ANALYSIS OF BIDDING BEHAVIOR OF CONTRACTORS
IN VARIOUS ECONOMIC CONDITIONS USING UTILITY ASSESSMENT

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ABSTRACT

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Submitted to the Department of Civil Engineering on May 20, 1975 in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

Existing bidding strategies use expected monetary value as the decision criterion to account for the behavior of general contractors in risky situations.

We show that this criterion has shortcomings and cannot explain what is observed in real world bidding. The use of utility theory provides a better way of analysing the contractors' behavior.

The results show that the economic position of a firm and the size of the project it bids on are two factors, amongst others, which are taken into consideration in bidding, factors, that existing bidding strategies usually neglect.

Thesis Supervisor

Richard de Neufville

Title

Professor of Civil Engineering

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1.1. **Statement of the problem**

All firms in the construction industry have had to resort to closed competitive bidding as a means for getting work. A contractor is given a set of plans and specifications and is requested to submit in a sealed envelope his bid, or the price for which he agrees to do the work. The contractor takes many factors into account before submitting his bid: he considers the competition on the job, the type of work involved, his need for work, his financial status, the requirements of the job in men, materials and equipment, the availability of those, the size of the job, its risk, the overhead involved, etc... He then relies on his judgment and experience to submit his final bid. This bid will be based on his cost estimate increased by a certain percentage, called the markup, which allows for profit, overhead and contingencies. If his markup is too low, he will get the job but he will either lose money on the job, or get a very low return on investment and thus he will barely be able to survive. Usually the only difference between a flourishing company and another on the edge of bankruptcy lies in the management decisions taken at critical points
in time.

One of the contractor's most important decisions is what optimum markup will insure maximum profits in the long run together with a good level of return on investment. This decision problem which faces the contractor can therefore be described as follows. After the contractor estimates the cost of the job he has to decide on the markup to be added, which can be any value between two extreme limits (usually 2% to 15%); then he has to observe what we call the state of nature, or the lowest bid among his competitors. If his bid is higher he will not get the job and will have lost the money spent on estimating the work which usually ranges between 0.5 to 2.0 percent of the total project cost. On the other hand, if his bid is the lowest, he will get the job and will end up after the execution of the work with a profit (or loss) equal to his markup minus job overhead minus variation in cost from the estimate. At the same time he suffers an opportunity loss which is the difference between his bid and the second lowest bid; this is referred to as the money left on the table, or the spread.

1.2. Bidding strategies and utility theory

To help the contractor determine the optimum markup, competitive bidding strategies have been developed by several
investigators. A strategy can be defined in a number of different ways, but perhaps the most suitable definition for our purposes is: A bidding strategy is the science and art of meeting competition under the most advantageous conditions possible in order to achieve a certain goal.

The problem we face can be stated in the following manner: Are these mathematical formulations of a fairly complex situation realistic enough to be applied in practice? Are the assumptions on which they are based justified? Is the actual behavior of contractors in real situations consistent with what is predicted by these strategies? In fact all bidding models considered that the contractors have expected monetary preferences, and that the number of bidders and the probability of winning are the major factors influencing the bid price. These factors can be represented schematically as follows:
where C.C.D.F is the complementary distribution function of the density distribution of markups: it gives the probability of winning given a certain markup.

However we feel in this study that the decision-makers have expected utility preferences, and that some other factors, like the relative size of the project and the economic situation ("good" or "bad" times), are also of major influence. We suggest the alternative representation:

1.3. Organization of the study

The second chapter of this study reviews the state of the art in 1975 concerning bidding strategies. It first introduces the basic idea common to all the models, and then discusses the sometimes contradicting refinements or
assumptions considered in the different strategies. The expected monetary value criterion which constitutes the basic principle of all the models is criticized in chapter 3 and the invalidity of such a criterion is shown. The same chapter also introduces the utility theory which was developed to deal more efficiently with uncertain situations. The next step is then to analyse actual behavior in bidding situations, in order to verify the validity of the expected utility criterion. The results of the analysis of public bids collected from two state agencies are presented in chapter 4. Chapter 5 is concerned with the development of a questionnaire for assessing the utility functions of some contractors in the Boston area. The factors influencing the utility functions are first determined, then the questions used and their interpretation in terms of the utility functions are considered. We finally discuss the difficulties encountered in the actual assessment, as well as the results obtained. Chapter 6 presents the interpretation of the assessed utility functions, followed by a correlation between the predicted behavior, obtained through the utility functions, and the measured behavior from public bids. This exposes the deficiency in the existing bidding strategies. The conclusion suggests some possible extensions of this study for future research.
CHAPTER 2

A REVIEW OF THE LITERATURE OF BIDDING STRATEGIES

2.1. Introduction

Numerous bidding strategies have been developed to apply to different kinds of situations. They can be classified according to whether they are concerned with:

(1) Determining the optimal bid for a single job.

(2) Sequential bidding, that is, simultaneous bidding on more than one contract.

(3) Situations involving lump-sum bids.

(4) Unbalanced bidding on unit price contracts.

Although most of the strategies deal with bidding against competitors, some of them also deal with bidding against the owner.

This study focuses on non-sequential closed competitive bidding on lump-sum contracts, since most other bidding situations can be considered as extensions of this basic model.

Almost all of the existing bidding strategies more or less follow the first bidding model, developed by Friedman (1956) for the oil industry. But many of the assumptions change, sometimes significantly, between different models. Furthermore each model considers different factors that,
according to the author, significantly affect the optimum bid, factors that are not considered or even are rejected by other models. The general contractor who is the potential user of such models should be aware of the weaknesses (present in the assumptions) involved in any specific model before he decides to use it.

We review and present the different bidding strategies currently available for use in the construction industry as follows: first the basic general model common to almost all strategies; secondly, and in some detail, all known deviations or elaborations around this model; finally, some of the models which differ significantly from the basic idea of the general model. This part is based on the study of different bidding models developed by Friedman (1956), Park (1966), Gates (1967), Morin and Clough (1969), Shaffer and Micheau (1971), which generally represent the state of the art in 1975.

2.2. The general model

The general model supposes that the objective of the company is to maximize the total expected profits, given by the general formula:

\[ E(P) = p(P) \times P \]

where \( E(P) \) is the expected profit
$P$ is the profit (or markup) included in the bid price $p(P)$ is the probability of being the low bidder given a profit $P$.

Based on past bidding data the probability $p_i(P)$ of beating competitor $i$ given $P$ can be determined. This is done by developing bidding patterns for the different competitors. Given competitor $i$'s bids on past projects, a frequency distribution of the ratio of competitor's bids as a percent of estimated cost can be plotted and a probability distribution function can be fitted (see figure 2.1). Then, for any given $P$, $p_i(P)$ can be found: it is the complementary distribution function (C.C.D.F)

$$p_i(P) = 1 - \int_{-\infty}^{1} p \, dy$$

If there are $n$ competitors the probabilities of beating each one individually are combined in a certain way (discussed later in this study) to give the probability $p(P)$ of beating them all given a certain profit level $P$. $E(P)$ is then plotted versus $P$ (expressed as a percentage of the estimated cost of the work) and the optimum profit $P_o$ can be determined. (see figure 2.2)

However there are significant deviations between the different strategies on the following points:

1) What is to be considered as profit.
$y = \frac{\text{COMPETITOR'S BIDS}}{\text{ESTIMATED COST}} \times 100$

**Figure 2.1** Probability distribution of the ratio of competitor's bids over estimated cost.
FIGURE 2.2 EXPECTED PROFITS.
2) How to obtain the probability of beating a given competitor.

3) How to combine the n individual probabilities in order to obtain the probability of beating the n competitors.

4) How to treat the individual competitors when their identity is either known or unknown.

5) How to deal with the case when the number of competitors is unknown.

In addition to the above mentioned points, which can be considered to have a direct relation to the general model, some other factors are introduced by different models and have a direct influence on the optimum markup. These include the following: the class of the work, its size and contingencies.

2.3. State of the art

2.3.1. Objectives

The assumptions and deviations between the different strategies will be presented in the same order as mentioned above. It is obvious that the optimum markup depends primarily on the objectives of the company. In the case of the construction industry there are many possible objectives:

1) Maximize total expected profit
2) Maintain a prescribed level of return on investment.
3) Minimize expected losses (during idle periods).
4) Minimize competitors' profits to maintain competitive position.
5) Keep a certain share of the market.
6) Increase volume of work as much as possible.
7) Increase volume of work to keep up with inflation only.
8) Try to maintain labor force at work at any cost.

Almost all of the bidding strategies developed until now have the objective of maximizing total expected profit (which is most common). But, for example, if a company's objective is to maintain its labor force, its optimum markup can well be negative. The user of bidding models should be aware of this basic assumption of maximization of expected profits which is the foundation of all the strategies.

2.3.2. **Profit**

The profit $P$ on a certain job can be considered to be equal to $B - C_a - OH$ where $B$ is the bid price, $C_a$ the actual cost of construction and $OH$ the overhead. Both Park (1966) and Gates (1967) assume in their models that profit is equal to the bid price ($B$) minus the estimated cost of construction ($C_o$). No consideration is given to overhead which is assumed to be included in the cost estimate and no correction is introduced to adjust for the fact that in actual cases
the cost of construction is different from the cost estimate. Gates recognizes this difference and contends that it is small enough to be neglected. He also suggested a correction for bias in a brief explanation of break-even analysis. Similarly, Friedman (1956) assumed that overhead is included in the cost estimate but he considered profit to be the difference between the estimated cost of fulfilling the contract corrected for bias and the bid amount. He suggests that one can develop, through a study of past data on estimates and actual costs, a probability distribution of the true cost as a fraction of the estimated cost. Letting $S$ be the ratio of true cost to estimated cost ($C_o$), $B$ the amount bid for the contract, $p(B)$ the probability that a bid $B$ will be the lowest and win, then the expected profit suggested by Friedman will be:

$$ E(P) = p(B) \int_0^\infty [B - S C_o] h(S) dS $$

where $h(S)$ is the probability of a certain $S$. Alternatively

$$ E(P) = p(B) \left[ B - C' \right] $$

where $C' = C_o \int_0^\infty S h(S) dS$ and is the expected actual cost.

On the other hand, Morin and Clough (1969) assert that the expected actual cost will equal the estimated cost. They found, from the study of data for a certain company, that
the ratio of actual to estimated cost approached a symmetrical distribution with a median of 1.0 and a standard deviation of less than 2%. But, unlike the previous models, they recognized the fact that overhead actually differs significantly from one company to another. So the profit to be maximize is the net profit which is the difference between the markup \((MP)\) and the overhead \((OH)\):

\[ E(P) = (MP - OH) p(MP) \]

where \(p(MP)\) is the probability of being the low bidder with a markup of \(MP\).

2.3.3. **Probability of beating a given competitor**

To determine the probability of beating a known competitor, all models suggest that one should study past bidding data and develop (in different ways) a probability function for the ratio of the competitor's bid to our estimated cost. Friedman (1956) and Park (1966) suggest fitting a continuous probability function to the available data; Casey and Shaffer (1964), a normal distribution function; Gates (1967) uses on the other hand a statistical linear regression to determine this probability and expresses the profit \(P\) as:

\[ P = a \log p_i + b \]

where \(p_i\) is the probability of beating competitor \(i\) given
a profit $P$. $a$ and $b$ are determined from the plot of $P$ versus \( \log p_i \) for all past bidding data.

