In presenting the dissertation as a partial fulfillment of the requirements for an advanced degree from the Georgia Institute of Technology, I agree that the Library of the Institute shall make it available for inspection and circulation in accordance with its regulations governing materials of this type. I agree that permission to copy from, or to publish from, this dissertation may be granted by the professor under whose direction it was written, or, in his absence, by the Dean of the Graduate Division when such copying or publication is solely for scholarly purposes and does not involve potential financial gain. It is understood that any copying from, or publication of, this dissertation which involves potential financial gain will not be allowed without written permission.

7/25/68

# A TECHNIQUE FOR CHOOSING AMONG ALTERNATIVE PROJECT PROPOSALS IN THE CONSTRUCTION INDUSTRY

A THESIS

Presented to

The Faculty of the Division of Graduate

Studies and Research

By

James Steven Blesse

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in the School of Industrial and Systems Engineering

Georgia Institute of Technology

March, 1972

A TECHNIQUE FOR CHOOSING AMONG ALTERNATIVE

PROJECT PROPOSALS IN THE CONSTRUCTION INDUSTRY

Approved:

Chairman

Date approved by Chairman: 3-16-72

## ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to his thesis advisor, Dr. J. Gordon Davis, for his invaluable guidance, criticism, and encouragement during the performance of this research. Dr. Davis was the catalyst that precipitated my interest in the construction industry.

Appreciation is extended to the members of my reading committee, Dr. Norman R. Baker and Dr. Donald O. Covault, for their suggestions and encouragement throughout the course of my research.

To Mr. Robert H. Strickland, Executive Secretary of the Georgia Branch of the Associated General Contractors of America, my appreciation for his cooperation and assistance. Mr. Strickland assisted greatly in broadening my knowledge of the construction industry and in referring me to general contractors.

To the general contractors and other members of the construction industry whom I had an opportunity to interview, my gratitude for their time and cooperation. Particular recognition is deserved by the following individuals for their comments, suggestions, and ideas: Mr. William Beckett of Godwin and Beckett Architects; Mr. Larry Gellersteat, Jr. of Beers Construction Company; Mr. Ira Hardin of Ira H. Hardin Company; Mr. Bernard Kroll of Holder Construction Company; Mr. Howard Smith of AB and E, Inc.; and Mr. Charles Snepp of Snepp and Associates, Inc.

To Mr. Robert M. Crumley and Mr. Edward Van Winkle, Jr. of Van Winkle and Company, Inc. goes my personal acknowledgment for their significant contributions toward the successful completion of this study and the validation of the technique that was developed.

To my wife, Nancy, a special acolade for her continuous encouragement, patience, and understanding during the course of my graduate studies.

To my children, Joseph, Debra, and Steven, a special "Thank You" for their love and understanding while having to do without a father on so many occasions.

Last, but certainly not least, to the United States Army my appreciation for allowing me an opportunity to further my education in graduate school.

# TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

# LIST OF TABLES

# LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Concluded)

## SUMMARY

The purpose of this research was to develop a technique for evaluating proposed projects in the construction industry during the pre-bid phase, when there is a continuous flow of potential projects requiring consideration. The technique will allow a contractor to repeatedly select from current information the most attractive project or mix of projects on which to bid, to do this more efficiently and accurately, and to increase his probability of having submitted the winning bid. The following specific objectives were established:

1. The development of a technique to assist general contractors in evaluating a project by providing a rapid approximation of its attractiveness.

2. The development of a procedure to enable general contractors to evaluate multiple proposed projects constituting a continuous flow throughout time.

3. The establishment of guidelines and procedures for the development and adaptation of scoring models.

4. The analysis of the effects of a contingency such as weather on a selected project.

5. The design of an operational subsystem with which a general contractor could employ the multi-project evaluation technique.

6. An evaluation of the applicability of the technique in a real-world situation.

Procedures for determining the information required by the technique were described, and the application of the technique was demonstrated in a local construction company. The technique utilizes an approximate annual rate of return to estimate the profitability of a project and uses a multi-criteria scoring model to estimate the inherent risk.

# CHAPTER I

# INTRODUCTION

## Purpose

The purpose of this research is to develop a technique for evaluating proposed projects in the construction industry during the pre-bid phase, when there is a continuous flow of potential projects requiring consideration. The technique will enable a general contractor to repeatedly select from current information the most attractive project or mix of projects on which to bid, will allow this selection to be made more efficiently and accurately, and will increase the contractor's probability of having submitted the winning bid.

## Source of Interest

The author initially became interested in the construction industry through a course in project management that required the application of the Critical Path Method (CPM) and other techniques to a real-world project. The selected project was the construction of a new building, and from this experience the author's interest in the construction industry grew. Specific interest in the subject of this research stemmed from a general interest in the construction industry and was stimulated by a variety of people, study, and other media.

The most influential factor in motivating this study was the past financial failure rate in the construction industry. The more that was learned, the more the author became convinced that an improved method for selecting projects on which to bid would significantly reduce the failure rate. In the past much attention has been given to improving the management of a construction project after the project has been selected or after the bid has been won. However, no amount of project management nor any optimization techniques can take an undesirable project and convert it into an attractive one. Assuring a mix of reasonably desirable projects can only be done in the pre-bid phase, and to date there has been little work done in this critical area.

## Background Information

The construction industry in the United States has a phenomenal growth record and for many years has made the greatest single contribution to the Gross National Product (GNP) (22). The effect of massive needs for labor, materials, equipment, and capital is felt in every sector of the economy. The industry has consistently comprised approximately 14 percent of the GNP and at construction sites has consistently employed more than 6 percent of the total civilian work-force (25). As utilized here, the total industry is a fusion of two categories: first, new construction work which includes major alterations and additions and second, maintenance and repair work. The first category alone annually comprises more than 10 percent of the GNP (25).

For many years the GNP has demonstrated a steady increase. In the six years since 1965 it has increased approximately 55 percent to an estimated 1,051 billion dollars. In Figure 1 is a graph illustrating the rise in the GNP since 1929 (19,11). This increase in the GNP has been

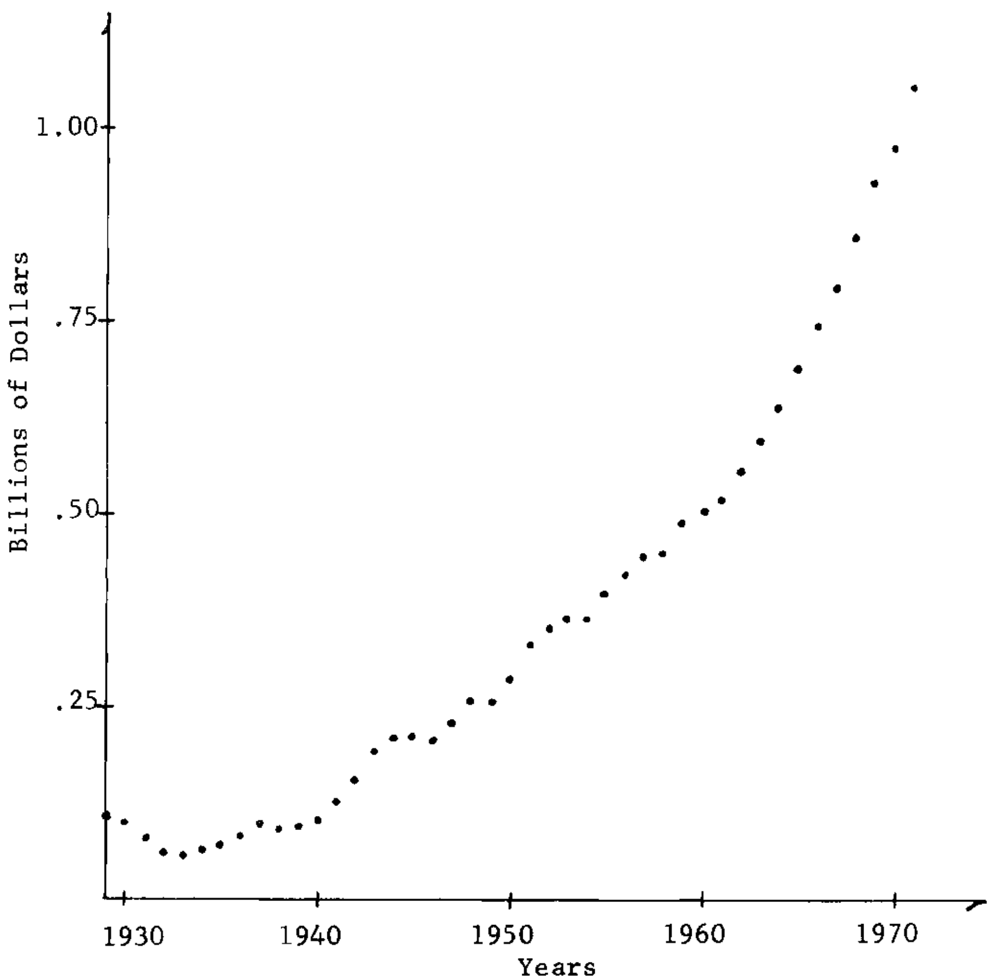



Figure 1. Rise in Gross National Product

accompanied by a somewhat commensurate increase in the size of the construction industry. A graph that gives a broad view of the growth of the industry since 1915 with a projection to the year 2000 is presented in Figure 2 (22). Admittedly a portion of this rise comes from the inflation in the value of the dollar which, of course, accounts for some of the increase in the GNP. However, the physical volume of new construction put in place has been establishing new records nearly every month and year (25).

Despite this attractive picture, the business failure rate in the construction industry has been unusually high for many years, especially among subcontractors. To make the situation even worse, the high failure rate has been coupled with an even higher liability rate which is illustrated in Table 1 (10). Although the number of failures remained a rather fixed proportion of the total business failures for a number of years, e.g., 1963 through 1967, the corresponding liabilities increased relatively as well as absolutely. Although the trend of increasing failures began to reverse itself in 1967, the rate remains significant, especially in light of the accompanying liabilities.

The majority of these reported failures have occurred in companies that were in business for five years or less; however, in 1965 a trend started which was toward more failures in companies that had been in business for ten or more years. The 2513 failures in 1965 were distributed as follows (22):

| Years in Business | Percent Failed |
|---|---|
| 5 years or less | 50 |
| 6-10 years | 26 |
| over 10 years | 24 |

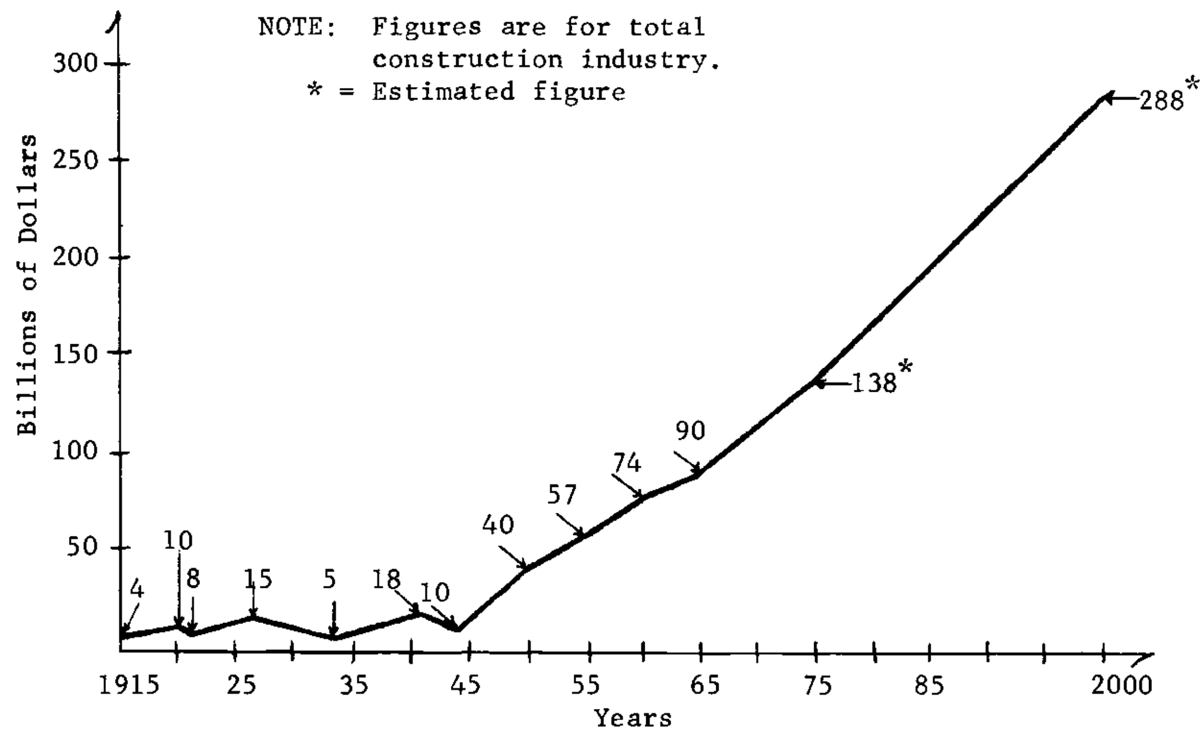



Figure 2. Growth of the Construction Industry

Table 1. Construction Failures and Liabilities

| Year | Failures | | Liabilities | |
|---|---|---|---|---|
| | No. | %* | Amt** | %*** |
| 1940 | 760 | 5.6 | 13,311 | 8.0 |
| 1945 | 92 | 11.4 | 3,559 | 11.8 |
| 1950 | 912 | 9.9 | 25,651 | 10.3 |
| 1955 | 1404 | 12.8 | 83,179 | 18.5 |
| 1960 | 2607 | 16.9 | 201,369 | 21.4 |
| 1961 | 2752 | 16.1 | 333,043 | 30.5 |
| 1962 | 2703 | 17.1 | 243,535 | 20.0 |
| 1963 | 2401 | 16.7 | 231,354 | 17.1 |
| 1964 | 2388 | 17.7 | 262,392 | 19.7 |
| 1965 | 2513 | 18.6 | 290,980 | 22.0 |
| 1966 | 2510 | 19.3 | 326,376 | 23.6 |
| 1967 | 2261 | 18.3 | 323,680 | 25.6 |
| 1968 | 1670 | 17.3 | 212,459 | 22.6 |
| 1969 | 1590 | 17.4 | 171,717 | 15.0 |
| 1970 | 1687 | 15.7 | 231,533 | 12.3 |

*Percent of total failures of all failing U.S. industries.

**Stated amounts are in thousands of dollars.

***Percent of total liabilities of all failing U.S. industries.

This increased failure of older and larger companies having greater assets resulted in more than a proportionate increase in the total amount of liabilities.

The failure rate which is mentioned above is based upon reported business failures. Business failures are those businesses that ceased operations following assignments or bankruptcy; ceased with loss to creditors after actions such as execution, foreclosure, or attachment; voluntarily withdrew leaving unpaid obligations; were involved in court actions such as receivership, reorganization, or arrangement; or voluntarily compromised with creditors out of court (5). There are two additional ways whereby a business may discontinue operation: first, closeout where the owner voluntarily ceases operations, frequently with large financial losses and second, sellout where the owner sells at a profit or loss to preclude disaster.

It is logical to assume that the failure rate is actually even higher than reported. For example, from data published in 1960, California had approximately 320,000 businesses of which approximately 2,500 failed, 30,000 closed out, and 20,000 sold out during the year (22). With the assumption that one half of the businesses in the latter two categories were on the verge of failure, there were ten additional business failures for each reported failure. Correspondingly, for each reported failure in the construction industry there may be ten other contracting firms that also fail in some manner and cease operation.

Some factors contributing to this high failure rate are (1):

1. The ease of entry into the industry.
2. Poor management and supervision.

3. Inadequate estimating, bidding, and cost control techniques.

4. Inability to determine the amount of involvement in more than one project at the same time.

5. Failure to minimize construction time through efficient scheduling of individual activities.

6. Inadequate cost analysis preceeding the bidding phase.

7. Inaccurate analysis of demand for those engaged in speculative bidding.

8. Inefficient control of overhead.

There appears to be a seven year period during which contracting firms are most vulnerable to failure. This period begins between the first and second years of business and extends to a point between the eighth and ninth years of business. From the graph presented in Figure 3 for failures in 1970, it can be seen that the peak of business failures occurred in the construction industry in firms that had been in business for approximately three years. The assumption that precipitating causes extend back at least a year establishes the start of the seven year period. Early failure is the probable result of inexperience in new construction companies. The end of the period is established approximately a year before the tenth year after which approximately 25.9 percent of all contractor failures occurred. About this time previously successful firms attempt to expand into new types of construction in which the company does not have the required expertise.

The average profit of general construction firms has exhibited a steady decrease from approximately 3.44 percent in 1946 to 1.15 percent

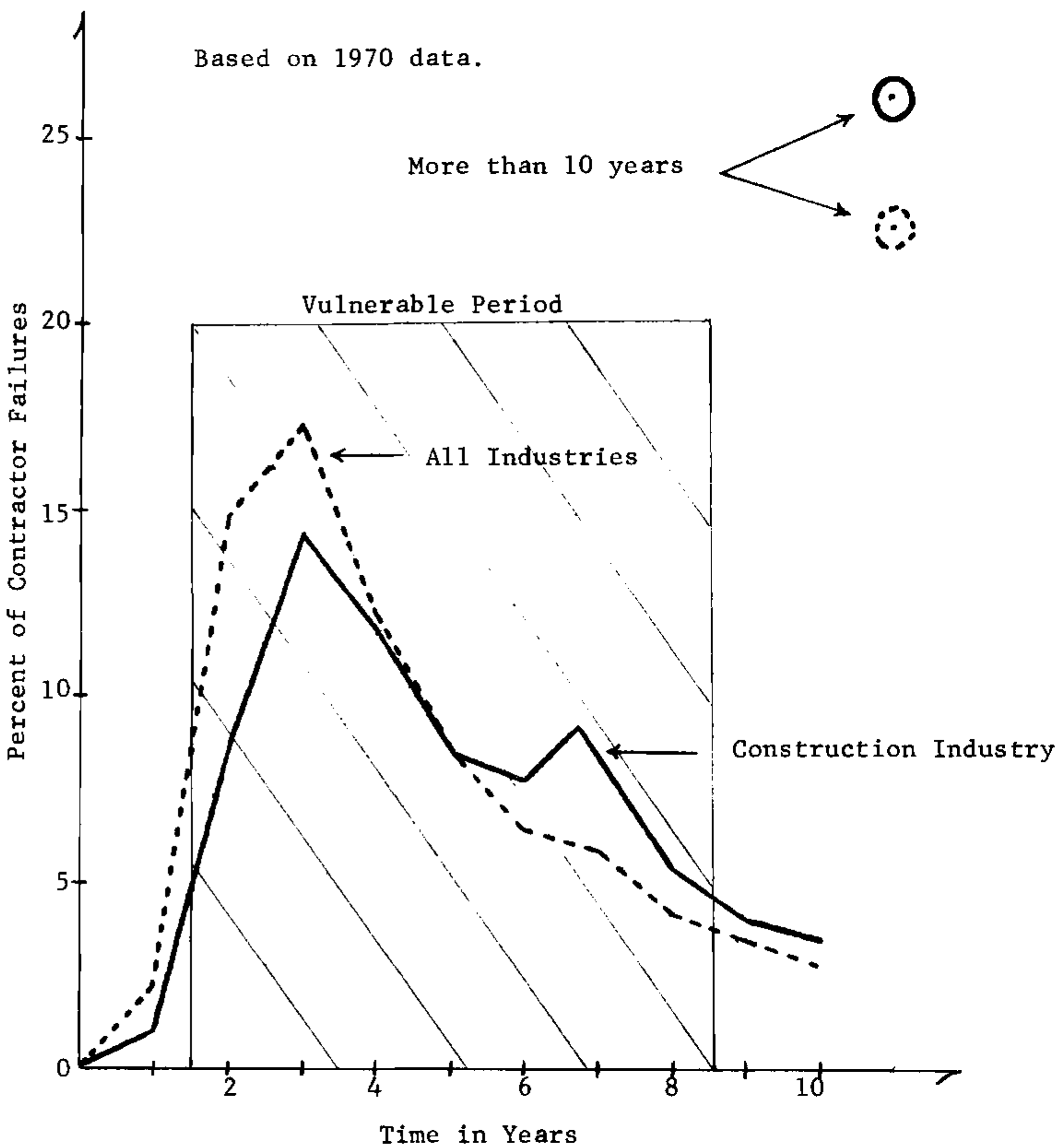



Figure 3. Vulnerable Period for Construction Companies

in 1970. The latter figure is the mean average profit for all general contractors, regardless of size, who were members of the Associated General Contractors of America (AGC) organization. Since this organization should include the better contractors, an average profit figure less than 1.15 percent can be predicted for non-AGC members and for firms in the less profitable size categories. The figures in Table 2 reflect the trend of decreasing profit in the construction industry (24).

During the past 15 years competition has forced profits down, unions have forced labor costs up, and material suppliers have demanded more for their products. "The low profit stature of the construction industry is the direct result of such factors as low bids, rising costs, keen competition, and inadequate management" (22). Little can be done by the individual contractor to improve the second and third factors. Although management can be improved, the first factor appears to offer the greatest potential for quickly improving the profit status of a construction company.

The connection of bidding and profit was emphasized in 1964 by Mr. Frank T. Fitzgerald, Vice President of Continental Illinois National Bank and Trust Company in Chicago, who said that loans to contractors are one of the most dangerous areas of bank lending. "He attributed this chiefly to the borrowers' narrowed profit margins resulting from intense bidding competition and from what he said has been a high rate of failures of contractor concerns" (2). The importance of the bid cannot be over emphasized. If it is too high, the construction company will not receive the contract. If it is too low, the contract for a project may be won,

Table 2. General Contractor Profits

| YEAR | PROFIT* |
|---|---|
| 1962 | 1.9 |
| 1964 | 1.5 |
| 1966 | 1.3 |
| 1968 | 1.3 |

*This is the mean average profit as a percentage of gross volume for Associated General Contractor members in the five to six million dollar volume of business category.

but the profit margin will be inadequate. Unexpected circumstances may easily lead to financial loss.

In summary, the past failure rate in the construction industry has been high with even higher liabilities. The facts appear to indicate that this high failure rate is, at least in part, the result of companies becoming involved in unattractive and unprofitable projects. There is uncertainty over which job to bid as part of the uncertainties associated with a construction job. If a technique were developed to assist contractors in selecting their projects, the unsatisfactory failure rate could be reduced, and the construction industry as a whole would benefit. The need for such a technique was emphasized by Burkart (4), as chairman of a committee on research requirements for construction. The committee proposed numerous research topics of which several are included in this study and are directly related to the technique that is developed.

## General Approach

The general approach used in conducting this research is also utilized to present the results. Initially, the necessary assumptions and constraints were developed to set the problem in its own environment so that it might be analyzed from the proper perspective. These are discussed in Chapter II. Then, the technique that is to be utilized for the evaluation of a particular project was developed and is the basis for Chapter III. The technique was developed in a flexible form to allow any general contractor to modify the form and to adjust the parameters to meet his particular situation and requirements. The technique is based upon the use of a multi-criteria scoring model to evaluate risk and an approximate annual rate of return to evaluate profit.

The basic technique for the evaluation of a single project was extended to enable the technique to be applied to the evaluation of multiple projects that constitute a continuous flow arriving through time. In this manner projects are ranked in a dynamic fashion where the consideration of each additional project may influence the rank of one or more of the projects previously considered. This material is presented in Chapter IV.

To demonstrate the applicability of the technique it was utilized by the author in work with Van Winkle and Company, Inc., which is a general contracting firm in Atlanta, Georgia. A discussion of the trial application and an evaluation of the results are presented in Chapter V. Chapter VI contains a subsystem which was designed to assist a general contractor in employing the proposed evaluation technique that was developed during this research.

The material developed in this study should be a significant contribution toward filling the void that has existed in project management techniques employed by general contractors during the pre-bid phase of any construction project. In addition, the technique will provide such contractors with a means of increasing the probability of their being involved in attractive, desirable projects that will have a higher probability of providing a better return on the time and money expended by the contractor during the life of the project.

# CHAPTER II

# PROBLEM ENVIRONMENT

## Objectives

The following specific objectives were established as the primary elements related to the achievement of the stated general purpose of this research:

1. The development of a technique to assist general contractors in evaluating a project by providing a rapid approximation of its attractiveness.

2. The development of a procedure to enable general contractors to evaluate multiple proposed projects constituting a continuous flow throughout time.

3. The establishment of guidelines and procedures for the development and adaptation of scoring models.

4. The analysis of the effects of a contingency such as weather on a selected project.

5. The design of an operational subsystem with which a general contractor could employ the multi-project evaluation technique.

6. An evaluation of the applicability of the technique in a real-world situation.

## Assumptions and Constraints

Placing the problem into a proper environment that is sufficiently defined to allow the study to proceed with meaning is achieved by making certain assumptions and defining particular constraints. First, it is assumed that the reader has a sufficient knowledge of networks and CPM to make it unnecessary to discuss the fundamentals of these subjects.

With regard to the problem, it is assumed that the general contracting company can handle only one additional project and would prefer to select the most attractive one on which to bid. The attractiveness of a particular project might vary among companies, and a company may even find that all projects under consideration are unattractive based upon a low cut-off score. It is also assumed that the general contractor is interested in private and public competitive bids, although many of the procedures could be applied to negotiated contract work. In the company there is adequate knowledge and experience to use CPM with one-time estimates for the project activity durations in lieu of multiple-time estimates.

It is further assumed that the general contractor desires to have a formalized technique to assist in choosing among competing projects and that he desires to expend minimum time, effort, and capital on this technique to achieve a reasonably accurate evaluation of each project. An analysis and bid require time and money to prepare. A swift evaluation will allow more time to be utilized in preparing the competitive bid for submission prior to the bid cut-off time which, in turn, will improve its quality and its probability of success.

Finally, it is recognized that the technique presented in this study will not be universally adaptable by all general contractors without modification. Depending upon the size, goals, and other factors of a specific company, some adjustments may be required in the technique or in the parameters of the scoring model for this general method to satisfy the particular requirements of an individual company.

## Bidding Procedure

Any construction project includes three basic elements. The first element is the project owner who decides on the need for the project and furnishes the money to pay for it. An architect, the second element, designs the project for the owner, inspects the project during the construction phase to insure that the work and materials conform to the project specifications, and generally represents the owner in dealing with the contractor. The contractor is the final element and is the project bid winner who has been awarded the contract. He constructs the project for the owner as prescribed in the architect's plan.

The sequence of events which occur from the time a project is conceived until the contract for the project is awarded is complex and, depending on the particular situation, can include some peculiar variations. Nevertheless, the comprehension of subsequent material in this research may be facilitated through a discussion of a typical sequence of events for a private bid. The events to be discussed are summarized in the flow chart which is presented as Figure 4. The sequence is not inflexible, and events may be added to or deleted from the list.

Every construction project begins with the owner conceiving the idea or recognizing the need for the project. Studies are initiated by the owner to determine the feasibility of the project. If these studies

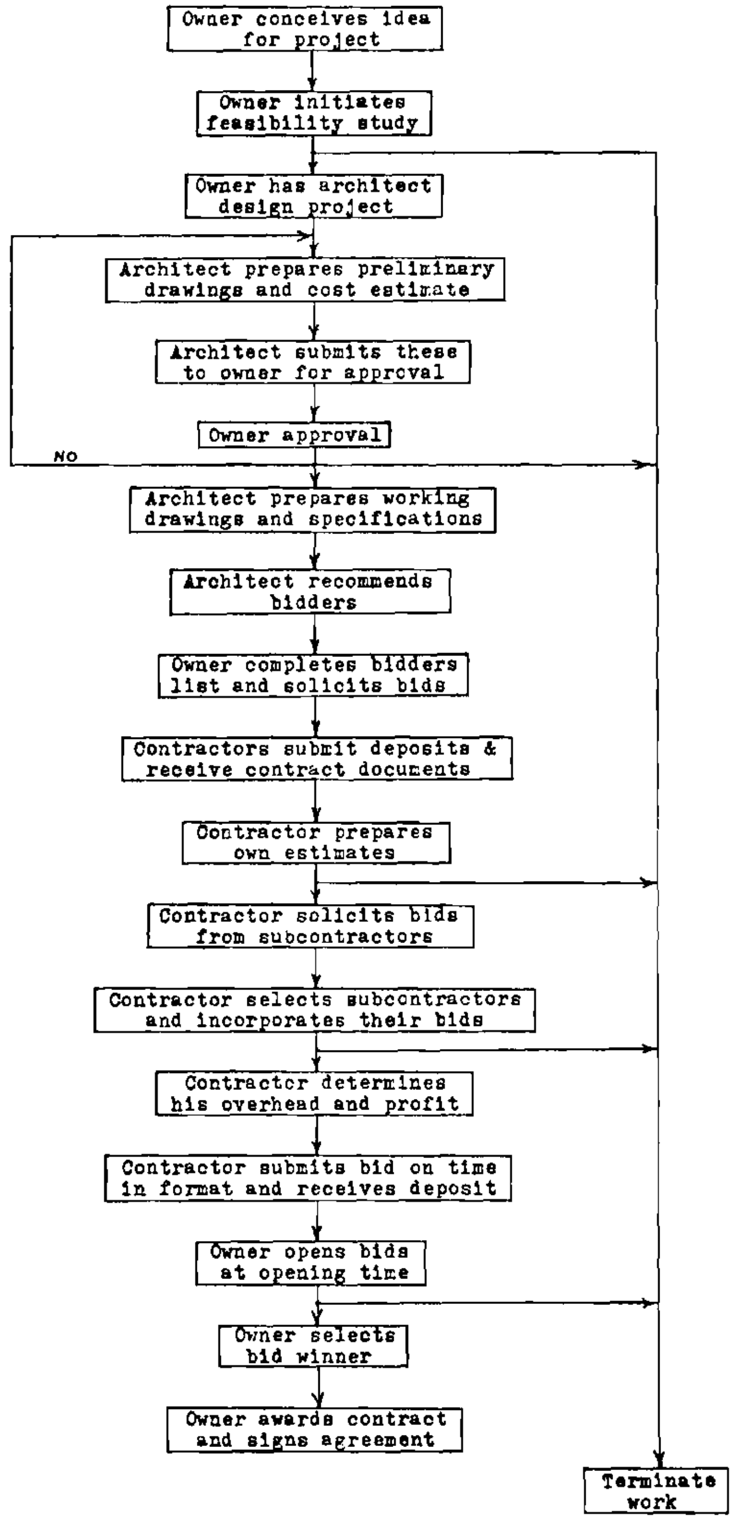



Figure 4. Flow Diagram of Project Conception through Contract Award

indicate feasibility, the owner engages an architect to design the project. The formal agreement between the owner and the architect is normally based upon a fixed percentage of the cost to the owner of the work designed by the architect.

The architect obtains from the owner a set of criteria for the project and then develops the first preliminary drawings and a preliminary cost estimate. These are submitted for approval to the owner who is concerned not only with the design but also with the cost. When approval has been given, the architect prepares the working drawings which are detailed drawings of all phases of the construction project. He also prepares the project specifications which describe the construction and the materials to be utilized. It is these two items, the drawings and the specifications, that are henceforth in this study called the bid documents.

At this point the bidders list is prepared by the owner. He normally requests that the architect recommend the names of interested, high quality contractors who specialize in work of the character and scope involved in the project. Needless to say, the owner is free to add the names of other contractors to the list. However, adequate price competition can generally be obtained from as many as five bidders. This will depend on the size of the project, but normally varies between five and twelve bidders. When the bidders list has been completed, bids are solicited from the contractors and must be submitted to the owner no later than a specified date, which is largely dependent upon the size and complexity of the project. Adequate time in which to prepare the bid is essential and in general should not be less than two weeks.

To each bidder who submits the required deposit ($25.00-$500.00) the owner issues a complete set of contract documents which consists of the (8):

1. Notification of bidders.
2. Instructions to bidders.
3. Required format for bid.
4. Contract.
5. Contract conditions (general and special).
6. Project specifications (general and special).
7. Drawings.

It should be remembered that items 6 and 7 comprise the bid documents, as defined earlier.

Each contractor utilizes the bid documents to prepare a cost estimate for the project. He develops direct and indirect cost figures for the work that he will perform and simultaneously develops his plan for the way in which the project will be completed. Required work that is beyond the capability of the contractor is planned to be subcontracted to appropriate organizations. The contractor solicits bids from subcontractors for specified work, selects the winners, and incorporates their bids into the cost estimate for the entire project to which the contractor adds a margin to cover his overhead and profit. The completed bid is submitted to the owner after which the contractor receives his deposit.

At the established opening time and frequently in the presence of all bidders and other interested persons, the owner opens the bids. If all bidders have met the necessary qualifications and prerequisites, the bid should be awarded to the contractor with the lowest bid. The signing of the contract terminates the sequence of events under discussion.

The construction contract agreement between the owner and the contractor will be of the form stipulated in the contract documents. This contract is generally based on a stipulated sum or on the cost plus a fixed fee, although other contract variations do exist. In either case the contractor generally receives a series of partial and final payments which is established in the contract. For example, no later than the fifth day of the month a contractor must present to the architect an invoice stating the quantity and cost of work that has been completed. This includes materials that have been delivered to the site but have not yet been installed. The architect substantiates the invoice for the owner who in turn pays the contractor no later than the fifteenth day of the month. The owner normally retains five or ten percent of the payments until the project has been completed and accepted. This payment process will be discussed in more detail in the following chapter.

# CHAPTER III

# SINGLE PROJECT EVALUATION TECHNIQUE

## Introduction

The proposed technique for evaluating a particular construction project during the pre-bid phase involves a number of steps that culminate in an evaluation of the risk and profit. Although a specific contracting firm might decide to delete from or to add to the presented sequence, it should be remembered that this technique is flexible and can be modified to suit the individual needs of a given company.

Lest the reader become confused, the following explanation must be made. In the previous chapter a number of steps were presented to depict a typical sequence of events between the conception of a project and the award of a contract. These steps will not be mentioned further. Another sequence of steps will be presented near the end of this chapter to depict the proposed evaluation technique. Rather than present the entire sequence of steps for evaluating a project at this time, certain of the steps will be discussed in detail in the succeeding sections of this chapter. The complexity of these steps necessitates their being developed more explicitly than other steps in the proposed technique.

The proposed evaluation technique involves the continuous and progressive screening of a project. If a project survives the preliminary screening, the bid documents will be obtained, and the project will be processed through a final screening. Several of the steps which occur during the final screening phase require the use of the bid documents and are rather complex. Consequently, these steps will be discussed in the following sections of this chapter before the entire evaluation technique is presented.

The next, or second, section involves developing the estimated amount of work and materials required to complete the project. From this, estimates are developed for project cost and for activity durations. The third section deals with the construction of the project network from which the project duration and the critical path are obtained. The fourth section consists of the analysis of certain contingencies that may arise and affect the cost and/or duration of the project. The fifth section demonstrates a different solution to the problem of how to take a contingency such as weather into consideration when planning a project. This step terminates in an adjusted network. The sixth section concerns the application of bidding strategy from which an expected profit is determined. The seventh section involves the analysis of anticipated cash flows as a means of determining a measure of profitability. The eighth section deals with the development of the multi-criteria scoring model. In the last section of this chapter the various steps are assembled, and the method of employing the technique to evaluate a single project is discussed.

## Estimating the Costs and Durations

There are two types of estimates that are obtained directly from the bid documents. The first type is an estimate of the quantities of required materials. The second type is an estimate of the amounts of essential labor and services that are independent of the materials employed.

Estimates of the quantities of required materials, including equipment, are expressed in appropriate units, such as cubic yards of concrete, etc. These estimates are utilized in conjunction with appropriate cost tables to produce a series of estimated material costs. Simultaneously the quantity estimates are utilized in conjunction with work-rate tables and with past experience to obtain the number of time units that will be required to install the specific material. The time units are expressed in hours, days, weeks, or any other appropriate form and are the basis for arriving at estimated duration times for the various project activities. These time units then interact with the appropriate wage schedules to produce a series of estimated labor costs which are directly related to and are dependent upon the amounts of materials employed.

The second type of estimate is divided into two parts. The first part involves labor that is directly related to non-material consuming project activities, such as hauling away excavated earth, cleaning up, etc. In a manner similar to the procedure employed with materials, estimates are developed for the amount of work to be accomplished, e.g., haul away 600 cubic yards of excavated material, and are used in conjunction with work-rate tables and with past experience to arrive at the number of time units that will be required to perform the activity. These time units also interact with the appropriate wage schedules to produce another series of estimated labor costs.

The other part of the second type of estimate which is normally specified in the general conditions of the project specifications considers labor and services that are indirectly related to the entire project but do not fall into the company overhead classification. Examples of this are having an engineer on site during part of the construction and having utilities available on site during the construction phase. These estimates are expressed in time units from which estimated costs are developed. Examples of the general procedure that is utilized in obtaining the above estimates are presented in Figure 5.

