processes

Process	Equation	Capacity range, 1,000-bbl/stream-day	
		Minimum	Maximum
Atmospheric distillation	$RCF = 0.05\ C^{0.64}$	10	200
Vacuum distillation	$RCF = 0.05\ C^{0.61}$	5	100
Fluid coking	$RCF = 0.17\ C^{0.69}$	5	80
Delayed coking	$RCF = 0.15\ C^{0.69}$	5	80
Visbreaking	$RCF = 0.06\ C^{0.60}$	5	80
Catalytic cracking	$RCF = 0.15\ C^{0.66}$	5	60
Hydrocracking	$RCF = 0.27\ C^{0.61}$	5	60
Hydrotreating:			
Cat cracker feed	$RCF = 0.11\ C^{0.65}$	5	80
Vacuum gas oil	$RCF = 0.09\ C^{0.65}$	5	80
Atmospheric gas oil and cracked naphtha/distillate	$RCF = 0.04\ C^{0.65}$	5	60
Resid desulfurization:			
Normal conditions	$RCF = 0.20\ C^{0.58}$	5	80
Moderate conditions	$RCF = 0.21\ C^{0.67}$	5	80
Severe conditions	$RCF = 0.21\ C^{0.76}$	5	80
Hydrogen production	$RCF = 0.10\ C^{0.61}$	5*	300*
Sulfur recovery	$RCF = 0.005\ C^{0.65}$	10†	1,000†
Catalytic reforming:			
Cyclic	$RCF = 0.13\ C^{0.79}$	5	50
Semiregenerative	$RCF = 0.10\ C^{0.76}$	5	50
Alkylation	$RCF = 0.26\ C^{0.61}$	5	20

*Million std.-ft^3/calendar-day

†Long-tons/stream-day

Table 3

ILLUSTRATIVE RCF CALCULATION

Process Type	Capacity	RCF
Atmospheric distillation	150 MB/D	1.30
Vacuum distillation	65 MB/D	0.63
Catalytic reforming (cyclic)	30 MB/D	1.90
Atmospheric gas oil hydrotreating	60 MB/D	0.53
Alkylation	15 MB/D	1.37
Fluid cat cracking	45 MB/D	1.83
Resid desulfurization	40 MB/D	1.73
Delayed coker	40 MB/D	1.90
Sulfur (2 units)	150 LT/D each	0.25
H_2 production	45 MMSCD/D	0.99
Total process RCF		12.43

AN INDUSTRY INVESTMENT-COST BASELINE

After calculating RCF for all the projects in the database, we performed regression analyses, using RCF as the independent variable and normalized investment cost as the dependent variable. The RCF values varied from a minimum of 0.3 to a maximum of 11.6, with a mean of 5.6. The resulting equation for investment cost I, $million (4th quarter, 1983), is:

$$I = 57.9(RCF)^{1.15}$$

For this equation, $R^2 = 0.93$, $F = 165$, and the average standard error of prediction is +15 percent, -13 percent. The RCF exponent is greater than 1.00, which indicates that the investment requirements grow somewhat faster than the RCF. The primary reason for this is the effect of offsite and utility costs. Projects with low RCFs usually entail only the addition of a unit or two to an existing refinery. Offsite and utility investments are often unnecessary. As a project grows, however, offsite and utility costs become a larger share of the total investment.

LIMITATIONS OF THE RCF METHOD

To identify the remaining variance in project cost, we examined other characteristics of the projects in our database, such as project management organization, contract type, characteristics of the owner firm and the experience of its project personnel, concurrence between project phases, size of utility and offsite facilities, and site-related difficulties. However, none of these improved our understanding of project costs for the units in the database.

The limited sample size and the small variance make the probability of successfully introducing additional significant variables low. Further statistical explanation of the variance would require a larger sample. Nevertheless, by performing an RCF analysis on a completed, or a nearly completed, project and adjusting costs to fourth-quarter 1983 dollars, an engineer should be able to evaluate the relative investment efficiency of an oil-refinery project.

The RCF method can also be used to estimate project costs, but only in the conceptual planning stage, when limited information is known, such as unit capacities, probable site, and extent of offsites. Having such information, an engineer can calculate RCF and determine a range of estimates. However, the results, being broadly based, would only represent an *average* estimate, which can only serve as a guide and which can, and should be, modified to reflect any detailed project information available or specific experience known by the estimator.

Furthermore, the method is susceptible to differences in cost escalation (converting costs to a constant-year dollar value could introduce inaccuracies), economic climate (contractor fees, labor costs, material availability and prices will vary), project site (significant, for example, between an inland refinery, no marine facility, and a coastal one), feedstock and products, governmental regulations (changes in environmental, health and safety rules) and auxiliary facilities (availability of utilities, administrative buildings required, etc.).

Such factors may make the cost of a project seem high or low when it is, in fact, optimal for the particular circumstances. Therefore, the RCF method should be used to compare a company's overall record of project costs against the industry norm, and not to compare one project with another.

OBSERVATIONS

Major refinery projects are complex endeavors that span many years and require the integration of many activities and groups. We recognized that a simple model could not capture all these facets. At issue was whether a general investment-cost model could be developed that would be useful and would not demand more specialized or detailed knowledge than would be readily available during the concept formulation phase.

The RCF approach fulfills these requirements. Easy to use and not calling for detailed engineering data, it is accurate enough to permit comparison of a broad range of refinery projects. We have provided RCF-vs.-capacity relationships for only the major refining processes, but equations for other processes can easily be derived by means of the method described.

In the RCF-vs.-capacity relationships, the capacity exponents, which are equivalent to the process cost-capacity scaling factors, range from 0.58 to 0.79, with a mean of 0.66. With the exception of two processes, the variation about the mean is small. Therefore, in the absence of additional data, we recommend using a capacity exponent of 0.66 for refinery processes that are not included in Table 2.

In conjunction with the RCF variable, we examined project characteristics that have proven useful as explanatory variables in other analyses [6]. However, the limited sample size and small variance made the introduction of additional significant variables difficult. Until a larger sample size becomes available, further statistical explanation of the variance is unlikely. It should be noted that any project to be evaluated by the techniques developed here must be consistent with the basic assumptions under which the relationships were developed. In particular, development and pricing policies must be similar to those of the 1970s and early 1980s.

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