When the identity of the competitor is unknown or when insufficient data are available to develop the probability functions, all the above models combine past data to get a general bidding pattern for a typical competitor.

The OPBID model of Morin and Clough varies significantly from the other models. First they felt that recent data should receive more weight than older data because the competitive situation changes with time, they suggested using an exponential weighting scheme; secondly they classified competitors as being either key or average, depending on the percentage of past biddings they participated in. If this percentage is greater than a certain specified ratio (0.4 to 0.5 was suggested) the competitor is classified as key competitor, if it is lower the competitor is considered as average. The advantage of this classification is that it is a weighting scheme in which companies competing on a relatively large number of jobs are given much more attention than occasional competitors. Finally in order to assess the probability of winning with a given bid, the OPBID model uses a discrete probability distribution which has the following three advantages:

1) It eliminates errors introduced by fitting smooth
probability curves to existing data.

2) It permits fast calculations by a digital computer

3) It provides a general model that can be used by different contractors.

2.3.4. **Probability of beating a number of competitors**

Given that the number $n$ of competitors on a certain project is known and given the probability $p_i(B)$, all models follow more or less one of two methods to determine the probability of beating the $n$ competitors.

Some of the authors (Clough, Friedman, Park) assume that the probability of beating any given competitor is independent of that of beating any other competitor, and therefore the probability of beating them all is the product of the individual probabilities.

$$p_n(B) = \prod_{i} p_i(B)$$

$p_n(B)$ is the probability of winning over the $n$ competitors given a bid price $B$.

In the case of Clough's model this probability is:

$$p_n(B) = \left[ \prod_{N_{key}} p_i(B) \right] \left[ p_{av}(B) \right]^{N_{av}}$$

where $n$ can be subdivided in $N_{key}$ competitors and $N_{av}$ average competitors.
When the identity of the competitors is not known the probability of winning becomes:

\[ p_n(B) = \left[ p_{av}(B) \right]^n \]

The second method, developed by Gates, rejects the idea of the probabilities of beating individual competitors being statistically independent, and contends that when you beat a certain competitor you will revise your estimate of beating the others. The probability of winning becomes:

\[ p_n(B) = \frac{1}{\sum_n \left[ \frac{1 - p_i(B)}{p_i(B)} \right] + 1} \]

When the identity of the competitors is not known is simplifies to the following:

\[ p_n(B) = \frac{n \, p_{av}(B)}{n \, (1 - p_{av}(B)) + 1} \]

Broemser (1968) developed and used another method in his model. He dissociates the probability of winning from the number of competitors on a given job and contends that it is sufficient to beat the lowest bidder. So, using past data, he determines the distribution of \( r_a \), the ratio of the lowest competitor's bid to the estimated cost, by a linear regression which attempts to explain the behavior of the
low competitor by certain requirements of the particular job. These include estimates of the percent of cost not subcontracted, the duration of the job, the ratio of job duration to estimated cost, and the cost. This model tries to go around the problem of determining the probability of beating n competitors by implicitly assuming a certain relation between the number of competitors and the characteristics of the job.

When the number of competitors is unknown the different strategies use different ways to predict this number. In his original work, Friedman suggested the use of one of two methods:

1) The number of competitors might be given by a Poisson distribution whose parameters are determined from tests of past data.

2) A linear regression is used on past data of number of bidders against the cost estimate of the contract. He assumes that the larger the size of the contract, the higher the number of competitors.

Similarly Park assumes that the number of competitors is a function of the job size, and that this number increases until a certain limit job size then decreases for larger sizes.

On the other hand, Gates as well as Morin and Clough
suggests using the mean of the number of competitors encountered on previous biddings, since, using real world data they could not come up with a relation similar to that suggested by Friedman and Park.

2.3.5. Refinements

Some other refinements were introduced by some bidding models. These concern the class and size of the work as well as contingencies. Morin and Clough suggested the classification of historical data in different "classes of work" since the chances of winning with a certain markup on one class of work might be different from the chances of winning with the same markup on a different class of work due to the variability of risks involved or the time required for execution. Park suggested an interesting extension for his bidding model. He recognized that the optimum mark up depends on the size of the job, the larger the job, the lower the optimum markup, and suggests the following relationship:

\[
\left[ \frac{C_{o_1}}{C_{o_2}} \right]^x = \frac{MP_2}{MP_1}
\]

where \( C_{o_1} \) is the estimated direct cost on job 1, and \( MP_1 \) the optimum markup on job 1. The exponent \( x \) can be determined from the bidding history and he proposes a value of 0.2 in his article.
As far as contingencies are concerned Gates (1971) categorized contingencies into four groups: mistakes, subjective uncertainties, objective uncertainties, and chance variations. He dealt with such problems as mistakes of omission, problem of natural events, production rates etc... and he used analytical methods based on statistics and probability to obtain for each case likelihood of occurrence, costs and finally expectation values.

2.4. Other strategies

This section presents two models which significantly vary from the fundamental idea of the general bidding model. The first is the "least bidding strategy" developed by Gates and the second is the strategy proposed by Shaffer and Micheau (1971).

The "least bidding strategy" is based on Gates' finding that the average spread (\( B_{av} \)) is a function of the size (\( C \)) of the low bid. Specifically he came up with the following expression:

\[
B_{av} = 1.08 C^{0.734}
\]

He also found in his original study that

\[
\frac{67 P'}{B_{av}} = 1 - (p)
\]
where $P'$ is the amount to be added to the completed bid and $(p)$ the probability of still being the low bidder after increasing the bid by $P'$.

Using these relations and assuming that you were 100% certain (relatively) that for your initial bid $B$ you would be the low bidder, Gates determined the optimum amount $P'$ to add to your bid to maximize your expected profit. This is given by:

$$P' = 0.80 C^{0.734} - 0.50 B$$

It is interesting to note at this point that a similar relation was found by Park relating the percent average spread to the number of bidders and he suggests a linear relation: the higher the number of bidders the smaller the average spread, but he did not pursue his idea further.

All the models presented until this point rely only on mathematical expressions using past bidding data, and the contractor had only to input his information into the model to come up with an optimum bid. An extension of previous models was presented by Shaffer and Micheau (1971) who recognized that too many variables influence actually the selection of an optimum bid, that no model took all of these into consideration, and that judgment based on experience can be of great value in arriving at a final choice of a bid. So they suggested a combination of formal and informal means,
with the formal means being competitive strategy models and the informal means being personal judgment of the contractor. The whole object was to determine with the formal means an upper and a lower bound to provide the contractor with a focus for his judgment. The actual selection of the bid would be obtained solely by informal means, the lower bound of the range would be the bid that would give the contractor the greatest chance of submitting the low bid for the project and the upper bound would be the bid that would give him the greatest chance of submitting the second low-bid.

Shaffer and Micheau also recognized the fact that different bidding models apply best to different situations and that a person cannot a priori decide that this particular bidding strategy will apply best to all companies or to a particular company. So they recommend to select a few strategies and to test these using past bidding data and then the models to be used to determine the upper and lower bound will be those whose results have had the greatest success on historical data of yielding the low and second low bids respectively.

2.5. Conclusion

Although most of the strategies follow the same basic idea presented in the general model, apparent large differences exist in many of the fundamental points considered. These
points of disagreement can be restricted to two major ones:
1) What is profit.
2) How to get the combined probability of winning.
As far as profit is concerned, some models assumed the actual cost to be equal to the estimated cost and most of the models did not consider overhead which affects obviously the probability of winning. However this disagreement is mostly superficial. As regards the correction for bias of the estimated cost, it is safe to assume that the estimator, based on a knowledge of his past performance, will continuously adjust his method for computing the estimate to account for the bias that has occurred in the past; there will then be no need to correct for bias. Consider on the other hand the overhead; if it is accounted for in the cost estimate (as assumed in most strategies) and is high, the probability of winning for a given markup will be lower than when the overhead is low for the same markup. However if the overhead of a certain company did not fluctuate much in past bids and is still at the same level, one can affirm that this overhead would have influenced the "bidding patterns" developed for the competitors and no other correction is required.
As far as the probability of winning against a number of competitors is concerned, numerous articles and discussions were written to support either of the two assumptions presented by Friedman and Gates - Stark (1968), Baumgarten
(1970), Benjamin (1970), Naykki (1973), Dixie (1974) — while other articles tried to reconcile them — Rosenshine (1972) — All the strategies agreed, however, on the fact that the higher the number of competitors, the lower the probability of winning and therefore the lower, the optimum markup (see figure 2.3).

Nearly all of the models presented developed or introduced certain relations between the different variables, and certain factors which they considered would have an effect on the optimum bid. But as suggested by Benjamin Neal (1972) the weaknesses and the disagreements between the different models may be due to the fact that they use single variable statistical techniques to deal with a situation which is actually much more complex.

Although there is much controversy between the different bidding models studied in this part, all agreed on the basic assumption of maximization of total expected profits. They all implicitly assume that people behave in a specific way, behavior which may not be observed in real world situations. To consider that people actually decide according to expected monetary value may be a major weakness. Although this is the subject of the next chapter, a simple example illustrates this point: if a person behaved consistently with the above assumption then he should be indifferent between participating to a lottery offering an equal chance of
FIGURE 2.3  OPTIMUM MARKUP VERSUS NUMBER OF COMPETITORS.
gaining or losing $10,000, or not participating at all. But in fact most, if not all, people will not even consider such a lottery. The fact that all models do not account for the effect of various economic conditions on the optimum bid is one aspect of this weakness. All available bidding strategies indicate that the contractor should add the same markup for a given project, regardless of the economic conditions. In fact, one might expect that in bad economic conditions the bids will be lower: the contractors are much more interested in winning the contract due to the fact that they are more in need for work than in normal times. Other aspects of the weakness of the models will be discussed later on, in this study.

The next step is therefore to introduce a criterion, expected utility value, that would do away with the weakness of the expected monetary value criterion. We then determine through an analysis of actual bidding data the behavior of the contractors in various economic conditions. The aim is to test the validity of the existing models and of the expected utility value criterion to determine if its use gives consistent results with observed real world behavior.
CHAPTER 3

UTILITY THEORY AND ASSESSMENT

3.1. Introduction

The review of various models of bidding strategies in the literature shows that all of them deal with expected monetary value as a decision criterion. This makes implicit assumptions which may bias the evaluation of a bid, and lead to erroneous conclusions. The first assumption is that a unit of loss has the same value as a unit of gain, i.e. that a contractor should be indifferent between staying in his present situation and having a lottery where he can lose \$A with a probability of \(0.5\) or win \$A with a probability of \(0.5\). That may be true if \(A\) equals \$1 or \$10 but if the amount of money goes to \$10,000 or \$100,000 the contractor may think he is better off away from that gamble. The fact is that people generally give more weight to losses than to gains, and taking expected monetary value does not take into account the spread of the outcomes.