After the cost estimates have been obtained, they are assembled under various headings, such as earthwork, steelwork, concrete, masonry, electrical, etc., which will be determined by the nature of the project, the required bid format, and company policy. Since a considerable portion of most large projects is subcontracted, appropriate subcontractors (subs) must be contacted to obtain the estimate for their work that is included in the project. Here consideration should be given to developing work packages. This would facilitate the future use of PERT/Cost as a project management tool, if the contracting company were to be awarded the project. This recommendation is, of course, based upon the assumption that the company uses PERT/Cost.

Certain items need to be added to the above estimated costs. These items include project costs for taxes, insurance, bonding fees, and overhead which is a function of the anticipated project duration. Note that profit has not been included in these items, which comprise the total project cost, but will be added later. This information is presented on the summary sheet of the cost estimate, an example of which is located at Appendix B.

1. Estimated Material Cost:

   Concrete = $(600\ yd^3) \cdot (\$13.50/yd^3) = \$8{,}100.00$

2. Estimated Activity Duration:

   Steel Erection = $(150\ \text{tons}) \div (25\ \text{tons/day}) = 6\ \text{days}$

3. Estimated Labor Costs (related to materials):

   Roof Nailer = $(600\ ft) \div (300\ ft/day) \cdot (8\ hrs/day) \cdot (\$28.13/hr)^*$

   $= \$450.00$

4. In certain cases where the duration of an activity may be immaterial and/or where valid data may not be available, the following method for estimating cost may be useful. Estimate the amount of work to be accomplished, e.g., fine grade 2975 square feet, and then use it in conjunction with the correct cost per unit of work calculation. For example:

   Fine Grading Cost = $(2975\ ft^2) \cdot (\$.05/ft^2)$

   $= \$149.00$

*The figure of $28.13 per hour represents the total amount of wages per hour paid to the work crew.

Figure 5. Examples for Obtaining Estimates

The total cost of completing a project is dependent upon the material, equipment, and labor costs; and upon the administration and supervision charges, interest, site expenses, and penalty payments. The first group of costs are direct costs, as they are directly related to individual activities and vary with the duration of the specific activity. The second group of costs are indirect costs, since they are not related to activity durations, normally vary almost linearly with the project duration, and are estimated for the entire project.

The manner in which the project direct and indirect costs are combined to achieve the total cost at alternative project lengths is shown in the graph in Figure 6. From this figure it is evident that the minimum project cost, $\$^*$, will occur at a particular project length or duration, $d^*$. However, during the pre-bid project evaluation no attempt is made to locate $d^*$ for this specific project. Although it is optimal to operate at this point, time and costs tend to preclude locating it at this time. Proper analysis and experience should place the contractor sufficiently close to the point for the evaluation being made. If the decision is made to bid on the project, efforts can be undertaken at that time to locate $d^*$ and $\$^*$.

## Constructing the Network

Although many contractors do not develop a project network until the bid has been won, it is a decided aid during the pre-bid phase and should be employed. Historical data from similar size and/or cost projects should not be copied in an effort to obtain an estimate of the project duration, as no two projects are identical. Even the minimum of variation

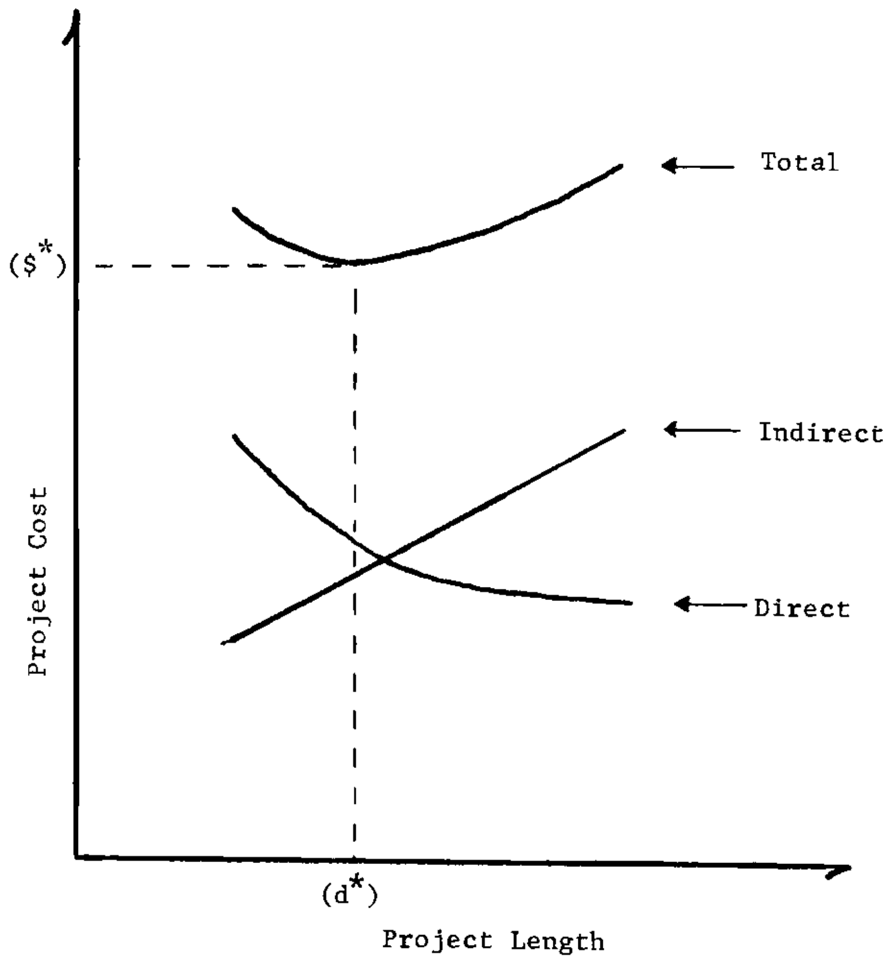



Figure 6. Project Cost Curves

dictates that a separate network and duration estimate must be developed for each project. The network does not have to be constructed in detail, since this can be done later. From the network the critical path can be determined and the project analyzed more thoroughly. Although done on an elementary level, this will cause problems and options to be discovered earlier, will result in a better project plan, and will produce a more accurate cost estimate. This is especially true where the proposed project is significantly different from any other project which the contractor has undertaken in the past. Last, but not least, it should be mentioned that there are contractors who have voluntarily submitted a project network with their bid and were awarded the contract, although their bid was not the lowest figure (21).

For a long time it has been realized that complex construction projects require special management tools. PERT (Project Evaluation and Review Technique) and CPM (Critical Path Method) were developed in response to this requirement. Although these techniques were developed in different environments, PERT and CPM are basically similar network approaches from which more than a hundred variations by name have grown.

In brief, the network is constructed by dividing the project into its separate activities which are represented by arrows. These arrows are connected together by nodes in the correct order of their sequence to depict the anticipated flow of work during the construction of the project. Duration estimates are assigned to each activity in the manner described in the previous section. Appendix C contains a completed sample network that utilizes the activities-on-arrows convention.

When the network has been completed, the necessary calculations for determining the project duration and critical path can be performed manually or with the aid of an electronic computer. The choice would depend on a variety of factors which will not be discussed here. For purposes of demonstration the sample network has been processed on a Burroughs B-5500 electronic computer utilizing the PROMIS (Project Oriented Management Information System) Time program. The computer output is presented in Appendix D and has the activities sorted by early start date, early finish date, predecessor number, and successor number.

## Planning for Contingencies

During the construction of any project the occurrence of chance events, i.e., contingencies, may adversely affect the cost and/or duration of the project. Plans must be developed and reflected in the project network and cost estimate to minimize the effects of such events whose duration may be a random variable. There are two basic classes of contingencies. One class is comprised of chance events that may or may not occur and is discussed in the following paragraph. The other class of contingencies is comprised of events that will occur throughout the duration of the project and is discussed in the next section of this chapter.

Contingencies that may or may not occur are varied and must be considered individually for each project. Examples include strikes, nonavailability or late arrival of materials and equipment, defective materials, critical construction errors, and incorrect drawings or specifications. Each contingency must be analyzed to determine its possible effect on the project. If the influence of a contingency is judged to be adverse, there are several ways in which the effect of the occurrence of such an event may be minimized. First, a cushion may be built into the project plan by increasing the estimated project duration and cost. Second, the project plan may be modified to avoid a contingency by performing activities in a different sequence, by using slack time to start an activity at a later date, or by crashing an activity to complete it earlier.

Contingencies must be anticipated. Appropriate subjective analysis can produce plans that will minimize or preclude any adverse effects. Further discussion of this point is not considered germane to this research.

## Adjusting the Network for Weather

Contingencies that occur throughout the duration of a project must also be considered. Although a contractor knows that events such as rain and absenteeism will occur during any project, the magnitude and frequency of these events is unknown. To minimize the effects of such events the estimated project duration and cost may be increased arbitrarily to provide a larger cushion. However, there is an objective quantitative method for considering the effects of such events on a construction project. Weather will be used to illustrate this method, and it should be of particular interest to contractors who may be considering a project that will be located in a different climatic area.

Every project will normally lose some time because of bad weather, such as rain and low temperature. Of course, weather varies from one geographical region to another which is a fact that will influence the importance of considering the weather effects on a project. The total weather effect is comprised of two factors: first, the weather and second, the degree to which an activity is weather sensitive. For the project duration and the scheduled event dates to be more realistic, the weather must be considered when preparing the project network. Furthermore, adjusting the initial network for weather will not only realistically increase the planned duration of a project, but may also cause the critical path to change. Knowledge of such facts could save a contractor considerable money in the form of penalty payments.

To obtain historical weather data for the Atlanta, Georgia area, the Atlanta Weather Bureau was contacted. Data was extracted from the records for the 53 years of 1918 through 1970 (12). Pertinent facts were collected concerning rain and cold. The author defined rain as rainfall equal to or greater than .01 inches during a 24 hour period from midnight to midnight. A figure greater than .01 inches could be used, if the data were extracted in a different manner from the historical records. It was assumed that any amount of rain would have the same effect on an activity.

Cold was defined as a maximum daily temperature equal to or less than 45 degrees Fahrenheit. Typical construction specifications state that concrete will not be poured and bricks will not be laid unless the temperature is above 40 degrees or is 40 degrees and rising. If the maximum daily temperature does not equal or exceed 46 degrees, concrete and brick work may well be interrupted or delayed. It was assumed that any temperature below 46 degrees in the Atlanta area would have the same effect on an activity. The reader may perceive that a high daily temperature may also cause the work on certain activities to be less efficient; however, this situation has not been included as an influencing factor in this study.

With certain terms having been defined, the theoretical development of the weather adjustment method will be presented. The examination of the historical weather data for rain or temperature on a specific date was defined as a random experiment.

Let $$f_{ir} = R_{ir} \div n, \; 0 \leq f_{ir} \leq 1$$

where $f_{ir}$ = relative frequency of rain on the $i^{th}$ calendar day

$R_{ir}$ = number of occurrences of rain on the $i^{th}$ calendar day in n years

$n$ = number of years, and

$i = 1,2,3,\ldots,365$ (during non-leap years).

It is assumed that $n = 53$ is a sufficiently large number that the relative frequency of occurrence does exhibit statistical regularity.

Thus, $$\lim_{n \to 53} (R_{ir} \div n) = p_{ir}$$

where $p_{ir}$ = the probability of rain on the $i^{th}$ calendar day.

Now look at a network activity with a scheduled duration of $1 \leq j \leq k$ days. Let $R_{jr}$ be a discrete random variable having a Bernoulli distribution such that

$$R_{jr} = \begin{cases} 1, & \text{if there is rain on the } j^{th} \text{ activity day.} \\ 0, & \text{otherwise.} \end{cases}$$

Let $R$ = the number of activity days on which it rains.

Thus, $$R = R_1 + R_2 + R_3 + \ldots + R_k = \sum_{j=1}^{k} R_{jr}$$

And, $$E(R) = E\left(\sum_{j=1}^{k} R_{jr}\right) = \sum_{j=1}^{k} E\left(R_{jr}\right)$$

Let $p_{jr} = P(R_{jr} = 1)$ = the probability of rain on the $j^{th}$ activity day.

Therefore, $$E\left(R_{jr}\right) = 0 \cdot \left(1 - p_{jr}\right) + 1 \cdot \left(p_{jr}\right) = p_{jr}$$

Consequently, $$E(R) = \sum_{j=1}^{k} p_{jr} \quad \text{QED}$$

The above formula states that the expected number of days of rain during any activity with a scheduled duration of k days can be determined from a summation of the daily probabilities of rain on the activity days involved. The probabilities are actually obtained from the probabilities of rain on the corresponding calendar dates.

The above comments concerning rain can also be directly applied to cold weather. The same 53 years were used to obtain historical data concerning the frequency with which the maximum daily temperature was less than or equal to 45 degrees. The following notation is used for cold: $p_{ic}$ = the probability of cold on the $i^{th}$ calendar day; and $p_{jc}$ = the probability of cold on the $j^{th}$ activity day. The $p_{ir}$ and $p_{ic}$ for the Atlanta area are located in Tables 3 and 4, respectively.

Having developed expressions for the expected number of days of

Table 3. Probability of Rain in the Atlanta Area

RAIN FACTOR - (DAILY RAINFALL EQUAL TO OR GREATER THAN .01 HUNDREDTHS INCHES IN ATLANTA, GEORGIA)
(HISTORICAL FREQUENCY OF OCCURRENCE BY PERCENTAGE OF DATES)

| | JANUARY | FEBRUARY | MARCH | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER | OCTOBER | NOVEMBER | DECEMBER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .491 | .321 | .358 | .340 | .283 | .283 | .340 | .396 | .283 | .189 | .302 | .226 |
| 2 | .283 | .377 | .321 | .321 | .340 | .340 | .415 | .340 | .170 | .226 | .283 | .245 |
| 3 | .321 | .453 | .321 | .302 | .340 | .264 | .528 | .415 | .245 | .208 | .226 | .358 |
| 4 | .226 | .415 | .415 | .415 | .321 | .321 | .396 | .358 | .491 | .170 | .208 | .302 |
| 5 | .396 | .264 | .340 | .377 | .264 | .208 | .453 | .396 | .377 | .226 | .226 | .377 |
| 6 | .415 | .415 | .472 | .377 | .302 | .358 | .396 | .340 | .321 | .245 | .208 | .245 |
| 7 | .415 | .358 | .415 | .264 | .321 | .358 | .453 | .396 | .170 | .321 | .264 | .302 |
| 8 | .358 | .302 | .264 | .283 | .226 | .283 | .453 | .340 | .208 | .340 | .208 | .358 |
| 9 | .377 | .472 | .302 | .283 | .245 | .321 | .434 | .245 | .264 | .189 | .189 | .358 |
| 10 | .340 | .283 | .340 | .377 | .208 | .302 | .302 | .358 | .340 | .151 | .302 | .264 |
| 11 | .302 | .302 | .377 | .453 | .377 | .321 | .358 | .302 | .264 | .189 | .264 | .377 |
| 12 | .302 | .340 | .377 | .283 | .358 | .377 | .377 | .321 | .226 | .094 | .283 | .491 |
| 13 | .415 | .453 | .491 | .208 | .358 | .321 | .434 | .340 | .226 | .113 | .189 | .453 |
| 14 | .340 | .396 | .415 | .264 | .340 | .453 | .453 | .340 | .189 | .170 | .226 | .415 |
| 15 | .415 | .415 | .358 | .321 | .283 | .377 | .415 | .453 | .358 | .226 | .226 | .396 |
| 16 | .283 | .377 | .340 | .264 | .264 | .377 | .472 | .415 | .245 | .264 | .340 | .321 |
| 17 | .358 | .340 | .340 | .264 | .245 | .283 | .396 | .340 | .170 | .245 | .226 | .321 |
| 18 | .472 | .396 | .302 | .264 | .245 | .340 | .396 | .302 | .189 | .132 | .302 | .358 |
| 19 | .453 | .396 | .434 | .151 | .377 | .358 | .566 | .358 | .358 | .208 | .358 | .358 |
| 20 | .340 | .377 | .377 | .226 | .396 | .264 | .434 | .189 | .245 | .226 | .170 | .321 |

Table 3. (Concluded)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | .321 | .264 | .358 | .283 | .264 | .358 | .434 | .302 | .208 | .226 | .264 | .302 |
| 22 | .283 | .302 | .302 | .340 | .264 | .264 | .321 | .264 | .170 | .208 | .302 | .302 |
| 23 | .396 | .358 | .321 | .208 | .302 | .358 | .377 | .302 | .057 | .226 | .283 | .340 |
| 24 | .491 | .434 | .358 | .321 | .302 | .415 | .340 | .283 | .264 | .245 | .302 | .302 |
| 25 | .321 | .434 | .302 | .340 | .283 | .566 | .396 | .264 | .208 | .151 | .245 | .434 |
| 26 | .358 | .302 | .453 | .283 | .321 | .453 | .415 | .208 | .283 | .208 | .321 | .264 |
| 27 | .358 | .358 | .491 | .453 | .340 | .245 | .264 | .340 | .358 | .132 | .396 | .283 |
| 28 | .377 | .358 | .245 | .377 | .264 | .358 | .453 | .283 | .358 | .245 | .321 | .396 |
| 29 | .283 | .358 | .302 | .283 | .302 | .396 | .302 | .302 | .245 | .170 | .302 | .415 |
| 30 | .415 | | .377 | .283 | .264 | .302 | .340 | .302 | .208 | .321 | .189 | .340 |
| 31 | .321 | | .340 | | .302 | | .415 | .245 | | .321 | | .509 |

Table 4. Probability of Cold in the Atlanta Area

COLD FACTOR = (MAXIMUM DAILY TEMPERATURE EQUAL TO OR LESS THAN 45 DEGREES FAHRENHEIT)
(HISTORICAL FREQUENCY OF OCCURRENCE BY PERCENTAGE OF DATES)

| | JANUARY | FEBRUARY | MARCH | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER | OCTOBER | NOVEMBER | DECEMBER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .358 | .189 | .113 | | | | | | | | .019 | .170 |
| 2 | .415 | .170 | .170 | | | | | | | | .000 | .113 |
| 3 | .208 | .208 | .226 | | | | | | | | .038 | .132 |
| 4 | .264 | .151 | .151 | | | | | | | | .019 | .057 |
| 5 | .283 | .151 | .113 | | | | | | | | .000 | .019 |
| 6 | .283 | .132 | .170 | | | | | | | | .000 | .113 |
| 7 | .264 | .189 | .113 | | | | | | | | .019 | .132 |
| 8 | .340 | .226 | .151 | | | | | | | | .019 | .170 |
| 9 | .358 | .189 | .094 | | | | | | | | .019 | .189 |
| 10 | .302 | .226 | .057 | | | | | | | | .019 | .189 |
| 11 | .302 | .226 | .075 | | | | | | | | .038 | .226 |
| 12 | .264 | .170 | .075 | | | | | | | | .057 | .245 |
| 13 | .377 | .113 | .075 | | | | | | | | .019 | .226 |
| 14 | .226 | .151 | .094 | | | | | | | | .038 | .283 |
| 15 | .283 | .226 | .075 | | | | | | | | .075 | .264 |
| 16 | .283 | .283 | .038 | | | | | | | | .057 | .208 |
| 17 | .226 | .132 | .000 | | | | | | | | .057 | .208 |
| 18 | .264 | .113 | .019 | | | | | | | | .057 | .245 |
| 19 | .264 | .189 | .000 | | | | | | | | .094 | .321 |
| 20 | .264 | .264 | .038 | | | | | | | | .038 | .283 |

Table 4. (Concluded)

| | | | | | |
|---|---|---|---|---|---|
| 21 | .264 | .132 | .057 | .057 | .245 |
| 22 | .264 | .189 | .000 | .094 | .170 |
| 23 | .321 | .151 | .019 | .094 | .264 |
| 24 | .321 | .132 | .019 | .075 | .245 |
| 25 | .321 | .189 | .019 | .170 | .321 |
| 26 | .208 | .151 | .019 | .151 | .245 |
| 27 | .302 | .245 | .057 | .132 | .208 |
| 28 | .283 | .113 | .000 | .189 | .283 |
| 29 | .302 | .154 | .000 | .094 | .358 |
| 30 | .170 | | .000 | .094 | .302 |
| 31 | .208 | | .000 | | .245 |

NOTE: COLD DAYS WERE ALSO RECORDED IN APRIL AND OCTOBER FROM 1918 THROUGH 1970 AS INDICATED BELOW:

| APRIL DATE | RECORDED YEAR | OCTOBER DATE | RECORDED YEAR |
|---|---|---|---|
| 1 | 1931 | 23 | 1937 |
| 3 | 1936 | 26 | 1926 |
| 10 | 1918 | 30 | 1925 |
| 11 | 1918 | 31 | 1925 AND 1930 |

rain, $E(R)$, and for the expected number of days of cold, $E(C)$; the expected number of days of bad weather, $E(X)$, for an activity was defined as

$$E(X) = E(R + C) = E(R) + E(C).$$

This expression is based upon the assumption that the events of rain and cold are mutually exclusive. From such an assumption it follows that

$$P(\text{Rain} \cup \text{Cold}) = P(\text{Rain}) + P(\text{Cold}).$$

Although the two events are actually independent, the assumption that they are mutually exclusive greatly simplifies the computations without seriously affecting the accuracy of the results.

The expected number of days of rain or cold must be combined with a factor that represents the Loss of Efficiency due to Weather (LEW) which was defined as the percent decrease in the efficiency of working on an individual project activity due to rain or cold. This is assigned to each activity based on the discretion and experience of the contractor. The LEW assigned will, in some cases, depend not as much on the type activity as it will on the location of the project site and where in the network the activity is located. For example, weather will have more of an adverse effect on pouring a concrete parking area than it will on pouring a concrete floor in a partially enclosed building. Hypothetical LEW factors for individual activities in the sample project are presented in Table 5.

The LEW factors for rain and cold are combined with the probabilities of rain and cold to determine the number of days to be added to the original estimated duration of each activity. The number of days to be

Table 5. Loss of Efficiency Due to Weather (LEW) Factors for Sample Project

| Pred Number | Succ Number | Description | LEW Rain | LEW Cold |
|---|---|---|---|---|
| 1 | 2 | MOVE IN AND SETUP LAYOUT | .0 | .0 |
| 2 | 3 | MACH EXCAVATION W. SIDE | .7 | .3 |
| 3 | 4 | DRILL CASSIONS | .6 | .2 |
| 3 | 7 | FORM/POUR WEST RT. WALL | .5 | 1.0 |
| 3 | 9 | POUR SET BED | .5 | 1.0 |
| 3 | 10 | MACH EXCAVATION E. SIDE | .7 | .3 |
| 4 | 5 | POUR AND FINISH CASSIONS | .5 | 1.0 |
| 4 | 7 | EXCAVATE/POUR GR. BEAMS | .5 | 1.0 |
| 4 | 10 | DRILL/SET (H) PILES | .6 | .2 |
| 5 | 6 | SET AB AND BASE PLATES | .2 | .0 |
| 5 | 8 | POUR ELEVATOR BASE | .5 | 1.0 |
| 6 | 12 | ERECT STR. STEEL TOWER | .6 | .2 |
| 6 | 14 | POUR CORE SLAB | .5 | 1.0 |
| 7 | 8 | FORM/POUR A-LINE RT WALL | .5 | 1.0 |
| 8 | 6 | FORM/POUR WING WALLS | .5 | 1.0 |
| 9 | 10 | POUR PRECAST LAGGING | .5 | 1.0 |
| 10 | 11 | SET STR. STEEL KICKERS | .2 | .0 |
| 11 | 6 | EXCAVATE/SET PRECAST LAG | .7 | .3 |
| 12 | 13 | INSTALL MET DECK, FLOOR 1 | .6 | .2 |
| 12 | 18 | FIREPROOF COLS AND BEAMS | .4 | .2 |
| 12 | 19 | METAL STAIRS, GROUND TO 1 | .4 | .1 |
| 12 | 26 | ERECT PARK DECK STEEL | .6 | .2 |
| 12 | 34 | ELEVATOR PLUNGER & RAILS | .2 | .1 |
| 13 | 15 | INSTALL MET DECK, FLOOR 2 | .6 | .2 |
| 13 | 18 | ELEC IN BSMT/MAIN CD RUN | .1 | .1 |
| 13 | 22 | POUR FLOOR 1 | .5 | 1.0 |
| 13 | 25 | MECH EQP BSMT/MAIN DUCTS | .2 | .1 |

Table 5. (Continued)

| Pred Number | Succ Number | Description | LEW Rain | LEW Cold |
|---|---|---|---|---|
| 14 | 13 | MASONRY IN CORE | .5 | 1.0 |
| 15 | 16 | INSTALL MET DECK, FLOOR 3 | .6 | .2 |
| 16 | 17 | INSTALL MET DECK, FLOOR 4 | .6 | .2 |
| 17 | 18 | INSTALL ROOF DECK | .6 | .2 |
| 17 | 34 | DRYWALL IN ELEV CORE | .0 | .0 |
| 18 | 35 | PARAPET/WINDOWWALL, FL 4 | .0 | .1 |
| 18 | 48 | INSTALL SKYLITES | .6 | .2 |
| 19 | 20 | METAL STAIRS, FL 1 TO 2 | .4 | .1 |
| 20 | 21 | METAL STAIRS, FL 2 TO 3 | .4 | .1 |
| 21 | 17 | METAL STAIRS, FL 3 TO 4 | .4 | .1 |
| 22 | 23 | POUR FLOOR 2 | .5 | 1.0 |
| 23 | 24 | POUR FLOOR 3 | .5 | 1.0 |
| 24 | 18 | POUR FLOOR 4 | .5 | 1.0 |
| 25 | 48 | INSTALL MECH EQUIP ROOF | .5 | .1 |
| 26 | 27 | LAY STEEL PARK DECK | .6 | .2 |
| 27 | 28 | POUR PARK DECK | .5 | 1.0 |
| 28 | 29 | DEMOLISH OLD BUILDING | .2 | .1 |
| 29 | 30 | INSTALL STORM DRAINAGE | .7 | .3 |
| 30 | 31 | LAY BLACKTOP PAVING | .8 | 1.0 |
| 31 | 32 | PAINT PARKING STRIPS | 1.0 | .1 |
| 32 | 33 | LANDSCAPE | .8 | .1 |
| 33 | 48 | CLEANUP OUTSIDE | .2 | .1 |
| 34 | 48 | INSTALL ELEVATOR | .0 | .0 |
| 35 | 36 | INSTALL CEILING GRID, FL 4 | .0 | .0 |
| 35 | 37 | HM FRAMES & WD DOORS, FL 4 | .0 | .0 |
| 35 | 38 | INSTALL OVERHEAD ELEC, 4 | .0 | .0 |
| 35 | 39 | INSTALL DUCTWORK, FLOOR 4 | .0 | .0 |
| 35 | 40 | INSTALL ROUGH PLUMBING, 4 | .0 | .0 |
| 35 | 46 | WINDOWWALL FLOORS 3,2,1 | .4 | .1 |
| 35 | 48 | ROOFING AND SHEET METAL | .6 | .2 |

Table 5. (Concluded)

| Pred Number | Succ Number | Description | LEW Rain | LEW Cold |
|---|---|---|---|---|
| 36 | 37 | INSTALL DRYWALL, FLOOR 4 | .0 | .0 |
| 37 | 41 | INSTALL CEILING TILE, FL 4 | .0 | .0 |
| 37 | 42 | INSTALL CERAMIC TILE, FL 4 | .0 | .0 |
| 37 | 44 | MILLWORK, FLOOR 4 | .0 | .0 |
| 37 | 45 | CONNECT MECH SYSTEM, FL 4 | .0 | .0 |
| 39 | 37 | INSTALL DIFFUSERS, FL 4 | .0 | .0 |
| 41 | 44 | INSTALL ELEC FIXTURES, 4 | .0 | .0 |
| 42 | 43 | SET PLUMBING FIXTURES, 4 | .0 | .0 |
| 43 | 44 | INSTALL TOILET ACC., FL 4 | .0 | .0 |
| 44 | 47 | PAINT AND COVER WALL, FL 4 | .0 | .0 |
| 44 | 48 | LAY FLOOR COVERING, FL 4 | .0 | .0 |
| 45 | 48 | CHECK & BAL MECH SYSTEM | .0 | .0 |
| 47 | 48 | CLEANUP & PUNCH LIST, FL 4 | .0 | .0 |
| 48 | 49 | INSTALL DUCTWORK, FLS 321 | .0 | .0 |
| 48 | 50 | INSTALL OVERHEAD ELEC 321 | .0 | .0 |
| 48 | 53 | INSTALL ROUGH PLUMB.,321 | .0 | .0 |
| 49 | 50 | INSTALL CEILING GRID, 321 | .0 | .0 |
| 50 | 51 | INSTALL DRYWALL, 321 | .0 | .0 |
| 50 | 55 | CONNECT MECH SYS, 321 | .0 | .0 |
| 50 | 56 | INSTALL ELEC FIX., 321 | .0 | .0 |
| 51 | 52 | INSTALL CEILING TILE, 321 | .0 | .0 |
| 51 | 56 | PAINT & COVER WALLS, 321 | .0 | .0 |
| 53 | 54 | LAY CERAMIC TILE, 321 | .0 | .0 |
| 54 | 52 | SET PLUMB. FIXTURES, 321 | .0 | .0 |
| 55 | 57 | CHECK & BAL SYS, 321 | .0 | .0 |
| 56 | 57 | COVER FLOORS, 321 | .0 | .0 |
| 57 | 58 | FINAL CLEANUP | .0 | .0 |
| 58 | 59 | FINAL INSPECTION | .0 | .0 |

added is equal to the expected number of days to be lost, E(Lost), during an activity. Then, for any activity

$$\text{Days Added} = E(\text{Lost}) = LEW(\text{Rain}) \cdot E(R) + LEW(\text{Cold}) \cdot E(C).$$

The specific $p_{ir}$ and $p_{ic}$ are obtained by taking the activity early start (ES) date from the initial network computation at Appendix D and then obtaining the corresponding $p_{ir}$ and $p_{ic}$ from Tables 3 and 4.

An example of the computational method that is utilized is:

Activity Number: 2-3

Original Duration: 5.0

ES: 9 Nov 72

Correction for Rain:

$$LEW(\text{Rain}) \cdot E(R) = LEW(\text{Rain}) \cdot \sum_{j=1}^{5} p_{jr}$$

$$= (.7) \cdot (1.283) \qquad = 0.8981$$

Correction for Cold:

$$LEW(\text{Cold}) \cdot E(C) = LEW(\text{Cold}) \cdot \sum_{j=1}^{5} p_{jc}$$

$$= (.3) \cdot (.208) \qquad = \underline{0.0624}$$

Total Duration: 5.9605

Adjusted Duration: 6.0

The final adjusted duration is based upon rounding to the nearest whole or half day. Any reasonable variation in this method could be employed, if greater accuracy were deemed necessary.

It should be noted that, as one progresses through the network with these calculations, subsequent activity ES dates must be incremented by the appropriate number of days to compensate for the number of days that have been added to the durations of preceding activities. This must be done while referring to the project network and the critical path to insure that the correct number of days are added to the original ES date of each activity. If this is not done, the $p_{ir}$ and $p_{ic}$ will not be selected for the correct calendar dates corresponding to the new activity ES dates in the adjusted network. For purposes of demonstration, the sample network has been reprocessed utilizing the same PROMIS Time program and is presented in Appendix E with the same activity sort code as previously employed.

From this adjusted network it can be seen that the critical path has shifted from activities 1-2-3-4-5-8-6-12-13-18-35-36-37-41-44-47-48-49-50-51-56-57-58-59 to activities 1-2-3-4-5-8-6-$\binom{12}{14}\overset{*}{-}$13$\overset{*}{-}$22$\overset{*}{-}$23$\overset{*}{-}$24$\overset{*}{-}$18-35-36-37-41-44-47-48-49-50-51-56-57-58-59, where *'s denote changes. The adjusted network has three branches that are subcritical by an amount of less than three days of slack time. In a project of this duration these subcritical paths, at least, require the same attention as does the critical path. In addition, the early finish (EF) date of 22 April 1974 in the original network increased to 22 May 1974 in the adjusted network. This increase represents the addition of five weeks to the original duration of 76 weeks.

Other methods could be employed to provide a weather adjustment for the project network. One possibility might be to use a reduced number of working days per week during periods that have a high probability of bad weather to make the initial network calculations. Although this might give a more rapid approximation for the duration of the adjusted network, it would not only be indeterminably inaccurate but would also indiscriminately increase the duration of activities that were not weather sensitive. Another possibility might be the combination of the two network computations to produce an adjusted network initially. However, the author feels that it is imperative for a contractor to start with an unadjusted network which can be used as a basis for evaluating any subsequent adjustments that are made to the network. Other alternatives also exist; however, the method which has been developed appears to offer a good balance between accuracy and a reasonable speed of calculation.

At this point it should be noted that, when one or more days are added to the duration of an activity, the probability of rain or cold on the added day or days should also be considered. This would require the continual recalculation of the days to be added and would result in an infinite series. Consequently, this problem is ignored during application of this method by merely making the calculation once to determine the number of days to be added to an activity, regardless of the original duration of the activity.

This theoretical deficiency is reconciled by the fact that the above method for predicting the expected number of days of rain or cold in the distant future is objective in nature and is a great improvement over present techniques involving subjective analysis. Since the infinite series problem is avoided, the number of days to be added to an activity through this method will tend to be biased on the conservative, or low, side. However, there is an opposite influence from two other sources.

The number of days will tend to be biased on the high side, because the events of rain and cold were assumed to be mutually exclusive when, in fact, they can occur together. In addition, some activities have LEW factors that sum to a number greater than 1.0. This implies that the total loss of efficiency from rain and cold is greater than 100 percent which is impossible and tends to bias the number of days on the high side. The net result of these different biases is not considered to be significant.

In summary, weather and various contingencies, as mentioned in the previous section of this chapter, must be analyzed for each project. When it is appropriate, realistic and objective adjustments must be made in the project duration and/or cost prior to formulating the competitive bid.

## Applying Bidding Strategy

"Historically, many more contractors have probably been hurt as a result of poor bidding practices than have been hurt by poor building practices" (25). This statement emphasizes the importance of bidding. As Mr. William R. Park, senior engineering economist at Midwest Research Institute in Kansas City, Missouri, said (13):

> Anyone can bid low enough to get a job, or high enough to insure a profit if he does get a job. It is the area between the extremes of unrealistically low and unachieveably high markups that skillful management methods must be employed to insure an effective competitive strategy.

Without sufficient well-founded successful bids a construction company will be committed below its potential. This situation may cause a contractor to bid a project below cost to hold his organization together, to keep his supervisors or equipment busy, or for any number of reasons. For example, if a contractor believed that there would not be any profitable projects on which to bid during the next X months, he might determine that it would be less unprofitable to take a job for X months on which he would lose $10,000 as opposed to taking no job and having to pay $20,000 in overhead expenses during the same period of X months. Although taking a job below cost may seem advisable in this and other situations, such a course of action is not recommended. This position is supported by Mr. Charles Snepp (23), who stated that, if a contractor is heavily committed in undesirable projects, he will not have the time to locate or handle desirable ones. Once a contractor takes his first job below cost, he has started down a rocky road from which it is difficult to turn. Consequently, it is assumed in this study that a contractor will not consider such a course of action.

The competitive bid of a general contractor is critical for two main reasons. It determines whether or not his bid will be successful, and it determines his margin of profit. Mr. Emmett H. Karrer (14) said, "If a contractor is to remain in business, he must make a profit on his work." This fundamental statement apparently has been forgotten by some contractors. Not only should a margin of profit be included in the bid, but methods should also be sought whereby it may be increased once the contract has been awarded. It should be noted that it is partially this process of awarding contracts to the lowest bidder that has caused the construction industry to have the lowest margin of net profit of all other industries.

Bidding strategy, as developed in this chapter, is a method through which a contractor may determine his expected profit on a project and the corresponding probability of his being the low bidder. It is a means of obtaining an advantage over competitors not only through intuition and experience but also through the use of quantitative analysis methods that utilize statistics and mathematics.

To employ bidding strategy a contractor must have some basic data on his bidding competitors. Greater amounts of data and more accurate information on them will make the strategy even more effective. The majority of these data are obtained from past bids in which the contractor was involved with various competitors. It is possible to ascertain their past bids through announcements that are made when many of these contracts are awarded. Obviously, this represents a dynamic environment where personnel changes, experience, etc. will affect the behavior of a competitor. Consequently, all data must be up-dated frequently, if a contractor is to be able to reasonably predict the behavior patterns of his competitors.