The size of the loss that one can afford mainly depends upon one's assets. For instance a small contractor might not be willing to bid on a risky \$10,000,000 job, because if it fails, he may go bankrupt. On the other hand a bigger
company may take it, for, in the worst case it may run into a cash problem. However, if the small company is at the point where it needs a high gain to avoid bankruptcy, it might take the project on the grounds that if it fails the bankruptcy will only be a little worse, whereas if it succeeds, it will not go bankrupt at all. All these factors are not taken into account by the expected monetary value criterion, for it makes the assumption that everyone shares the same values for all items at all times. These various difficulties encountered in using this criterion can be cleared up by the use of a recently developed tool of decision analysis: utility theory.

3.2. Utility

3.2.1. Expected utility

Given a certain number of axioms, which we will discuss later, a utility function can be defined as the representation of a set of numbers which are generated for each possible outcome of a decision, numbers which can be used to order all choices according to their desirability to the decision-maker.

An outcome can be represented by a vector of attributes. In this study we will only be concerned with utility functions with one attribute. Such functions scale preferences
for the attribute - in this case, the percentage of markup on a project. Instead of working with expected monetary values we will use expected utility value. This criterion enables us to compare two possible decisions, knowing the various values of the attribute which result from the decisions. We proceed in the following manner: letting \( U(x) \) be the utility function of a contractor, the expected value of the utility \( EUV \) of a decision is

\[
EUV = \sum_{i=1}^{n} p_i U(x_i)
\]

where \( x_i \) is the value of the attribute corresponding to one of the \( n \) possible outcomes of the decision, and \( p_i \) the probability of occurrence of this outcome. To compare two decisions, one compares their two expected utility values, and chooses the decision with the maximum expected utility.

3.2.2. **Selling and buying price of a lottery**

Suppose that you own a lottery ticket which gives you a 50-50 chance of winning $1000 or $0, and that we ask you to sell that ticket for $300. Must you accept? Such a decision can be represented by (Raiffa 1968)
If you are indifferent between the two choices, $300 is said to be the certainty equivalent of the lottery ($1000, .5 ; $0, .5). This can be represented by

\[
1 \times U(300) = 0.5 \times U(1000) + 0.5 \times U(0)
\]
$300 is said to be the selling price of such a lottery.

We can consider another type of lottery corresponding to the following question: how much would you pay to have a 50-50 chance of winning $1000? This can be represented by

\[
\begin{array}{c}
\$0 \sim \\
\begin{cases}
0.5 \quad \$1000 - b \\
0.5 \quad -b
\end{cases}
\end{array}
\]

where \(b\) is the amount you would pay. \(b\) is said to be the buying price of the lottery.

3.2.3. Properties of utility functions

Very often a utility function is monotonic. For instance if the attribute is the profit on a project, more is better: the utility function is monotonically increasing.

If the utility of a decision is twice the utility of another decision, it does not mean that the results of the former decision will be twice as good. The function has ordinal properties and not cardinal ones, it works exactly as temperature scaling. You can compare two temperatures and say that one day is hotter or colder than another one; nevertheless, one cannot say that a given day with a temperature of 60°F is twice as hot as another with a 30°F reading.
You can take a linear transformation of the utility function $U(x)$, which transforms $U(x)$ into $V(x) = a U(x) + b$ ($a > 0$), without changing the relative ranking of the decisions; that is exactly what happens when temperature is expressed in degrees centigrade instead of degrees Farenheit. In that case $U(x)$ and $V(x)$ are said to be strategically equivalent.

A utility function is defined on a certain range which is meaningful to the person whose utility function is assessed. For instance it is meaningless for a general contractor to consider a 50% profit on a project, because he could never reach that. Therefore the range of definition of a utility function should cover all the values of the attribute which can be considered in any decision-making process. Then two utility values are assigned to two different outcomes (as $32^\circ F$ and $212^\circ F$ are respectively assigned to freezing point and boiling point of water). Usually the values 0 and 1 are respectively given to the lowest and highest value in the range considered. In the following example, which illustrates what we have said about utility functions until now, we consider a range of profit going from $-5\%$ to $10\%$. We assume that the worst thing which can happen on the project is a loss of $5\%$ and the best thing is a profit of $10\%$. 
In figure 3.1 we can see the following correspondance

<table>
<thead>
<tr>
<th>x</th>
<th>-5%</th>
<th>-1%</th>
<th>2%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>U(x)</td>
<td>0</td>
<td>.5</td>
<td>.75</td>
<td>1</td>
</tr>
</tbody>
</table>

In figure 3.2 we have another correspondance

<table>
<thead>
<tr>
<th>x</th>
<th>-5%</th>
<th>-1%</th>
<th>2%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>V(x)</td>
<td>5</td>
<td>10</td>
<td>12.5</td>
<td>15</td>
</tr>
</tbody>
</table>

It is easy to see that

\[ V(x) = 10 U(x) + 5 \]

Using these curves, let us find the certainty equivalent of the following lottery:

\[ x \sim \begin{cases} \text{-1% profit} \\ \text{.50} \\ \text{-10% profit} \end{cases} \]

Let us first compute the expected utility value \( U(x) \)

\[
U(x) = .5 U(-1\%) + .5 U(10\%)
\]

\[
= .5 \times .5 + .5 \times 1 = 0.75
\]
FIGURE 3.1 EXAM PLE OF UTILITY FUNCTION OF A CONTRACTOR ON A $1,000,000 JOB. $0 \leq U(x) \leq 1.$
**FIGURE 3.2** EXAMPLE OF UTILITY FUNCTION OF A CONTRACTOR ON A $1,000,000 JOB. $5 \leq V(x) \leq 15$. 
We conclude from figure 3.1 that $x$ equals 2%. Let us compute the expected utility value $V(x)$:

$$V(x) = 0.5 V(-1\%) + 0.5 V(10\%)$$

$$= 0.5 \times 10 + 0.5 \times 15 = 12.5$$

From figure 3.2, we conclude that $x$ equals 2%. As expected the answer obtained with $V(x)$ is the same as the one obtained with $U(x)$, since the two are strategically equivalent.

3.2.4. Risk premium and risk behavior

The risk premium is defined as the difference between the expected monetary value and the certainty equivalent. In the above example we found that the certainty equivalent was 2%. The expected value is:

$$0.5 \times 10\% + 0.5 \times -1\% = 4.5\%$$

The risk premium $r$ equals:

$$r = 4.5\% - 2\% = 2.5\%$$

If the risk premium is positive, the decision-maker is said to be risk-averse. In case of a negative risk premium he is said to be risk-positive. If the risk premium is equal to zero, he is said to be an EMV'er. Figure 3.3 shows the three characteristic shapes of utility curves. Curve I
FIGURE 3.3 CHARACTERISTIC SHAPES OF UTILITY CURVES.
represents the utility curve of a decision-maker who decides according to expected monetary value over the whole range. Curves II and III respectively represent risk-averse and risk-positive behavior over the whole range.

It is often interesting to measure risk-aversion, and to be able to say that a decision-maker is more or less risk-averse than another. The risk premium is not a good measure when the range of the utility function is changed. Pratt (1964) showed that if $U(x)$ is the utility function, the ratio $r(x) = -U''(x) / U'(x)$ gives a good measure of risk-aversion. It is easy to see that $r(x)$ is identical for two strategically equivalent utility functions.

As was said earlier, the existence and properties of utility functions are based on a certain number of axioms. One of them deserves some special attention, because of the criticism it receives. It is the transitivity of preferences: if you prefer outcome A to outcome B and B to C you must prefer A to C. Raiffa (1968) shows that somebody who has an intransitive behavior is bound to lose all his assets to someone who adequately uses this intransitivity.

3.3. **Utility assessment**

To use the expected utility criterion in the bidding strategy of a contractor, you need to assess his utility
function. Such assessments have been made in other fields: Grayson (1960) made a study of oil wildcatters, Swalm (1966) and Spetzler (1968) of business executives, Lorange and Norman (1970) of shipowners, de Neufville and Keeney (1971) of executives of the Mexican Ministry of Public Works and Willenbrock (1973) of contractors. In all these studies, the interview method was used to assess utility functions; a discussion of the validity of such a procedure is made by Lorange and Norman (1970).

The type of questions asked in any of the interviews is as follows: For what amount of money will you be indifferent between \( X \) and the following lottery?

\[
\begin{array}{c}
X_1 \\
\sim \\
X_2 \\
\end{array}
\]

In this lottery you can win \( X_1 \) with probability \( p \) and \( X_2 \) with probability \( 1-p \). Answers to a certain number of these questions enable the interviewer to draw the utility functions of the decision-maker. Two procedures can be used to obtain these curves. One is to let \( X_1 \) and \( X_2 \) be fixed and to vary \( p \); we call this the constant-attribute procedure. The other is to let \( p \) be fixed—generally equal to \( .5 \)—and vary \( X_1 \) and \( X_2 \); we call this the constant-probability
procedure.

Grayson (1960) and Spetzler (1968) used the constant-attribute procedure. Swalm (1966), de Neufville and Keeney (1971) and Willenbrock (1973) used the constant-probability procedure. Lorange and Norman (1970) used both procedures. These studies show that the persons interviewed have problems in dealing with probabilities different from .5. Grayson (1960) writes:

"Probabilities created the greatest difficulty in the experiment. Some operators do not normally use numerical probabilities in their decisions, and they found it strange to try to reach a decision on the basis of probabilities."

In Lorange and Norman's study this problem was reflected by the fact that shipowners were significantly more risk-averse vis-a-vis constant-attribute gambles than versus constant-probability gambles.

Both assessment procedures discussed above are valid, but the constant-probability one is more suitable because more easily understood by the decision-makers who are interviewed.

3.4. Conclusion

One of the useful properties of utility functions is their
flexibility. The assessment made today can be revised two months later if economic conditions, liquidity position of the company or availability of work have changed. This allows comparison between various behaviors of a decision-maker according to his liquidity position—good or weak—or according to the environment—normal or bad times—
CHAPTER 4

DATA ANALYSIS

We found that the best way to understand contractors' behavior when bidding on projects was to gather data on bids of past projects, to analyze them and, as far as possible to find relationships between various factors.

4.1. Gathering data

Theoretically we had the choice of picking data of bids of either public or private projects. In fact we chose to gather data on public projects. Data on private projects are not easily available both because owners are reluctant to give out the information and because the information needed for a good sample size is scattered among many owners. On the other hand bids on public projects are public information, in the United States, and are all available in the same place.

As we were mainly interested in building contractors we went first to the Massachusetts Bureau of Building Construction (B B C) where we gathered data of the years 1961 to 1974. We collected data on all projects of new construction which had a value of $100,000 or more. A description of various
features of these data is given in table A1 (Appendix A). The total number of projects, over the 14 years, is 167.

To obtain a larger sample size we went to the Massachusetts Department of Public Works (DPW) to get data of bids on highway projects. There we were able to collect data of highway projects of the years 1966 to 1974. These covered four types of projects: construction, reconstruction, highway work and resurfacing. A lower bound on the size of the projects was also fixed at $100,000. The main features of these data are given in table A2. The number of projects collected is greater than 650. Only the DPW data were analyzed on a computer. Note that in this case the fiscal year was used instead of the calendar year, because the statistics of the annual awards were provided in that manner.

In table A1 and A2 of appendix A, one finds the total amount of money awarded to projects by the BBC and the DPW, as well as the corrected amount in 1974 dollars using the engineering news-record cost indices.

4.2. Comparison of the number of bids per year with the yearly allocated award

Our first task in analyzing these data was to compare the number of projects awarded each year to the total amount
of money expressed in 1974 dollars allocated yearly, and to
see how they are related. If, for instance, the BBC was
only awarding new construction projects, one would expect
the two curves to be approximately parallel. As we can see
in figure 4.1, that is not quite the case. As a matter of
fact, the BBC also awards other types of work - renovation,
utilities for instance - and there is sometimes an unbal-
lanced year - 1971 for example where many renovation pro-
jects were awarded.

In the case of the data of the DPW (figure 4.2), it appears
that no relation exists between the two curves. Table A2
shows that when the construction award is sufficient, nu-
merous construction projects are started at the expense of
maintenance projects - highway work or resurfacing -, be-
cause the former usually require a much greater investment.
Conversely, when the money becomes scarce, maintenance pro-
jects take priority: as they are less expansive than cons-
truction projects, the total construction award can decrease
whereas the total number of projects awarded increases.
Therefore the total construction award cannot represent the
real situation of the market of projects available to con-
tractors bidding either on BBC work or on DPW work. In
order to compare the results to the nature of the economic
environnement, we needed a variable which represents the
availability of projects for contractors. For the reasons
FIGURE 4.1 • AMOUNT OF MONEY AWARDED AND NUMBER OF PROJECTS AWARDED PER YEAR VERSUS YEAR (B.B.C.).
FIGURE 4-2 AMOUNT OF MONEY AWARDED AND NUMBER OF PROJECTS AWARDED PER YEAR VERSUS YEAR (D.P.W.).
we expressed above, the number of bids per year and per type of work was chosen as a proxyvariable for that purpose. Projects of reconstruction, resurfacing and highway work are regrouped under the maintenance category in the following analysis.

4.3. Number of bidders per project

The relationship we found between the number of projects per year and the average number of bidders per project during that year was to be expected. The more projects are available for bidding, the lower the average number of bidders per project. See table A3, A4 and figure 4.3, 4.4, 4.5.

For the construction projects of either BBC or DFW the relationship is clearly apparent in figure 4.3 and 4.4. For maintenance projects the relationship is not obvious. That probably arises from the fact that we arbitrarily fixed a lower bound of $100,000 on the projects we took from DPW; unlike construction projects which are always over $100,000, many maintenance projects are below the $100,000 mark.

Therefore, our decision of taking a lower bound on projects introduced a bias. Nevertheless, the results show that this relationship is very likely to hold.

That led us to the concept of "bad" years and "good" years.
FIGURE 4.3 AVERAGE NUMBER OF BIDDERS PER PROJECT AND NUMBER OF PROJECTS VERSUS YEAR. (B.B.C.).
FIGURE 4.4 AVERAGE NUMBER OF BIDDERS PER PROJECT AND NUMBER OF PROJECTS VERSUS YEAR - CONSTRUCTION PROJECTS (D.P.W.).
FIGURE 4.5 AVERAGE NUMBER OF BIDDERS PER PROJECT AND NUMBER OF PROJECTS VERSUS YEAR - MAINTENANCE PROJECTS (D.P.W.).
"Bad years are those in which the number of projects available is low and consequently in which the average number of bidders per project is high, the reverse holding true for the definition of "good" years.

4.4. Deviation from estimate

To see how contractors behave in different economic conditions, we needed to have a variable which may be representative of their attitude. Assuming that the engineers' estimate is a fair evaluation of the total cost of the project, the deviation from estimate - quotient \((B-E)/E\), where \(B\) is the winning bid and \(E\) the engineers' estimate - was felt to be a good measure of the need of work. As expected this parameter was found to be dependent on two variables. The more bidders on a project, the lower the deviation from the estimate; the lower the number of projects available to be bid on, the lower the deviation from the estimate.

The data of the BBC (table A5, figure 4.6) were used in the following manner. As the data per year were not sufficient to give a meaningful answer we grouped "bad" years - average number of bidders per project greater than 7 - and good years - average number of bidders per project lower than 7 - We divided each group of projects into four subgroups according to the number of bidders per project - the groups
FIGURE 4.6 DEVIATION FROM ESTIMATE VERSUS NUMBER OF BIDDERS FOR GOOD AND BAD YEARS (B.B.C.).
are 1-2-3, 4-5-6, 7-8-9, 10-11-12 — We calculated the percentage difference between the winning bid and the engineers estimate for each bid. The curves of figure 4.6 represent the mean of this value for each subgroup. As can be seen the deviation from the estimate decreases as the number of bidders increases for the two curves. Moreover the "bad" year curve lies below the "good" year curve which means that in "bad" years contractors seem to bid nearer to the estimate.

As the sample size is larger in the DPW case we have been able to study the variation of the deviation from estimate for each year. Tables A6 and A7 indicate the number of projects having a certain number of bidders in a given year and the mean of the deviation from estimate for these projects. For each year we have the same relationship between deviation from estimate and number of bidders as in the BBC case. In order to show that the relation between quality of the year — "good" or "bad" — and the deviation from estimate holds, we assessed an approximate linear relation between the deviation from estimate and the number of bidders for each year:

\[ y = a n + b \]

where \( y \) is the deviation from estimate

\( n \) is the number of bidders
The values of the coefficients $a$ and $b$ can be found in table A8. We plotted some of these straight lines in figure 4.7. These show the same relation as did the BBC data: the curve of "good" year is over the curve of "bad" year.

These different relations between factors related to actual bids give us a little more insight into the contractors' behavior, which will be useful in interpreting the results of the utility assessment of the next chapter.
5.1. **Introduction**

After analyzing the bidding data on past projects, the next step was to develop a questionnaire to assess the utility functions of some general contractors in the Boston area. The purpose was to determine whether one can explain, through utility assessment, what is observed in real world situations, and subsequently to investigate the superiority of the expected utility criterion over the expected monetary criterion.

The decision-maker, in any bidding situation, will usually consider a number of factors before deciding on a final bid. These factors, often interrelated, are:
- Economic conditions prevailing in the construction industry.
- Assets position of the firm
- Size, type, location and duration of the project
- Percentage of project subcontracted
- Identity of owner, architect and competitors
- Number of competitors
- Availability of materials
- Possibility of price fluctuations and of labor strikes
As far as utility assessment is concerned, one can expect the asset position of the firm and the size of project to be major influences on the shape of the utility functions. The attitude towards a loss (or a gain) of a $1000 will differ depending on whether the company is making a lot of money or is struggling to survive. Similarly a 2% gain on a small project is viewed differently from a 2% gain on a large project. The economic situation will also have an effect on the shape of the utility curves, but because of its strong interrelation with the asset position of the firm, only one of these two factors will be varied in the utility assessment. Most of the remaining factors affect the risk of the job and therefore the outcomes: they are handled through the incorporation of probability in the use of the expected utility criterion.

5.2. Development of the questionnaire

5.2.1. General considerations

The utility assessment was conducted under varying assumptions of size of project and economic conditions. As far as the size of the project was concerned, two sizes were considered for each company interviewed; one corresponded to the normal size of projects handled by the firm; the second was roughly half-way between the normal size and the maximum
size ever undertaken by this particular company. The economic conditions were described as normal (or "good" times), and actual (in 1975 this meant "bad" times). All companies agreed that normal times corresponded to the years 1968, 1969, and also that actual times are bad. Therefore the utility assessment was conducted under four general conditions: good times and normal project, good times and large project, bad times and normal project, and finally bad times and large project.

To determine the range over which the utility assessment was to be conducted, a utility value of 1 was arbitrarily assigned to a 15% markup (profit and overhead). This was thought to be the maximum amount that any firm, in any conditions, can expect to make on a project. The value of 0 was assigned to the minimum rate of return (MRR) acceptable by the company. This minimum rate was determined by offering the decision-maker a project on a cost plus fixed fee basis, and determining the minimum fee for which he would consider accepting the contract.

5.2.2. Types of questions

The general type of questions used for utility assessment is the following: the decision-maker is offered two projects, one involving a fixed outcome, the second two outcomes with some chances of occurrence, and he is asked to give his
preferences. The purpose is to arrive at an indifference state between the two choices. As stated in a preceding chapter, there are two major ways that can be used to arrive at the indifference point, the first being to vary the probabilities of occurrence of the various outcomes, the second to vary the value of the outcomes.

The second procedure was followed in our assessment, since it was felt that the contractors would be much more sensitive to variations in monetary outcomes rather than to variations in probabilities. It also permits the elimination of a subjective interpretation of probabilities that could distort the shape of the utility function and give incorrect results. Furthermore the questions should permit the assessment of utilities for points within the range minimum rate of return and 15%, and also for points that are below this range. Since the contractor may be faced, in some risky situations, with the possibility of outcomes below his minimum acceptable return.

Another very important characteristic for the questions is that they should be phrased in a certain way that makes sense to the general contractor. They should represent specific situations that the contractor is likely to encounter in his every day work.

The first type of questions used for the utility assessment
is as follows: the contractor is offered two contracts. Contract A involves a job under a unit price arrangement with two equally likely monetary outcomes. These outcomes are the minimum rate of return, determined in a previous question, and 15% of the total cost of the project. Project A was represented by

\[
\begin{align*}
\text{15\%} \times \text{size of job} \\
\text{Minimum rate of return} \times \text{size of job}
\end{align*}
\]

Contract B involves a job on a cost plus fixed fee basis, and the contractor is guaranteed a certain monetary return. The contractor was then asked to decide whether he would choose contract A or contract B, if he had the opportunity to take only one. The fixed fee of project B was varied until the point of indifference between projects A and B was reached.

To determine the utilities of markups below the minimum rate of return, the same kind of questions could be used. Contract A would have its outcomes replaced by one which is smaller than the minimum rate of return (S) and one which is larger (L). Then, the fixed fee in contract B would be varied until, for a certain value, the indifference point between the two contracts is reached. Knowing the utilities
of the fixed fee (in contract B) and L, the utility of S could be found (it would be negative).

\[ L \]

\[ S \]

However the disadvantage of such type of questions soon became apparent. When the first contractor interviewed was offered contract A with the possibility of an outcome smaller than the minimum acceptable to him, he refused to consider such a project.

Another type of question was therefore devised in order to go around this difficulty. A job with two equally likely final costs was presented to the contractors, and they were asked what their minimum bid would be. If the final costs of the job are denoted by \( C_1 \) and \( C_2 \), the bid price by B and the present situation without the project by P.S. then we would have:

\[ P.S. \sim \begin{cases} 
B - C_1 - \text{cost of preparing bid} & \text{WIN} \\
B - C_2 - \text{cost of preparing bid} & \text{LOSE} \\
i.S. - \text{cost of preparing bid} & \end{cases} \]
Neglecting the cost of preparing the bid, which can be considered to be accounted for in the overhead of the company, we have:

\[ \frac{B - C_1}{C_1} \times 100\% \]

\[ \frac{B - C_2}{C_2} \times 100\% \]

P.S.