In employing bidding strategy as a step in project evaluation, it is assumed that a contractor desires a method that is quick and easy to use and achieves an acceptable degree of accuracy without requiring knowledge of advanced mathematics or calculus. The method to be developed satisfies these requirements. In addition, it is realized that a contractor may not have sufficient data on all potential projects to facilitate the use of an identical procedure on each. Consequently, the method that is presented consists of five different procedures for determining an optimum bid with its associated expected profit. In each procedure it is assumed that all competitors will arrive at approximately the same cost figure for each project. The basis for the first four procedures is presented by Rubey and Milner (20).

Procedure Number 1

This procedure can be employed in two different situations: (1) the contractor has no knowledge about the number of bidders or who they are and desires to beat his competitors and (2) the contractor is a lone bidder and is concerned about the project owner's accepting his bid. In either case, the strategy is the same, since the contractor must estimate the probability of being awarded the contract for a specific bid to determine his expected profit. If the bid price is too high, the probability of being awarded the contract is zero. Conversely, if it is too low, the probability is one. Between these two extremes are other bid prices of which each has an associated probability of being successful. Although these probabilities may be completely subjective, this procedure is consistent and makes explicit the normal procedure of formulating intuitive decisions about bidding.

The above reference to bid levels and the associated probabilities can be stated as a cumulative probability distribution. Using the estimated cost figure of c = \$1,148,500 from the sample project in Appendix B and assuming the following cumulative distribution, the procedure can be demonstrated. The terms which are used are: $x_i$ = a bid of a stated size; $p_i$ = the corresponding probability of no lower bid, i.e., of winning the contract; and $P(x_i)$ = the probability that the given bid is submitted, i.e., $P(x_i) = p_i - p_{i+1}$. It should be noted that $p_i$ is the probability that the owner will accept a given bid from a lone bidder. This probability could be equal to one for several consecutive bids and then drop to zero for the remaining higher bids. In addition, $p_i$ is the probability that a given bid will win, if it is submitted by a contractor when he has no knowledge about his competition. In the demonstration below, the unknowledgeable contractor and the lone bidder are assumed to utilize the same $p_i$, although the $p_i$'s can be different.

| $i$ | $x_i$ | $p_i$ | $P(x_i)$ |
|---|---|---|---|
| 1 | 1,108,500 | 1.00 | 0.07 |
| 2 | 1,148,500 | 0.93 | 0.15 |
| 3 | 1,188,500 | 0.78 | 0.32 |
| 4 | 1,228,500 | 0.46 | 0.17 |
| 5 | 1,268,500 | 0.29 | 0.16 |
| 6 | 1,308,500 | 0.13 | 0.13 |
| 7 | 1,348,500 | 0.00 | 0.00 |
| | | | 1.00 Total |

The respective expected profits, $E(P_i)$, are determined from the relationship $E(P_i) = p_i \cdot (x_i - c)$, which produces the following results:

| $i$ | $E(P_i)$ |
|---|---|
| 1 | -$40,000 |
| 2 | $0 |
| 3 | $31,200 |
| 4 | $36,800 |
| 5 | $34,800 |
| 6 | $20,800 |
| 7 | $0 |

The maximum expected profit is $36,800 and occurs at a bid of $1,188,500. This is the bid which the contractor should submit. It will yield a profit of approximately 3.1 percent.

Procedure Number 2

This procedure is utilized when the contractor knows neither the identity nor the number of his competitors, although he does know that he is not a lone bidder. Initially, the contractor must develop an estimate of the number of his competitors. The importance of this number can be seen in the hypothetical graph in Figure 7, where it is apparent that expected profit decreases as the number of competitors increases. Any contractor can develop such a graph from his own data and experience.

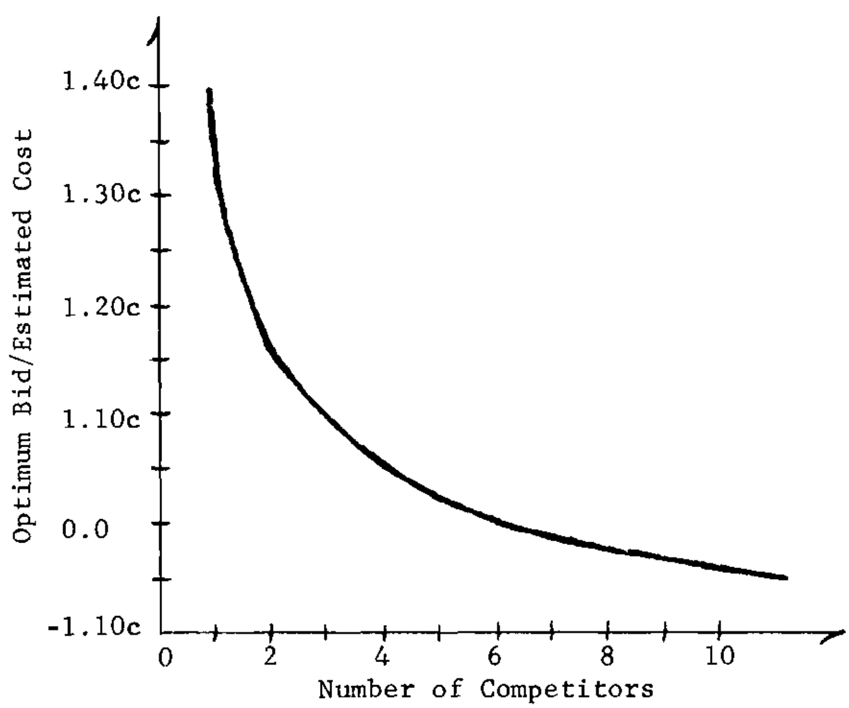



Figure 7. Effect of Number of Bidders

To develop an estimate of the number of competitors, a contractor should consider the size of the contract, as there may be a correlation between its size and the number of bidders. From past projects this number can be plotted against cost estimates to obtain a distribution to which a curve or straight line may be fitted. Figure 8 (20) is an example of the use of linear regression on the data to produce a straight line from which the contractor may obtain an estimate of the number of competitors by intersecting the horizontal axis at a point equal to his estimated project cost. However, this method is theoretical, and a contractor may feel that it is of little use. Not only may he bid on projects that vary greatly in size, but he may also find that the number of bidders varies only slightly between four and ten, regardless of the size of the project.

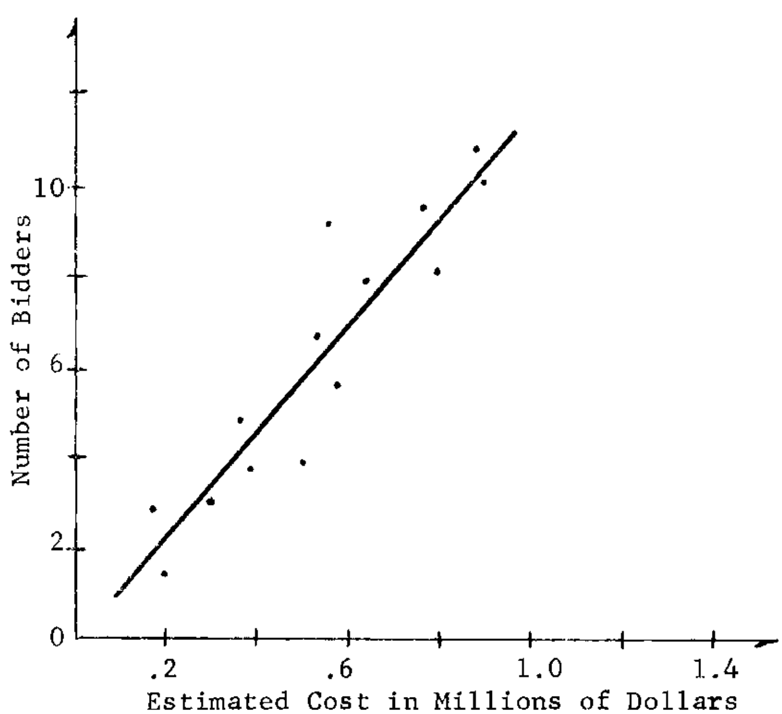



Figure 8. Estimated Number of Bidders

Lacking specific information about any of the competitors makes it necessary to introduce the concept of an average bidder. To obtain data for this bidder, the contractor must use the data collected from all past projects on ratios, R, of competitor's bids to the contractor's cost estimates. For example, the competitor's bid divided by the contractor's cost estimate equals $R_i$, and $R_i$ occurred N times. This frequency of occurrence data is consolidated into a single probability distribution from which the average cumulative probability distribution is obtained. The latter distribution gives the probability that a specific bid, represented by $R_i$, will be less than the bid of the average competitor.

Assuming that the number of competitors has been estimated at n = 5 and letting $\bar{x}$ = the bid of the average competitor, the relationship $P(x_i < \bar{x}_i) = (p_i)^n$ yields the following figures:

| $i$ | $R_i$ | $p_i$ | $P(x_i < \bar{x}_i)$ |
|---|---|---|---|
| 1 | 0.89 | 1.00 | 1.00 |
| 2 | 0.99 | 0.95 | 0.77 |
| 3 | 1.09 | 0.89 | 0.56 |
| 4 | 1.19 | 0.75 | 0.24 |
| 5 | 1.29 | 0.53 | 0.04 |
| 6 | 1.39 | 0.32 | 0.00 |
| 7 | 1.49 | 0.20 | 0.00 |
| 8 | 1.59 | 0.07 | 0.00 |
| 9 | 1.69 | 0.03 | 0.00 |
| 10 | 1.79 | 0.00 | 0.00 |

The respective $E(P_i)$ are obtained from the equation $E(P_i) = P(x_i < \bar{x}_i) \cdot (R_i c - c)$.

| $i$ | $E(P_i)$ |
|---|---|
| 1 | -.1100c |
| 2 | -.0077c |
| 3 | .0504c |
| 4 | .0456c |
| 5 | .0116c |
| 6 | .0000c |
| 7 | .0000c |
| 8 | .0000c |
| 9 | .0000c |
| 10 | .0000c |

Thus, the maximum expected profit is 0.0504c or $57,884, which corresponds to a bid of 1.09c or $1,251,865.

Procedure Number 3

This procedure is employed when the contractor does not know the identity of his competitors but does know their number. Consequently, the format of procedure number 2 can be utilized by deleting the step in which the estimate of the number of competitors is obtained, since this number is given.

Procedure Number 4

This procedure is used when the contractor knows both the identity and the number of his competitors. For each competitor, the appropriate bid data are utilized to determine the probability that the contractor's bid is less than the bid of the particular competitor. For two competitors, A and B, the following information might be obtained:

| $i$ | $R_i$ | $P(x_i < x_{Ai})$ | $P(x_i < x_{Bi})$ |
|---|---|---|---|
| 1 | 0.89 | 1.00 | 1.00 |
| 2 | 0.99 | 0.98 | 0.94 |
| 3 | 1.09 | 0.92 | 0.86 |
| 4 | 1.19 | 0.79 | 0.72 |

| | | | |
|---|---|---|---|
| 5 | 1.29 | 0.49 | 0.45 |
| 6 | 1.39 | 0.17 | 0.19 |
| 7 | 1.49 | 0.06 | 0.05 |
| 8 | 1.59 | 0.02 | 0.03 |
| 9 | 1.69 | 0.00 | 0.00 |

To obtain the probability that the contractor's bid is less than the bids of both A and B, the product of the separate probabilities is formed. This becomes the following expression:

$$P\{(x_i < x_{Ai}) \cap (x_i < x_{Bi})\} = P(x_i - x_{Ai}) \cdot P(x_i - x_{Bi})$$

The $E(P_i)$ is determined in the same manner that was explained in procedure number 2.

| $i$ | $P\{(x_i < x_{Ai}) \cap (x_i < x_{Bi})\}$ | $E(P_i)$ |
|---|---|---|
| 1 | 1.00 | -.1100c |
| 2 | 0.92 | -.0092c |
| 3 | 0.79 | .0711c |
| 4 | 0.57 | .1083c |
| 5 | 0.22 | .0638c |
| 6 | 0.03 | .0117c |
| 7 | 0.00 | .0000c |
| 8 | 0.00 | .0000c |
| 9 | 0.00 | .0000c |

Although this procedure has been demonstrated for only two competitors, it may be extended for any number, if the required data are available. Of course, as the number of bidders increases, the expected profit decreases. In the above example, the maximum expected profit is 0.1083c or $124,382, which corresponds to a bid of 1.19c or $1,366,715.

## Procedure Number 5

This last procedure is presented by Mr. William R. Park (18) and is based upon graph analysis. It can be employed under the same conditions as were procedures 1, 2, 3, and 4.

The graph in Figure 9 illustrates how the optimum bid is found and shows the probability of a contractor's underbidding one of his principal competitors by placing any specific bid. The solid curve represents the probability of underbidding the particular competitor, and the dotted curve represents the expected profit from an associated bid. Zero expected profit occurs when the bid equals the estimated cost. Bids below that point have a negative expectation, and those above it reach a maximum value, e.g., 0.11c for a bid of 1.20c with an associated probability of success of 0.44, and then approach zero again as the bid gets unreasonably high. The use of this graph is similar to procedure number 1.

Graphs resembling Figure 9 can be developed for any competitor on whom there are sufficient data. Information from each graph can be summarized like the example in Table 6 (18) in which is presented the probability of underbidding five competitors and the corresponding expected profit. This is similar to procedure number 4.

A graphical method can also be used in lieu of procedures number 2 and 3. The same technique as was demonstrated in procedure number 2 must be utilized to determine the estimated number of bidders. A graph is developed for the average bidder from data on all competitors and is employed in the same manner as explained in the above paragraph.

<u>Summary</u>

The procedures that have been developed for a competitive bidding strategy will provide contractors with a guide for:

1. Determining the probability of being the low bidder on a particular project.

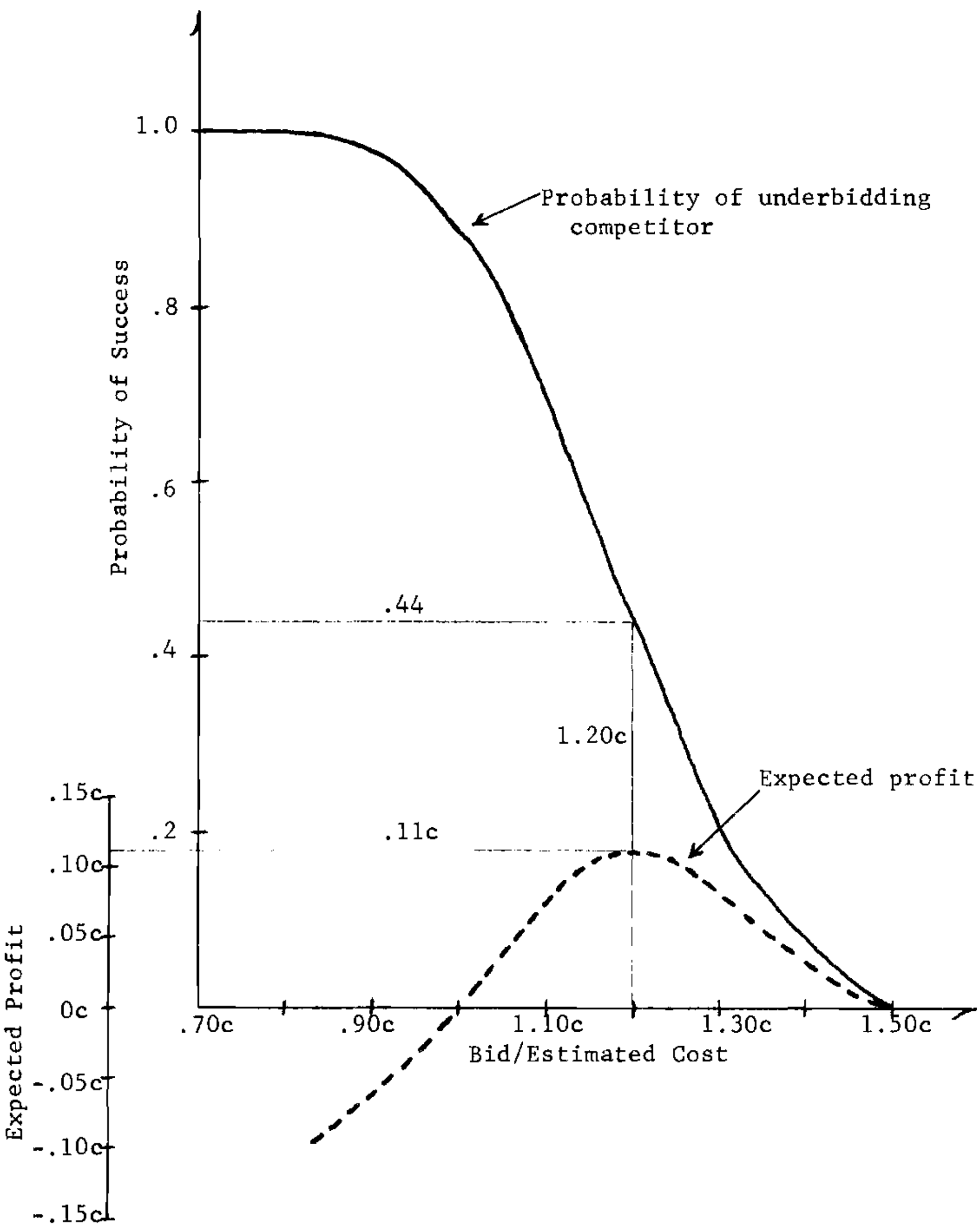



Figure 9. Optimum Expected Profit

Table 6. Example of Expected Profit Determination

| $i$ | $R_i$ | $p_A$ | $p_B$ | $p_C$ | $p_D$ | $p_E$ | $p_{All}$ | $E(P_i)$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.00 | .83 | .77 | .83 | .71 | .78 | .294 | .00000c |
| 2 | 1.01 | .81 | .73 | .80 | .68 | .76 | .245 | .00245c |
| 3 | 1.02 | .80 | .70 | .77 | .65 | .73 | .204 | .00408c |
| 4 | 1.03 | .78 | .66 | .73 | .61 | .70 | .160 | .00480c |
| 5 | 1.04 | .76 | .62 | .70 | .58 | .68 | .130 | .00520c |
| 6 | 1.05 | .74 | .59 | .66 | .54 | .65 | .101 | .00505c |
| 7 | 1.06 | .72 | .56 | .61 | .50 | .61 | .075 | .00450c |
| 8 | 1.07 | .70 | .54 | .56 | .47 | .58 | .057 | .00399c |
| 9 | 1.08 | .68 | .52 | .51 | .43 | .56 | .043 | .00344c |
| 10 | 1.09 | .66 | .49 | .46 | .40 | .53 | .032 | .00288c |
| 11 | 1.10 | .64 | .47 | .40 | .37 | .51 | .023 | .00230c |
| 12 | 1.11 | .62 | .45 | .34 | .34 | .48 | .016 | .00176c |
| 13 | 1.12 | .60 | .44 | .29 | .31 | .46 | .011 | .00132c |
| 14 | 1.13 | .57 | .42 | .25 | .29 | .44 | .008 | .00104c |
| 15 | 1.14 | .55 | .40 | .21 | .26 | .41 | .005 | .00070c |
| 16 | 1.15 | .53 | .38 | .17 | .24 | .39 | .003 | .00045c |

NOTE: In this example of bidding against all five competitors, the maximum expected profit is .00520c which results from a bid of 1.05c.

2. Determining the maximum expected profit for a particular project.

3. Identifying projects for which there is an unacceptably low probability of being the low bidder.

Although a contractor desires to maximize his expected profit by submitting the "optimum" bid, his expected margin of profit on any bid is determined by subtracting the estimated project cost from the bid price.

## Investigating the Cash Flows

The determination that a project has a desirable margin of profit is not an end in itself. The profit may be expressed in dollars or as a percentage and is rather deceptive, unless two additional factors are also investigated: first, the amount and timing of the cash flows during the construction of the project and second, the degree of risk associated with the profit. For example, a project with a small return having a low risk may be preferable to a large return at a high risk. To clarify the discussion that is to ensue, a brief description of the general cash flows of the contractor for a typical construction project should prove beneficial.

The contractor receives funds from the project owner in accordance with the provisions of the contract agreement. A standard stipulated sum agreement states that (8):

> The Contractor, not latter than the fifth day of every month, should present to the Engineer (i.e., the architect) an invoice covering the total quantities under each major element of the work that has been completed from the start of the project up to and including the last day of the preceding month. The invoice should include an allowance for the cost of material

required in the project that has been delivered at the site but has not as yet been incorporated or installed in the work.

Not later than on the fifteenth day of the month the Owner should, after deducting previous payments made, pay to the Contractor ninety percent of the amount of the invoice. The retained ten percent may be held by the Owner until the value of the project completed at the end of any month equals fifty percent of the total amount, at which time, if satisfactory progress is being made, the remaining monthly payments may be made in full (or 95 percent) for the work completed during each month. Payments for work under subcontracts to the general contract should be subject to the same conditions after the work under the subcontract involved has been fifty percent completed.

Final payment of all moneys due should be made within thirty days of completion and acceptance of the project, or there should be added daily interest on the amount due at the rate of six percent per annum.

To complete this description of cash flows, it must be mentioned that an accompanying disbursement of funds is simultaneously made by the contractor to subcontractors, material suppliers, and his own employees and for miscellaneous expenses. The contractor pays the subcontractors in the same manner that he is paid by the owner. Thus, for all practical purposes the subcontractors are paid by the owner. The material suppliers must be paid by the tenth of the month following delivery for the contractor to receive a cost discount. This cost to the contractor is also, in effect, borne by the owner. The personnel who are directly employed by the contractor are normally paid weekly or twice a month. The contractor must bear this and other miscellaneous costs for which, in the optimum situation, sufficient funds will be available to cover the costs from sources other than the contractor's pre-project assets. In other words, the contractor hopes to provide for such costs by "getting ahead" on the progress payments received from the owner.

In general, a contractor gets ahead by being overpaid during the early part of a project. This may be accomplished in three ways. First, the contractor may have submitted an unbalanced itemized bid in which he intentionally overestimated the cost of the initial activities and underestimated the cost of the final activities. Second, he may expend as much money as possible on the initial activities. Third, he may be overly optimistic in preparing the initial monthly payment requests which state the amount of work done to date, if his integrity, the architect, and the owner will allow such a procedure.

The degree to which a contractor is able to get ahead will affect his final profit margin and will determine the amount of working capital required by him for the project. It is imperative that a contractor make the money of others work for him by using the funds of the owner, the suppliers, and the subcontractors as much as possible. However, a contractor must have sufficient funds readily available to defray any expenses, if the requirement should arise. The importance of this statement is even more critical in light of the uncertainty that accompanies both the size and timing of these expenses. The average construction company requires working capital that is equal to approximately 20 percent of the estimated project cost (6).

Accurate cash flows for any construction project are quite difficult to develop during the pre-bid evaluation. Although a cash flow projection is sometimes required by a project owner or a bonding company, it does not seem wise for a contractor to expend an unrequired effort in developing cash flows that have such an inevitable degree of uncertainty in the amount and timing of the flows for the contractor.

More consideration must be given to the subcontractors to be involved in the project, since they share a major portion of the financial burden of any project through the ten percent retained by the contractor. Furthermore, on large projects approximately 85 percent of the work is subcontracted. The importance of subcontractors can be better appreciated by studying the following analysis of the sample project. It is recommended that a similar analysis be made by the contractor as a step in evaluating any project.

| | | |
|---|---|---|
| **Bid Price Elements:** | | |
| Subcontractor Price (81.5%) | 934,780 | |
| Contractor Cost (18.5%) | 213,720 | |
| Total Estimated Cost | | 1,148,500 |
| Profit Margin | | 40,000 |
| Bid Price | | 1,188,500 |
| **Receipts from Owner:** | | |
| Interim (assumed to be a constant 90% of full payment) | | 1,069,650 |
| Final (10% of bid price) | | 118,850 |
| Total | | 1,188,500 |
| **Disbursements by Contractor:** | | |
| Interim: | | |
| Subcontractors (90%) | 841,302 | |
| Contractor Cost | 213,720 | |
| Subtotal | | 1,055,022 |
| Final: | | |
| Subcontractors (10%) | | 93,478 |
| Total | | 1,148,500 |
| **Cash Flows:** | | |
| Interim: | | |
| Receipts | 1,069,650 | |
| Disbursements | 1,055,022 | |
| Interim Profit | | 14,628 |
| Final: | | |
| Receipts | 118,850 | |
| Disbursements | 93,478 | |
| Final Profit | | 25,372 |
| Total Profit | | 40,000 |

Several things are apparent from this analysis. First, subcontractors will perform 81.5 percent of the estimated cost of the work which is not unusual in a project of this size. Second, the total profit of \$40,000 is comprised of an interim profit of \$14,628 and a final profit of \$25,372.

The effect which the percentage of subcontracted work will have on the contractor's profit is significant and must be considered. It is obvious that a contractor can increase his profit by doing the subcontracted work himself. Although a contractor is neither as efficient nor can work as economically as a subcontractor, he could pocket some of the subcontractor's profit for himself. However, it is assumed that a contractor is indifferent between subcontracting the work and earning a slightly greater profit at a higher level of risk and work.

To determine a general expression for the effect of subcontractors: Let

$$X = Y + Z + P_T$$

where

$X$ = contract, or bid, price

$Y$ = contractor's cost

$Z$ = subcontractor price, and

$P_T$ = total profit.

The contractor's interim receipts from the owner are equal to (1 - r) percent of the contract price where r = the percent retained. The contractor desires these receipts to be greater than his interim disbursements which are comprised of his own expenses plus (1 - r) percent of the subcontractors' payments. Thus,

$$(1 - r)X > (1 - r)Z + Y$$

$$X - rX > Z - rZ + Y$$

$$X - rX > Z - rZ + X - Z - P_T$$

$$rZ > rX - P_T$$

$$Z > X - \frac{P_T}{r}$$

and,

$$Z > X - 10P_T \text{ (when } r = 10\%)$$

This relationship must exist if the interim profit figure is to be positive. In the sample project, the "Subcontractor Price" must be greater than $788,500, which is 68.7 percent of the estimated total cost. The more this figure is increased; the larger the interim profit will be. The effect of the percentage of subcontracted work on the interim profit of the sample project is summarized below:

| % Subcontracted | Interim Profit | Final Profit | Total Profit |
|---|---|---|---|
| 0.0 | -$78,850 | $118,850 | $40,000 |
| 68.7 | $0 | $ 40,000 | $40,000 |
| 100.0 | $36,000 | $ 4,000 | $40,000 |

Although the figure for total profit is the same in each case, there is actually such a significant difference in the alternatives that the latter one is clearly the most desirable. It should be noted, however, that subcontracting 100 percent of the estimated total cost of a project is unrealistic. If a contractor undertakes any project, there are certain inescapable costs, such as taxes, insurance, and building permit fees, which he must pay. Nevertheless, the $36,000 received as interim profit in the above summary not only demonstrates the financial advantage in subcontracting more of the work but also is theoretically the most attractive alternative. The attractiveness is indicated by two facts. First, this is the most positive interim profit. A contractor does not want a negative interim profit, because it would require him to use more of his own funds or to borrow greater amounts of capital to defray project expenses. Second, the time value of money makes the \$36,000 worth more than if the same amount were received as a final profit. However, the actual increase in the worth of the interim profit is impossible to calculate without a cash flow projection.

The interim profit figure is also influenced by the location of the subcontracted work in the duration of a project. This influence is caused by the time value of money and will not be calculated without a cash flow projection. Consequently, the cost of subcontracted work is assumed to be spread evenly throughout a project. In addition to the influence of the percent of subcontracted work on the interim profit, the percent of retainage held by the owner from the contractor and by the contractor from the subcontractors will also affect the interim profit. The effect of these two percentages can be shown by developing a general expression for the interim profit.

It is known that:

$$P_I = P_T - P_F$$

$$P_F = r(X - Z)$$

$$X = Y + Z + P_T$$

$$Z = s(X - P_T)$$

$$Y = (1 - s)(X - P_T)$$

where $P_T$ = total profit

$P_I$ = interim profit

$P_F$ = final profit

$X$ = bid price

$Y$ = contractor's cost

$Z$ = subcontractor price

$r$ = percent retained (assumed to be equal for contractor and subcontractor), and

$s$ = percent subcontracted.

Starting with the first known relationship:

$$
\begin{aligned}
P_I &= P_T - P_F \\
&= X - Y - Z - P_F \\
&= X - Y - Z - r(X - Z) \\
&= X - (1 - s)(X - P_T) - rX + rZ - Z \\
&= X - X + sX + P_T - sP_T - rX + (r - 1)(s(X - P_T)) \\
&= sX + P_T - sP_T - rX + rsX - sX - rsP_T + sP_T \\
&= X(s - r + rs - s) + P_T(1 - s - rs + s) \\
&= X(rs - r) + P_T(1 - rs)
\end{aligned}
$$

Using this general expression for $P_I$ and assuming $X = \$1,000,000$ and $P_T = \$40,000$, specific figures for $P_I$ were calculated for various values of $s$ at $r = .05$ and $r = .10$. The results of these calculations are presented in Table 7.

Table 7. The Effect of Two Variables on Interim Profit

| s (%) | r (%) | |
|---|---|---|
| | 5.0 | 10.0 |
| 0.0 | -10,000 | -60,000 |
| 5.0 | - 7,600 | -55,000 |
| 10.0 | - 5,200 | -50,400 |
| 15.0 | - 2,800 | -45,600 |
| 20.0 | - 400 | -40,800 |
| 25.0 | 2,000 | -36,000 |
| 30.0 | 4,400 | -31,200 |
| 35.0 | 6,800 | -26,400 |
| 40.0 | 9,200 | -21,600 |
| 45.0 | 11,600 | -16,800 |
| 50.0 | 14,000 | -12,000 |
| 55.0 | 16,400 | - 7,200 |
| 60.0 | 18,800 | - 2,400 |
| 65.0 | 21,200 | 2,400 |
| 70.0 | 23,600 | 7,200 |
| 75.0 | 26,000 | 12,000 |
| 80.0 | 28,400 | 16,800 |
| 85.0 | 30,800 | 21,600 |
| 90.0 | 33,200 | 26,400 |
| 95.0 | 35,600 | 31,200 |
| 100.0 | 38,000 | 36,000 |

The constant difference of \$2,400 for $r = .05$ stems from the general expression for $P_I$ where $r = .05$ and X and $P_T$ equal the assumed constants. Thus,

$$\begin{aligned} P_I &= 1{,}000{,}000(.05s - .05) + 40{,}000(1 - .05s) \\ &= 50{,}000s - 50{,}000 + 40{,}000 - 2{,}000s \\ &= 48{,}000s - 10{,}000 \end{aligned}$$

Each 5 percent increment of s changes $P_I$ by \$2,400. A similar analysis for $r = .10$ indicates that $P_I$ changes by \$4,800. Although these calculations would be different if the subcontracted work were concentrated in one portion of the project duration, the important thing to notice in Table 7 is the effect which a change in s or r can have on the interim profit, which has a decided influence on the attractiveness of the profit in a project.

Before developing a measure of the profit in a project, construction profits, in general, demand further attention. The average profit in the construction industry is not as low as indicated by the figures in Table 2 which are a ratio of the net profit to the contract price, or gross revenue. There are many ways in which a "profit" may be determined. The numerator may be a "before taxes" or an "after taxes" value of the net profit or gross profit. The denominator may be the contract price, the estimated cost, or the contractor's cost. A standard definition of profit is the ratio of the financial gain to the amount of capital invested.

A contractor who handles a large volume of construction work based upon the dollar value of the projects on which he was awarded the contract may have a low percentage of profit on each dollar of work. However, he may make a satisfactory or unusually large profit as a percentage of the capital which he has invested in a project. Consequently, contractor profits as a percentage of his capital investment are undoubtedly more meaningful for the construction industry.

It was previously stated that a contractor requires pre-project capital equal to approximately 20 percent of the estimated project cost. This is assumed to be true; however, there are several points which make it imperative that each contractor determine his own capital investment requirements for a project. The amount of required investment is influenced by the interim profit figure, the contractor's ability to "get ahead" on progress payments, the percentage of non-subcontracted work, and other factors.

At this point the problem is one of developing an objective evaluation of the profit in different projects that have inherent variations in duration, cost, etc. In this situation the author feels that the application of an approximate annual rate of return will provide a reasonable evaluation. The rate of return approach has several advantages over other methods for evaluating profit. The concept of the rate of return as a profit measure expressed as a percentage is easy to comprehend and directly relates to the profit goals of a construction firm. Moreover, the rate of return approach simplifies the ranking problem. Other methods such as annual cost and present worth make it difficult to rank the relative profitability and attractiveness of projects that require different capital investments for different periods of time (3). An approximation of the true rate of return must be employed, because the absence of cash flow projections precludes the use of more exact methods.

The approximate annual rate of return is applied not only to the total profit but also to the interim profit. The net size of the interim profit is all that can be determined, for it is impossible to determine the timing of the receipts without a cash flow projection. It could be assumed that this profit is received at a particular point, e.g., the mid-point, in the project duration, but such an assumption may be incorrect and is unnecessary. It is assumed, however, that the interim profit, regardless of size, is received at approximately the same point in the duration of each project. Consequently, it is the size, not the timing, that is important in analyzing the interim profit of a project. To obtain a valid comparison of the interim profit with the total profit for either the annual profit or the approximate annual rate of return, the same period of time must be used for the project duration.

The rate of return analysis is performed by using a graph similar to the one in Figure 10. The graph has one axis on which is plotted the capital investment, V, and

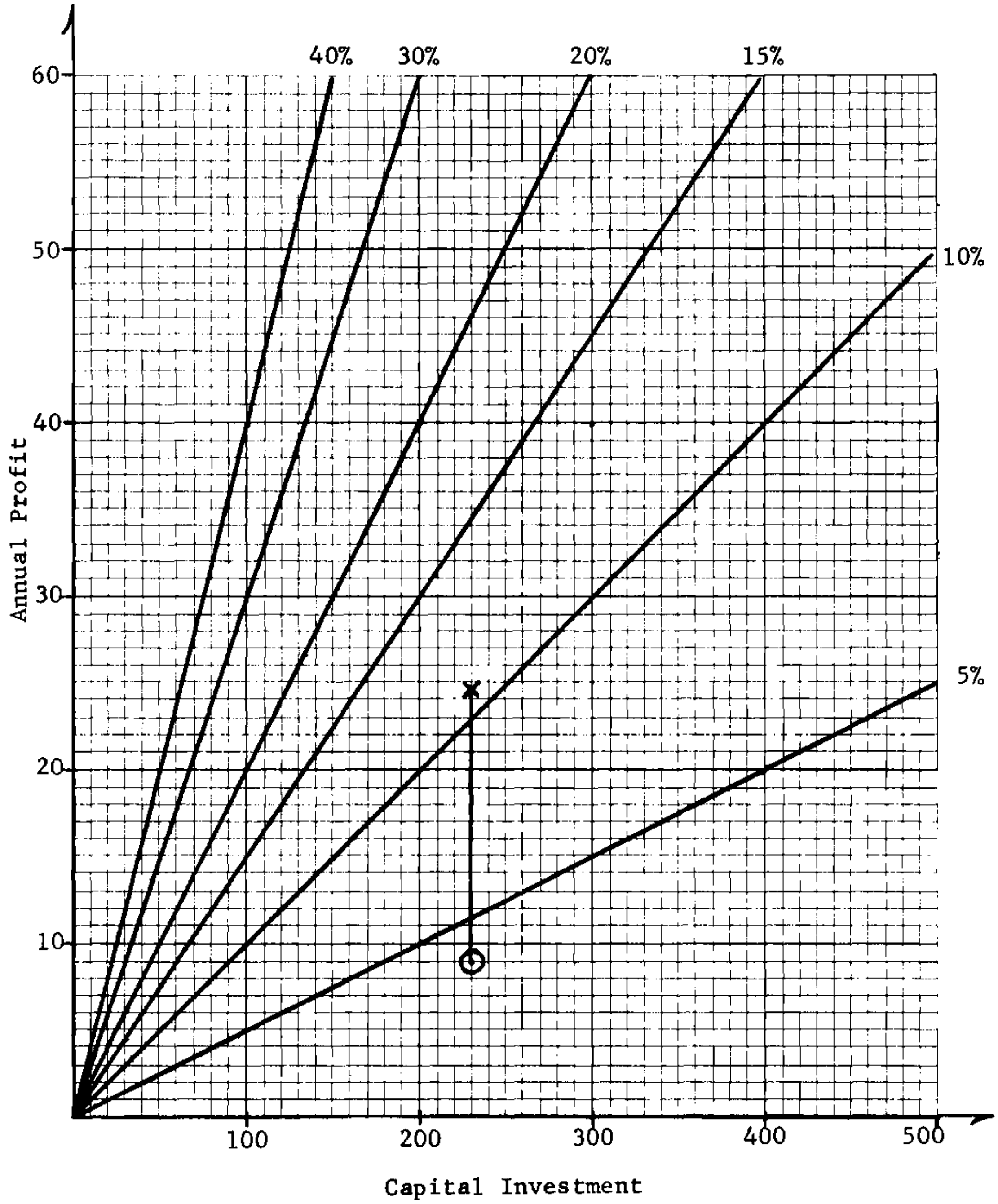
$$V = .2c$$

where c = estimated project cost.