The outcomes have been replaced by the percentage profit for consistency. Let \( \varepsilon \) represent a very small positive value, then one could say that:

\[ \text{P.S. } \sim \text{ MRR } - \varepsilon \]

since, theoretically, the contractor would refuse the job if the return was slightly smaller than the minimum rate of return. He would therefore be indifferent between his present situation and a return of \( \text{MRR } - \varepsilon \). Since \( \varepsilon \) is a very small value the continuity of the function \( U(x) \) implies

\[ U(\text{MRR } - \varepsilon) \approx U(\text{MRR}) \]

Therefore

\[ \text{P.S. } \sim \text{ MRR} \]

Using the axiom of transitivity (see chapter 3) we obtain:
EQUATING THE UTILITIES ON BOTH SIDES:

\[ U(MRR) = Pr(\text{win}) \cdot U(\text{job}) + (1 - Pr(\text{win})) \cdot U(MRR) \]

where \( U(MRR) \) is the utility of MRR

\( Pr(\text{win}) \) is the probability of winning the bid

We therefore obtain \( U(MRR) = U(\text{job}) \) and

This is equivalent to saying that the contractor is indifferent between a project with the minimum rate of return and the uncertain final cost project with his minimum bid, since if the minimum bid or the minimum rate of return are decreased by \( \varepsilon \), both projects will be unacceptable to him.
From $U(MRR) = 0.5 U\left(\frac{B-C}{C_1} x 100\right) + 0.5 U\left(\frac{B-C}{C_2} x 100\right)$

it is evident that:

$U\left(\frac{B-C}{C_2} x 100\right) < U(MRR) < U\left(\frac{B-C}{C_1} x 100\right)$

and because of the assumption of monotonicity of the utility function:

$\frac{B-C}{C_2} x 100 < MRR < \frac{B-C}{C_1} x 100$

The utility of $\frac{B-C}{C_1} x 100$ can be obtained from the utility function assessed, using the first type of questions, for the range MRR to 15%. The utility of MRR being known (equal to zero), one can therefore obtain the utility of $\frac{B-C}{C_2} x 100$ which lies below the MRR.

5.2.3. Final form of the questionnaire

One of the major constraints that determined the final form of the questionnaire was the time needed by the contractor to go over and answer all parts. A limit of 40 minutes was arbitrarily set to be the maximum amount not to be exceeded. The introduction to the questionnaire consisted of a relatively short part describing the work that had already been done and the final aim of this study. The purpose was to explain to the contractor the usefulness of the questionnaire, and also to motivate him in order to obtain answers
that really represented his preferences.

The first series of questions are intended to give an idea of the present status of the company, type of work in which it is involved and the goals of the firm. No specific answers were required but rather the contractor was asked to give answers of the type: normal, lower than normal or higher than normal, since it was felt that most of the contractors would be reluctant to give exact figures which, moreover, would be of no use for the purpose of this study.

The remaining part of the questionnaire consists of three basic questions repeated under different situations. These are: normal size job and good times, large size job and good times, normal size job and bad times, and finally large size job and bad times. The three types of questions were discussed in a previous part of this chapter: the first was used to determine the minimum rate of return; the second to determine the utility of one point within the range $\mu R$ and 15%; and the third to determine the utility of one point below this range. In this question the variation in the costs was taken equal to 15%, since it was felt that a relatively large difference should exist in order to obtain a better reaction to the risk of the job and therefore a better assessment. However, it turned out that this difference was in fact too large and is unlikely to occur on any
type of job. A smaller difference in the order of 5% to 7% would have been preferable.

The utilities of at least two other points, in the range considered, were in fact needed to obtain a reasonably accurate utility curve. However due to the time constraint we were limited to only three questions per situation and furthermore the exact shape of the utility curves was of no direct interest in this study since we were mainly concerned with obtaining a measure of the variation in risk-aversion. A form of the questionnaire with certain fictitious sizes of jobs and answers appears in appendix D.

5.3. Utility assessment and results

5.3.1. From theory to practice

The first problem encountered was how to get to know general contractors interested enough to give us 40 minutes of their time. The Massachusetts Chapter of the Associated General Contractors (AGC) provided us with the name of two general contractors who, in their turn, introduced us to other contractors in the Boston area. The utility assessment was conducted for the decision-makers in five firms representing a fairly good cross-section of the industry in terms of sizes. The questionnaire could not be sent by mail to general contractors because the nature of the questions
involved necessitated the presence of at least one of us to
direct the decision-maker and explain what is exactly
needed.

The most common problem encountered in the utility assess-
ment was that many decision-makers considered the questions
to be too hypothetical. For example when some of the gene-
ral contractors were asked for the minimum acceptable rate
of return on a certain project given certain economic con-
ditions, they answered that it depended on the identity of
the owner or the number of jobs undertaken by the company:
we had to make reasonable assumptions in each case. Simi-
larly some of the contractors interviewed used subjective
probabilities in their answers for certain questions. When
they were asked to bid on the job with uncertain final costs
they gave amazingly low bids; when we explained once more
that the final costs had equal chance of occurrence and that
this was totally independent of their control, the bids were
much higher. In fact when the decision-makers were faced
with the uncertain costs most of them were confident that
they were capable of bringing the final cost near the lower
bound and they gave their bids accordingly.

Another common type of pitfall encountered was that when the
contractor gave us his minimum acceptable rate of return,
say 5\%, and was then asked if he would accept 4.5\% generally the answer was yes. In fact the contractor gave us the rate of return he would like to get, not the minimum acceptable to him. So we kept asking the contractors, in all questions for their attitudes towards different values below the first answer they gave, therefore making sure that the final answer really represented the minimum rate of return, bid or fee acceptable to them.

Some other problems encountered were that two of the companies interviewed had enough work actually going that they felt they are personally operating in good conditions. Therefore they said that their answers given for actual times will be the same as those for good times: the four situations were hence reduced to two. Furthermore these contractors considered the question of uncertain cost situation in a specific way: they argued that since they are in relatively good operating conditions, they will bid by adding the minimum rate of return to the higher cost, neglecting completely the possibility of occurrence of the lower cost.

5.3.2. **Treatment of data**

All the answers to the questions on the utility assessment, whether given in percentage or gross monetary values, were dealt with as a percentage of the cost of the project.
The minimum rate of return and the 15% markup were respectively given utility values of 0 and 1. The markup having the 0.5 utility was obtained through the second type of questions discussed earlier. Finally a point with a negative utility value was obtained.

In order to interpret the results, constant risk aversion was assumed throughout the range of assessment. This kind of behavior is represented by utility curves of the form:

\[ U(x) = a - b \, e^{-c \cdot x} \quad a, b, c > 0 \]

In our case: \( x \) is the markup, percent of total cost

\( U(x) \) is the utility of a markup \( x \)

The risk aversion function \( r(x) \) is the appropriate measure of the degree of risk aversion. For the exponential function given above:

\[ r(x) = - \frac{U''(x)}{U'(x)} = - \frac{b \, c^2 \, e^{-c \cdot x}}{-b \, c \, \exp(-c \cdot x)} = c \]

where \( U''(x) \) is the second derivative of \( U(x) \) with respect to \( x \) and \( U'(x) \) the first derivative with respect to \( x \).

The assumption of constant risk aversion was resorted to for two major reasons: the first is that due to the variation in the ranges of the different utility assessments, the risk premium could not be utilized for comparing degrees of risk aversion and no other practical criteria could be used for this purpose; the second reason is that since the shape of
the utility curve is of no concern to us, the exponential form was assumed because it provides an easy measure of the degree of risk aversion.

Although the two types of questions utilized for the utility assessment are complementary, the results obtained from these different types of questions were treated separately. The reason is that it was not possible to fit a curve of the exponential form through the four points obtained (with one point having negative utility). Since the major concern in this study is to determine the change in risk aversion given different conditions, the data was treated in the following ways: first a utility curve of the exponential form was fitted through the points MRR, 15% markup and the point with a 0.5 utility value; then the results obtained from the type of questions involving uncertain final costs were treated separately, and a constant risk aversion type of curve was also used. Subsequently these two situations will be referred to respectively as the certain cost situation and the uncertain cost situation.

In the uncertain cost situation, utility values of 0 and 1 were arbitrarily assigned to the two uncertain monetary outcomes, \( \frac{E-C_1}{C_1} \) and \( \frac{E-C_2}{C_2} \), and the utility of the MRR was therefore 0.5.
5.3.3. Results

The utility functions obtained for the 5 general contractors are presented in table B1 of appendix B. The utility assessment in the uncertain cost situation could not be obtained for contractors 1, 2 and 3. All three neglected completely the possibility of occurrence of the low cost and gave their bids considering the high cost only. They considered the project to be too risky, and this for various reasons; contractors 2 and 3 are operating in relatively good conditions while contractor 1 is dealing with negotiated types of contracts and felt that if he had to bid on such a risky project he will be on "the safe side". Furthermore contractors 2 and 3 could not consider the bad times situations because their companies were never, in these last 15 years, in bad working conditions. Finally the answers of contractor 5 on the uncertain cost and good times situation were not considered because they were obviously inconsistent. The results concerning the minimum assessed rate of return are presented in table B2. The minimum rate of return appeared to be significantly higher in good times than in bad times regardless of the size of the job. It was also higher for the normal size jobs than for the large size jobs given the same economic conditions.

As far as variations in the degree of risk aversion are
concerned, the certain cost situation and the uncertain cost situation will be considered separately.

All the contractors, in the certain cost situation, appeared to be much more risk averse for the normal size jobs in bad times than in normal times: the risk aversion \( c \) (table B1) varied from below 10 values in good times to the 20's and 30's in bad times. For the large size jobs, the contractors appeared to be much more risk averse than for the normal size jobs. Consequently the risk aversion was much less affected by good and bad times. One can therefore expect the bids, for normal size jobs, to be much lower in bad times than in good times, since higher risk aversion means that lower outcomes are given relatively more value. However the bids, for large size jobs, will vary much less with changing economic conditions.

In the uncertain cost situation, the risk aversion was very high given good times, regardless of the size of the job. This risk aversion diminished drastically for the normal size jobs in bad times but did not almost vary for the large size jobs. One can expect therefore the contractors to take much more risk and bid much lower in normal size jobs in bad times than in good times.
5.4. **Conclusion**

We were mainly concerned in this chapter with the assessment of the utility functions for some general contractors in the Boston area. The assumptions used and difficulties encountered in both the development stage of the questionnaire and the actual assessment were discussed in some detail. Then the results of the assessment were presented, their detailed interpretation and relation to observed behavior being the object of our next chapter.
CHAPTER 6

COMPARISON OF RESULTS

6.1. Introduction

The object of this chapter is to interpret the results obtained from the utility assessment in terms of what is to be observed in practice, we then correlate the expected behavior and the actual behavior obtained from the analysis of public bids in order to investigate the superiority of the expected utility value criterion over the expected monetary value criterion used in all bidding strategies. Finally we use, in an example, the utility functions assessed for one of the contractors and the expected monetary value approach to determine variations in the optimum markup given different situations.

6.2. Interpretation of the results of the utility assessment

6.2.1. Certain Cost Situation

This refers to the situation in which the contractor is sure, beforehand, that his estimated cost will be equal to his actual cost after execution of the work. Most of the bidding strategies in the literature considered the certain
cost situation, and some of the researchers asserted that the ratio of actual to estimated cost is represented by a normal probability density of mean 1 and standard deviation smaller than 2%. In fact there are several situations in which this may be true; the most common ones are when the contractor is dealing with jobs that are of a type well known to him; or when he is involved in cost plus fixed fee contracts on regular types of constructions.

6.2.1.1. **Normal size of jobs**

The general shapes of the assessed utility function in good and bad times are represented in figure 6.1. In good times, the interviewed contractors appear to have a higher acceptable minimum rate of return and a smaller degree of risk aversion than in bad times. One can expect therefore lower optimum markups in bad times than in good times, because increased risk aversion means in this case that the contractor will prefer lower markups with an increased chance of winning, to higher markups. The contractor is much more concerned with the possibility of losing the job and will consequently submit a low bid. This effect of risk aversion on the level of the bids will be proven below for the contractors interviewed.

Let \( w(x) \) be the ratio of the utility function of a contractor in bad times, \( U(x) \), over his utility function in good
LEGEND:  
MRR_b = MINIMUM RATE OF RETURN IN BAD TIMES  
MRR_g = MINIMUM RATE OF RETURN IN GOOD TIMES

FIGURE 6.1 UTILITY FUNCTIONS GIVEN CERTAIN COST AND NORMAL SIZE OF JOB.
times, \( V(x) \). We find that, for the contractors interviewed, \( w(x) \) is decreasing with increasing values of \( x \). The general shape of the curve obtained is shown in figure 6.2. The optimum markup in good times, \( x_0 \), is the number that maximizes the expected utility value:

\[
E(V(x)) = p(x) V(x)
\]

where \( p(x) \) is the previously defined probability of winning given a markup \( x \). \( p(x) \) is decreasing with increasing values of \( x \) because it represents the complementary cumulative distribution function of the repartition of bids (C.C.D.F), a function which is decreasing by definition. Plotting the expected utility function for good times we get the curve shown in figure 6.3.

We will now show that, for the same number of competitors and therefore the same probability distribution of winning, the optimum markup in bad times, \( x'_0 \), is always lower than or equal to \( x'_0 \).

If we assume that \( x'_0 = c \), with \( c > x'_0 \), we should have:

\[
E(U(c)) > E(U(x'_0)), \text{ since } c \text{ is optimum in bad times.}
\]

The expected utility of \( x \) in bad times is:

\[
E(U(x)) = p(x) U(x) = p(x) V(x) \frac{U(x)}{V(x)}
\]

\[= p(x) V(x) w(x) = E(V(x)) w(x)\]
FIGURE 6.2 PLOT OF THE RATIO, W(x), OF UTILITIES IN BAD AND GOOD TIMES.
FIGURE 6.3 EXPECTED UTILITY FUNCTION IN GOOD TIMES.
Considering now the ratio of expected utilities:

\[
\frac{E(U(c))}{E(U(x'_o))} = \frac{E(V(c))}{E(V(x'_o))} \times \frac{w(c)}{w(x'_o)}
\]

Since \(x'_o\) is the optimum markup in good times we have:

\[
\frac{E(V(c))}{E(V(x'_o))} < 1
\]

Furthermore since we have assumed \(c > x'_o\), we obtain from figure 6.2 \(w(c) < w(x'_o)\), and so the ratio \(w(c)/w(x'_o)\) is less than 1. Therefore:

\[
\frac{E(U(c))}{E(U(x'_o))} < 1
\]

and \(E(U(c)) < E(U(x'_o))\), this contradicts the assumption that \(c\) is the optimum in bad times. We have therefore proven that, for the assessed utility functions and for any shape of the C.C.D.F, the optimum markup in bad times can never exceed \(x'_o\). In fact as will be shown later in this chapter, the optimum markup in bad times is always either less than or equal to the one in good times, the equality holding true only in a very special case.

6.2.1.2. Large size of jobs

The general shapes of the assessed utility functions in
varying economic conditions are shown in figure 6.4. As before, the contractors appear to have, in good times, a higher minimum rate of return than in bad times. However, as seen in table B.1, the degree of risk aversion is very little affected by changing times, and therefore the difference between the optimum markups in good and bad times is expected to be very small. Contractors will have more or less the same relative preferences between the various uncertain outcomes which are the different markups with their respective probabilities of winning.

Table 6.1 summarizes the variation of the degree of risk aversion (c) with varying sizes of projects and economic conditions.

Table 6.1 : Variations in the degree of risk aversion, certain cost case.

<table>
<thead>
<tr>
<th>Times</th>
<th>Size of job</th>
<th>Good</th>
<th>Bad</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Small (c 0.075)</td>
<td>Large (c 0.28)</td>
</tr>
<tr>
<td></td>
<td>Large</td>
<td>Large (c 0.28)</td>
<td>Large (c 0.33)</td>
</tr>
</tbody>
</table>
FIGURE 6.4 UTILITY FUNCTIONS GIVEN CERTAIN COST AND LARGE SIZE OF JOB.
Furthermore one can expect that, in good times, the markups on the large jobs will be lower than those on the smaller jobs.

6.2.2. Uncertain cost situation

The decision-maker is often faced with the problem of estimating work with uncertainties as to the final cost. Until now no specific tools were available to the contractor for dealing rigorously and consistently with such situations. The uncertainty may be related to the type of job or it may be caused by external environmental factors. The contractor may, for example, be bidding for the first time on a certain type of job and there is a possibility that he will not consider certain costly aspects of the work. The job may also be of such a nature that one cannot determine in advance the construction method which is best suited and the contractor will have to resort to a trial approach in the field; this is especially the case for underwater or soil foundations types of work. Another characteristic type of uncertainty is when the specifications recommend a specific type of material, which is costly, and leave the possibility to the contractor of using an equivalent type of material conditional on obtaining the agreement of the owner. This usually happens on governmental jobs, and the contractor is uncertain whether to base his estimations on the relatively
cheap material which may be rejected by the owner, or consider only the specified type and risk losing the job because of his high bid. The uncertainty resulting from external environmental factors may be caused for example by weather conditions, possible strikes of the labor force, fluctuations in prices of materials, irregular and late payments by the owner or faulty plans by the architect.

An uncertain cost bidding situation can be represented by the following:

\[
\begin{array}{c}
B - C_1 \\
B - C_2 \\
P.S.
\end{array}
\]

where \(C_1\) is the maximum cost of the work, \(C_2\) the minimum cost, \(p\) the probability of occurrence of \(C_1\), \(B\) the bid price and \(p(B)\) the probability of winning given \(B\). It is assumed for simplicity that there are only two possible costs, but one can easily extend the problem for an infinity of possible costs knowing the probability distribution function of their occurrence. Furthermore, the cost of preparing the bid is not accounted for since most of the time it is considered as being part of the company overhead.
The above tree representation can be simplified to the following:

```
  B - C_1
    \   /
   P(B) - P
     \   /
     P(B) - (1-P)
       E - C_2
```

The probability $p(B)$ of being the low bidder cannot be obtained through the use of statistical methods presented in a previous chapter. The contractor should assess and use his judgmental probabilities of chances of winning. As Raiffa (1968) said:

"As far as action is concerned ... you should feel free to use these judgmental probabilities just as if they were the real thing ..."

6.2.2.1. Normal size of jobs

Given the same uncertain situation the contractor appears much more risk averse in good times than in bad times. We shall see that this behavior implies lower level of markups in bad times than in good times, similarly to the certain cost situation. Increasing risk aversion, in the uncertain cost case, means that the smaller outcomes that are below the contractor's minimum rate of return are given much more importance or weight in arriving to the final decision. The
contractor will therefore increase his bid in order to account for the possible occurrence of these outcomes with negative utility.

6.2.2.2. **Large size of job**

The assessed utility functions for contractor 4 showed that the degree of risk aversion is very little affected by bad times. In fact $c$ decreases by 9% in bad times for the large size of jobs as compared to a 90% decrease for normal sizes. One can therefore expect the variation in optimum markups with changing economic conditions to be very small for the large projects.

6.2.2.3. **Illustration**

An example will help to clarify the above points. Let us consider a project with two equally likely uncertain final costs, $C_1$ and $C_2$. It can be represented by:

\[
\begin{array}{c}
C_1 \quad \$1,000,000 \\
\downarrow \quad .50 \\
\downarrow \quad .50 \\
C_2 \quad \$900,000
\end{array}
\]

Assuming a certain $p(B)$ for different levels of the bid $B$ and using the utility functions of a normal job assessed for contractor 4 (table B1), we can determine the optimum bids...
in the following situations:
1) Using expected monetary value criterion.
2) Using expected utility for good times.
3) Using expected utility for bad times.
The results of the computation are shown in table C1 of appendix C, where:

\[ V(x) = 1.0 - 522 \ e^{-0.69 \ x} \quad \text{good times} \]
\[ U(x) = 1.45 - 1.67 \ e^{-0.07 \ x} \quad \text{bad times} \]

An optimum bid price of $1,100,000 was obtained given good times, as compared to a $1,050,000 given bad times. Furthermore the bid price obtained using the expected monetary value criterion was also $1,050,000 but this is due to the fact that the increment between two successive bids was too large for a good sensitivity in the results. The optimum bid in good times was higher than the one in bad times, which is the expected result. Moreover the optimum bid suggested by the expected monetary value criterion is unacceptable, in good times, by the decision-maker since a negative utility value is associated with such a bid.

Let us consider the same example and assume that it is a relatively large job as far as contractor 4 is concerned. Using his utility functions assessed for a large project we can determine his optimum bid; the calculations are shown in table C2. The optimum bid obtained in good times was
$1,100,000 compared to $1,075,000 in bad times. The bid in bad times is, as expected, lower than the one in good times. The level of the bid appears also to be less affected by changing economic conditions, the larger the size of the job. Furthermore the level of the bid is proportionally higher, in good times, the larger the relative size of the project.

Table 6.2 summarizes the variations in the degree of risk aversion in the uncertain cost case, given varying sizes of projects and economic conditions.

Table 6.2 : Variations in the degree of risk aversion, uncertain cost case.

<table>
<thead>
<tr>
<th>Size of job</th>
<th>Times</th>
<th>Good</th>
<th>Bad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td></td>
<td>Large (c 0.69)</td>
<td>Small (c 0.07)</td>
</tr>
<tr>
<td>Large</td>
<td></td>
<td>Large (c 0.69)</td>
<td>Large (c 0.63)</td>
</tr>
</tbody>
</table>

We can therefore conclude that, for the contractors interviewed, we observe the same behavior in both certain and uncertain cost cases. The level of the bids in good times is
higher than in bad times, this variation in the level being much smaller the larger the relative size of the job. Finally the markup, in good times, on large jobs is higher than the markup on small jobs.