On the other axis is plotted the annual profit for both the total profit, $P_T$, and the interim profit, $P_I$. For the annual total profit,

$$AP_T = \frac{P_T}{d_T}$$

and for the annual interim profit,




NOTE: Figures are in thousands of Dollars
X = Total Profit
O = Interim Profit

Figure 10. Graphical Analysis of Approximate Annual Rate of Return

$$AP_I = \frac{P_I}{d^+}$$

where $d^+$ = project duration in years plus 1/12 of a year for the time extension until final payment, i.e., $d^+ = d + .083$.

The intersection of V and each profit measure determines the approximate annual rate of return for the corresponding profit. This determination is facilitated by drawing iso-interest lines from the origin of the graph.

The two annual profit measures for the sample project appear in Figure 10 and were calculated as follows:

$$V = .2(1,148,500) = \$229,700$$

$$AP_T = \frac{40,000}{(81/52 + .083)} = \$24,400$$

$$AP_I = \frac{14,628}{1.638} = \$8,950$$

From the graph the approximate annual rate of return was estimated at 11 percent for the total profit and at 4 percent for the interim profit. The less distance that there is between the total and interim profits, the more desirable is the project.

Although the rates of return may be calculated, the main emphasis is on a graphical solution. A contractor may establish a cut-off percentage for profit, e.g., all projects must have a total profit greater than 5 percent, and a glance at the graph in Figure 10 will determine whether a project is attractive. However, in any project there is a certain amount of inherent risk that will also affect the attractiveness of the project. The multi-criteria scoring model which is developed in the next section evaluates the inherent risk in a project.

## Developing the Scoring Model

In the construction industry, the decision to accept or reject the opportunity to bid on a project is critical and may affect the future financial position of a firm. A contractor's initial interest in a project will be influenced by preliminary information concerning the structure, the owner, the architect, and other relevant factors. The decision to bid must be made in the two to three week period between the availability of the bid documents and the time designated for opening the bids. During this period the contractor must also allow sufficient time for the preparation of his bid. For example, the bid on a million dollar project will require approximately seven to ten days to prepare (24).

Whether the decision is right or wrong, the submission of a bid leads to a virtually irreversible process. If a contractor is the low bidder, he will be awarded the contract and must complete the work, even at a financial loss, under the provisions of the agreement, or he may default in which case the reputation of the firm will suffer severe damage. If a contractor decides not to bid on a project, he loses all opportunity to do so after the bids are opened.

The analysis in the preceding section of this chapter may lead one to believe that a project with an attractive approximate annual rate of return will be desirable. However, there are many other significant factors that influence the desirability of a project and determine the actual profit, if any, to be realized from its execution. Many of these factors can be anticipated and analyzed during the pre-bid evaluation. Although this is frequently done by contractors through an intuitive analysis of the subjective input data, the number of factors requiring consideration casts suspicion on the validity of the evaluation. This analysis could be performed by establishing criteria with which to evaluate each factor. The number of factors to be evaluated, however, demands a formal structure that will permit the independent evaluation of each factor while combining the evaluations in a logical manner. A device that integrates the use of relevant evaluation criteria during the pre-bid phase to obtain a measure for risk in the entire project is a multi-criteria scoring model.

For the project evaluation process, one might envision the use of other models, e.g., economic models, risk analysis models, and constrained optimization models such as linear or integer programming. Nevertheless, a scoring model has several advantages that dictate its use in this process. As Moore and Baker (16) state,

> Primary among these advantages is the fact that the scoring model is the only model to permit the explicit inclusion of subjective or qualitative factors that may influence the decision to undertake a project. ...Another advantage of the scoring model is the opportunity to use simple, low-cost methods of data acquisition. In situations where the uncertainty associated with a project does not permit a meaningful point estimate of performance to be made, interval estimates not only suffice but give a true picture of the accuracy of the information being used. ...Since the model builder is free to include whatever factors he finds relevant to the decision, the scoring model becomes adaptable to the conditions of data availability associated with the problem or decision situation.

In developing a scoring model for use in the construction industry to evaluate project risk, it is necessary to make several assumptions.

First, it is assumed that the reader has a sufficient knowledge of scoring models to make it unnecessary to delve deeply into the developmental theory. It is assumed that "knowledge of how a project scores with respect to one criterion contains no information regarding how the project will score relative to any other criteria" (17). It is further assumed that project performance with respect to each evaluation criterion is distributed according to the normal distribution. This final assumption demands some explanation.

The actual distributions of project performance can often be obtained by producing frequency histrograms from historical data maintained by the construction company. When insufficient information is available, subjective distributions may be obtained through experience or intuition in the company and revised as the supply of historical data is improved. However, in the absence of specific data or information to the contrary, all distributions of project performance will be assumed to be normal. This places the greatest number of projects near the center, or mean, of the distribution and places significantly good and bad projects near a tail of the distribution where such projects will receive low and high risk scores, respectively. The assumption of normality is facilitated by the fact that scoring models are rather insensitive to errors made in estimating the shape of the distribution. Furthermore, the assumption simplifies any calculations that must be performed.

The mean and standard deviation of each project performance distribution are used to partition the corresponding performance measurement scale into equal or unequal intervals. Intervals of equal width, except for the end intervals, will be used, since they simplify calculations and produce scores that are sensitive to statistically low and high levels of project performance. To obtain equal intervals, all values of project performance, to include extreme values, should be distributed symmetrically to the left and right of the mean and should correspond to the standard deviations, as demonstrated in the following example and as illustrated in Figure 11 (16):

| Performance Distribution | Performance Measurement | Score |
|---|---|---|
| Under $\mu - 1.75\sigma$ | 15 or less | 9 |
| $\mu - 1.75\sigma$ to $\mu - 1.25\sigma$ | 15 - 25 | 8 |
| $\mu - 1.25\sigma$ to $\mu - 0.75\sigma$ | 25 - 35 | 7 |
| $\mu - 0.75\sigma$ to $\mu - 0.25\sigma$ | 35 - 45 | 6 |
| $\mu - 0.25\sigma$ to $\mu + 0.25\sigma$ | 45 - 55 | 5 |
| $\mu + 0.25\sigma$ to $\mu + 0.75\sigma$ | 55 - 65 | 4 |
| $\mu + 0.75\sigma$ to $\mu + 1.25\sigma$ | 65 - 75 | 3 |
| $\mu + 1.25\sigma$ to $\mu + 1.75\sigma$ | 75 - 85 | 2 |
| Over $\mu + 1.75\sigma$ | 85 or more | 1 |

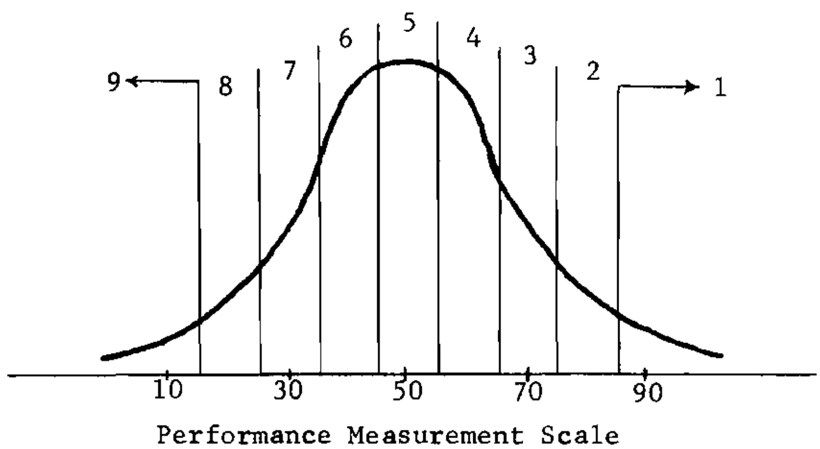



Figure 11. Scored Performance Distribution

It should be noted that the performance measurement scale can be expressed in percentages, dollars, time units, numbers, or any other measurement that adequately describes the various values that a particular level of performance may receive. In the above example, the nine measurements, if all are used, could easily have read, Terrible, Very Bad, Below Average, Average, Above Average, Good, Very Good, and Excellent.

The contractor's estimate, even from historical data, of the mean value of project performance for any criterion is subject to considerable error. Consequently, it is important that the mean value be estimated as accurately as possible and be centered on the distribution mean. If the mean value of performance is incorrectly estimated, valuable results are still possible, but the model will be unable to differentiate between certain extreme values of performance. For example, Figure 12 shows the results of a 50 percent underestimation of the performance mean. Rather than performance values being scored on the solid curve distribution, they should be scored on the dotted curve distribution. Hence, for this criterion, the model is unable to distinguish between a project having an average level of performance and one having a high level.

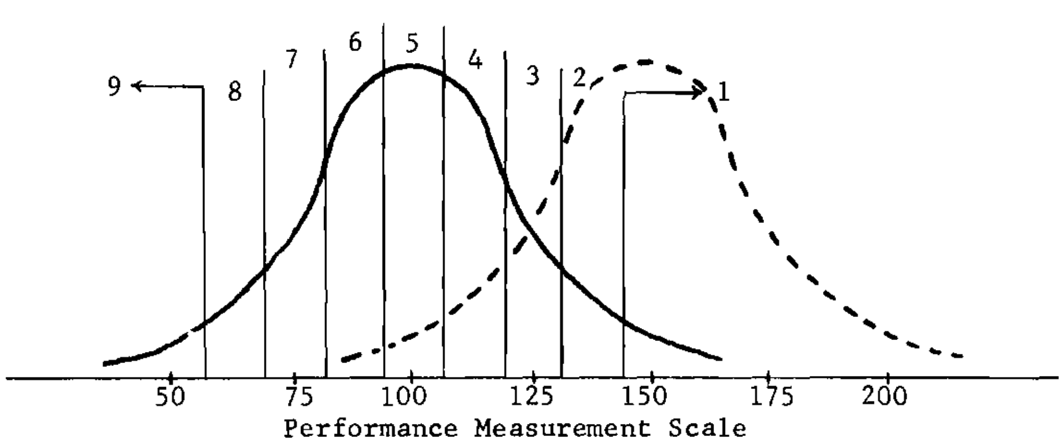



Figure 12. Error in Estimating a Performance Mean

## Criteria Selection

The first step in developing the scoring model is the consideration of the specific objectives of the construction company. Information obtained in personal interviews conducted by the author supported the hypothesis that the primary objective of most contractors is profit. To achieve this objective attractive construction projects must be selected. To select such projects appropriate criteria that are relevant to the evaluation of the risk in a construction project must be determined. The final list of criteria may vary among individual contractors.

Moore and Baker (16) describe several properties which a criteria list should possess. It should be complete; each criterion should be truly relevant and measurable; and there should be a minimum overlap between criteria. A number of criteria between five and ten is generally considered sufficient for project evaluation. Appendix F contains a list of 12 evaluation criteria for assessing the risk in a construction project. The list is arranged in no particular order and for a typical construction company is believed to be representative, based upon information assembled during this research.

The reader may question whether all of the criteria are relevant to the evaluation of the risk per se in a proposed project. Criteria D, I, J, K, and L may appear especially questionable. However, the author has extended the definition of risk (see Appendix A) to include these criteria which affect the attractiveness of a proposed project and the ability of a contractor to win the bid or undertake the project.

Performance Measurement

The second step in developing the scoring model is the formulation of a performance measure and scale, i.e., a scoring function, for each evaluation criterion. A scoring function is a process or an established relationship for each criterion that assigns a value from the scoring scale to a measure or an estimate of the project performance. A contractor may use either a point or an interval estimate for each criterion to measure project performance and may use either a discrete or a continuous scale to score that performance.

Both point and interval estimates were used to describe the project performance measures for the criteria in Appendix F. Point estimates were considered appropriate to measure quantitative criteria such as the number of bidders and the number of uncontrollable organizations. Interval estimates were utilized for all qualitative criteria and for one quantitative criterion, i.e., the amount of labor, which was expressed in percentage intervals. The preponderance of qualitative criteria in Appendix F makes the interval estimate appear most useful.

The scale selected to measure project performance cannot be more definitive than the performance values supplied by the contractor. These scales are subdivided into nine scoring intervals. Although nine is not a mandatory number, it is considered optimal by the author in this situation. Less than nine intervals decreases the discriminatory power of the scoring model and reduces the ability of the model to compensate for errors made in estimating a performance mean, while more than nine generally exceeds a person's ability to measure judgmental data (16). The same number of intervals should be used for every criterion. As mentioned earlier, the scoring intervals will be of equal width except for the end intervals that include the extreme points of each performance scale. Moore and Baker (16) suggest the use of interval widths that are "equal to one-half the estimated standard deviation of each project performance distribution function."

A discrete or a continuous scale may be used to score any measure of project performance. A discrete scale contains only integer-valued scores, while a continuous scale contains all numerical values between and inclusive of the end points. Discrete scales were used to score all measures of performance for the criteria in Appendix F, as this was considered simplier and more appropriate for these criteria.

Once it has been decided how to measure each performance distribution and to partition the scoring intervals, the appropriate quantitative or qualitative descriptions are assigned to each score, numbered one through nine. The scores for all performance measures must be selected from this same interval (1 - 9). If a criterion were scored from a different interval, e.g., (7 - 15), it would be weighted differently than the other criteria. The method for assigning criteria weights will be discussed in the following subsection of this chapter.

Although the maximum number of performance measurement descriptions is nine, there may be less. For qualitative criteria that require subjective evaluations, two or three descriptions with the corresponding scores may be sufficient for evaluation. For example, performance measures a, b, c, and d may be assigned scores of 1, 4, 6, and 9, respectively. However, a contractor is not limited to these specified scores in subjectively evaluating such a criterion. He may assign any score (1 - 9) that he considers appropriate.

Descriptive terms for the criteria in Appendix F have been assigned scores. The interval estimates which were developed to measure project performance could be made more explicit for a specific contractor. It should be realized that the risk evaluation criteria will normally be utilized by the same person in each construction company and that they may be modified to fit the particular needs of a company or individual.

Criteria Weights

The third step in developing the scoring model is the assignment of a weight to each criterion to specify its relative importance. This step is obviously based upon the assumption that all criteria are not equally important. The weight may be assigned, for example, through an exponential or a logarithmic function. However, the use of coefficients to weight the criteria will keep the mathematics at a much less complex level. Although this importance coefficient of a criterion score is constant, it may be adjusted to reflect a change in the relative importance of a criterion and in the perceived environment in which the contractor is operating.

Eckenrode (9) discusses weighting criteria by six methods which are ranking, rating, complete paired comparisons, successive comparisons, and two methods using partial paired comparisons. He determines that no significant difference exists in the developed sets of weights by using any of the methods, although the simple ranking method is the easiest to use. Regardless of the method that is employed, the weights must be carefully assigned to maintain the relative importance of the evaluation criteria.

Weights were not assigned to the criteria in Appendix F at this point in the research but were assigned during the trial application of the scoring model. The assignment of criteria weights should reflect the priorities of an individual contractor. For the author to have arbitrarily made such an assignment would have clouded the discussion that is presented in Chapter V.

Model Structure

The final step in developing the scoring model is the collection of the various criteria scores and their respective criteria weights. This will produce a dimensionless number as the score of a specific project or a portion thereof. The number is a measure of the risk in the corresponding scored portion of the project and should be interpreted accordingly by the contractor.

Two indices that may be used to form the project score from the products of each criterion score and weight are the additive index and the multiplicative index. The additive index adds the products to form the project score, while the multiplicative index multiplies the products to form the score. Although the multiplicative index produces a wider range of project scores, it tends to favor projects that are given average evaluations on all criteria over projects that are given extreme evaluations. Furthermore, the multiplicative index is more sensitive to errors that may be made in estimating the mean of the performance distribution. Consequently, the additive index will be used to produce the project score.

The model may be structured in one of several ways to produce an evaluation of the risk in a project. Regardless of the method that is used, it must be logical and must be used consistently on all projects until the method is revised. Furthermore, the method must produce an evaluation that is meaningful and can be understood by the contractor. In brief, the method must assist him in making his evaluation of the inherent risk involved in a project.

A common method for structuring a scoring model is one that combines risk and profit evaluations to produce a single overall project score. Although some decision makers might prefer this method, it makes it difficult for the contractor to know whether the single score represents high return and low risk or vice versa. This method unjustifiably combines cost and performance factors and appears to be impractical in this situation. The structure of the scoring model should be based upon an evaluation of the inherent risk in a project and should not include an evaluation of profit. Although a contractor is primarily concerned with the profit and risk in a proposed project, the two items should not be combined in a single value scoring model. The evaluation of profit is based upon the approximate annual rate of return and will be discussed further in the last section of this chapter. Risk is determined from the 12 criteria which are combined in the following scoring model:

$$R = \sum_{j=1}^{n} W_j \cdot C_j$$

where $R$ = risk score for project

$W_j$ = weight for criterion j

$C_j$ = performance score for criterion j, and

j = number of criteria (j = 1,2,3,...,n).

This multi-criteria scoring model is used to evaluate the risk in a project. It is employed as soon as there is sufficient information with which to analyze the first criterion. The risk score is cumulative and is developed by summing the weighted performance score of each criterion which is evaluated as soon as appropriate information becomes available. A risk score which is expressed as a single value may not convey sufficient information to a decision maker who desires to know the composition and source of the risk in a project. To provide this additional information, a graph that is similar to the hypothetical one in Figure 13 may be employed. The risk score for each evaluated criterion, numbered 1 through 12, is plotted separately on the graph in such a manner that the score for each criterion contributes visibly to the total risk score for the project. From this graph a contractor not only can determine the total risk in a project but also can ascertain the source and magnitude of each element of the risk.

Model Evaluation

After the scoring model has been developed, it must be evaluated for accuracy. This evaluation begins by checking each aspect of the model design and structure to determine the possible effects upon a resulting project score. The structural parameters, e.g., the scoring functions, are altered until a satisfactory degree of model performance is obtained. In all cases the accuracy of the model is compared with some standard, or benchmark, which probably will be the method, either mathematical or

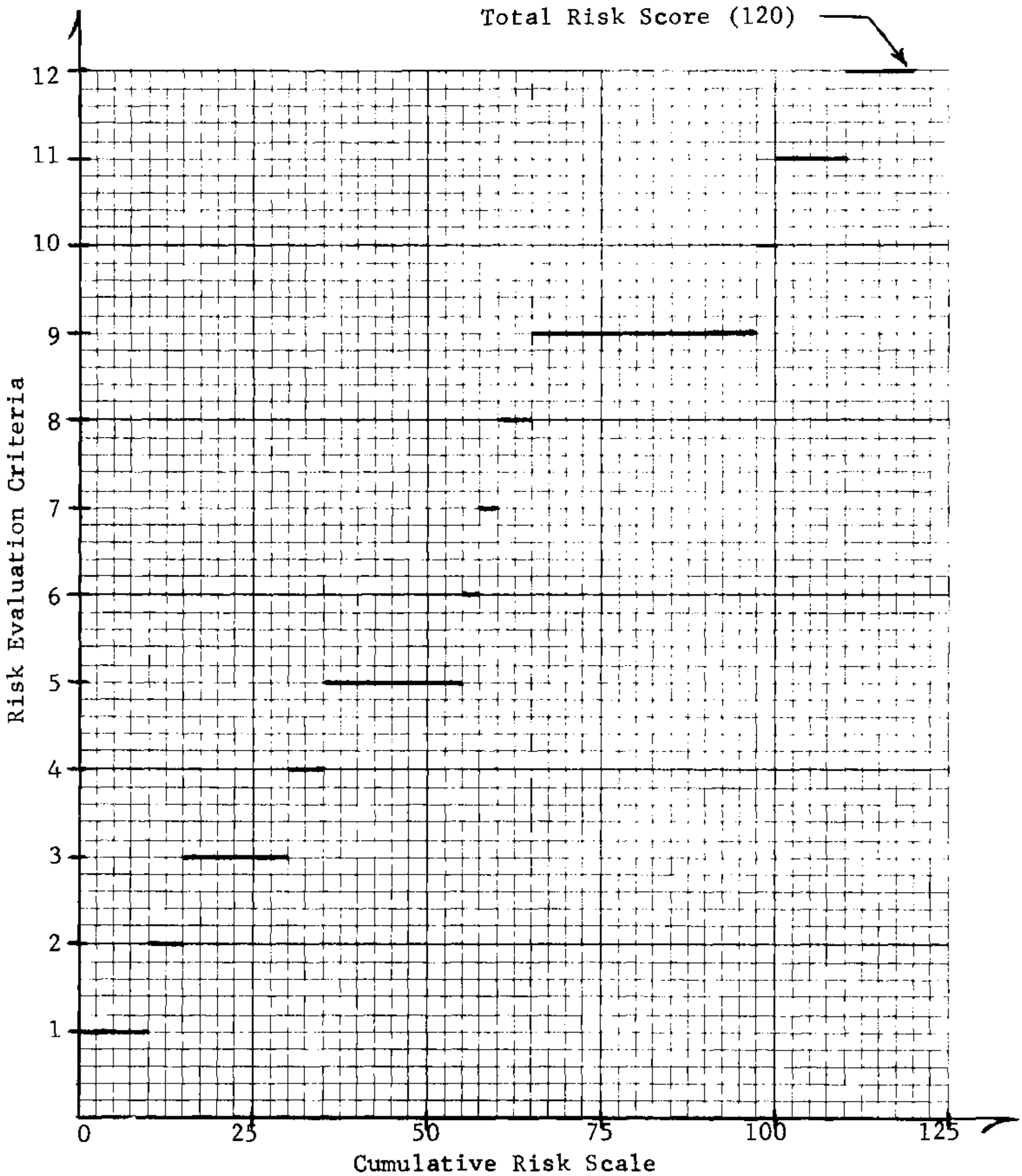



Figure 13. Graphical Analysis of Risk

intuitive, that was used by the contractor for the evaluation of project risk prior to the scoring model.

Next, the model must be tested and verified. It is assumed that the contractor has sufficient data from past projects to experiment with the scoring model. A variety of past projects which must include some that are considered good, bad, and average are reevaluated using the scoring model. Any inconsistencies between the model and the benchmark are analyzed to determine the source of the discrepancy. This analysis may lead to the conclusion that a criterion was improperly weighted or that an important factor was excluded from the model. Conversely, it may be decided that the source of the discrepancy is the benchmark and the inconsistency of the intuitive evaluation. The model has been initially verified when it produces consistent, accurate results for mean and extreme project performances.

The evaluation of the scoring model is not complete without some form of sensitivity analysis to determine what alterations in the model are possible without affecting the overall project evaluation. If the results of this analysis indicate that the model is too sensitive to relatively unimportant criteria or is insensitive to important criteria, the criteria weights, or possibly the model structure, should be adjusted to give the model the necessary degree of sensitivity.

At this point the scoring model will be placed into operation. After each application of the model the results should be analyzed to determine if any adjustments to the model are warranted. As mentioned earlier, changes in the construction company or in the operational environment may dictate adjustments to the model. In any case, the continued use of the model in evaluating project risk will allow the project performance distributions to be reestimated which should improve the reality and accuracy of the scoring model. This should result in a model which the contractor is confident can produce a reliable evaluation of the inherent risk in a proposed construction project.

## Employing the Technique

The previous sections of this chapter have dealt with the more complex project evaluation steps which occur during the final screening phase after the contractor has received the bid documents. There is also a preliminary screening phase which begins when the contractor receives the initial word that there will be a project. This initial word normally comes from the owner or from the architect, although some large contracts are initially publicized in the trade journals of the construction industry. In any case, the initial word generally contains sufficient information with which to evaluate the first ten criteria in Appendix F.

The complete technique involves the continuous and progressive evaluation of a project during the preliminary and final screening phases. The steps involved in these phases must be integrated into a logical sequence that will facilitate a contractor's employment of the technique in evaluating a construction project. This section discusses, in a general way, the sequence which a contractor should follow in employing the technique to obtain maximum benefit from its use. The technique is not, however, a rigid sequence of events but is flexible and can be modified based upon the availability of information to meet the needs of an individual contractor or of a specific situation.

Because a contractor gathers a great deal of information about a construction project prior to having his name placed on the bidders list or prior to obtaining the bid documents, the evaluation of risk through the use of the multi-criteria scoring model can begin at an early date. At any time during the preliminary phase, additional information may permit the contractor to reevaluate some previously analyzed criterion, or may precipitate his decision that the project is unattractive and deserves no further consideration. During the preliminary analysis, such a decision will be based solely upon the fact that the project or a specific criterion contains a risk evaluation score that is too high, since, at that time, a contractor will have no information on which to base an evaluation of the profit in the project.

If a contractor determines that a project is attractive after the preliminary analysis, he will confirm his name on the bidders list and receive the bid documents. At this point in the sequence, the contractor begins the final analysis of the project and must be careful not to needlessly harass subcontractors by having them prepare bids for work on a project for which a bid may not be submitted. He will continue to develop his evaluation of the risk in the project through the use of the multi-criteria scoring model and will also begin his evaluation of the profit in the project. The evaluation of profit has been discussed in the previous sections of this chapter and is based upon an approximate annual rate of return.

For any given rate of return it is assumed that there is a level of risk below which a contractor finds a project attractive and above which he finds it unattractive. The intersection of a rate of return and this specific level of risk forms a point of indifference. A sufficient number of these points can be located to form an indifference curve, as illustrated in the theoretical example in Figure 14. The actual shape of the indifference curve will depend upon how averse to risk the contractor is. If the intersection of the rate of return and the level of risk for a project under consideration is above the indifference curve, the project is deemed attractive, and vice versa.

The proposed technique enables a contractor to continuously and progressively evaluate the inherent risk in a project with the multi-criteria scoring model and, when the information becomes available, to also evaluate the profit in a project. These two evaluations would be combined on a single graph similar to the one in Figure 14. Since this one graph may not provide sufficient information to the decision maker, two additional graphs could be included. The first graph is similar to the one in Figure 10 and provides additional information on the rate of return for the project. The second graph is similar to the one in Figure 13 and provides additional information on the composition of the risk in the project.

During the preliminary and final evaluation of a project, the decision that the project is unattractive may occur in several ways. The project may be unattractive because of risk or profit, or both. The risk may be unacceptably high on a single critical criterion, e.g., no chance of getting the necessary loan for the project. The total project score may exceed a cut-off value which indicates that there is too much risk

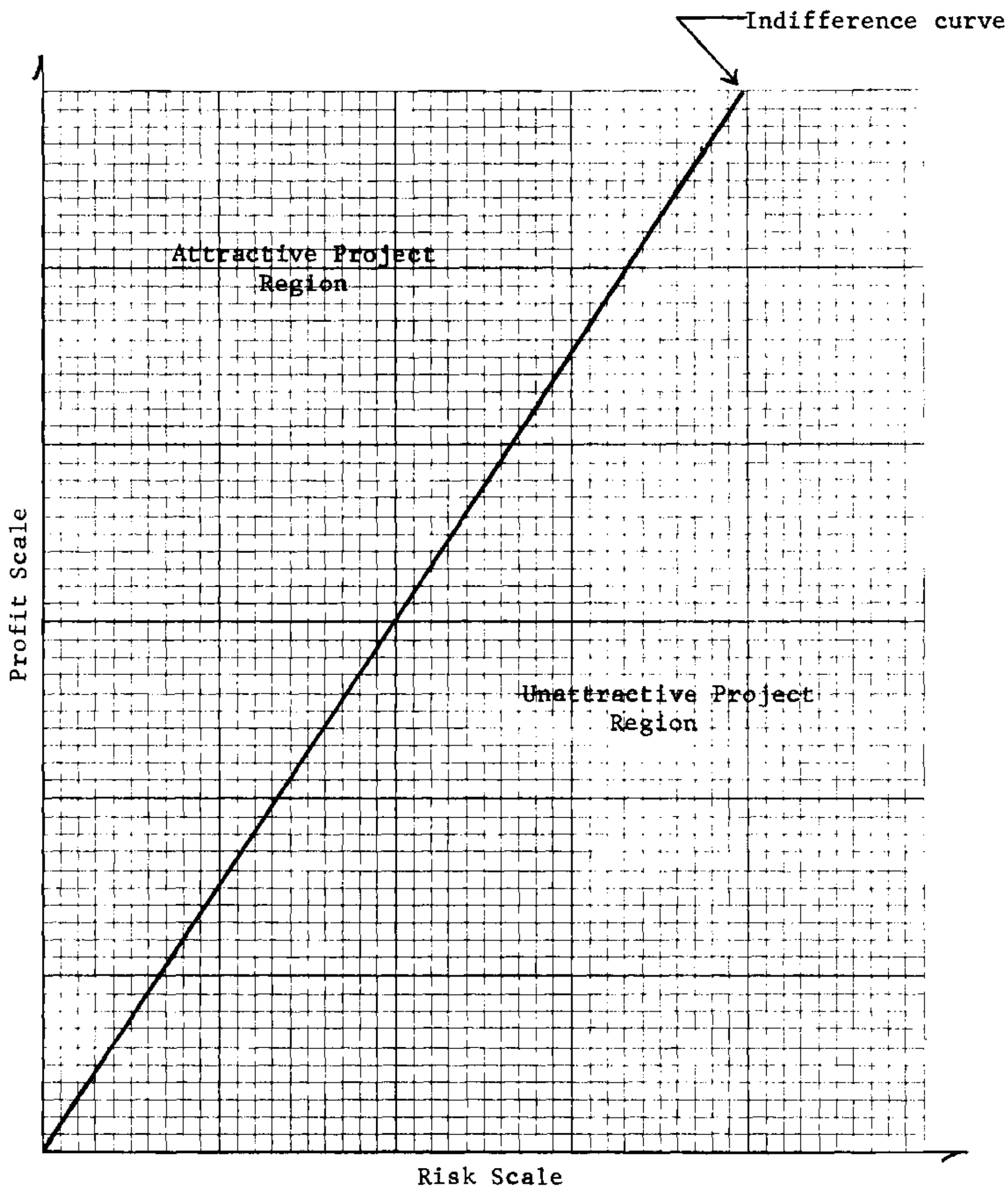



Figure 14. Theoretical Indifference Curve between Profit and Risk

involved in the project. The rate of return on the total profit may be below an established minimum value, or the interim profit may be too low. In any case the proposed technique will assist a contractor in deciding which projects are attractive and deserve further consideration.

In Figure 15 is a flow diagram that describes the sequence to be followed in employing the technique. The sequence starts when the contractor receives the first information about the project and ends when the bid is submitted or when the decision is made that the project is unattractive. Each step in the sequence is followed by a decision node where the contractor must decide whether or not to continue the project evaluation process. It should be noted that there are two critical steps in the sequence. The first is the preliminary evaluation of the project risk prior to the contractor's confirming his name on the bidders list. The second critical step is the final evaluation of the total project prior to refining and submitting the actual bid. Although the decision that the project is unattractive may be made after performing any step, these two decisions are the most critical, for each of them significantly and progressively commits the contractor to a project.

A warning to users of this technique will terminate this chapter. The technique, to include the scoring model, is not designed to make any decisions for the contractor. It can decide neither the attractiveness of a project nor the advisability of bidding on a project. The technique merely takes the evaluator's mental process and converts it into an analytical one. There are intangible factors, such as the possibility of a subcontractor's going bankrupt or of the contractor's making a mistake in

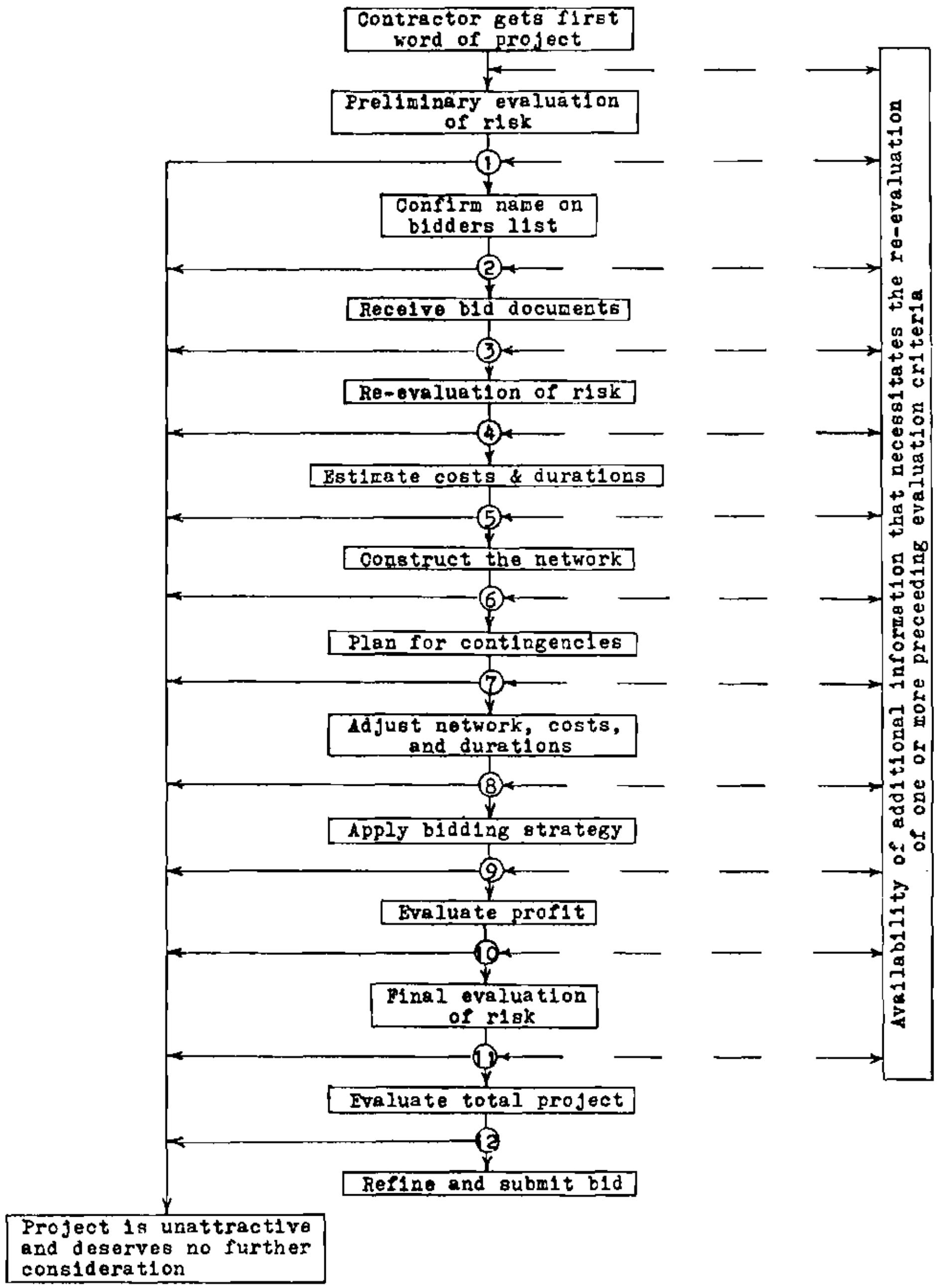



Figure 15. Flow Diagram of a Single Project Evaluation Technique

preparing the estimate of the project cost, which are not incorporated into the technique but will influence the attractiveness of a project. The technique, if properly employed with an evaluation of the intangible factors, will be a valuable tool to assist the contractor in assessing the attractiveness of a project and in deciding whether or not to bid on it.

# CHAPTER IV

# TECHNIQUE EXTENSION FOR MULTIPLE PROJECTS

## Introduction

The technique developed in the previous chapter used a multi-criteria scoring model and an approximate annual rate of return to evaluate a single proposed construction project during the pre-bid phase. It can be extended to enable a contractor to simultaneously evaluate multiple projects that constitute a continuous flow through time. This represents a dynamic situation in which the projects under evaluation continue to change through time as projects are added to and deleted from the list of those being considered. In this dynamic situation proposed projects and opportunities to bid occur randomly over time. The project evaluation process is still a sequence of decisions, but the contractor must now choose between a current opportunity and the possibility of a more lucrative project at a later date.

All projects must be evaluated to increase the probability that the most attractive of them will be selected as the project on which to place the greatest effort in preparing the competitive bid. Multiple projects cannot be evaluated by merely applying the previous technique to each project separately. Although the technique forms the basis for this evaluation, it must be modified.

The objective of this extended technique is not only to select the most attractive project, but also to enable a contractor to establish a general ranking of all proposed projects. The technique can also be used to scan a large number of possible projects to reduce the number that must be analyzed in greater detail.