6.3. Comparison of results

6.3.1. Predicted behavior

Using the collected public bidding data to generate probabilities, and the assessed utility functions for normal sizes of jobs, we will determine the optimum markups of contractor 1, in the certain cost situation, as a function of the number of bidders and changing economic conditions. We will then verify whether the actual behavior obtained from the analysis of the data is similar to the predicted behavior. Discrete probabilities of winning for various levels of markups and different numbers of competitors were calculated on a computer utilizing the data of the DPW; these data were preferred to those of the BBC because of their larger size. The C.C.D.F obtained appear in figure 6.5, 6.6, 6.7, 6.8 and tables C3, C4, C5, C6. The sizes of projects considered ranged between $100,000 and $1,000,000, the upper limit being imposed to eliminate all construction types of projects and restrict the analysis to maintenance projects. The bidding data of all years (1966 to 1975) were consi-
FIGURE 6.5 COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION FOR 3 COMPETITORS.
FIGURE 6.6 COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION FOR 4 COMPETITORS.
FIGURE 6.7 COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION FOR 5 COMPETITORS.
FIGURE 6.8 COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION FOR 6 COMPETITORS.
dered in order to have a sufficient number of bids for each specified number of competitors. Furthermore the markup was taken to be the difference between the bid price and the cost estimate (EC) divided by the cost estimate:

\[ X = \frac{B - EC}{EC} \]

This cost estimate was defined to be equal to the engineer's estimate (EE) minus 5%, the 5% being the arbitrarily assumed allowance for overhead and profit present in the agency's estimate. The optimum markups were then respectively computed using the expected monetary value criterion and the utility functions assessed for contractor 1 given a normal size of job and varying economic conditions. The general shape of the curves showing the optimum markups as a function of the number of competitors appear in figure 6.9, with the exact values given in table C7. It appears that, consistently with what is predicted by the bidding strategies, the level of the markups is decreasing the higher the number of competitors. Furthermore the optimum markups in bad times and using expected monetary values are coinciding, but this is due to the fact that discrete probability functions are used; these are not sensitive enough to show the differences that exist in this specific case. In fact the optimum markups were calculated for another form of the C.C.D.F,
NUMBER OF BIDDERS

FIGURE 6.9 OPTIMUM MARKUPS FOR CONTRACTOR 1, CERTAIN COST SITUATION, USING EXPECTED UTILITIES AND MONETARY VALUES.

-COST = 0.95 EE-
form corresponding to a different assumption of the percentage of overhead and profit included in the engineer's estimate on the public bids. Figure 6.10 shows the curve obtained for a 7% allowance, the values appear in table C8. One can see that the optimum markup using expected monetary values are lower than those obtained using expected utilities in bad times. Most importantly, optimum markups, in good times, are in both cases higher than the optimum markups in bad times.

6.3.2. Actual behavior

The bidding strategies using the expected monetary value criterion suggest the same markup given the same probability distribution of winning and regardless of the economic condition of the firm. On the other hand the expected utility criterion suggests that, for the contractors interviewed, the optimum markups in good times are higher than those in bad times. If the expected monetary value criterion reflected the true behavior of the contracting companies, one should observe more or less the same level of bids for the same number of competitors regardless of the year. But if the expected utility criterion is the correct one to use, then the markups in good years will be higher than those in bad years for the same number of competitors. The analysis of public bids showed in figure 4.6 that this latter beha-
FIGURE 6.10 OPTIMUM MARKUPS FOR CONTRACTOR 1, CERTAIN COST SITUATION, USING EXPECTED UTILITIES AND MONETARY VALUES.

\[ \text{COST} = 0.93 \text{ EE} \]
vior is actually observed; this showed that general contractors behave in a way as to maximize their expected utilities, and furthermore that the general shape of the utility functions found for the contractors interviewed, are representative of the preferences in the industry as a whole.

6.4. Conclusion

This chapter explains in a first step the results of the utility assessment, in both certain and uncertain cost cases. We find that the contractors will bid consistently lower in bad times than in good times. The second step correlates the actual behavior obtained through the analysis of public bids in chapter 4, with the predicted behavior obtained by using the utility functions of one of the contractors interviewed. The expected utility value criterion appears to be a more realistic criterion to use than the expected monetary value.
CHAPTER 7

CONCLUSION

As we have shown in the preceding chapters, some factors which are important in bidding behavior are not considered in the existing bidding strategies. In chapter 2 we have seen that the following diagram is used in all cases.

\[ \text{NUMBER OF BIDDERS} \]

\[ \text{C.C.D.F} \rightarrow \text{BID PRICE} \]

where C.C.D.F is a complementary distribution function \( G(x) \) which gives the probability of winning the bid, for any level of markup. This function is generally generated from past data.

By considering the data of actual bidding we showed that the number of bidders depends on the number of projects available to the bidders (see chapter 4). On the other hand we showed that a contractor determines his markup according to the utility of this markup to him (see chapter 3). The utility assessments that we made on contractors of the
Boston area show that at least two factors influence the utility function of a contractor; these are the size of the project and the economic condition of his firm at the time he bids, this condition generally being related to the economic condition of the construction industry as a whole (see chapter 5). Therefore we suggest that a diagram which is more closely representative of real world bidding is as follows:

This diagram may not be complete but it gives a better idea of what should be taken into account by bidding strategies in order for them to be more useful. In that respect we think there are at least three possible extensions of this study which could lead to the development of better bidding
strategies.

It would be interesting to assess the utility of one contractor very precisely and use his past bids to compare the predictions given by the expected monetary value model and those given by the expected utility value model.

Another line of study would be to verify which of the statistical methods of the literature can best be used for predictive purposes. It might even be interesting to use multivariate statistical analysis to determine how different variables which have an influence on the bid are correlated.

In our study we have been concerned by utility functions with one attribute only. During our interviews we saw that other objectives than monetary outcomes are taken into consideration. Some of them are: expand as much as possible, expand to keep up with inflation, prestige of the work. In the case of a contractor who wants to expand as much as possible, he will take a much lower profit to have more jobs. In that case a second attribute would be the volume of work on hand. In the case of the prestige attribute, a good example is the case of a contractor who accepted a $250,000 worth job in the White House for a nominal markup of $1. The use of a one attribute utility function will have shortcomings in this case. Consequently we think that a multi-attribute utility function could be defined and that its
combination with multivariate statistical analysis may lead to the development of good and hopefully more useful bidding strategies.
REFERENCES


6. de Neufville, R. and R.L. Keeney (1972) "Multiattribute Preference Analysis: the Mexico City Airport" Transportation Research, April, pp. 63-75


### Table A1: BBC data, main features

<table>
<thead>
<tr>
<th>Calendar year</th>
<th>Total construction award</th>
<th>Corrected value ($1974)</th>
<th>Corre. factor</th>
<th>Number of projects collected</th>
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<tbody>
<tr>
<td>1961</td>
<td>28,437,260</td>
<td>60,571,400</td>
<td>2.13</td>
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<tr>
<td>1962</td>
<td>21,226,812</td>
<td>44,576,300</td>
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<td>1963</td>
<td>32,106,696</td>
<td>64,534,500</td>
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<td>42,225,777</td>
<td>86,883,800</td>
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<tr>
<td>1965</td>
<td>44,361,143</td>
<td>89,165,900</td>
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<td>1966</td>
<td>32,069,899</td>
<td>61,157,300</td>
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<tr>
<td>1967</td>
<td>34,196,479</td>
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<td>1968</td>
<td>41,685,853</td>
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<td>1969</td>
<td>59,928,186</td>
<td>92,888,700</td>
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<td>1970</td>
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<td>124,206,726</td>
<td>1.44</td>
<td>16</td>
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<tr>
<td>1971</td>
<td>247,745,497</td>
<td>312,159,326</td>
<td>1.26</td>
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<td>1972</td>
<td>157,327,847</td>
<td>184,073,581</td>
<td>1.17</td>
<td>21</td>
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<tr>
<td>1973</td>
<td>59,015,706</td>
<td>63,146,800</td>
<td>1.07</td>
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<tr>
<td>1974</td>
<td>17,975,973</td>
<td>17,975,973</td>
<td>1.00</td>
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Table A2: DPW data, main features

<table>
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<tr>
<th>Fiscal year</th>
<th>Total construction award</th>
<th>Corrected value ($1974)</th>
<th>Number of projects</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Const.</td>
</tr>
<tr>
<td>1966*</td>
<td>83,101,064</td>
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<tr>
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<td>15</td>
</tr>
<tr>
<td>1968</td>
<td>102,931,319</td>
<td>178,071,182</td>
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</tr>
<tr>
<td>1969</td>
<td>95,249,553</td>
<td>153,351,780</td>
<td>15</td>
</tr>
<tr>
<td>1970</td>
<td>125,852,673</td>
<td>188,779,009</td>
<td>16</td>
</tr>
<tr>
<td>1971</td>
<td>61,035,346</td>
<td>81,047,717</td>
<td>10</td>
</tr>
<tr>
<td>1972</td>
<td>106,453,506</td>
<td>125,615,137</td>
<td>6</td>
</tr>
<tr>
<td>1973</td>
<td>132,016,067</td>
<td>141,257,719</td>
<td>11</td>
</tr>
<tr>
<td>1974</td>
<td>Unavailable</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>1975*</td>
<td>Unavailable</td>
<td>-</td>
<td>2</td>
</tr>
</tbody>
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* In 1966 the number of projects is taken from January 1966 to June 1966, in 1975 from July 1974 to December 1974.
Table A3: Number of projects versus average number of bidders per project - BBC -

<table>
<thead>
<tr>
<th>Calendar year</th>
<th>Number of projects</th>
<th>Average number of bidders</th>
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<tbody>
<tr>
<td>1961</td>
<td>4</td>
<td>10.75</td>
</tr>
<tr>
<td>1962</td>
<td>4</td>
<td>10.00</td>
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<tr>
<td>1963</td>
<td>6</td>
<td>7.50</td>
</tr>
<tr>
<td>1964</td>
<td>10</td>
<td>7.50</td>
</tr>
<tr>
<td>1965</td>
<td>11</td>
<td>7.18</td>
</tr>
<tr>
<td>1966</td>
<td>15</td>
<td>6.40</td>
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<td>1967</td>
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<td>6.25</td>
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<tr>
<td>1968</td>
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<td>4.23</td>
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<td>1969</td>
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<td>16</td>
<td>5.75</td>
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<td>1971</td>
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<td>1973</td>
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<tr>
<td>1974</td>
<td>10</td>
<td>9.60</td>
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Table A4: Number of projects versus average number of bidders per project - DPW -

<table>
<thead>
<tr>
<th>Fiscal year</th>
<th>Construction</th>
<th></th>
<th>Maintenance</th>
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<tr>
<td></td>
<td>N.P</td>
<td>A.N.B</td>
<td>N.P</td>
</tr>
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<td>1966</td>
<td>12</td>
<td>6.60</td>
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<td>1969</td>
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<td>5.36</td>
<td>56</td>
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<td>1970</td>
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<td>48</td>
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<tr>
<td>1973</td>
<td>11</td>
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<td>1974</td>
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<td>5.12</td>
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<tr>
<td>1975</td>
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<td>7.50</td>
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</table>

N.P : Number of projects
A.N.B : Average number of bidders per project

- 121 -
Table A4: Number of projects versus average number of bidders per project - DPW - (continued)