## Preliminary Evaluation Phase

The multi-criteria scoring model which was developed in the previous chapter for evaluating the risk in a single project may be expanded to allow more than one project to be evaluated. This is accomplished by introducing an index that distinguishes between the various projects under consideration. The resulting scoring model takes the following form:

$$R_i = \sum_{j=1}^{n} W_j \cdot C_{ij}$$

where $R_i$ = risk score for project i

$W_j$ = weight for criterion j

$C_{ij}$ = performance score for criterion j on project i

i = number of project (i = 1,2,3,...,m), and

j = number of criteria (j = 1,2,3,...,n).

Assuming that contractors are averse to risk, the objective of a contractor is to minimize the risk which he can anticipate in a project. To be selected, a project not only must have the minimum risk score but also must have been evaluated below any cut-off score which may have been established for a single evaluation criterion or for an entire project.

In considering some of the ramifications of risk analysis during the evaluation of multiple projects, it may be helpful for the reader to refer to the sequence of events presented in the flow diagram in Figure 15. At any decision node there may be one or more construction projects. All of these projects must be evaluated for risk which may be subdivided into two basic categories, i.e., risk determined during the preliminary evaluation phase and risk determined during the final evaluation phase. The first category contains ten evaluation criteria ($j = 1,2,3,\ldots,10$) and the second contains two ($j = 11,12$).

In the first category the problem is how to compare projects which may have been evaluated on different numbers of criteria. This is a situation which occurs when the initial information received on each project is not equally complete and subjective evaluations cannot be used to tentatively score the unevaluated criteria. A mean value of $C_{ij} = 5$ cannot be assumed for unevaluated criteria, as this may discriminate for or against a project. The minimum risk score cannot be used to select the most attractive project, since this would favor projects that have been evaluated on fewer criteria. Remembering the above statement regarding cut-off scores, it appears that a contractor should continue to evaluate a project until he must confirm his name on the bidders list. More than one project may congregate at this point while the contractor waits for the time when he must confirm his name on the bidders list for one of the projects.

To compare projects that are in the preliminary evaluation phase, there are two general considerations. First, project k is less attractive and should be evaluated carefully, if:

$$R_{k(10)} \geqq R_{i(L)} + \sum_{\substack{j=1 \\ j \notin L}}^{10} W_j \cdot a_j \qquad \text{for } i \neq k$$

where $R_{k(10)}$ = risk score on project k for 10 criteria

$R_{i(L)}$ = risk score on project i for L criteria

$a_j$ = maximum score (less than any cut-off) for criterion j, and

L = set of criteria on which project i has been evaluated.

In other words, a project evaluated on 10 criteria is less attractive, if there is another project evaluated on less than 10 criteria whose total risk score for 10 criteria, even in the worst case, will not exceed $R_{k(10)}$.

The second consideration for two projects in the preliminary evaluation phase is that project i is less attractive and should be evaluated carefully, whenever:

$$R_{i(L)} + \sum_{\substack{j=1 \\ j \notin L}}^{10} W_j \cdot b_j \geqq R_{k(10)} \qquad \text{for } i \neq k$$

where $b_j$ = minimum score for criterion j (normally $b_j = 1$).

The above expression states that a project evaluated on a number of criteria less than 10 is less attractive, if the project cannot have a score for 10 criteria, even in the best case, less than $R_{k(10)}$.

To compare projects where one is in the preliminary evaluation phase and the other is in the final phase, there are two general considerations. First, project k is less attractive, if:

$$R_{k(10)} + \sum_{j=11}^{12} W_j \cdot b_j \geqq R_{i(12)}$$

where $R_{i(12)}$ = risk score for all 12 criteria on project i, which is being evaluated in the final phase.

In other words, a project evaluated on 10 criteria is less attractive, if the addition of the minimum possible score for the last two criteria will cause the total risk score for the project to exceed or be equal to the score of another project which already has been evaluated on all 12 criteria. The decision of whether to drop project k in this situation is a determination that must be made by the contractor. The variables affecting the decision will include the difference in the risk scores of the projects, how badly the contractor needs another project, any feeling which he may have regarding the level of profit which project k may have, and so forth.

The second consideration where one project is in the preliminary evaluation phase and the other is in the final phase is that a project i is less attractive, if:

$$R_{k(10)} + \sum_{j=11}^{12} W_j \cdot a_j \leqq R_{i(12)}$$

This expression states that a project evaluated on all 12 criteria is less attractive, if there is another project evaluated on 10 criteria whose total risk score for 12 criteria, even in the worst case, will not exceed $R_{i(12)}$. The decision of whether to drop project i in this situation will include the factors mentioned above plus a consideration of the amount of work remaining to be expended on project i.

The four general expressions above merely provide an indication of the relative attractiveness of a project. Since the magnitude of the risk scores is unspecified and the profit for projects in the preliminary evaluation phase is unknown, there is no basis on which to decide that a project is absolutely unattractive. For example, one project may be less attractive than another, but both projects may be considered attractive based upon very low risk scores. Although the four expressions may be simplified by disregarding the criteria weights, the author feels that it is less confusing if a contractor continues to use the same procedure that has been established for determining risk scores as a means of comparing alternative projects.

The discussion of risk considerations for multiple projects is incomplete without an investigation of the order in which a contractor should process the initial bulk of information to evaluate the criteria on a project. The criterion which a contractor should evaluate first is the one that is the most critical or has the greatest probability of causing the project to be rejected. This strategy creates a procedure whereby a project is evaluated on criteria in the order of the decreasing probability that the project will be rejected. The objective is to eliminate an unattractive project as early as possible. If this criterion rank cannot be established, a project should be evaluated on criteria in the order of the increasing cost or time required for the evaluation. This strategy causes unattractive projects to be eliminated after the expenditure of minimum time or money.

## Final Evaluation Phase

Assuming that a project has been judged attractive based upon the preliminary evaluation of risk, the project then enters the final evaluation phase. During this phase the evaluation of the project risk is completed. The primary effort, however, is directed toward an evaluation of the profit in the project. Again it may be helpful for the reader to refer to the flow diagram in Figure 15 while considering some of the ramifications of profit analysis during the evaluation of multiple projects.

Although there may be one or more projects at any decision node in the final evaluation phase, it is assumed that there will be many less projects in this phase than in the preliminary evaluation phase during which a contractor can carry a project for relatively little cost while refining the risk score for the project. In the final phase to receive the bid documents, a contractor must surrender a deposit which is returned only if he submits a bid which, in turn, requires time and money to prepare. It must be realized that the step after decision node number 4, i.e., estimating the project cost and duration, is time consuming, e.g., seven to ten days for a million dollar project. This and the following steps must be completed in time for the project bid to be submitted by the established deadline. Consequently, there may be little or no slack time in producing a project bid during this phase which will limit the number of projects that a contractor can process at any given time.

In spite of the limited number, a procedure is required whereby a contractor can compare projects that may be located at different nodes in the final evaluation phase. Since the projects at nodes 2 through 9 have not been evaluated for profit, any comparison that is made between projects must be based upon the available risk scores and must be performed as discussed in the previous section of this chapter. It is possible that a contractor may be able to make some subjective comparisons between such projects. In addition, information obtained by executing a step in the final sequence may interact with an evaluation criterion to adjust a previous risk score, e.g., learning that the bid documents are not adequate.

Another requirement during the final evaluation phase is having a decision rule at each node to assist a contractor in deciding whether or not to continue the evaluation of a particular project. These decision rules are basically related to cut-off scores which are discussed, in general, in a subsequent section of this chapter. At nodes number 4, 9, 10, and 11 the decision rule involves the comparison of a numerical evaluation to the appropriate cut-off score. If the evaluated score exceeds the cut-off score, the project is deemed unattractive. Considerations required at node number 12 are discussed in the next section of this chapter. The decision rule for node number 2 states that a project may become unattractive, if there is a long time interval between a contractor having confirmed his name on the bidders list and the availability of the bid documents. The rule also allows for the fact that, during the time interval, a contractor may receive advanced information which may cause a project to become unattractive, e.g., an unusually high number of competitors. At node number 3 the decision rule may state that a project is undesirable if the bid documents are not adequate. The decision rule at node number 5 is based upon whether the contractor feels that his estimate of the project cost and duration is accurate and competitive. Nodes number 6, 7, and 8 employ a subjective decision rule. The completion of any one of the three steps may develop information that causes a project to be deemed unattractive. The network may indicate that significant problems can be anticipated, or a large number of contingencies may cause too much uncertainty about the project cost or duration.

## Profit Analysis

The objective of a contractor is the maximization of the profit which he can anticipate from a project. There are several factors which must be considered in selecting the most profitable or economic project. The project must require a capital investment less than any established cut-off value which normally would be the amount of uncommitted capital available to the contractor, i.e., $V_i < V^*$; must require a bond less than the remaining bonding capacity of the contractor, i.e., $B_i < B^*$; and must have been evaluated above any minimum attractive rate of return, $\alpha_{marr}$, which may have been established for project profit. Furthermore, a contractor should select a project which minimizes the difference between the approximate annual rate of return, ROR, on the total profit, $\alpha_T$, and on the interim profit, $\alpha_I$.

Subject to these four requirements, the selected project should also have the most attractive return for the required investment. Based upon an original assumption that a contractor can handle only one additional project, all projects are, by definition, mutually exclusive alternatives. To compare one alternative with another it is necessary to examine the difference between their cash flows to determine the economic advantage of one over the other. This eliminates the possibility of using a present worth, PW, comparison on the total investment. Since construction projects do not have the same duration, it is quite difficult to evaluate projects using a PW comparison on the incremental difference between cash flows. Consequently, the ROR approach developed in the preceding chapter will be used to assist in analyzing the economic difference between alternative projects. The basis of this analysis is whether the added increment of investment required by one project over another will generate a ROR greater than $\alpha_{marr}$. Thus, the ROR is used not only for evaluating a single project but also for comparing alternative projects. By successively examining projects for which the ROR on the incremental investment is greater than $\alpha_{marr}$, a contractor can determine the most profitable project which will be the one having the maximum PW at $\alpha_{marr}$.

In selecting the most profitable project, the problem facing a contractor can be expressed as:

Maximize PW at $\alpha_{marr}$

Subject to: Minimize $(\alpha_{Ti} - \alpha_{Ii})$

$\alpha_{Ti} > \alpha_{marr}$

$V_i < V^*$

$B_i < B^*$

There is no analytical solution to the above mathematical expression. However, if the constraint of Min $(\alpha_{Ti} - \alpha_{Ii})$ is disregarded temporarily, a solution can be found for the reformulated expression, assuming that constraints 3 and 4 are satisfied. To facilitate the comparison of cash flows using the ROR, it is further assumed that $V_i$ occurs at time zero and $P_T$ occurs at time $d^+$ for each project.

To determine the project having the maximum PW at $\alpha_{marr}$, the analysis of the ROR on the additional investment for mutually exclusive projects, where i = the project which is the basis of comparison and j = the project which is being compared to i, is conducted in the following manner (10):

1. Reject all projects for which $\alpha_T \leqq \alpha_{marr}$.
2. Arrange projects in the order of increasing V.
3. Compare the first project (j = 1) with the "do nothing" alternative (i = 0).
4. Compute the ROR on the added investment, $\alpha_A$, for project j compared with i.
5. If $\alpha_A > \alpha_{marr}$, accept project j which becomes the next basis of comparison. Thus, i = j, j = j + 1, and return to step 3. If $\alpha_A \leqq \alpha_{marr}$, reject project j. Thus, i = i, j = j + 1, and return to step 3.

This procedure is continued until all projects have been compared with a basis. The last project to be the basis will be the project having the maximum PW at $\alpha_{marr}$.

For $\alpha_{marr}$ = 15 percent, the analysis to determine the most attractive project, i.e., the one having the maximum PW, is conducted as indicated in the following hypothetical example:

| PROJECT: | A | B | C |
|---|---|---|---|
| V | 150,000 | 200,000 | 300,000 |
| Total Profit | 40,000 | 50,000 | 66,000 |
| $d^+$ | 0.8 | 1.2 | 1.1 |
| $\alpha_T$ | 33.4 | 20.8 | 20.0 |
| Added Investment | | 50,000 | 100,000 |
| Added Profit | | 10,000 | 16,000 |
| $\alpha_A^*$ | 33.4 | 16.7 | 14.5 |

$$^*\alpha_A = \frac{\text{Added Profit}}{(\text{Added Investment}) \cdot d^+}$$

The above analysis indicates that project B is the most attractive of the three projects and is followed in order by projects A and C. Although $\alpha_T$ = 20.0 percent for project C, $\alpha_A$ = 14.5 percent which is less than $\alpha_{marr}$. The reader may question why PW is not listed for each project in this analysis. To do so would be rather meaningless, since it is difficult to compare the PW of projects which have different durations and required investments.

Having selected the project which has the maximum present worth in the reformulated problem, the requirement of Min $(\alpha_{Ti} - \alpha_{Ii})$ must be considered. The expression can be used to rank projects in ascending order of the difference. This list is compared to the list which is obtained by ranking projects based upon decreasing present worth. If the first project on each list is the same, that project, by definition, is the most profitable. If the projects are not the same, the contractor is faced with the problem of how to select the most profitable project. Rather than becoming engrossed in this problem, however, the contractor can direct his attention to the more important problem of selecting the most attractive project. Before this is done, however, the subject of cut-off scores requires some final comments.

## Cut-off Scores

A final point that requires consideration is the determination of the various cut-off scores. Each of these scores is a function of several variables and will tend to vary not only with time but also in proportion to the capabilities of a construction company and the current level of activity in the company. This level is determined by projects that are in progress plus projects that are under consideration. Available resource levels in the company will fluctuate as some projects are started and as others are terminated. The potential of the company to acquire resources from external sources may also vary.

The manner in which the variables affect different cut-off scores can best be described with the aid of the flow diagram in Figure 16. Projects which progress through the system influence cut-off scores through a feedback mechanism, which is represented by the dotted lines. Cut-off scores are also influenced through the periodic review in which the scores are reevaluated and adjusted, if necessary.

From the information contained in Figure 16, it is apparent that cut-off scores for the minimum attractive rate of return and for the evaluation criteria in both the preliminary and final evaluation phases are affected by several specific variables. Cut-off scores for all 12 evaluation criteria receive feedback from the evaluation of each proposed project on each of the criterion and from an assessment of the actual risk

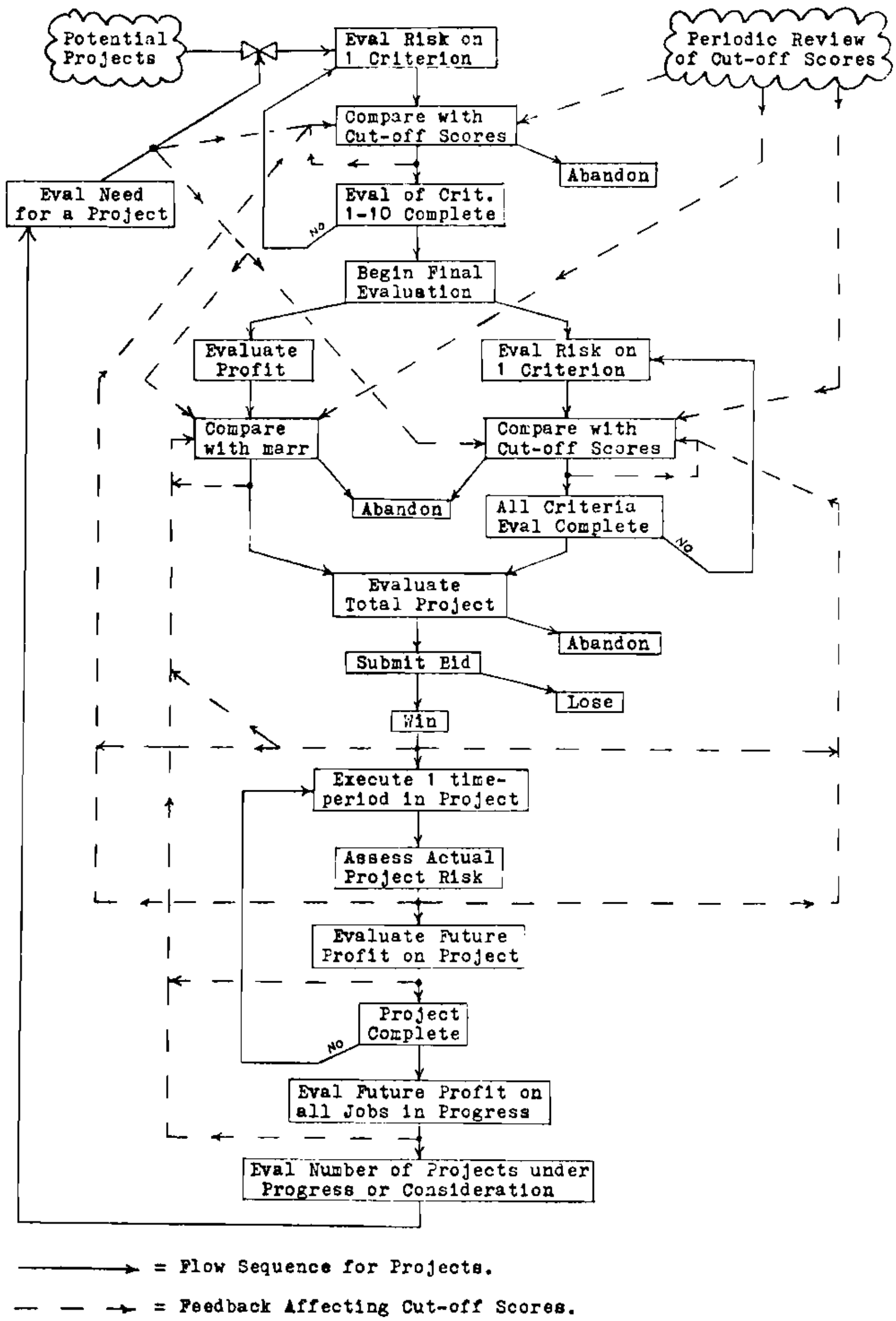



Figure 16. The Effect of Feedback on Cut-off Scores

in each project in progress. The $\alpha_{marr}$ receives feedback from the evaluation of each proposed project, from the periodic reevaluation of the future profit in each project, and from an assessment of the future profit in all projects in progress. Furthermore, each of the three cut-off scores receives feedback from the periodic review, from an overall evaluation of the need for a new project, and when a bid is won. Obviously, if a bid is won, there will be a greater need to adjust cut-off scores so that fewer potential projects are evaluated.

Potential projects flow into the system, i.e., come to the attention of the contractor, from a theoretically infinite source. The flow is regulated primarily by the evaluation of the need for an additional project. This need is influenced by factors, such as winning or losing a bid, that were not depicted in Figure 16. This was done for the sake of clarity in a diagram that is concerned with cut-off scores.

These brief comments plus Figure 16 should give the reader a better appreciation of cut-off scores and how they are adjusted. The efficient use of such scores based upon the contractor's experience and desires can improve the project screening procedure and evaluating technique.

## Selecting the Most Attractive Project

During the preliminary evaluation phase, the selection of the most attractive project was necessarily based upon an assessment of the risk in the first ten evaluation criteria. During the final evaluation phase, the discussion thus far has centered around an evaluation of the profit in a project. Neither risk nor profit alone determines the true attractiveness of a proposed construction project in the final analysis. Such a determination must be made by considering the two evaluations together. The fact must be stressed that the evaluation of project profitability succeeds the evaluation of total risk. Hence, any effort to compare the profitability of one project with another can, and should, be accompanied by a consideration of the total risk in each of the projects. Such a determination is made during the step preceding decision node number 12.

The profitability of each project will have been determined prior to this final step. The determination was based primarily upon a present worth analysis at $\alpha_{marr}$ using an approximate annual rate of return which was described earlier in this chapter. In addition, the determination of profitability was influenced by the difference between $\alpha_T$ and $\alpha_I$ in each project, since a smaller difference indicated that a greater percentage of the total profit would be received during the construction of a project which, in turn, indicated a more favorable cash flow for the contractor.

The total risk in each project also will have been determined prior to the overall evaluation step. The measure of the total risk in each project was completed during the step preceding decision node number 11 by adding the evaluation of risk in the last two criteria to the earlier evaluation of the first ten criteria.

During the last step in the final evaluation of each project, a comparison is made to determine which is the most attractive project and to establish a general order of the projects according to their overall attractiveness. This can best be accomplished with the aid of a graph on which each project is plotted by using axes to measure the total risk and the approximate annual rate of return. Both $\alpha_T$ and $\alpha_I$ are measured on the rate of return axis. It should be noted that such a graph gives no indication of present worth which must be considered separately.

Figure 17 is an example of the graph on which five hypothetical potential projects have been plotted. The five proposals are projects A, B, and C, which were mentioned earlier in this chapter during the discussion of present worth, and projects D and E, which are introduced here to assist in demonstrating the selection procedure.

To further assist in the selection of the most attractive project, graphs similar to the one in Figure 10 and in Figure 13 could be prepared for each project. These graphs would provide additional information in a visual form to assist the decision maker in evaluating each project, in selecting the most attractive project, and in ranking the projects in their order of overall desirability.

The information that has been developed concerning the profit and risk in each project may be summarized by listing the projects in decreasing order of attractiveness. This is done as shown in the following hypothetical example:

| PW | $\alpha_T - \alpha_I$ | RISK |
|---|---|---|
| B | B | D |
| A | D | C |
| C | A | A |
| E | E | B |
| D | C | E |

An analysis is made of this summary and of the graph in Figure 17 in an attempt to determine the overall attractiveness of each project. The determination may be difficult to make and will require a decision

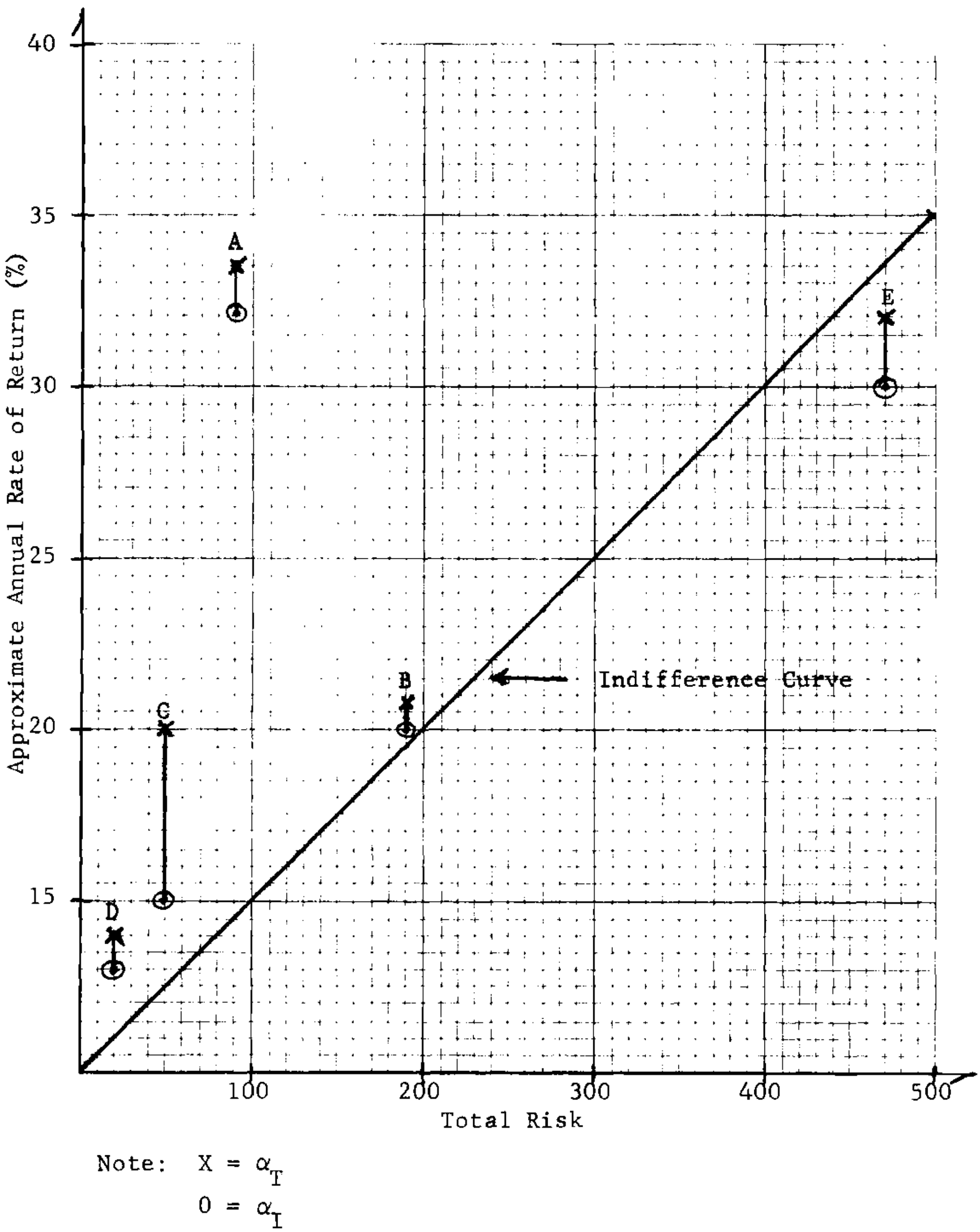



Figure 17. Graphical Comparison of the Attractiveness of Multiple Projects

from the contractor. The analysis in which IC = the indifference curve, $\Delta\alpha = \alpha_T - \alpha_I$, PW = the present worth, and R = the total risk score might be made as follows for each project:

Project A: High $\alpha_T$, low R, small $\Delta\alpha$, but not the greatest PW.

Project B: Greatest PW, small $\Delta\alpha$, but has high R and plots close to IC.

Project C: Low R, but PW was unsatisfactory, and $\Delta\alpha$ is large.

Project D: Lowest R, small $\Delta\alpha$, but plots below $\alpha_{marr}$.

Project E: High $\alpha_T$, small $\Delta\alpha$, but high R and plots below IC.

From the above analysis the decision might be made that project A is the most attractive and is followed in order by projects B, C, D, and E. The actual decision will depend upon the significance of the various differences in risk and profit for each project. It must be remembered that the evaluation process alone does not decide which is the most attractive project. That decision is made by the contractor who must consider the relevant intangible factors that may add to or detract from the level of project risk determined from the scoring model.

# CHAPTER V

# TRIAL APPLICATION OF TECHNIQUE

## General Procedure

The proposed project evaluation technique that was developed in the preceding chapters was presented to Van Winkle and Company, Inc., which is a medium size general contracting firm located in Atlanta, Georgia. There the technique was subjected to a trial application not only to demonstrate the procedure but also to test the technique in a real-world environment.

The general procedure that was followed during the application phase contained several steps. First, the evaluation criteria for the scoring model were ranked, rated, and weighted. Then, the model was validated by employing it as part of the proposed technique to evaluate past projects. The results which were obtained from the application of the technique were analyzed to determine whether or not adjustments in the scoring model or in the technique were required.

## Criteria Weighting

The 12 evaluation criteria and their respective scoring functions which were developed in Chapter III and presented in Appendix F were selected to assess the risk in a project. Any one of the methods mentioned in Chapter III could have been used to weight the relative importance of the criteria. It was decided to employ a combination of the ranking and rating methods. Ranking by itself would not have been a valid method for assigning criteria weights, as it implicitly and incorrectly, in this case, assumes equal intervals between the criteria. However, the two methods can easily be used in succession to obtain the weights in situations where one or more evaluators are involved.

If one evaluator had determined all criteria weights, the method of ranking could have been followed by successive ratings. In this latter method the evaluator would assign the most important criterion a value of 100 and then assign to each lower ranked criterion a value that is proportional to 100 and reflects the relative importance of the lower ranked criterion. The process would be repeated in reverse order by starting with the lowest ranked criterion and assigning to each higher ranked criterion a value that is proportional to the lowest value. The cycle would be repeated until the decending and ascending scales are identical.

Ranking

During the trial application, however, two persons from the firm determined the criteria weights for the scoring model. The list of criteria was presented individually to the two evaluators on index cards on which each criterion was separately recorded with the title, the corresponding alphabetic letter for ease of reference, and the description of the evaluation criterion. The evaluators used the cards to rank the criteria in their order of importance.

The results of the ranking are presented in Table 8 for evaluators number one and two. Since there are two rankings, the Spearman rank correlation coefficient could be used to determine whether the evaluators are in agreement. However, the use of this procedure is restricted to the two evaluator situation and is, therefore, considered too inflexible for general use where the number of evaluators may exceed two.

Table 8. Evaluation Criteria Rankings

| | Criteria | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | J | K | L |
| Evaluator #1 | 9 | 10 | 4 | 12 | 8 | 5 | 11 | 3 | 2 | 1 | 7 | 6 |
| Evaluator #2 | 9 | 7 | 11 | 12 | 8 | 6 | 10 | 2 | 5 | 1 | 3 | 4 |
| Total | 18 | 17 | 15 | 24 | 16 | 11 | 21 | 5 | 7 | 2 | 10 | 10 |
| (Total - 13) | 5 | 4 | 2 | 11 | 3 | - 2 | - 8 | - 8 | - 6 | - 11 | - 3 | - 3 |
| $(\text{Total} - 13)^2$ | 25 | 16 | 4 | 121 | 9 | 4 | 64 | 64 | 36 | 121 | 9 | 9 |

NOTE: $m(n + 1) \div 2 = 13$, and

$$S = \sum_{i=1}^{12} (\text{Total} - 13)_i^2 = 492$$

Consequently, the Kendall coefficient of concordance, W, was used to express the degree of agreement among k sets of rankings. The Kendall coefficient is computed using the following formula:

$$W = \frac{12S}{m^2(n^3 - n)}$$

where S = sum of the squares of the deviations of the total of the ranks assigned to each criterion from $m(n + 1) \div 2$

m = number of rankings, and

n = number of criteria.

W varies from 0 to 1, 0 signifying perfect disagreement and 1 signifying perfect agreement between the rankings. For 12 criteria, the hypothesis that the evaluators are in disagreement may be tested by calculating

$$\chi^2 = m(n - 1)(W)$$

which is approximately distributed as chi-square with $\nu = n - 1$ degrees of freedom.

From the two rankings of the 12 criteria in Table 8,

$$W = \frac{12(492)}{4(1728 - 12)} = .861$$

and

$$\chi^2 = 2(12 - 1)(.861) = 18.95$$

Examination of a chi-square table (15) for $\nu = 11$ degrees of freedom shows that $\chi^2 = 17.275$ at the 10 percent significance level. The calculated value is slightly greater than this and is, therefore, slightly significant at the 10 percent level. In other words, the hypothesis that the evaluators disagree can be rejected.

Rating

After ranking the criteria, each evaluator was asked to rate the relative importance of each criterion by assigning to it an appropriate value from a continuous scale marked in integer units from 1 to 100, inclusive. This was accomplished by having each evaluator take the alphabetic letter for his most important criterion and write it adjacent to 100 on the rating scale. Each successive criterion was written adjacent to an appropriate value on the scale to reflect the relative importance of the criterion as perceived by the particular evaluator. Since the evaluators were in reasonably good agreement on the ranking of the criteria, the use of average ratings to determine the criteria weights was especially appealing.

In the trial application the rating which each evaluator assigned to each criterion is presented in Table 9. In lieu of an average rating per se, the same effect is achieved with the following formulas to calculate the criteria weights, $W_j$:

$$V_j = \sum_{i=1}^{m} V_{ij}$$

and

$$W_j = \frac{V_j}{\sum_{j=1}^{n} V_j}$$

where $V_j$ = total rating assigned to criterion j by all evaluators

$V_{ij}$ = rating assigned to criterion j by evaluator i

$i$ = number of evaluators ($i = 1,2,3,\ldots,m$), and

$j$ = number of criteria ($j = 1,2,3,\ldots,n$).

The calculated weight for each evaluation criterion is also listed in Table 9.

## Model Verification

To test and evaluate the scoring model which was developed, seven past projects were selected to assist in analyzing the model. All seven projects had been considered attractive by the firm, as the firm had submitted competitive bids on each of them. It was realized that this would

Table 9. Evaluation Criteria Ratings and Weights

| Criteria | Evaluator #1 | Evaluator #2 | | $V_j$ | $W_j$ |
|---|---|---|---|---|---|
| A | 52 | 50 | | 102 | 5.93 |
| B | 51 | 75 | | 126 | 7.32 |
| C | 97 | 30 | | 127 | 7.38 |
| D | 24 | 20 | | 44 | 2.56 |
| E | 70 | 60 | | 130 | 7.56 |
| F | 90 | 85 | | 175 | 10.16 |
| G | 25 | 45 | | 70 | 4.07 |
| H | 98 | 98 | | 196 | 11.40 |
| I | 99 | 90 | | 189 | 11.00 |
| J | 100 | 100 | | 200 | 11.60 |
| K | 85 | 96 | | 181 | 10.51 |
| L | 89 | 92 | | 181 | 10.51 |
| | | | TOTAL | 1721 | 100.00 |

bias the evaluation of the model but was considered an acceptable initial step in view of the limited data that were available from past unattractive projects.

While testing the scoring model, measures of profitability for each of the seven projects were included so that the complete technique could also be evaluated. The measures of profitability, i.e., $\alpha_T$ and $\alpha_I$, which were discussed in Chapters III and IV, were calculated for each of the seven projects. One modification, however, was required before the calculations could be performed. The total profit and overhead items in the cost estimate had to be combined into a gross profit term, since the firm prepared its competitive bids in this manner. Although the same symbols are used to express the measures of profitability, the calculated percentages are proportionally higher. This creates no problem, because the same procedures are applied to each project, and the projects are compared against each other.

To calculate the measure of risk for each of the projects, it was necessary to make several assumptions. Each project had been evaluated at different times in the past and thus each one may have received varying scores on the evaluation criteria "chance of getting a loan and bond," I, and "timeliness of project," J. To evaluate the scoring model, constant values of 2 and 3 were assumed to be the respective scores for these criteria. It was believed that evaluating the seven projects at the same point in time would provide the best test of the model. For all other criteria, an effort was made to assign scores based upon the evaluation which a particular project received during the final bid preparation phase. This effort, of course, was founded on the assumption that such evaluations could be accurately remembered without being influenced by subsequent events or information.

For each project one of the criteria, i.e., "amount of own labor," F, was objectively scored from an analysis of data obtained from the cost estimate. Although this criterion is initially scored subjectively during the preliminary evaluation phase, an objective score is obtained through the reevaluation process in the final phase.

Disman (7) states that it is advisable for a single person to determine the final estimate for risk in a proposed project, as this will provide better validity and precision in project evaluation. With this thought in mind, the decision was made to use only one of the evaluators in the firm to assess the performance of a project on the various criteria. The evaluator was given brief instructions and asked to assign scores to each of the seven projects for all of the remaining criteria, i.e., A, B, C, D, E, G, H, K, and L. Scores were assigned to all projects for a single criterion before the next criterion was evaluated. This procedure causes the scores to better reflect the relative differences between the projects. The scores which were assigned to the evaluation criteria of each project appear in Table 10, which also lists $\alpha_T$, $\alpha_I$, and the percent of the contractor's labor for each project.

The total risk value that was obtained from the scoring model is listed below for the seven projects:

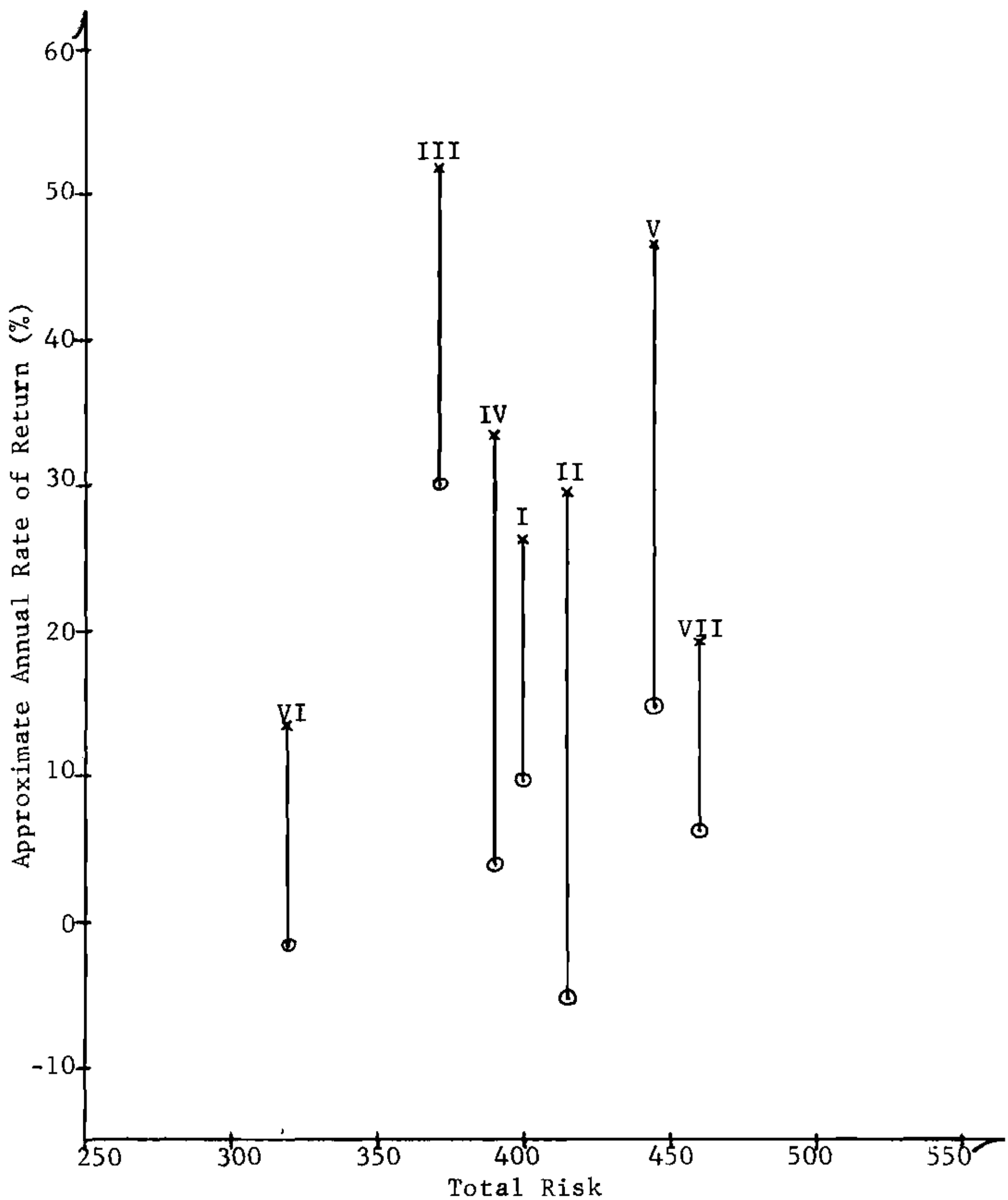
| PROJECT | RISK SCORE |
|---|---|
| I | 399 |
| II | 416 |
| III | 371 |
| IV | 389 |
| V | 445 |
| VI | 319 |
| VII | 461 |

These values were used with the corresponding measures of profitability for each project to produce the graph in Figure 18. On one hand there appear to be distinguishable intervals between the risk score for each project, but little difference in risk actually exists for two projects that are scored within approximately 25 points of each other. From a different point of view, there is relatively little "spread" between the projects, especially for risk. This is to be expected, as all of the projects were deemed attractive by the firm and are clustered in an "attractive region" of the graph. Furthermore, a contractor might be presented with a situation in which he had the opportunity to bid on more than one of these projects at the same time. If the proposed technique can discriminate between projects in such a situation, it should be able to handle more extreme and realistic situations and to discriminate to a better degree between such projects.

Having completed the initial testing of the model with the seven attractive projects, an effort was made to incorporate several unattractive projects. Although three projects were obtained, very limited data were available on them, as none had progressed to the final evaluation phase in which the profit for a project could be calculated from the cost estimate. Consequently, these unattractive projects had to be evaluated on risk alone, using the ten criteria from the preliminary evaluation phase.

Table 10. Evaluation Criteria Scores for Seven Projects

| Criteria | Project | | | | | | |
|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII |
| A | 7 | 4 | 4 | 4 | 5 | 4 | 8 |
| B | 9 | 5 | 3 | 5 | 3 | 4 | 7 |
| C | 4 | 4 | 5 | 4 | 4 | 3 | 4 |
| D | 5 | 5 | 5 | 5 | 5 | 1 | 5 |
| E | 1 | 2 | 1 | 7 | 9 | 1 | 5 |
| F | 1 | 6 | 4 | 4 | 9 | 4 | 3 |
| G | 6 | 5 | 5 | 4 | 4 | 4 | 6 |
| H | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| I | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| J | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| K | 4 | 8 | 6 | 4 | 3 | 4 | 7 |
| L | 7 | 4 | 5 | 4 | 5 | 4 | 6 |
| Labor (%) | 7.6 | 17.0 | 12.4 | 12.1 | 24.0 | 13.4 | 10.7 |
| $\alpha_T$ | 26.2 | 29.7 | 51.7 | 33.6 | 46.5 | 13.4 | 19.2 |
| $\alpha_I$ | 9.8 | - 5.1 | 30.0 | 4.0 | 14.7 | - 1.3 | 6.2 |




Note: $X = \alpha_T$
$0 = \alpha_I$

Figure 18. Graphical Representation of Seven Projects

Again criterion I and J were assumed to have scores of 2 and 3, respectively.

The three unattractive projects were compared to each other and to the seven attractive projects for which a preliminary evaluation score was developed from information contained in Table 10. The scores which were assigned by the firm to the evaluation criteria of the unattractive projects appear below:

| Criteria | Project/VIII | IX | X |
|---|---|---|---|
| A | 5 | 5 | 5 |
| B | 9 | 9 | 5 |
| C | 6 | 7 | 7 |
| D | 5 | 5 | 5 |
| E | 9 | 9 | 9 |
| F | 9 | 9 | 9 |
| G | 5 | 6 | 9 |
| H | 5 | 5 | 9 |
| I | 2 | 2 | 2 |
| J | 3 | 3 | 3 |

From the scoring model a preliminary risk value for criteria A through J was calculated for each project and is listed below:

| PROJECT | RISK SCORE |
|---|---|
| I | 283 |
| II | 290 |
| III | 256 |
| IV | 304 |
| V | 360 |
| VI | 234 |
| VII | 325 |
| VIII | 446 |
| IX | 457 |
| X | 486 |

## Evaluation

Having tested the scoring model by reevaluating ten past projects, an analysis of the results was made to evaluate the model by comparing the accuracy of the model with a benchmark. The selected benchmark was the previous method used by the firm for assessing the attractiveness of a project. Since the method was based upon intuition, the consistency and accuracy of the benchmark were unknown. However, the past success of the firm would indicate that the benchmark may provide a reasonably valid assessment.

The results obtained from the scoring model for the three unattractive projects agreed with the benchmark. If a preliminary evaluation cut-off score for risk is assumed in the vicinity of 400, all of the three projects would be considered unattractive. Furthermore, the model indicated that project X was the most unattractive which agreed with the benchmark. The significance of these scores can be better appreciated when they are compared with the preliminary evaluation scores received by the seven attractive projects.

The preliminary evaluation score which each of the seven projects received placed them in the attractive project category. To analyze the results obtained from the scoring model, these scores were used to rank the seven projects in a preliminary order of attractiveness. This order was compared with one in which the projects were intuitively ranked by the firm. A summary of the comparison is presented in Table 11.

The Kendall coefficient of concordance was used to test the hypothesis that the two rankings are in disagreement. Using the procedure that was explained earlier,

$$W = \frac{12(82)}{4(343 - 7)} = .732$$

and

$$\chi^2 = 2(7 - 1)(.732) = 8.78$$

Examination of a chi-square table for $\nu = 6$ degrees of freedom shows that $\chi^2 = 8.558$ at the 20 percent significance level. Since the calculated value is slightly greater than this, it was concluded that the model and the benchmark were in satisfactory agreement. The rankings, however, are not identical, and this observed inconsistency could be caused by deficiencies in the model or in the benchmark, or both. The cause of the inconsistency was relatively unimportant, since the scoring model was judged to be sufficiently accurate without adjustment in assessing the attractiveness of a project.

Table 11. Comparison of Model to Benchmark for Ranking Projects

| | Project | | | | | | |
|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII |
| Benchmark Order | 7 | 4 | 3 | 2 | 5 | 1 | 6 |
| Model Order | 3 | 4 | 2 | 5 | 7 | 1 | 6 |
| Total | 10 | 8 | 5 | 7 | 12 | 2 | 12 |
| (Total - 8) | 2 | 0 | -3 | -1 | 4 | - 6 | 4 |
| $(\text{Total} - 8)^2$ | 4 | 0 | 9 | 1 | 16 | 36 | 16 |

NOTE: $m(n + 1) \div 2 = 8$, and

$$S = \sum_{i=1}^{7} (\text{Total} - 8)_i^2 = 82$$

Sensitivity Analysis

To complete the verification of the scoring model, a sensitivity analysis was performed to determine what alterations in the model were possible without affecting the overall evaluation of the risk in a project. A thorough analysis was hampered by the manner and the situation in which the model had been employed. The complicating factors were:

1. The results were biased by having utilized a preponderance of attractive projects. Moreover, this precluded the reevaluation of any scoring distributions.

2. The use of a single evaluator precluded the analysis of any differences between evaluators.

In spite of these complications, a two step analysis was performed.

The first step was an analysis of the scoring model itself to determine whether there were any inconsistencies in the criteria weightings. This was accomplished by examining the effects of changes in the score assigned to each evaluation criterion on the total risk score. Since the model uses an additive index and each criterion weight is constant, the effects of changes were analyzed by inspection. Obviously, a unit change in a criterion score will change the total risk score for a project by an amount equal to the weighting factor of the particular evaluation criterion. The project evaluator in the firm noted no weighting inconsistencies. The model adequately represented the perceived importance relationships among the criteria.

The second step in the sensitivity analysis was an examination of the results obtained from the scoring model. The purpose of the examination was to determine whether or not the order among projects based upon total risk was significant. If a small change in one of the criterion scores for a project altered the ranking of two projects, their differences based upon total risk would be considered rather insignificant. Such information would be useful in assessing the comparative attractiveness of two projects.

Calculations were made of the necessary changes required in the score of each evaluation criterion to independently alter the order of project attractiveness. These calculations were performed in a general manner to permit the analysis of the order among all seven attractive projects as opposed to merely analyzing the order among selected projects. The values that were obtained express the amount of change required in a criterion score to shift the total risk score by 10, 20, 25, and 30 points. These values are listed in Table 12.

In the seven projects, the minimum difference in total scores was 10 for projects I and IV, while the maximum difference was 142 for projects VI and VII. Between these two extremes there were other differences that varied depending on the two projects being compared. When a small change, which was defined to be two points or less, in one of the criterion scores altered the order of two projects, the difference between the projects was considered insignificant. The figures in Table 12 show that the difference must increase to approximately 25 points before all evaluation criteria require a change in score greater than two points to alter the order of two projects. Therefore, the difference between two projects was considered significant, if there was a difference of 25 points or more in their total risk scores.

Table 12. The Effect of Altering Criteria Scores

| Criteria | Difference in Total Risk Scores | | | |
|---|---|---|---|---|
| | 10 | 20 | 25 | 30 |
| A | 1.69 | 3.38 | 4.22 | 5.06 |
| B | 1.37 | 2.74 | 3.42 | 4.10 |
| C | 1.36 | 2.71 | 3.39 | 4.06 |
| D | 3.91 | 7.81 | 9.77 | 11.70 |
| E | 1.32 | 2.65 | 3.31 | 3.97 |
| F | .98 | 1.97 | 2.46 | 2.96 |
| G | 2.46 | 4.91 | 6.15 | 7.37 |
| H | .88 | 1.75 | 2.19 | 2.63 |
| I | .91 | 1.82 | 2.27 | 2.72 |
| J | .86 | 1.72 | 2.16 | 2.58 |
| K | .95 | 1.90 | 2.38 | 2.86 |
| L | .95 | 1.90 | 2.38 | 2.86 |

An analysis of the seven projects indicated that there was an insignificant difference between the order of projects III-IV, I-IV, I-II, and V-VII. This result was not surprising, since these were attractive projects originally. From this portion of the sensitivity analysis, no adjustments were made in the scoring model, as it was considered sufficiently accurate and sensitive based upon the limited testing.

## Employment of Technique

The seven attractive projects that have been mentioned previously were selected to demonstrate the employment of the evaluation technique. The trial application of the technique in analyzing the seven projects consisted of three steps which correspond to the steps preceding decision nodes 10, 11, and 12 in Figure 15. First, the profit in each project was evaluated; second, the total risk in each project was evaluated; and third, each project was given a total evaluation in which the combined effects of profit and risk were examined and the most attractive project was selected. During the trial application, no effort was made to determine any cut-off scores or to determine an indifference curve, as the personnel in the firm lacked familiarity with the consequences of establishing such scores or the curve at a particular level. More experience with the measurement values was required for an adequate appreciation of their significance in other than a comparative situation.

To evaluate the profitability of each project, a present worth analysis was made by following the procedure outlined in Chapter IV. Since it was assumed that $\alpha_{marr} = 10$ percent, none of the seven projects was eliminated from consideration. The projects were arranged and compared in the increasing order of the required capital investment which, it should be remembered, has been assumed equal to 20 percent of the project cost. The results of the comparison appear in Table 13 and clearly indicate that project V had the most attractive PW at $\alpha_{marr}$ and was followed in order by projects III, II, and VI.

The evaluation of profit would be incomplete unless the difference between $\alpha_T$ and $\alpha_I$ were examined. Obviously, the cash flows for a project influence its attractiveness. If more of the profit is received during the construction phase, a project is more attractive for two reasons. The extra money can be used in lieu of the contractor's assets to defray construction expenses, and the time value of money increases the worth of the total profit. In Chapter III, $\alpha_I$ was developed as an indicator of the interim cash flow. Since a large $\alpha_I$ in relation to $\alpha_T$ is desired, a project having a smaller difference between the two values is more attractive. The calculation of this difference for the four projects mentioned in the present worth analysis is listed below:

| PROJECT | $\alpha_T - \alpha_I$ |
|---|---|
| V | 31.8 |
| III | 21.7 |
| II | 34.8 |
| VI | 14.7 |

An examination of these calculations indicated that the cash flow of project III was preferred to that of project V. Although project VI had a small difference between $\alpha_T$ and $\alpha_I$, the low present worth and the negative $\alpha_I$ made the project relatively unattractive.

Table 13. Comparison of Present Worth

| Project: | II | III | IV | VII | V | I | VI |
|---|---|---|---|---|---|---|---|
| V | 132825 | 166315 | 212307 | 300585 | 309329 | 347070 | 1046889 |
| Total Profit | 27500 | 90000 | 50000 | 66762 | 120000 | 84638 | 200000 |
| $d^+$ | 0.698 | 1.045 | 0.698 | 1.160 | 0.833 | 0.928 | 1.428 |
| $\alpha_T$ | 29.7 | 51.7 | 33.6 | 19.2 | 46.5 | 26.2 | 13.4 |
| Added Investment | | 33490 | | | 143014 | | 737560 |
| Added Profit | | 62500 | -- | -- | 30000 | -- | 80000 |
| $\alpha_A$ | 29.7 | 178.5 | | | 25.2 | | 7.61 |

Next, an evaluation was made of the risk in each project with particular attention being given to the projects having the more desirable profit indicators, i.e., projects III and V. The information developed during the verification of the scoring model and during the sensitivity analysis was used to evaluate the risk in the projects. The total risk score in ascending order for each project was:

| PROJECT | RISK |
|---|---|
| VI | 319 |
| III | 371 |
| IV | 389 |
| I | 399 |
| II | 416 |
| V | 445 |
| VII | 461 |

These risk scores indicated that project VI had the minimum risk and that there was a significant difference between the risk in projects III and V. To further examine the risk in each project, graphs similar to the one in Figure 13 could be prepared, although this was not done during the trial application. However, reference was made to Table 10 in which it was noted that two projects received maximum scores of 9 on certain evaluation criteria. Specifically, project I received a 9 on criterion B, and project V received a 9 on criteria E and F.

The last step in the employment of the technique involved the total evaluation of each project. An analysis of the combined effects of profit and risk was performed using the above evaluations and the graph in Figure 18. A summary of this analysis in which the projects were ranked in descending order of attractiveness appears below:

| PW | $\alpha_T - \alpha_I$ | RISK |
|---|---|---|
| V | VII | VI |
| III | VI | III |
| II | I | IV |
| VI | III | I |
| I | IV | II |
| VII | V | V |
| IV | II | VII |

Based upon the analysis of the results obtained from the application of the evaluation technique to the seven projects, project III was judged by the author to have the best combination of profit and risk and was selected as being the most attractive project. No further effort to rank the projects was made by the author, since any trade-off between risk and profit involves a decision process and is determined by the contractor's aversion to risk.

## Assessment of Technique

The trial application of the proposed evaluation technique in a situation which included only attractive projects located at the same point in the project evaluation process was a less than conclusive test. However, the limited initial application was considered successful in demonstrating and testing the applicability of the technique. This was especially true in view of the ability of the demonstrated procedure to discriminate between the attractive projects. To better assess the value and feasibility of the proposed evaluation technique, the construction firm was asked to provide relevant comments. These comments form the basis for the following remarks in this chapter.

The firm felt that there is a significant need for a technique that can be used by a contractor to assess the attractiveness of a potential construction project and to assist in deciding on which project to bid. Many contractors use their intuition to assess projects and have little knowledge of more objective or refined methods. Such contractors would be unable to make any meaningful comparison of the profit or risk between two alternative projects. The firm also stated that, in general, contractors are too prone to make snap decisions because of the relatively short period of time in which such decisions may normally be made. Consequently, a salient requirement exists for a procedure that will improve both the accuracy and speed of the contractor's decision.

In regard to the applicability of the proposed evaluation technique, the firm indicated that a thorough appraisal could not be made until the technique was subjected to further and wider application. However, from their limited contact with the technique, they believed that it had potential application not only for large, medium, and small general contractors, but also for other contractors, to include subcontractors. It was mentioned that the technique would be especially useful for a contractor engaged in heavy construction, such as bridge and tunnel building, where the risks and profits are higher than in general construction.

The potential cost to a contractor in utilizing the technique was considered insignificant, and no effort was made to estimate the expense. This cost would not influence the applicability of the technique.

The simplifying assumptions which were made during the development of the proposed technique were judged to have little effect on the applicability. If the technique were refined and employed in a particular construction company, several of the assumptions might be relaxed. In general, the consideration of intangible factors in evaluating a project could compensate for any restrictions or limitations in the technique.

The firm believed that any ultimate application of the technique would be determined by how simple it was to use and how demanding it became for time. In brief, the required inputs to the technique must be reasonable and readily available. Consequently, there was some question as to whether the development of a formal network for a project and the application of bidding strategy were essential. These and other items like planning for contingencies are frequently considered by a contractor in a less rigorous manner. The author recognized this as a valid comment but stressed the point that these were not essential formal steps in the application of the technique, which had been purposely developed in a flexible form that could be modified by a contractor to meet his own needs.

It was recognized by the firm that the utilization of the technique produced an added benefit. It helped a contractor in thinking about a project, sharpened his intuition, and brought a greater insight concerning the various elements of a project that influence its attractiveness.

In summary, the firm felt that there is a definite need for a method to evaluate construction projects and that the proposed technique might satisfy the requirement, if it were not allowed to become too complex. The technique was recommended for further study to obtain a better appraisal of its overall applicability.

# CHAPTER VI

# DESIGN OF OPERATIONAL SUBSYSTEM

Various aspects of the proposed project evaluation technique have been presented and discussed in the preceding chapters. Although the technique has been described in detail and subjected to a trial application, nothing has been said about the subsystem with which a contractor could employ the technique on an operational basis. The design of such an operational subsystem will facilitate not only the contractor's implementation of the technique but also the reader's comprehension by summarizing much of the material that has been presented. Discussion of the subsystem is divided into two phases: preparatory and operational.

## Preparatory Phase

Before the subsystem can be placed into operation, there are preparatory steps which must be taken by the contractor. In general, these steps are performed only once and involve the determination or estimation of specific items that are required by the evaluation technique in the operational subsystem. Provisions are made in the operational phase for adjusting any items through reevaluation processes.

During the preparatory phase the following steps must be taken:

1. Develop a list of the evaluation criteria for use in assessing the risk in a construction project.

2. Determine the distribution of project performance for each of

the criteria from past historical data, or estimate the distributions based upon experience in the firm.

3. Formulate a scoring function for each criterion.

4. Assign a weight to each evaluation criterion, using one of the methods mentioned in Chapter III.

5. Test and verify the scoring model, using the procedure included in Chapters III and V.

6. Establish cut-off scores for values of project risk.

7. Establish cut-off scores, especially a minimum attractive rate of return, for values of profit in a proposed project.

8. Use data on competitors to develop sufficient information for the application of bidding strategy, as described in Chapter III.

The last step is non-essential in placing the subsystem into operation, if the contractor does not use the expected profit concept to determine his margin of profit for a project.

## Operational Phase

Having developed the information required by the project evaluation technique, a contractor can implement the technique by placing it into operation as a subsystem that is used within the construction company to evaluate potential projects. The design of such an operational subsystem is presented in Figure 19. Although the subsystem is similar to the feedback mechanism presented in Figure 16, the similarity stems from the fact that the feedback mechanism for adjusting cut-off scores operates within the operational subsystem. The detailed feedback process was omitted from Figure 19 for the sake of clarity and is represented by a

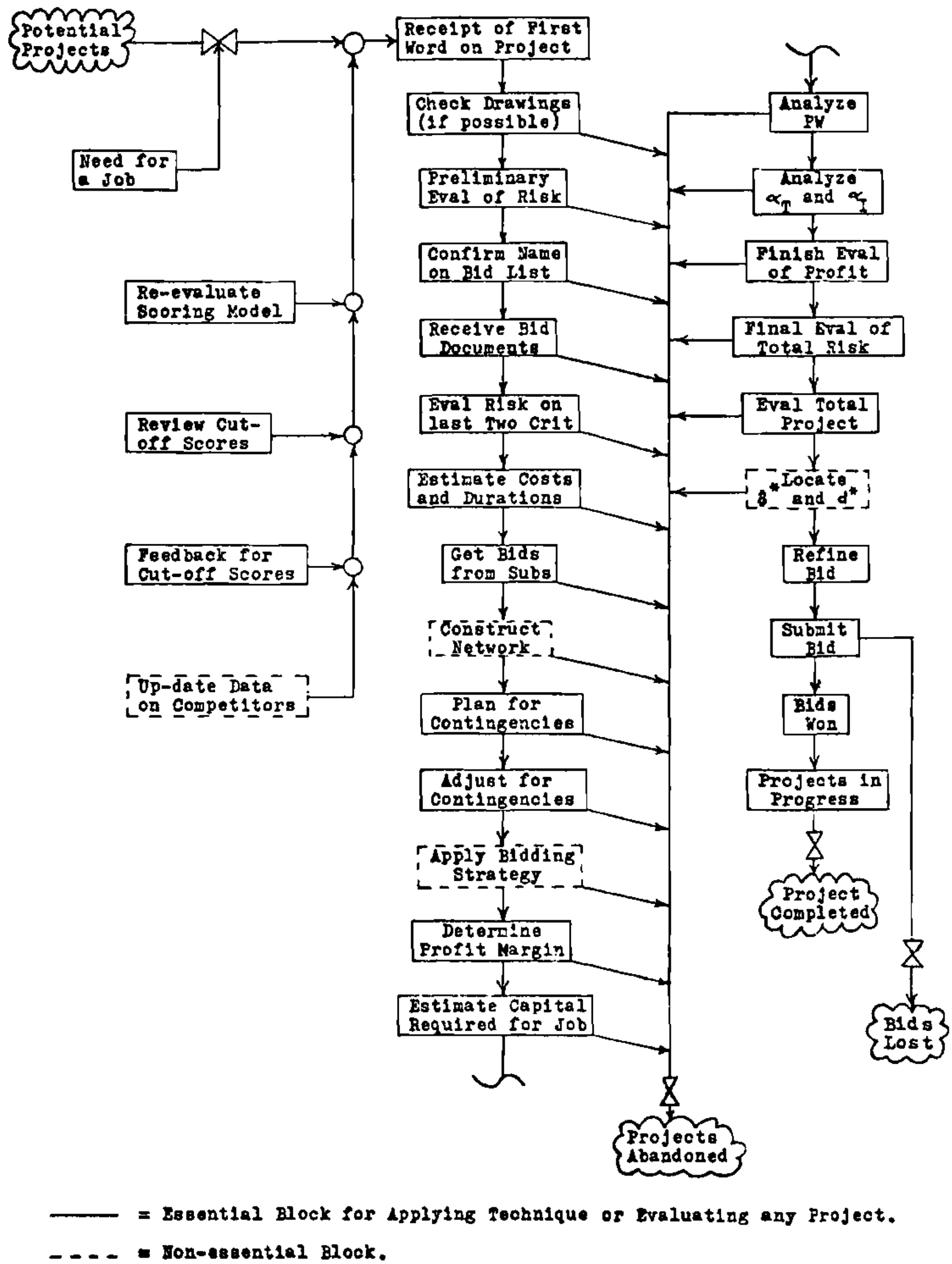



Figure 19. An Operational Subsystem for Implementing the Evaluation Technique

single block as input to the subsystem.

Although each block in the subsystem will not be discussed individually, several of the blocks do warrant specific comments. These are blocks which have a particular impact on the functioning of the subsystem or have not received adequate emphasis in the preceding chapters. Blocks in the latter category are discussed first.

In the check drawings block, the contractor should attempt to look at the recent drawings of the proposed project, as they may be a better source of information than the owner, for example. The drawings may indicate such a complex project that the contractor decides not to get involved, or they may provide additional information with which to make the preliminary evaluation of risk. These drawings, if available, will be in the possession of the owner, the architect, or a professional organization such as the builders exchange.

In the determine profit margin block, the contractor may use one of several methods for determining the margin of profit to be added to the estimated project cost. The methods include intuition, adding a fixed percent of the cost, or calculation of the expected profit through the application of bidding strategy.

The final evaluation of total risk block includes a subjective adjustment of criteria K and L, as mentioned in Appendix F, to reflect the probability of winning the bid. This probability is determined from the application of bidding strategy, which the author believes is nonessential to the application, but does enhance the capability, of the technique. If bidding strategy is not employed by the contractor, the above block will not contain the subjective adjustment.

In the locate $\$^*$ and $d^*$ block, the contractor should attempt to locate these optimum points of operation. Knowledge of their location should enable a contractor to operate closer to them and should, therefore, improve his actual profit. However, this block is not considered essential by the author to the application of the project evaluation technique.

In Figure 19 there are several blocks that are particularly important to the operational design and functioning of the subsystem. The need for a job block acts as a control mechanism to adjust the flow of potential projects into the subsystem, as it did in Figure 16. As the need for an additional job increases, the block will cause more potential projects to enter the subsystem where they are evaluated by the contractor. As the need for a job decreases, the opposite effect is created.

In addition to feedback within the subsystem, three blocks, which are reevaluate scoring model, review cut-off scores, and up-date data on competitors, are shown as providing input to the subsystem. However, these three blocks are not judged by the author to be true input, because they are periodic in nature and could be represented as impulses to the subsystem. The complete subsystem is characterized by one input and three outputs: Potential construction projects provide the input to the subsystem. The output consists of projects on which the decision was made that they were unattractive, on which the work has been completed, and on which the bid was not won.

The implementation of the proposed project evaluation technique in an operational subsystem similar to the one in Figure 19 should assist contractors in making reasonable profits a reality rather than an illusive goal.

# CHAPTER VII

# CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research was to develop a technique for evaluating proposed projects in the construction industry during the pre-bid phase, when there is a continuous flow of potential projects requiring consideration. Procedures for determining the information required by the technique were described, and the application of the technique was demonstrated. Of particular importance was the multi-criteria scoring model which was developed to measure the inherent risk in a project. The design of an operational subsystem with which a contractor could employ the technique was discussed.

Several specific objectives of this research were outlined in Chapter II. In the next section of this chapter, conclusions related to each objective and to the entire study are presented. In the final section of the chapter, recommendations for improvements in the evaluation technique and for possible future study are presented.

## Conclusions

The first objective of this research was the development of a technique to assist general contractors in evaluating a project by providing a rapid approximation of its attractiveness. The procedure which was developed and discussed in Chapter III is a systematic method for determining the information required to analyze and evaluate a construction project. The procedure focuses upon the approximate annual rate of return to estimate the profitability of a project and upon the multi-criteria scoring model to estimate the inherent risk. In the preliminary evaluation phase, the measure of risk was used to assess the attractiveness of a project. In the final evaluation phase the two estimates were integrated to provide an indication of project attractiveness.

The single project evaluation technique was expanded to enable general contractors to evaluate multiple proposed projects constituting a continuous flow throughout time. This was the second objective of the research. The expanded technique that was developed and discussed in Chapter IV provides an objective basis for the comparison of multiple projects and for the selection of the most attractive project or mix of projects. In addition, guidelines were presented to assist in the analysis of project risk and profit.

The third objective of this research was the establishment of guidelines and procedures for the development and adaptation of scoring models. These guidelines and procedures were described primarily in Chapter III. Although scoring model theory was given only a broad presentation, the critical aspects of the design of the model were discussed. This included the selection of evaluation criteria, scoring functions, criteria weights, and the evaluation of the model.

The analysis of the effects of a contingency such as weather on a project, which was the fourth objective, was discussed in Chapter III as a type of contingency requiring consideration. A different solution to the problem of how to take weather into consideration when planning a project was created and demonstrated on a sample project.

The accomplishment of the fifth objective involved the design of an operational subsystem with which a general contractor could employ the multi-project evaluation technique. The design was presented in Chapter VI. It is a scientific approach to the difficult problem of assessing the potential profitability and risk in construction projects. The subsystem involves objective and quantitative procedures and may be modified by a contractor who desires to expend less effort and money in evaluating projects.

The final objective of this research was an evaluation of the applicability of the technique in a real-world situation and was accomplished in Chapter V. There are limitations in the scoring model and in the technique that preclude the evaluation of all factors which may influence the attractiveness of a construction project. The technique is meant to be used only as a tool to aid a contractor in choosing among alternative project proposals and not as a decision maker or as the sole decision criterion. In this light and as a means of enhancing a contractor's insights into the differences among projects, the technique was considered to have potential applicability. The extent of this application is unknown, and further use of the technique in other construction companies is required before the true applicability of the technique can be determined.

In general, the project evaluation technique resulting from this research offers a contractor the means whereby he may systematically and consistently analyze and evaluate all proposed construction projects. This represents a significant improvement over current project evaluation methods that are based upon intuitive analysis and judgment. The technique which has been developed will allow a contractor to repeatedly select from current information the most attractive project or mix of projects on which to bid, to do this more efficiently and accurately, and to increase his probability of having submitted the winning bid. Personnel in the Van Winkle and Company construction firm indicated that their contact with the technique led them to believe that it was applicable in general construction companies. Hence, it is concluded that the purpose of this research has been achieved.

## Recommendations

The comprehensive scope of this research has made it difficult to present a more detailed study of the procedures and theories that have been mentioned. This difficulty is further compounded by the variety of areas which are touched while discussing the construction industry and the selection of projects. Many of these areas offer obvious opportunities for further research.

Before suggesting such areas, there are several recommendations to be made for improving the evaluation technique that was described. These recommendations are:

1. Develop procedures to permit the deletion of unrealistic or restrictive assumptions that were made to facilitate the use of the technique. The more significant of these assumptions were:

   a. The cost of subcontracted work is spread evenly throughout a project.

   b. The interim profit is received at approximately the same point in the duration of each project.

c. Project performance with respect to each evaluation criterion is distributed according to the normal distribution.

2. Develop a method to permit the application of the technique to interdependent projects that include negotiated contract work.

The areas which were mentioned as offering opportunities for further research were encountered during the course of this research. These topics are:

1. Investigate the impact of a value engineering incentive clause on the profit which a contractor may anticipate from a project.

2. Determine the feasibility in the construction industry of all competitive bidders using the architect's work estimate as the basis for computing their job cost estimate.

3. Develop a method for combining the variables obtained from work and cost estimates with standardized subnetworks to rapidly produce a project network.

4. Investigate the financial impact on the contractor and on the project owner of starting all project activities at the late start date rather than the early start date.

5. Investigate the feasibility of using the risk philosophy of a specific construction firm to combine the proposed measures of risk and profit into a single measure of project attractiveness.

6. Investigate the effect of changes in the timing of subcontracted work on the profit received by a contractor.

7. Develop a method with which a contractor may easily determine the cash flow projection in a proposed construction project.

# APPENDICES

# APPENDIX A

## DEFINITION OF TERMS

Activity. Any element of a project that consumes resources and/or time and has an identifiable start and end.

Bid documents. The working drawings and the project specifications used by the contractor in preparing his bid.

Competitive bidding. The submission of estimates of cost through which a project owner may compare the services offered by contractors prior to the selection of one as the contract winner.

Cost estimate. The instrument which is obtained from a detailed analysis of the bid documents and which is the basis for the bid that is submitted for a project.

Critical path. The connected sequence of activities through a project network where any delay in the completion of an activity will delay completion of the entire project.

Expected profit. The average profit per bid that a contractor may anticipate if the bid were duplicated on a large number of projects having the same estimated cost and if the probability of being awarded the contract remained fixed.

LEW. The loss of efficiency due to weather is the percent decrease in the efficiency of working on an individual project activity due to rain and/or cold.

Network. A graphical representation of a project plan that shows the activity interrelationships.

PERT/Cost. A technique that uses the project network as a basis for cost accounting. Expenditures may be coded by activities or groups of activities to allow contractors to monitor the costs and the schedule of a project.

Planning. The detailed examination of each activity in a project to determine the best methods and procedures to complete the work at minimum cost.

Private bid. A bid open only to selected contractors.

Project. An enterprise involving a number of interrelated activities.

Public bid. A bid open to all contractors who can obtain the required amount of bonding to work on projects that are generally public or government types.

Risk. The danger of financial loss to a contractor, if he undertakes a particular project. It includes non-profit factors which directly or indirectly influence the attractiveness of a project.

Scheduling. The determination of the interrelationships among the various project activities, the duration of each, and the total project duration.

Scoring model. A mathematical model that integrates the use of numerous selected criteria to obtain an overall evaluation score for each project under consideration.

Work package. The combination of a group of project activities to facilitate the analysis and control of resources and costs. This is normally employed as an element of PERT/Cost.

# APPENDIX B

## COST ESTIMATE SUMMARY SHEET FOR SAMPLE PROJECT

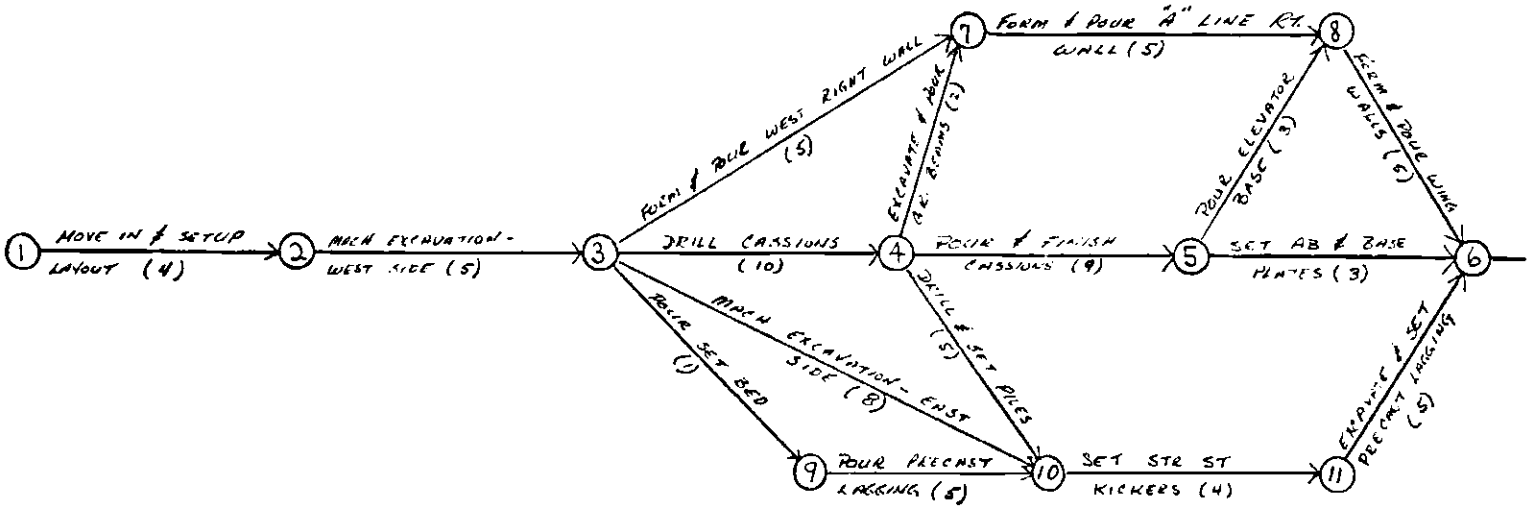
| | Item | Labor | Mat'l | Subs | Total |
|---|---|---|---|---|---|
| 1. | General Conditions | 42333 | 7575 | 10625 | 60533 |
| 2. | Site Work | 742 | 4542 | 6194 | 11478 |
| 3. | Earth Work | 149 | | 5000 | 5149 |
| 4. | Foundation | 1462 | | 26138 | 27600 |
| 5. | Concrete | 17619 | 27267 | 8777 | 53663 |
| 6. | R. I. Steel | | 4694 | 1710 | 6404 |
| 7. | Masonry | 15456 | 9753 | | 25209 |
| 8. | Structural Steel Deck | | | 157589 | 157589 |
| 9. | Miscellaneous Steel | 2393 | 2485 | | 4878 |
| 10. | Rough Carpentry | 1044 | 380 | | 1424 |
| 11. | Millwork | 2820 | 5168 | 1752 | 9740 |
| 12. | Drywall Construction | | | 63223 | 63223 |
| 13. | Insulation | | | 8948 | 8948 |
| 14. | Moisture Protection | 470 | 705 | 329 | 1504 |
| 15. | Roofing Sheet Metal | | | 8735 | 8735 |
| 16. | Metal Door & Frames | 455 | 928 | | 1383 |
| 17. | Windowwall Glass & Glazing | | | 160667 | 160667 |
| 18. | Acoustical | | | 26921 | 26921 |
| 19. | Ceramic Tile & Brick Pavers | | | 8915 | 8915 |
| 20. | Floor Covering | | | 28400 | 28400 |
| 21. | Painting | | | 19530 | 19530 |
| 22. | Stucco & Plaster Fireproofing | | | 16815 | 16815 |
| 23. | Wall Covering | | | | |
| 24. | Appliance & Accessory | | | 11710 | 11710 |
| 25. | Specialties | 726 | 4165 | 4400 | 9291 |
| 26. | Finishing Hardware | 200 | 10200 | | 10400 |
| 27. | Furnishings | | | | |
| 28. | Elevator | | | 45992 | 45992 |
| 29. | Mechanical | | | 175100 | 175100 |
| 30. | Electrical | | | 130000 | 130000 |
| 31. | Sprinkler | 200 | 300 | 7310 | 7810 |
| | Subtotals | 86069 | 78162 | 934780 | 1099011 |
| | Taxes & Insurance | 11189 | 2349 | 215 | 13753 |
| | Building Permit & A.G.C. | | | | 4484 |
| | Products Liability | | | | 118 |
| | Bond | | | | 6095 |
| | Overhead | | | | 25039* |
| Total Cost | | | | | $1148500 |

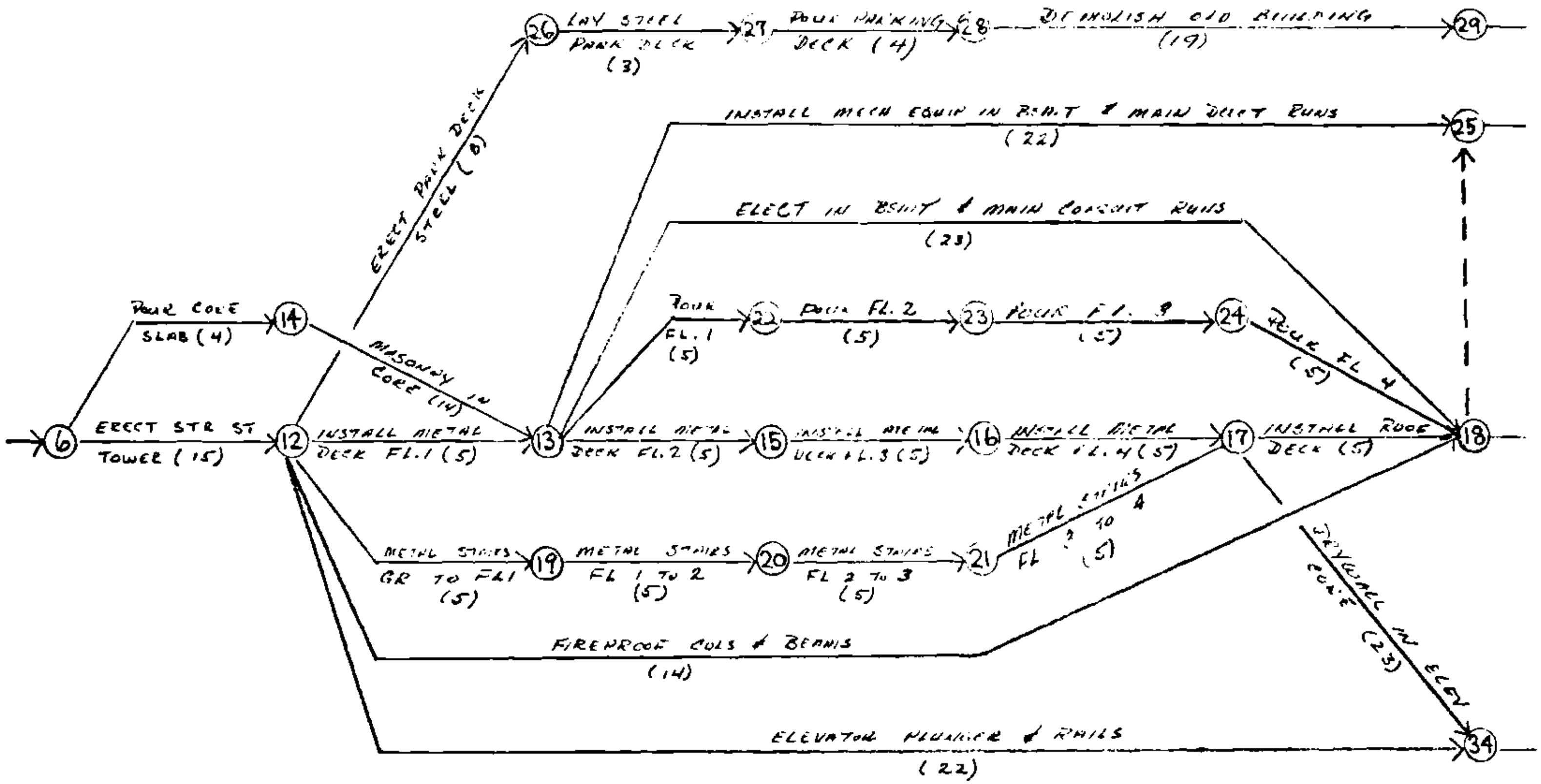
*To this figure a margin for profit must be added to arrive at the figure that will be submitted as the competitive bid.

# APPENDIX C

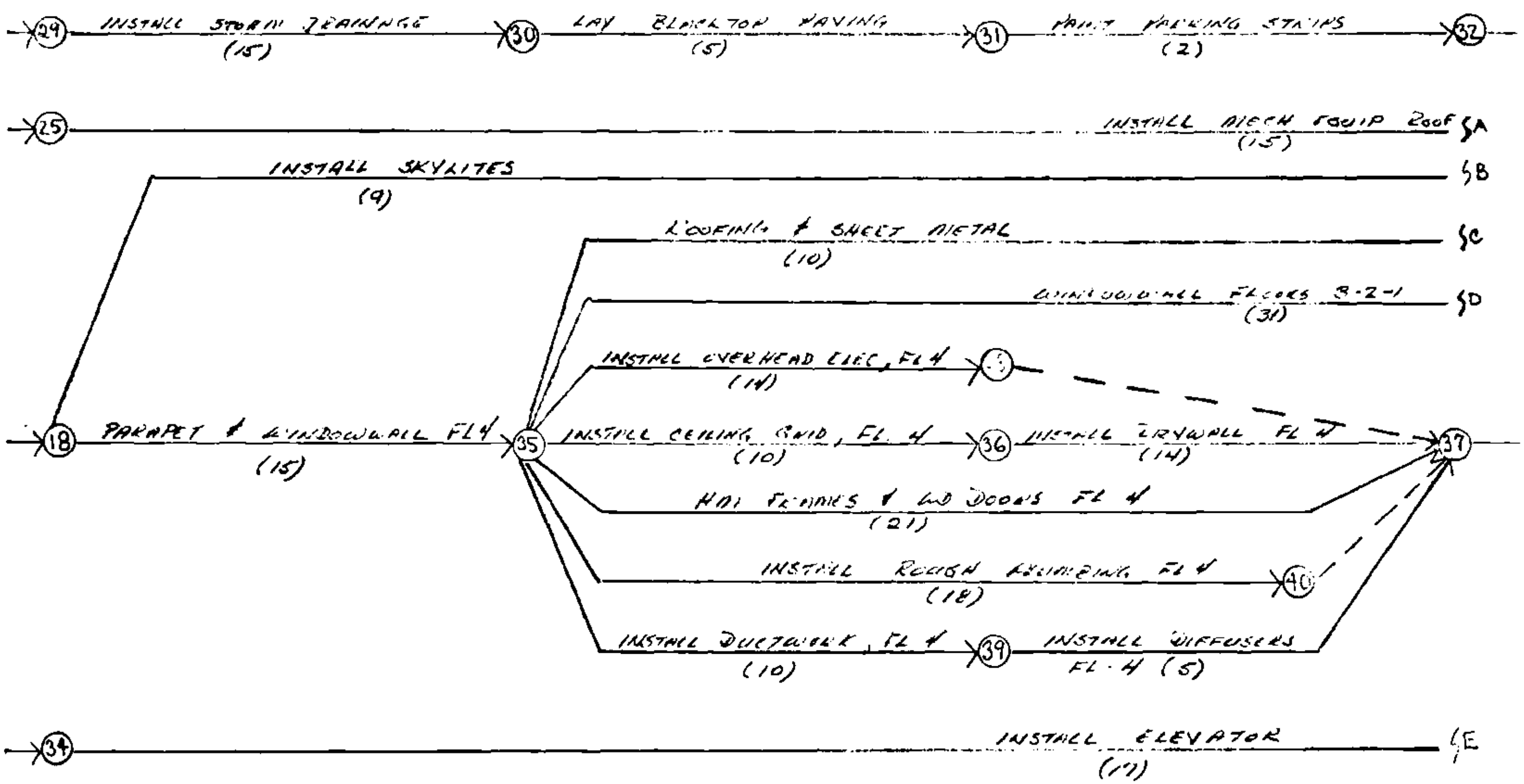
## SAMPLE PROJECT NETWORK

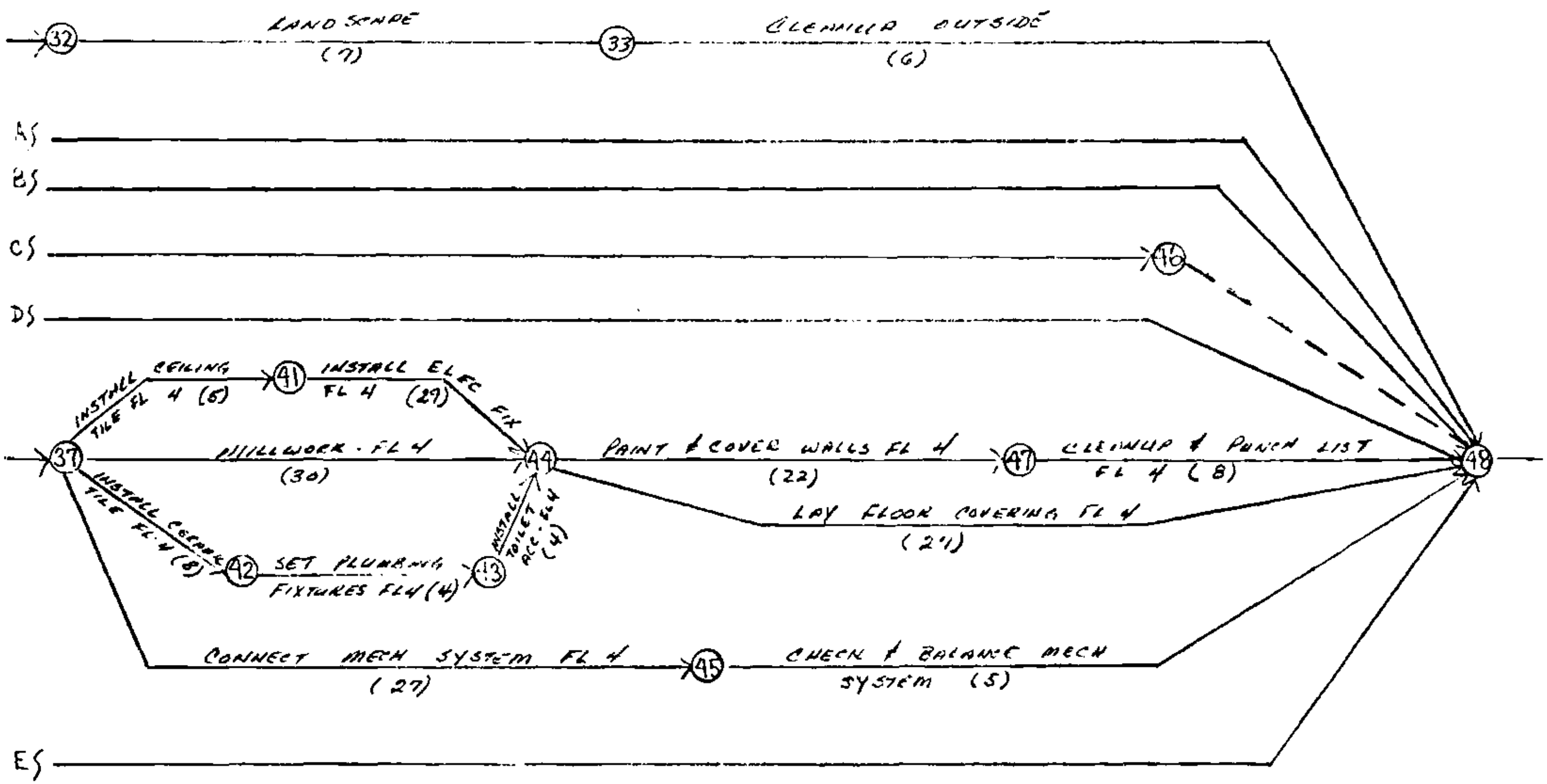
NOTE: ( ) = ACTIVITY DURATION IN DAYS.

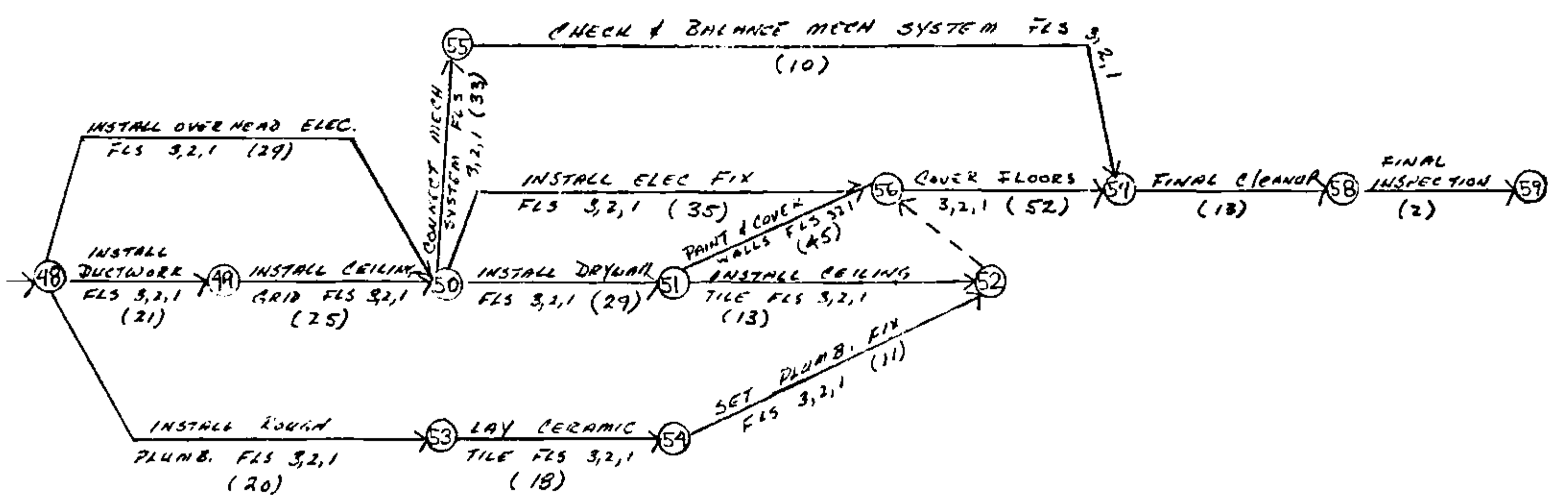




6
POUR CORE SLAB (4)
14
ERECT STR ST TOWER (15)
12
ERECT PARK DECK STEEL (8)
26
LAY STEEL PARK DECK (3)
27
POUR PARKING DECK (4)
28
DEMOLISH OLD BUILDING (19)
29
INSTALL MECH EQUIP IN BSMT & MAIN DUCT RUNS (22)
25
ELECT IN BSMT & MAIN CONDUIT RUNS (23)
MASONRY IN CORE (14)
INSTALL METAL DECK FL. 1 (5)
13
POUR FL. 1 (5)
22
POUR FL. 2 (5)
23
POUR FL. 3 (5)
24
POUR FL 4 (5)
INSTALL METAL DECK FL. 2 (5)
15
INSTALL METAL DECK FL. 3 (5)
16
INSTALL METAL DECK FL. 4 (5)
17
INSTALL ROOF DECK (5)
18
METAL STAIRS GR TO FL1 (5)
19
METAL STAIRS FL 1 TO 2 (5)
20
METAL STAIRS FL 2 TO 3 (5)
21
METAL STAIRS FL 3 TO 4 (5)
FIREPROOF COLS & BEAMS (14)
DRYWALL IN ELEV CORE (23)
ELEVATOR PLUNGER & RAILS (22)
34


29
INSTALL STORM DRAINAGE
(15)
30
LAY BLACKTOP PAVING
(5)
31
PAINT PARKING STRIPS
(2)
32
25
INSTALL MECH EQUIP ROOF
(15)
A
INSTALL SKYLITES
(9)
B
ROOFING & SHEET METAL
(10)
C
WINDOWWALL FLOORS 3-2-1
(31)
D
INSTALL OVERHEAD ELEC, FL 4
(14)
18
PARAPET & WINDOWWALL FL 4
(15)
35
INSTALL CEILING GRID, FL 4
(10)
36
INSTALL DRYWALL FL 4
(14)
37
HM FRAMES & WD DOORS FL 4
(21)
INSTALL ROUGH PLUMBING FL 4
(18)
40
INSTALL DUCTWORK, FL 4
(10)
39
INSTALL DIFFUSERS
FL-4 (5)
34
INSTALL ELEVATOR
(17)
E


LANDSCAPE
(7)
CLEANUP OUTSIDE
(6)
INSTALL CEILING TILE FL 4 (8)
INSTALL ELEC FIX FL 4 (27)
MILLWORK - FL 4
(30)
INSTALL CERAMIC TILE FL 4 (8)
SET PLUMBING FIXTURES FL 4 (4)
INSTALL TOILET ACC FL 4 (4)
PAINT & COVER WALLS FL 4
(22)
CLEANUP & PUNCH LIST FL 4 (8)
LAY FLOOR COVERING FL 4
(21)
CONNECT MECH SYSTEM FL 4
(27)
CHECK & BALANCE MECH SYSTEM (5)


CHECK & BALANCE MECH SYSTEM FLS 3,2,1 (10)
INSTALL OVERHEAD ELEC. FLS 3,2,1 (29)
CONNECT MECH SYSTEM FLS 3,2,1 (33)
INSTALL ELEC FIX FLS 3,2,1 (35)
COVER FLOORS 3,2,1 (52)
FINAL CLEANUP (13)
FINAL INSPECTION (2)
INSTALL DUCTWORK FLS 3,2,1 (21)
INSTALL CEILING GRID FLS 3,2,1 (25)
INSTALL DRYWALL FLS 3,2,1 (29)
PAINT & COVER WALLS FLS 3,2,1 (45)
INSTALL CEILING TILE FLS 3,2,1 (13)
SET PLUMB. FIX FLS 3,2,1 (11)
INSTALL ROUGH PLUMB. FLS 3,2,1 (20)
LAY CERAMIC TILE FLS 3,2,1 (18)
48
49
50
51
52
53
54
55
56
57
58
59

# APPENDIX D

## COMPUTER ANALYSIS OF INITIAL PROJECT NETWORK

```
********************************* B U R R O U G H S     P R O M I S     R E P O R T *************************************PAGE    1

                                        DECEMBER  9, 1971       7:38 PM

                                         REPORT NO.=       1   REPORT TYPE =  ACTIVITY
NETWORKS-REPORTED :                     NUMBER OF NETWORKS =       1
720078.
REPORT SORTED BY :
ES     ,EF     ,PRED   ,SUCC   .
IN ASCENDING ORDER....
REPORT EDITED BY :

DELETE DUMMY ACTIVITIES.
... NETWORK INFORMATION ...
  NETWORK NO : 720078 NETWORK NAME :     PROPOSED CONST PROJECT                  CUSTOMER ID : JONES
               NETWORK DATE INFORMATION
NETWORK START DATE : 06 NOV 72       NETWORK END DATE : 16 MAY 74       NETWORK REPORT DATE   06 NOV 72
               NETWORK CALENDAR INFORMATION
NETWORK CALENDAR DURATION : 02 YEARS     NETWORK CALENDAR START DATE:   06 NOV 72
               DECLARED HOLIDAYS
23 NOV 72   25 DEC 72   01 JAN 73   19 FEB 73   28 MAY 73   04 JUL 73   08 OCT 73   22 OCT 73   22 NOV 73   25 DEC 73
01 JAN 74   18 FEB 74
               FILES USED BY THIS NETWORK
                     ACTIVITY
                     EVENT
               GLOBAL CONTROL INFORMATION FOR THIS NETWORK
                      WORK -PATTERN
                                   HOURS PER SHIFT    8.0
                                   SHIFTS PER DAY     1.0
                                   DAYS PER WEEK      5.0
STARTING EVENTS:       1
                 1.
ENDING EVENTS:         1
                59.
```

| PRED NUMBER | SUCC NUMBER | EARLIEST START | EARLIEST FINISH | EXP. TIME | LATEST START | LATEST FINISH | TOTAL SLACK | D E S C R I P T I O N |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 06 NOV 72 | 09 NOV 72 | 4.0 | 06 NOV 72 | 09 NOV 72 | .0+ | MOVE IN AND SETUP LAYOUT |
| 2 | 3 | 09 NOV 72 | 16 NOV 72 | 5.0 | 09 NOV 72 | 16 NOV 72 | .0+ | MACH EXCAVATION W. SIDE |
| 3 | 9 | 16 NOV 72 | 17 NOV 72 | 1.0 | 05 DEC 72 | 06 DEC 72 | 12.0+ | POUR SET BED |
| 3 | 7 | 16 NOV 72 | 24 NOV 72 | 5.0 | 05 DEC 72 | 12 DEC 72 | 12.0+ | FORM/POUR WEST RT. WALL |
| 3 | 10 | 16 NOV 72 | 29 NOV 72 | 8.0 | 01 DEC 72 | 13 DEC 72 | 10.0+ | MACH EXCAVATION E. SIDE |
| 3 | 4 | 16 NOV 72 | 01 DEC 72 | 10.0 | 16 NOV 72 | 01 DEC 72 | .0+ | DRILL CASSIONS |
| 9 | 10 | 17 NOV 72 | 27 NOV 72 | 5.0 | 06 DEC 72 | 13 DEC 72 | 12.0+ | POUR PRECAST LAGGING |
| 4 | 7 | 01 DEC 72 | 05 DEC 72 | 2.0 | 08 DEC 72 | 12 DEC 72 | 5.0+ | EXCAVATE/POUR GR. BEAMS |
| 4 | 10 | 01 DEC 72 | 08 DEC 72 | 5.0 | 06 DEC 72 | 13 DEC 72 | 3.0+ | DRILL/SET (H) PILES |
| 4 | 5 | 01 DEC 72 | 14 DEC 72 | 9.0 | 01 DEC 72 | 14 DEC 72 | .0+ | POUR AND FINISH CASSIONS |
| 7 | 8 | 05 DEC 72 | 12 DEC 72 | 5.0 | 12 DEC 72 | 19 DEC 72 | 5.0+ | FORM/POUR A-LINE RT WALL |
| 10 | 11 | 08 DEC 72 | 14 DEC 72 | 4.0 | 13 DEC 72 | 19 DEC 72 | 3.0+ | SET STR. STEEL KICKERS |
| 5 | 6 | 14 DEC 72 | 19 DEC 72 | 3.0 | 21 DEC 72 | 27 DEC 72 | 5.0+ | SET AB AND BASE PLATES |
| 5 | 8 | 14 DEC 72 | 19 DEC 72 | 3.0 | 14 DEC 72 | 19 DEC 72 | .0+ | POUR ELEVATOR BASE |
| 11 | 6 | 14 DEC 72 | 21 DEC 72 | 5.0 | 19 DEC 72 | 27 DEC 72 | 3.0+ | EXCAVATE/SET PRECAST LAG |
| 8 | 6 | 19 DEC 72 | 27 DEC 72 | 5.0 | 19 DEC 72 | 27 DEC 72 | .0+ | FORM/POUR WING WALLS |
| 6 | 14 | 27 DEC 72 | 03 JAN 73 | 4.0 | 29 DEC 72 | 05 JAN 73 | 2.0+ | POUR CORE SLAB |
| 6 | 12 | 27 DEC 72 | 18 JAN 73 | 15.0 | 27 DEC 72 | 18 JAN 73 | .0+ | ERECT STR. STEEL TOWER |
| 14 | 13 | 03 JAN 73 | 23 JAN 73 | 14.0 | 05 JAN 73 | 25 JAN 73 | 2.0+ | MASONRY IN CORE |
| 12 | 13 | 18 JAN 73 | 25 JAN 73 | 5.0 | 18 JAN 73 | 25 JAN 73 | .0+ | INSTALL MET DECK,FLOOR 1 |
| 12 | 19 | 18 JAN 73 | 25 JAN 73 | 5.0 | 23 JAN 73 | 30 JAN 73 | 3.0+ | METAL STAIRS,GROUND TO 1 |
| 12 | 26 | 18 JAN 73 | 30 JAN 73 | 8.0 | 17 APR 73 | 27 APR 73 | 62.0+ | ERECT PARK DECK STEEL |
| 12 | 18 | 18 JAN 73 | 07 FEB 73 | 14.0 | 07 FEB 73 | 28 FEB 73 | 14.0+ | FIREPROOF COLS AND BEAMS |
| 12 | 34 | 18 JAN 73 | 20 FEB 73 | 22.0 | 30 MAY 73 | 29 JUN 73 | 92.0+ | ELEVATOR PLUNGER & RAILS |
| 13 | 15 | 25 JAN 73 | 01 FEB 73 | 5.0 | 30 JAN 73 | 06 FEB 73 | 3.0+ | INSTALL MET DECK,FLOOR 2 |
| 13 | 22 | 25 JAN 73 | 01 FEB 73 | 5.0 | 30 JAN 73 | 06 FEB 73 | 3.0+ | POUR FLOOR 1 |
| 19 | 20 | 25 JAN 73 | 01 FEB 73 | 5.0 | 30 JAN 73 | 06 FEB 73 | 3.0+ | METAL STAIRS, FL 1 TO 2 |

| PRED NUMBER | SUCC NUMBER | EARLIEST START | EARLIEST FINISH | EXP. TIME | LATEST START | LATEST FINISH | TOTAL SLACK | D E S C R I P T I O N |
|---|---|---|---|---|---|---|---|---|
| 13 | 25 | 25 JAN 73 | 27 FEB 73 | 22.0 | 01 JUN 73 | 03 JUL 73 | 89.0+ | MECH EQP BSMT/MAIN DUCTS |
| 13 | 18 | 25 JAN 73 | 28 FEB 73 | 23.0 | 25 JAN 73 | 28 FEB 73 | .0+ | ELEC IN BSMT/MAIN CD RUN |
| 26 | 27 | 30 JAN 73 | 02 FEB 73 | 3.0 | 27 APR 73 | 02 MAY 73 | 62.0+ | LAY STEEL PARK DECK |
| 15 | 16 | 01 FEB 73 | 08 FEB 73 | 5.0 | 06 FEB 73 | 13 FEB 73 | 3.0+ | INSTALL MET DECK,FLOOR 3 |
| 20 | 21 | 01 FEB 73 | 08 FEB 73 | 5.0 | 06 FEB 73 | 13 FEB 73 | 3.0+ | METAL STAIRS, FL 2 TO 3 |
| 22 | 23 | 01 FEB 73 | 08 FEB 73 | 5.0 | 06 FEB 73 | 13 FEB 73 | 3.0+ | POUR FLOOR 2 |
| 27 | 28 | 02 FEB 73 | 08 FEB 73 | 4.0 | 02 MAY 73 | 08 MAY 73 | 62.0+ | POUR PARK DECK |
| 16 | 17 | 08 FEB 73 | 15 FEB 73 | 5.0 | 13 FEB 73 | 21 FEB 73 | 3.0+ | INSTALL MET DECK,FLOOR 4 |
| 21 | 17 | 08 FEB 73 | 15 FEB 73 | 5.0 | 13 FEB 73 | 21 FEB 73 | 3.0+ | METAL STAIRS, FL 3 TO 4 |
| 23 | 24 | 08 FEB 73 | 15 FEB 73 | 5.0 | 13 FEB 73 | 21 FEB 73 | 3.0+ | POUR FLOOR 3 |
| 28 | 29 | 08 FEB 73 | 08 MAR 73 | 19.0 | 08 MAY 73 | 05 JUN 73 | 62.0+ | DEMOLISH OLD BUILDING |
| 17 | 18 | 15 FEB 73 | 23 FEB 73 | 5.0 | 21 FEB 73 | 28 FEB 73 | 3.0+ | INSTALL ROOF DECK |
| 24 | 18 | 15 FEB 73 | 23 FEB 73 | 5.0 | 21 FEB 73 | 28 FEB 73 | 3.0+ | POUR FLOOR 4 |
| 17 | 34 | 15 FEB 73 | 21 MAR 73 | 23.0 | 29 MAY 73 | 29 JUN 73 | 71.0+ | DRYWALL IN ELEV CORE |
| 18 | 48 | 28 FEB 73 | 13 MAR 73 | 9.0 | 12 JUL 73 | 25 JUL 73 | 94.0+ | INSTALL SKYLITES |
| 18 | 35 | 28 FEB 73 | 21 MAR 73 | 15.0 | 28 FEB 73 | 21 MAR 73 | .0+ | PARAPET/WINDOWWALL, FL 4 |
| 25 | 48 | 28 FEB 73 | 21 MAR 73 | 15.0 | 03 JUL 73 | 25 JUL 73 | 88.0+ | INSTALL MECH EQUIP ROOF |
| 29 | 30 | 08 MAR 73 | 29 MAR 73 | 15.0 | 05 JUN 73 | 26 JUN 73 | 62.0+ | INSTALL STORM DRAINAGE |
| 35 | 36 | 21 MAR 73 | 04 APR 73 | 10.0 | 21 MAR 73 | 04 APR 73 | .0+ | INSTALL CEILING GRID,FL4 |
| 35 | 39 | 21 MAR 73 | 04 APR 73 | 10.0 | 03 APR 73 | 17 APR 73 | 9.0+ | INSTALL DUCTWORK,FLOOR 4 |
| 35 | 48 | 21 MAR 73 | 04 APR 73 | 10.0 | 11 JUL 73 | 25 JUL 73 | 78.0+ | ROOFING AND SHEET METAL |
| 35 | 38 | 21 MAR 73 | 10 APR 73 | 14.0 | 04 APR 73 | 24 APR 73 | 10.0+ | INSTALL OVERHEAD ELEC, 4 |
| 34 | 48 | 21 MAR 73 | 13 APR 73 | 17.0 | 29 JUN 73 | 25 JUL 73 | 71.0+ | INSTALL ELEVATOR |
| 35 | 40 | 21 MAR 73 | 16 APR 73 | 18.0 | 29 MAR 73 | 24 APR 73 | 6.0+ | INSTALL ROUGH PLUMBING,4 |
| 35 | 37 | 21 MAR 73 | 19 APR 73 | 21.0 | 26 MAR 73 | 24 APR 73 | 3.0+ | HM FRAMES & WD DOORS,FL4 |
| 35 | 46 | 21 MAR 73 | 03 MAY 73 | 31.0 | 11 JUN 73 | 25 JUL 73 | 57.0+ | WINDOWWALL FLOORS 3,2,1 |
| 30 | 31 | 29 MAR 73 | 05 APR 73 | 5.0 | 26 JUN 73 | 03 JUL 73 | 62.0+ | LAY BLACKTOP PAVING |
| 39 | 37 | 04 APR 73 | 11 APR 73 | 5.0 | 17 APR 73 | 24 APR 73 | 9.0+ | INSTALL DIFFUSERS, FL 4 |

| PRED NUMBER | SUCC NUMBER | EARLIEST START | EARLIEST FINISH | EXP. TIME | LATEST START | LATEST FINISH | TOTAL SLACK | D E S C R I P T I O N |
|---|---|---|---|---|---|---|---|---|
| 36 | 37 | 04 APR 73 | 24 APR 73 | 14.0 | 04 APR 73 | 24 APR 73 | .0+ | INSTALL DRYWALL, FLOOR 4 |
| 31 | 32 | 05 APR 73 | 09 APR 73 | 2.0 | 03 JUL 73 | 06 JUL 73 | 62.0+ | PAINT PARKING STRIPS |
| 32 | 33 | 09 APR 73 | 18 APR 73 | 7.0 | 06 JUL 73 | 17 JUL 73 | 62.0+ | LANDSCAPE |
| 33 | 48 | 18 APR 73 | 26 APR 73 | 6.0 | 17 JUL 73 | 25 JUL 73 | 62.0+ | CLEANUP OUTSIDE |
| 37 | 41 | 24 APR 73 | 01 MAY 73 | 5.0 | 24 APR 73 | 01 MAY 73 | .0+ | INSTALL CEILING TILE,FL4 |
| 37 | 42 | 24 APR 73 | 04 MAY 73 | 8.0 | 18 MAY 73 | 31 MAY 73 | 18.0+ | INSTALL CERAMIC TILE,FL4 |
| 37 | 45 | 24 APR 73 | 01 JUN 73 | 27.0 | 08 JUN 73 | 18 JUL 73 | 32.0+ | CONNECT MECH SYSTEM,FL 4 |
| 37 | 44 | 24 APR 73 | 06 JUN 73 | 30.0 | 30 APR 73 | 12 JUN 73 | 4.0+ | MILLWORK, FLOOR 4 |
| 41 | 44 | 01 MAY 73 | 12 JUN 73 | 29.0 | 01 MAY 73 | 12 JUN 73 | .0+ | INSTALL ELEC FIXTURES, 4 |
| 42 | 43 | 04 MAY 73 | 10 MAY 73 | 4.0 | 31 MAY 73 | 06 JUN 73 | 18.0+ | SET PLUMBING FIXTURES, 4 |
| 43 | 44 | 10 MAY 73 | 16 MAY 73 | 4.0 | 06 JUN 73 | 12 JUN 73 | 18.0+ | INSTALL TOILET ACC.,FL 4 |
| 45 | 48 | 01 JUN 73 | 08 JUN 73 | 5.0 | 18 JUL 73 | 25 JUL 73 | 32.0+ | CHECK & BAL MECH SYSTEM |
| 44 | 47 | 12 JUN 73 | 13 JUL 73 | 22.0 | 12 JUN 73 | 13 JUL 73 | .0+ | PAINT AND COVER WALL,FL4 |
| 44 | 48 | 12 JUN 73 | 20 JUL 73 | 27.0 | 15 JUN 73 | 25 JUL 73 | 3.0+ | LAY FLOOR COVERING,FL4 |
| 47 | 48 | 13 JUL 73 | 25 JUL 73 | 8.0 | 13 JUL 73 | 25 JUL 73 | .0+ | CLEANUP & PUNCH LIST,FL4 |
| 48 | 53 | 25 JUL 73 | 22 AUG 73 | 20.0 | 05 NOV 73 | 04 DEC 73 | 71.0+ | INSTALL ROUGH PLUMB.,321 |
| 48 | 49 | 25 JUL 73 | 23 AUG 73 | 21.0 | 25 JUL 73 | 23 AUG 73 | .0+ | INSTALL DUCTWORK,FLS 321 |
| 48 | 50 | 25 JUL 73 | 04 SEP 73 | 29.0 | 17 AUG 73 | 27 SEP 73 | 17.0+ | INSTALL OVERHEAD ELEC321 |
| 53 | 54 | 22 AUG 73 | 17 SEP 73 | 18.0 | 04 DEC 73 | 31 DEC 73 | 71.0+ | LAY CERAMIC TILE, 321 |
| 49 | 50 | 23 AUG 73 | 27 SEP 73 | 25.0 | 23 AUG 73 | 27 SEP 73 | .0+ | INSTALL CEILING GRID,321 |
| 54 | 52 | 17 SEP 73 | 02 OCT 73 | 11.0 | 31 DEC 73 | 16 JAN 74 | 71.0+ | SET PLUMB. FIXTURES, 321 |
| 50 | 51 | 27 SEP 73 | 09 NOV 73 | 29.0 | 27 SEP 73 | 09 NOV 73 | .0+ | INSTALL DRYWALL, 321 |
| 50 | 55 | 27 SEP 73 | 15 NOV 73 | 33.0 | 29 JAN 74 | 18 MAR 74 | 83.0+ | CONNECT MECH SYS, 321 |
| 50 | 56 | 27 SEP 73 | 19 NOV 73 | 35.0 | 26 NOV 73 | 16 JAN 74 | 39.0+ | INSTALL ELEC FIX., 321 |
| 51 | 52 | 09 NOV 73 | 29 NOV 73 | 13.0 | 27 DEC 73 | 16 JAN 74 | 32.0+ | INSTALL CEILING TILE,321 |
| 51 | 56 | 09 NOV 73 | 16 JAN 74 | 45.0 | 09 NOV 73 | 16 JAN 74 | .0+ | PAINT & COVER WALLS, 321 |
| 55 | 57 | 15 NOV 73 | 30 NOV 73 | 10.0 | 18 MAR 74 | 01 APR 74 | 83.0+ | CHECK & BAL SYS, 321 |
| 56 | 57 | 16 JAN 74 | 01 APR 74 | 52.0 | 16 JAN 74 | 01 APR 74 | .0+ | COVER FLOORS, 321 |

| PRED NUMBER | SUCC NUMBER | EARLIEST START | EARLIEST FINISH | EXP. TIME | LATEST START | LATEST FINISH | TOTAL SLACK | D E S C R I P T I O N |
|---|---|---|---|---|---|---|---|---|
| 57 | 58 | 01 APR 74 | 18 APR 74 | 13.0 | 01 APR 74 | 18 APR 74 | .0* | FINAL CLEANUP |
| 58 | 59 | 18 APR 74 | 22 APR 74 | 2.0 | 18 APR 74 | 22 APR 74 | .0* | FINAL INSPECTION |

# APPENDIX E

## COMPUTER ANALYSIS OF ADJUSTED PROJECT NETWORK

```
******************************** B U R R O U G H S     P R O M I S     R E P O R T ************************************ PAGE     1

                                       DECEMBER 10, 1971      10:31 AM

                                       REPORT NO.=       1   REPORT TYPE =  ACTIVITY
NETWORKS-REPORTED :                  NUMBER OF NETWORKS =       1
720078.
REPORT SORTED BY :
ES      ,EF      ,PRED    ,SUCC    .
IN ASCENDING ORDER....
REPORT EDITED BY :

DELETE DUMMY ACTIVITIES.
... NETWORK INFORMATION ...
  NETWORK NO : 720078 NETWORK NAME :     ADJUSTED CONST PROJECT                CUSTOMER ID : JONES
               NETWORK DATE INFORMATION
NETWORK START DATE : 06 NOV 72       NETWORK END DATE : 28 JUN 74       NETWORK REPORT DATE   06 NOV 72
               NETWORK CALENDAR INFORMATION
NETWORK CALENDAR DURATION : 02 YEARS     NETWORK CALENDAR START DATE:   06 NOV 72
               DECLARED HOLIDAYS
23 NOV 72   25 DEC 72   01 JAN 73   19 FEB 73   28 MAY 73   04 JUL 73   08 OCT 73   22 OCT 73   22 NOV 73   25 DEC 73
01 JAN 74   18 FEB 74
               FILES USED BY THIS NETWORK
                     ACTIVITY
                     EVENT
               GLOBAL CONTROL INFORMATION FOR THIS NETWORK
                      WORK -PATTERN
                                   HOURS PER SHIFT    8.0
                                   SHIFTS PER DAY     1.0
                                   DAYS PER WEEK      5.0
STARTING EVENTS:       1
                 1.
ENDING EVENTS:         1
                59.
```

******************************** B U R R O U G H S    P R O M I S    R E P O R T *************************************

| PRED NUMBER | SUCC NUMBER | EARLIEST START | EARLIEST FINISH | EXP. TIME | LATEST START | LATEST FINISH | TOTAL SLACK | D E S C R I P T I O N |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 06 NOV 72 | 09 NOV 72 | 4.0 | 06 NOV 72 | 09 NOV 72 | .0+ | MOVE IN AND SETUP LAYOUT |
| 2 | 3 | 09 NOV 72 | 17 NOV 72 | 6.0 | 09 NOV 72 | 17 NOV 72 | .0+ | MACH EXCAVATION W. SIDE |
| 3 | 9 | 17 NOV 72 | 20 NOV 72 | 1.0 | 15 DEC 72 | 18 DEC 72 | 18.5+ | POUR SET BED |
| 3 | 7 | 17 NOV 72 | 28 NOV 72 | 6.0 | 12 DEC 72 | 20 DEC 72 | 16.0+ | FORM/POUR WEST RT. WALL |
| 3 | 10 | 17 NOV 72 | 04 DEC 72 | 10.0 | 12 DEC 72 | 27 DEC 72 | 16.0+ | MACH EXCAVATION E. SIDE |
| 3 | 4 | 17 NOV 72 | 06 DEC 72 | 12.0 | 17 NOV 72 | 06 DEC 72 | .0+ | DRILL CASSIONS |
| 9 | 10 | 20 NOV 72 | 30 NOV 72 | 6.5 | 18 DEC 72 | 27 DEC 72 | 18.5+ | POUR PRECAST LAGGING |
| 4 | 7 | 06 DEC 72 | 11 DEC 72 | 2.5 | 18 DEC 72 | 20 DEC 72 | 7.5+ | EXCAVATE/POUR GR. BEAMS |
| 4 | 10 | 06 DEC 72 | 15 DEC 72 | 6.5 | 18 DEC 72 | 27 DEC 72 | 7.5+ | DRILL/SET (H) PILES |
| 4 | 5 | 06 DEC 72 | 26 DEC 72 | 13.0 | 06 DEC 72 | 26 DEC 72 | .0+ | POUR AND FINISH CASSIONS |
| 7 | 8 | 11 DEC 72 | 20 DEC 72 | 7.5 | 20 DEC 72 | 03 JAN 73 | 7.5+ | FORM/POUR A-LINE RT WALL |
| 10 | 11 | 15 DEC 72 | 21 DEC 72 | 4.5 | 27 DEC 72 | 04 JAN 73 | 7.5+ | SET STR. STEEL KICKERS |
| 11 | 6 | 21 DEC 72 | 03 JAN 73 | 6.5 | 04 JAN 73 | 12 JAN 73 | 7.5+ | EXCAVATE/SET PRECAST LAG |
| 5 | 6 | 26 DEC 72 | 29 DEC 72 | 3.0 | 09 JAN 73 | 12 JAN 73 | 9.0+ | SET AB AND BASE PLATES |
| 5 | 8 | 26 DEC 72 | 03 JAN 73 | 4.5 | 26 DEC 72 | 03 JAN 73 | .0+ | POUR ELEVATOR BASE |
| 6 | 6 | 03 JAN 73 | 12 JAN 73 | 7.5 | 03 JAN 73 | 12 JAN 73 | .0+ | FORM/POUR WING WALLS |
| 6 | 14 | 12 JAN 73 | 22 JAN 73 | 6.0 | 12 JAN 73 | 22 JAN 73 | .0+ | POUR CORE SLAB |
| 6 | 12 | 12 JAN 73 | 08 FEB 73 | 19.0 | 12 JAN 73 | 08 FEB 73 | .0+ | ERECT STR. STEEL TOWER |
| 14 | 13 | 22 JAN 73 | 20 FEB 73 | 19.5 | 22 JAN 73 | 20 FEB 73 | .0+ | MASONRY IN CORE |
| 12 | 19 | 08 FEB 73 | 16 FEB 73 | 6.0 | 13 FEB 73 | 22 FEB 73 | 2.5+ | METAL STAIRS,GROUND TO 1 |
| 12 | 13 | 08 FEB 73 | 20 FEB 73 | 6.5 | 08 FEB 73 | 20 FEB 73 | .0+ | INSTALL MET DECK,FLOOR 1 |
| 12 | 26 | 08 FEB 73 | 23 FEB 73 | 10.0 | 30 APR 73 | 14 MAY 73 | 56.0+ | ERECT PARK DECK STEEL |
| 12 | 18 | 08 FEB 73 | 06 MAR 73 | 16.5 | 05 MAR 73 | 27 MAR 73 | 15.5+ | FIREPROOF COLS AND BEAMS |
| 12 | 34 | 08 FEB 73 | 15 MAR 73 | 24.0 | 27 JUN 73 | 01 AUG 73 | 96.5+ | ELEVATOR PLUNGER & RAILS |
| 19 | 20 | 16 FEB 73 | 27 FEB 73 | 5.5 | 22 FEB 73 | 01 MAR 73 | 2.5+ | METAL STAIRS, FL 1 TO 2 |
| 13 | 15 | 20 FEB 73 | 28 FEB 73 | 6.0 | 20 FEB 73 | 28 FEB 73 | 1.0+ | INSTALL MET DECK,FLOOR 2 |
| 13 | 22 | 20 FEB 73 | 28 FEB 73 | 6.5 | 20 FEB 73 | 28 FEB 73 | .0+ | POUR FLOOR 1 |

****************************** B U R R O U G H S   P R O M I S   R E P O R T ******************************

| PRED NUMBER | SUCC NUMBER | EARLIEST START | EARLIEST FINISH | EXP. TIME | LATEST START | LATEST FINISH | TOTAL SLACK | D E S C R I P T I O N |
|---|---|---|---|---|---|---|---|---|
| 13 | 18 | 20 FEB 73 | 26 MAR 73 | 24.0 | 21 FEB 73 | 27 MAR 73 | 1.5+ | ELEC IN BSMT/MAIN CD RUN |
| 13 | 25 | 20 FEB 73 | 26 MAR 73 | 24.0 | 26 JUN 73 | 31 JUL 73 | 89.5+ | MECH EQP BSMT/MAIN DUCTS |
| 26 | 27 | 23 FEB 73 | 01 MAR 73 | 3.5 | 14 MAY 73 | 18 MAY 73 | 56.0+ | LAY STEEL PARK DECK |
| 20 | 21 | 27 FEB 73 | 07 MAR 73 | 6.0 | 01 MAR 73 | 09 MAR 73 | 2.5+ | METAL STAIRS, FL 2 TO 3 |
| 15 | 16 | 28 FEB 73 | 08 MAR 73 | 6.0 | 01 MAR 73 | 09 MAR 73 | 1.0+ | INSTALL MET DECK,FLOOR 3 |
| 22 | 23 | 28 FEB 73 | 09 MAR 73 | 6.5 | 28 FEB 73 | 09 MAR 73 | .0+ | POUR FLOOR 2 |
| 27 | 28 | 01 MAR 73 | 08 MAR 73 | 5.5 | 18 MAY 73 | 25 MAY 73 | 56.0+ | POUR PARK DECK |
| 21 | 17 | 07 MAR 73 | 15 MAR 73 | 6.0 | 09 MAR 73 | 19 MAR 73 | 2.5+ | METAL STAIRS, FL 3 TO 4 |
| 16 | 17 | 08 MAR 73 | 16 MAR 73 | 6.0 | 09 MAR 73 | 19 MAR 73 | 1.5+ | INSTALL MET DECK,FLOOR 4 |
| 28 | 29 | 08 MAR 73 | 06 APR 73 | 20.5 | 25 MAY 73 | 26 JUN 73 | 56.0+ | DEMOLISH OLD BUILDING |
| 23 | 24 | 09 MAR 73 | 19 MAR 73 | 6.5 | 09 MAR 73 | 19 MAR 73 | .0+ | POUR FLOOR 3 |
| 17 | 18 | 16 MAR 73 | 26 MAR 73 | 6.0 | 19 MAR 73 | 27 MAR 73 | 1.5+ | INSTALL ROOF DECK |
| 17 | 34 | 16 MAR 73 | 19 APR 73 | 24.5 | 26 JUN 73 | 01 AUG 73 | 71.5+ | DRYWALL IN ELEV CORE |
| 24 | 18 | 19 MAR 73 | 27 MAR 73 | 6.0 | 19 MAR 73 | 27 MAR 73 | .0+ | POUR FLOOR 4 |
| 18 | 48 | 27 MAR 73 | 11 APR 73 | 11.0 | 09 AUG 73 | 24 AUG 73 | 94.5+ | INSTALL SKYLITES |
| 18 | 35 | 27 MAR 73 | 20 APR 73 | 17.5 | 27 MAR 73 | 20 APR 73 | .0+ | PARAPET/WINDOWWALL, FL 4 |
| 25 | 48 | 27 MAR 73 | 20 APR 73 | 17.5 | 31 JUL 73 | 24 AUG 73 | 88.0+ | INSTALL MECH EQUIP ROOF |
| 29 | 30 | 06 APR 73 | 02 MAY 73 | 18.0 | 26 JUN 73 | 23 JUL 73 | 56.0+ | INSTALL STORM DRAINAGE |
| 34 | 48 | 19 APR 73 | 14 MAY 73 | 17.0 | 01 AUG 73 | 24 AUG 73 | 71.5+ | INSTALL ELEVATOR |
| 35 | 36 | 20 APR 73 | 04 MAY 73 | 10.0 | 20 APR 73 | 04 MAY 73 | .0+ | INSTALL CEILING GRID,FL4 |
| 35 | 39 | 20 APR 73 | 04 MAY 73 | 10.0 | 03 MAY 73 | 17 MAY 73 | 9.0+ | INSTALL DUCTWORK,FLOOR 4 |
| 35 | 48 | 20 APR 73 | 08 MAY 73 | 12.0 | 08 AUG 73 | 24 AUG 73 | 76.0+ | ROOFING AND SHEET METAL |
| 35 | 38 | 20 APR 73 | 10 MAY 73 | 14.0 | 04 MAY 73 | 24 MAY 73 | 10.0+ | INSTALL OVERHEAD ELEC, 4 |
| 35 | 40 | 20 APR 73 | 16 MAY 73 | 18.0 | 30 APR 73 | 24 MAY 73 | 6.0+ | INSTALL ROUGH PLUMBING,4 |
| 35 | 37 | 20 APR 73 | 21 MAY 73 | 21.0 | 25 APR 73 | 24 MAY 73 | 3.0+ | HM FRAMES & WD DOORS,FL4 |
| 35 | 46 | 20 APR 73 | 08 JUN 73 | 34.5 | 06 JUL 73 | 24 AUG 73 | 53.5+ | WINDOWWALL FLOORS 3,2,1 |
| 30 | 31 | 02 MAY 73 | 10 MAY 73 | 6.5 | 23 JUL 73 | 31 JUL 73 | 56.0+ | LAY BLACKTOP PAVING |
| 39 | 37 | 04 MAY 73 | 11 MAY 73 | 5.0 | 17 MAY 73 | 24 MAY 73 | 9.0+ | INSTALL DIFFUSERS, FL 4 |

| PRED NUMBER | SUCC NUMBER | EARLIEST START | EARLIEST FINISH | EXP. TIME | LATEST START | LATEST FINISH | TOTAL SLACK | D E S C R I P T I O N |
|---|---|---|---|---|---|---|---|---|
| 36 | 37 | 04 MAY 73 | 24 MAY 73 | 14.0 | 04 MAY 73 | 24 MAY 73 | .0+ | INSTALL DRYWALL, FLOOR 4 |
| 31 | 32 | 10 MAY 73 | 15 MAY 73 | 2.5 | 31 JUL 73 | 03 AUG 73 | 56.0+ | PAINT PARKING STRIPS |
| 32 | 33 | 15 MAY 73 | 25 MAY 73 | 8.5 | 03 AUG 73 | 15 AUG 73 | 56.0+ | LANDSCAPE |
| 37 | 41 | 24 MAY 73 | 01 JUN 73 | 5.0 | 24 MAY 73 | 01 JUN 73 | .0+ | INSTALL CEILING TILE,FL4 |
| 37 | 42 | 24 MAY 73 | 06 JUN 73 | 8.0 | 20 JUN 73 | 02 JUL 73 | 16.0+ | INSTALL CERAMIC TILE,FL4 |
| 37 | 45 | 24 MAY 73 | 03 JUL 73 | 27.0 | 11 JUL 73 | 17 AUG 73 | 32.0+ | CONNECT MECH SYSTEM,FL 4 |
| 37 | 44 | 24 MAY 73 | 09 JUL 73 | 30.0 | 31 MAY 73 | 13 JUL 73 | 4.0+ | MILLWORK, FLOOR 4 |
| 33 | 48 | 25 MAY 73 | 06 JUN 73 | 6.5 | 15 AUG 73 | 24 AUG 73 | 56.0+ | CLEANUP OUTSIDE |
| 41 | 44 | 01 JUN 73 | 13 JUL 73 | 29.0 | 01 JUN 73 | 13 JUL 73 | .0+ | INSTALL ELEC FIXTURES, 4 |
| 42 | 43 | 06 JUN 73 | 12 JUN 73 | 4.0 | 02 JUL 73 | 09 JUL 73 | 18.0+ | SET PLUMBING FIXTURES, 4 |
| 43 | 44 | 12 JUN 73 | 18 JUN 73 | 4.0 | 09 JUL 73 | 13 JUL 73 | 16.0+ | INSTALL TOILET ACC.,FL 4 |
| 45 | 48 | 03 JUL 73 | 11 JUL 73 | 5.0 | 17 AUG 73 | 24 AUG 73 | 32.0+ | CHECK & BAL MECH SYSTEM |
| 44 | 47 | 13 JUL 73 | 14 AUG 73 | 22.0 | 13 JUL 73 | 14 AUG 73 | .0+ | PAINT AND COVER WALL,FL4 |
| 44 | 48 | 13 JUL 73 | 21 AUG 73 | 27.0 | 18 JUL 73 | 24 AUG 73 | 3.0+ | LAY FLOOR COVERING,FL4 |
| 47 | 48 | 14 AUG 73 | 24 AUG 73 | 8.0 | 14 AUG 73 | 24 AUG 73 | .0+ | CLEANUP & PUNCH LIST,FL4 |
| 48 | 53 | 24 AUG 73 | 21 SEP 73 | 20.0 | 06 DEC 73 | 07 JAN 74 | 71.0+ | INSTALL ROUGH PLUMB.,321 |
| 48 | 49 | 24 AUG 73 | 24 SEP 73 | 21.0 | 24 AUG 73 | 24 SEP 73 | .0+ | INSTALL DUCTWORK,FLS 321 |
| 48 | 50 | 24 AUG 73 | 04 OCT 73 | 29.0 | 18 SEP 73 | 31 OCT 73 | 17.0+ | INSTALL OVERHEAD ELEC321 |
| 53 | 54 | 21 SEP 73 | 18 OCT 73 | 18.0 | 07 JAN 74 | 31 JAN 74 | 71.0+ | LAY CERAMIC TILE, 321 |
| 49 | 50 | 24 SEP 73 | 31 OCT 73 | 25.0 | 24 SEP 73 | 31 OCT 73 | .0+ | INSTALL CEILING GRID,321 |
| 54 | 52 | 18 OCT 73 | 05 NOV 73 | 11.0 | 31 JAN 74 | 15 FEB 74 | 71.0+ | SET PLUMB. FIXTURES, 321 |
| 50 | 51 | 31 OCT 73 | 12 DEC 73 | 29.0 | 31 OCT 73 | 12 DEC 73 | .0+ | INSTALL DRYWALL, 321 |
| 50 | 55 | 31 OCT 73 | 18 DEC 73 | 33.0 | 01 MAR 74 | 17 APR 74 | 83.0+ | CONNECT MECH SYS, 321 |
| 50 | 56 | 31 OCT 73 | 20 DEC 73 | 35.0 | 27 DEC 73 | 15 FEB 74 | 39.0+ | INSTALL ELEC FIX., 321 |
| 51 | 52 | 12 DEC 73 | 02 JAN 74 | 13.0 | 29 JAN 74 | 15 FEB 74 | 32.0+ | INSTALL CEILING TILE,321 |
| 51 | 56 | 12 DEC 73 | 15 FEB 74 | 45.0 | 12 DEC 73 | 15 FEB 74 | .0+ | PAINT & COVER WALLS, 321 |
| 55 | 57 | 18 DEC 73 | 03 JAN 74 | 10.0 | 17 APR 74 | 01 MAY 74 | 83.0+ | CHECK & BAL SYS, 321 |
| 56 | 57 | 15 FEB 74 | 01 MAY 74 | 52.0 | 15 FEB 74 | 01 MAY 74 | .0+ | COVER FLOORS, 321 |

******************************* B U R R O U G H S   P R O M I S   R E P O R T *************************************

| PRED NUMBER | SUCC NUMBER | EARLIEST START | EARLIEST FINISH | EXP. TIME | LATEST START | LATEST FINISH | TOTAL SLACK | D E S C R I P T I O N |
|---|---|---|---|---|---|---|---|---|
| 57 | 58 | 01 MAY 74 | 20 MAY 74 | 13.0 | 01 MAY 74 | 20 MAY 74 | .0* | FINAL CLEANUP |
| 58 | 59 | 20 MAY 74 | 22 MAY 74 | 2.0 | 20 MAY 74 | 22 MAY 74 | .0* | FINAL INSPECTION |

# APPENDIX F

## RISK EVALUATION CRITERIA AND PERFORMANCE SCORES

I. Owner (A)

A. Discussion: This is a subjective evaluation of the project owner. Is he able to make timely payments? Based upon past situations will he pay on time? Is he able to make decisions? Does he want to occupy the structure quickly?

B. Scoring:

| Performance | Score |
|---|---|
| Very Poor | 9 |
| | 8 |
| Below Average | 7 |
| | 6 |
| Average | 5 |
| | 4 |
| Above Average | 3 |
| | 2 |
| Outstanding | 1 |

II. Architect (B)

A. Discussion: This is a subjective evaluation of the architect. What type of reputation does he have? How severe are his inspections, and what margin of error will he tolerate? Have the plans and specifications been approved? Are the bid documents adequate?

B. Scoring:

| Performance | Score |
|---|---|
| Very Poor | 9 |
| | 8 |
| Below Average | 7 |
| | 6 |
| Average | 5 |
| | 4 |
| Above Average | 3 |
| | 2 |
| Outstanding | 1 |

III. Geographical Location (C)

A. Discussion: This is a rather subjective evaluation of the project location. The measurement is based upon the theory that the further away from the contractor a project is located, the more difficult it will be to supervise the work and to obtain adequate labor, subcontractors, and material.

B. Scoring:

| Performance | Score |
|---|---|
| | 9 |
| Out of Town | 8 |
| | 7 |
| Near Town | 6 |
| | 5 |
| In Town | 4 |
| | 3 |
| Near Firm | 2 |
| | 1 |

IV. Prestige of Project (D)

A. Discussion: This is a subjective evaluation of the prestige which the structure will possess or which the contractor will derive from having been associated with the project. Included in this evaluation is a consideration of possible follow-on work, either on the same project or on another project with the same or another owner.

B. Scoring:

| Performance | Score |
|---|---|
| Very Poor | 9 |
| | 8 |
| Below Average | 7 |
| | 6 |
| Average | 5 |
| | 4 |
| Above Average | 3 |
| | 2 |
| Outstanding | 1 |

V. Number of Uncontrollable Organizations (E)

A. Discussion: This is an estimate of the number of project organizations over which the contractor will be able to exercise no real control. In general, this number will be greater for projects that are larger and more complex. This is based upon the assumption that more uncontrollable organizations lead to greater coordination problems and time delays.

B. Scoring:

| Performance | Score |
|---|---|
| 8 or more | 9 |
| 7 | 8 |
| 6 | 7 |
| 5 | 6 |
| 4 | 5 |
| 3 | 4 |
| 2 | 3 |
| 1 | 2 |
| 0 | 1 |

VI. Amount of Own Labor (F)

A. Discussion: This is an estimate of the contractor's own labor cost expressed as a percentage of the total cost for labor, materials, and subcontractors. Labor is the most uncontrollable item for a contractor. A subjective evaluation may be employed to provide a preliminary analysis.

B. Scoring:

| Performance (%) | Score |
|---|---|
| 22.00 or more | 9 |
| 20.00 - 21.99 | 8 |
| 18.00 - 19.99 | 7 |
| 16.00 - 17.99 | 6 |
| 14.00 - 15.99 | 5 |
| 12.00 - 13.99 | 4 |
| 10.00 - 11.99 | 3 |
| 8.00 - 9.99 | 2 |
| 7.99 or less | 1 |

VII. Condition of Site (G)

A. Discussion: This is a subjective evaluation of the condition of the project site as it will appear during the majority of the construction. It includes a consideration of the site accessibility and exposure, which is an assessment of the effect that weather may have on the prepared site. For example, severe excavation and poor drainage will result in a muddy site that will impede work.

B. Scoring:

| Performance | Score |
|---|---|
| Very Poor | 9 |
| | 8 |
| Below Average | 7 |
| | 6 |
| Average | 5 |
| | 4 |
| Above Average | 3 |
| | 2 |
| Outstanding | 1 |

VIII. Ability to Handle Job (H)

A. Discussion: This is a subjective evaluation of the ability of the construction company to perform the required work. The evaluation includes several factors. First, how competitive is the company on this type project? Is this the type work which the company does best and fastest? Are there materials available from other company projects that can be used to reduce the cost? Are there other company projects nearby which may serve to reduce the cost of this new project? Second, what possibilities exist for reducing the estimated duration of the project? This may reduce the cost, or it may provide a time advantage. If a contractor can perform the work in less time, even at a higher cost, than his competitors, he may be awarded the contract. Consideration must also be given to completion deadlines and penalty payments. Depending on the situation, this consideration may result in a higher or lower score.

B. Scoring:

| Performance | Score |
|---|---|
| Very Poor | 9 |
| | 8 |
| Below Average | 7 |
| | 6 |
| Average | 5 |
| | 4 |
| Above Average | 3 |
| | 2 |
| Outstanding | 1 |

IX. Chance of Getting a Loan and Bond (I)

A. Discussion: This is a subjective evaluation of the contractor's chances of getting a loan to cover the anticipated expenses that he will incur during the construction of the project. This loan may or may not be necessary. It also includes an assessment of the contractor's bonding capacity.

B. Scoring:

| Performance | Score |
|---|---|
| Improbable | 9 |
| | 8 |
| Probable | 7 |
| | 6 |
| Reasonably Probable | 5 |
| | 4 |
| Highly Probable | 3 |
| | 2 |
| Certain (or no loan needed) | 1 |

X. Timeliness of Project (J)

A. Discussion: This is a subjective evaluation by the contractor of the timing of a new project. This also includes an assessment of how the starting date and the required company resources for the project will fit into existing company commitments.

B. Scoring:

| Performance | Score |
|---|---|
| Very Poor | 9 |
| | 8 |
| Below Average | 7 |
| | 6 |
| Average | 5 |
| | 4 |
| Above Average | 3 |
| | 2 |
| Outstanding | 1 |

XI. Number of Bidders (K)

A. Discussion: This is a number that represents all known or estimated bidders on the project, to include the contractor making the evaluation.

B. Scoring:

| Performance | Score |
|---|---|
| 11 or more | 9 |
| 10 | 8 |
| 9 | 7 |
| 8 | 6 |
| 7 | 5 |
| 6 | 4 |
| 5 | 3 |
| 4 | 2 |
| 3 or less | 1 |

XII. Quality of Competition (L)

A. Discussion: This is a subjective evaluation of the overall nature of the competition. The supposition is that a contractor will be less competitive and will not want to bid against contractors who employ non-union labor, do poor quality work, or are dishonest.

B. Scoring:

| Performance | Score |
|---|---|
| Very Poor | 9 |
| | 8 |
| Below Average | 7 |
| | 6 |
| Average | 5 |
| | 4 |
| Above Average | 3 |
| | 2 |
| Outstanding | 1 |

NOTE: When the final evaluation is made of the total risk in a project, the last two criteria, K and L, should be adjusted subjectively to reflect the probability, determined from the application of bidding strategy, of winning the bid at the level of profit which is included in the bid price.

# BIBLIOGRAPHY

## Literature Cited


1. "Aspects of Construction Failures," Construction Review, Vol. 11, No. 8, August 1965, pp. 7-8.

2. "Banker Says Financing Contractors Remains 'Dangerous'," Wall Street Journal, 29 January 1964, p. 18.

3. Norman N. Barish, Economic Analysis: For Engineering and Managerial Decision-Making, New York: McGraw-Hill Book Company, 1962.

4. W. F. Burkart and others, "Outline of Research Requirements for Construction," Journal of the Construction Division, American Society of Civil Engineers, Vol. 94, No. CO2, October 1968, pp. 233-244.

5. "Construction Failures Decline in 1967," Construction Review, Vol. 14, No. 2, February 1968, p. 11.

6. Robert Crumley, Personal conversation, Atlanta, Georgia, 19 January 1972.

7. Solomon Disman, "Selecting R & D Projects for Profit," Chemical Engineering, Vol. 69, December 1962, pp. 87-90.

8. Clarence J. Douglas and Elmer L. Munger, Construction Management, Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1969.

9. Robert T. Eckenrode, "Weighting Multiple Criteria," Management Science, Vol. 12, November 1965, pp. A180-A192.

10. The Failure Record Through 1970, New York: Dun and Bradstreet, Inc., 1970.

11. "GNP Rises," Graph in The Atlanta Journal and Constitution, 2 January 1972, p. 1-J.

12. "Historical Climatic Record," Daily weather data for Atlanta, Georgia, prepared by the Atlanta Weather Bureau, 1918-1970.

13. "How Much to Make to Cover Costs," Engineering News-Record, Vol. 171, Pt. 2, 19 December 1963, pp. 168 and 170.

BIBLIOGRAPHY (Continued)

14. Emmett H. Karrer, Paper presented to the Fifth World Meeting of the International Road Federation, London, England, 18-24 September 1966.

15. Maurice G. Kendall, Rank Correlation Methods, London: Charles Griffin & Company Limited, 1962.

16. John R. Moore, Jr. and Norman R. Baker, "An Analytical Approach to Scoring Model Design — Application to Research and Development Project Selection," IEEE Transactions on Engineering Management, Vol. EM-16, No. 3, August 1969, pp. 90-98.

17. John R. Moore, Jr. and Norman R. Baker, "Computational Analysis of Scoring Models for R and D Project Selection," Management Science, Vol. 16, No. 4, December 1969, pp. B212-B232.

18. William R. Park, "How Low to Bid to Get Both Job and Profit," Engineering News-Record, Vol. 168, Pt. 2, 19 April 1962, pp. 38-40.

19. Myron H. Ross, Income: Analysis and Policy, New York: McGraw-Hill Book Company, 1969.

20. Harry Rubey and Walker W. Milner, Construction and Professional Management: An Introduction, New York: The Macmillan Company, 1971.

21. Louis R. Shaffer and others, The Critical Path Method, New York: McGraw-Hill Book Company, 1965.

22. John B. Shuler, "Business Failures in Construction," Journal of the Construction Division, ASCE, Vol. 93, No. CO2, September 1967, pp. 73-93.

23. Charles Snepp, Personal interview, Atlanta, Georgia, 6 December 1971.

24. Robert H. Strickland, Personal interview, Atlanta, Georgia, 9 November 1971.

25. Robert H. Strickland, Speech Notes in the office of the Associated General Contractors of America, Atlanta, Georgia.

26. Gerald J. Thuesen, Class lecture on engineering economy, Georgia Institute of Technology, Atlanta, Georgia, 11 May 1970.

## BIBLIOGRAPHY (Continued)

### Other References


Antill, James M., Civil Engineering Management, New York: American Elsevier Publishing Company, Inc., 1970.

Baumgartner, John S., Project Management, Homewood, Illinois: Richard D. Irwin, Inc., 1963.

Beckett, William, Personal interview, Atlanta, Georgia, 12 November 1971.

Bureau of the Census, 1967 Census of Construction Industries, Vol. I & II, Washington: U.S. Government Printing Office, 1971.

Casey, B. J., and L. R. Shaffer, "An Evaluation of Some Competitive Bid Strategy Models for Contractors," Construction Research Series, No. 12, Urbana, Illinois: Department of Civil Engineering, University of Illinois, 1968.

Crumley, Robert M., Personal interview, Atlanta, Georgia, 10 November 1971.

Crumley, Robert M., Personal interview, Atlanta, Georgia, 22 November 1971.

Dean, Burton V., and Meir J. Nishry, "Scoring and Profitability Models for Evaluating and Selecting Engineering Projects," Journal of the Operations Research Society of America, Vol. 12, No. 4, July-August 1965, pp. 550-570.

Fulkerson, D. R., "A Network Flow Computation for Project Cost Curves," Management Science, Vol. 7, No. 2, January 1961, pp. 167-178.

Gellersteadt, Larry L., Jr., Personal interview, Atlanta, Georgia, 19 November 1971.

Gates, Marvin, "Bidding Strategies and Probabilities," Journal of the Construction Division, ASCE, Vol. 93, No. CO1, March 1967, pp. 75-107.

Gates, Marvin, "Statistical and Economic Analysis of a Bidding Trend," Journal of the Construction Division, ASCE, Vol. 86, No. CO3, November 1960, pp. 13-35.

Godfrey, Robert S., Building Construction Cost Data, Duxbury, Massachusetts: Robert Snow Means Company, Inc., 1971.

Graese, C. E., "Cost Control in the Construction Industry," Management Controls, Vol. 13, No. 4, April 1966, p. 65.

BIBLIOGRAPHY (Continued)

Hardin, Ira H., Personal interview, Atlanta, Georgia, 30 September 1971.

Industry Studies Department, Dun and Bradstreet, Inc., "Contractor Bankruptcy Drops to 8 Year Low," Construction Methods, Vol. 50, Pt. 1, February 1968, pp. 30-32.

Kroll, Bernard, Personal interview, Atlanta, Georgia, 23 November 1971.

Miller, James R., III, Professional Decision Making, New York: Praeger Publishers, 1970.

Moder, Joseph J., and Cecil R. Phillips, Project Management with CPM and PERT, New York: Van Nostrand Reinhold Company, 1970.

Moore, John R., Jr., Research and Development Project Selection: Theoretical and Computational Analysis of a Project Scoring Model, Ph.D. Dissertation, Purdue University, 1968.

O'Brien, James J., CPM in Construction Management, New York: McGraw-Hill Book Company, 1965.

O'Shea, John B., "The CPM-By-Calendar Algorithm," Journal of the Construction Division, ASCE, Vol. 94, No. CO2, October 1968, pp. 139-160.

Ott, George W., "Simplified CPM for Contractors," Management Controls, Vol. 13, No. 4, April 1966, pp. 71-73.

Pacifico, Carl, Effective Profit Techniques for Managers, West Nyack, New York: Parker Publishing Company, Inc., 1968.

Park, William R., The Strategy of Contracting for Profit, Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1966.

Parsons, E. A., and others, Management in Civil Engineering, London: E. & F. N. Spon LTD, 1965.

Pennell, Donald R., "Recent Critical Path Method Developments for the Construction Industry," Northwest Roads and Street Conference, 1963, pp. 44-59.

PROMIS Time Module Reference Manual, Detroit, Michigan: Burroughs Corporation, 1968.

Schimpler, Charles C., A Decision-Theoretic-Approach to Weighting Community Development Criteria and Evaluating Alternative Plans, Ph.D. Dissertation, Purdue University, 1967.

BIBLIOGRAPHY (Concluded)


Shaffer, Louis R., and Terry W. Micheau, "Bidding with Competitive Strategy Models," Journal of the Construction Division, ASCE, Vol. 97, No. CO1, March 1971, pp. 113-126.

Shaffer, L. R., "Calendar-Day CPM," Civil Engineering, Vol. 39, August 1969, pp. 65-68.

Siegel, Samuel, Nonparametric Statistics for the Behavioral Sciences, New York: McGraw-Hill Book Company, 1956.

Smith, Howard, Personal interview, Atlanta, Georgia, 30 September 1971.

Snepp, Charles, Personal interview, Atlanta, Georgia, 23 November 1971.

Snepp, Charles, Telephone conversation, Atlanta, Georgia, 18 January 1972.

Sokol, Andrew, Jr., Contractor or Manipulator?, Coral Gables, Flordia: University of Miami Press, 1968.

Staffurth, C., editor, Project Cost Control Using Networks, London: The Operational Research Society and The Institute of Cost and Works Accountants, 1969.

Stark, Robert M., and Robert H. Mayer, Jr., "Some Multi-Contract Decision-Theoretic Competitive Bidding Models," JORSA, Vol. 19, No. 2, March-April 1971, pp. 469-483.

Woodgate, Harry S., Planning By Network, London: Business Publications Limited, 1967.