<table>
<thead>
<tr>
<th>Fiscal year</th>
<th>Reconstruction</th>
<th>Highway work</th>
<th>Resurfacing</th>
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<td>N.P</td>
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<td>3</td>
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<td>4</td>
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<td>3.10</td>
<td>22</td>
</tr>
<tr>
<td>1969</td>
<td>30</td>
<td>3.93</td>
<td>6</td>
</tr>
<tr>
<td>1970</td>
<td>29</td>
<td>4.04</td>
<td>9</td>
</tr>
<tr>
<td>1971</td>
<td>29</td>
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<td>1972</td>
<td>27</td>
<td>5.63</td>
<td>15</td>
</tr>
<tr>
<td>1973</td>
<td>62</td>
<td>5.02</td>
<td>0</td>
</tr>
<tr>
<td>1974</td>
<td>30</td>
<td>5.70</td>
<td>1</td>
</tr>
<tr>
<td>1975</td>
<td>18</td>
<td>7.10</td>
<td>0</td>
</tr>
</tbody>
</table>

N.P : Number of projects
A.N.B : Average number of bidders per project
Table A5: Deviation of bids from estimated cost for BBC (% of estimated cost)

<table>
<thead>
<tr>
<th>Number of bidders</th>
<th>Good years</th>
<th>Bad years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2-3</td>
<td>8.76</td>
<td>5.03</td>
</tr>
<tr>
<td>4-5-6</td>
<td>4.71</td>
<td>1.32</td>
</tr>
<tr>
<td>7-8-9</td>
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<td>-4.31</td>
</tr>
<tr>
<td>10-11-12</td>
<td>-3.03</td>
<td>-5.32</td>
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</tbody>
</table>

Good years: 66, 67, 68, 69, 70, 71

Bad years: 61, 62, 63, 64, 65, 72, 73, 74
Table A6 : Deviation of bids from estimate for DPW
(% of estimate cost)

<table>
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<tbody>
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<td>Number of bidders</td>
<td>D.E</td>
<td>N.P</td>
<td>D.E</td>
<td>N.P</td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
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<td>6.81</td>
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</tr>
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<td>3</td>
<td>2.83</td>
<td>9</td>
<td>3.00</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>-2.34</td>
<td>8</td>
<td>-0.62</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>-3.25</td>
<td>7</td>
<td>0.43</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>-5.33</td>
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<td>1.01</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>-4.56</td>
<td>4</td>
<td>4.17</td>
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</tr>
<tr>
<td>8</td>
<td>-5.74</td>
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<td>-</td>
<td>0</td>
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<td>9</td>
<td>-4.53</td>
<td>1</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>-2.40</td>
<td>1</td>
<td>-</td>
<td>0</td>
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</tbody>
</table>

D.E : Deviation from estimate \((B - E)/E \times 100\)

N.P : Number of projects
Table A7: Deviation of bids from estimate for DPW (% of estimate cost)

<table>
<thead>
<tr>
<th>Fiscal year</th>
<th>Number of bidders</th>
<th>1971</th>
<th>1972</th>
<th>1973</th>
<th>1974</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.E</td>
<td>N.P</td>
<td>D.E</td>
<td>N.P</td>
<td>D.E</td>
<td>N.P</td>
</tr>
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<td>9</td>
<td>3.00</td>
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<td>15</td>
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<td>13</td>
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<td>-0.72</td>
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<td>11</td>
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<td>-5.61</td>
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<td>-10.4</td>
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<td>-7.27</td>
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</table>

D.E : Deviation from estimate  \( \frac{(B - E)}{E} \times 100 \)

N.P : Number of projects
Table A8: Coefficients a and b found by linear regression

<table>
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<tr>
<th>Fiscal year</th>
<th>a</th>
<th>b</th>
<th>$r^2$ (fit)</th>
</tr>
</thead>
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<tr>
<td>1966</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1967</td>
<td>-2.77</td>
<td>11.50</td>
<td>0.85</td>
</tr>
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<td>1968</td>
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<td>0.73</td>
</tr>
<tr>
<td>1969</td>
<td>-3.18</td>
<td>17.49</td>
<td>0.81</td>
</tr>
<tr>
<td>1970</td>
<td>-3.93</td>
<td>18.06</td>
<td>0.84</td>
</tr>
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<td>1971</td>
<td>-4.30</td>
<td>20.86</td>
<td>0.91</td>
</tr>
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<td>1972</td>
<td>-3.84</td>
<td>10.82</td>
<td>0.51</td>
</tr>
<tr>
<td>1973</td>
<td>-3.69</td>
<td>10.25</td>
<td>0.94</td>
</tr>
<tr>
<td>1974</td>
<td>-1.25</td>
<td>10.74</td>
<td>0.28</td>
</tr>
<tr>
<td>1975</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</table>
Table B1: Assessed utility functions

A- Certain cost situation

  a- Normal size job

<table>
<thead>
<tr>
<th>Contractor</th>
<th>Good times</th>
<th>Bad times</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.33 - 4.42 e(^{-0.08x})</td>
<td>1.10 - 3.70 e(^{-0.24x})</td>
</tr>
<tr>
<td>2</td>
<td>(x^*)</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>2.73 - 3.06 e(^{-0.04x})</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>2.70 - 5.40 e(^{-0.08x})</td>
<td>1.08 - 8.52 e(^{-0.31x})</td>
</tr>
</tbody>
</table>

  b- Large size job

<table>
<thead>
<tr>
<th>Contractor</th>
<th>Good times</th>
<th>Bad times</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.01 - 5.03 e(^{-0.40x})</td>
<td>1.01 - 2.80 e(^{-0.34x})</td>
</tr>
<tr>
<td>2</td>
<td>1.25 - 2.25 e(^{-0.15x})</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>1.25 - 1.81 e(^{-0.13x})</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>1.16 - 11.0 e(^{-0.28x})</td>
<td>1.04 - 5.36 e(^{-0.33x})</td>
</tr>
</tbody>
</table>

* : Expected monetary valuer, \(r(x) = 0\)
Table B1: Assessed utility functions (continued)

B- Uncertain cost situation

a- Normal size job

<table>
<thead>
<tr>
<th>Contractor</th>
<th>Good times</th>
<th>Bad times</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>$1.00 - 512. e^{-0.69x}$</td>
<td>$1.45 - 1.67 e^{-0.07x}$</td>
</tr>
<tr>
<td>5</td>
<td>$1.00 - 256. e^{-0.69x}$</td>
<td>$1.43 - 1.53 e^{-0.08x}$</td>
</tr>
</tbody>
</table>

b- Large size job

<table>
<thead>
<tr>
<th>Contractor</th>
<th>Good times</th>
<th>Bad times</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>$1.00 - 512. e^{-0.69x}$</td>
<td>$1.00 - 41.2 e^{-0.63x}$</td>
</tr>
<tr>
<td>5</td>
<td>$1.00 - 256. e^{-0.69x}$</td>
<td>$1.01 - 1.82 e^{-0.25x}$</td>
</tr>
</tbody>
</table>
Table B2: Minimum rate of return for the various contractors interviewed (% return)

<table>
<thead>
<tr>
<th>Contractor</th>
<th>Normal size job</th>
<th>Large size job</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Bad times</td>
</tr>
<tr>
<td>1</td>
<td>8.</td>
<td>5.</td>
</tr>
<tr>
<td>2</td>
<td>5.</td>
<td>-</td>
</tr>
<tr>
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<td>3.</td>
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<tr>
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<td>8.</td>
</tr>
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<td>9.</td>
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</table>
APPENDIX C

TABLES OF COMPARISON OF RESULTS
Table C1: Optimum markup for contractor 1 on normal size of jobs, uncertain cost situation.

<table>
<thead>
<tr>
<th>B ($1000)</th>
<th>P(B)</th>
<th>B - C₁ ($1000)</th>
<th>B - C₂ ($1000)</th>
<th>X₁ (%)</th>
<th>X₂ (%)</th>
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<tbody>
<tr>
<td>950</td>
<td>0.95</td>
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<th>B ($1000)</th>
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<th>E(V(x))</th>
<th>E(U(x))</th>
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Table C2: Optimum markup for contractor 1 on large size of jobs, uncertain cost situation.

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Table C3: Cumulative distribution function (C.C.D.F) for 3 competitors. - markup in percentage -

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Table C4: Cumulative distribution function (C.C.D.F) for 4 competitors. - markup in percentage -

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<th>Markup</th>
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Table C5: Cumulative distribution function (C.C.D.F) for 5 competitors. - markup in percentage -

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Table C6: Cumulative distribution function (C.C.D.F) for 6 competitors. - markup in percentage -

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<td>-0.68</td>
<td>0.651</td>
<td>-4.63</td>
<td>0.977</td>
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<td>0.325</td>
<td>-0.84</td>
<td>0.674</td>
<td>-4.69</td>
<td>1.000</td>
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</table>
Table C7: Optimum markups for contractor 1, certain cost situation, using expected utility and monetary values.

Cost = 0.95 EE

<table>
<thead>
<tr>
<th>Number of competitors</th>
<th>Monetary value</th>
<th>Utility value</th>
<th>Bad times</th>
<th>Good times</th>
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<tbody>
<tr>
<td>3</td>
<td>9.69</td>
<td>9.69</td>
<td>12.12</td>
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<tr>
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<td>9.00</td>
<td>9.00</td>
<td>11.74</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>8.60</td>
<td>8.60</td>
<td>11.89</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6.93</td>
<td>6.93</td>
<td>10.06</td>
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Table C8: Optimum markups for contractor 1, certain cost situation, using expected utility and monetary values.

Cost = 0.93 EE

<table>
<thead>
<tr>
<th>Number of competitors</th>
<th>Monetary utility</th>
<th>Utility value</th>
<th>Bad times</th>
<th>Good times</th>
</tr>
</thead>
<tbody>
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<td>3</td>
<td>7.42</td>
<td>9.84</td>
<td>12.05</td>
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<td>4</td>
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<td>8.81</td>
<td>11.35</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5.56</td>
<td>8.17</td>
<td>10.94</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5.39</td>
<td>8.01</td>
<td>10.62</td>
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RISK PREFERENCE OF CONTRACTORS

The object of our study is to understand the behavior of the contractor when he bids on projects with different sizes and also when he bids in different overall economic conditions. The study is to be conducted on two levels.

We collected data on bids from the Bureau of Building Construction (we took all bids on new construction for projects of $100,000 or more covering the years 1961 to 1974). We went also to the Public Works Department and collected all highway work, construction and resurfacing bids from 1966 to 1974. These data were studied and the following results were apparent:

1- When the number of projects available per year is low, the number of bidders on a project is high.

2- When the number of bidders on a project is high, the lowest bid is below the estimate, whilst when the number of bidders on a project is low the lowest bid is well above the estimate.

Now the data is being analyzed in a computer for all possible trends.

We are now conducting interviews with general contractors in order to determine their attitudes in risky situations and how these change with different economic conditions.
A similar study on highway contractors was conducted in 1972 and results were published in the "Journal of the Construction Division", ASCE, - July 1973 -

The utility of such studies is that they are attempts to understand how a decision-maker arrives at decisions and what his attitude is towards risk in order to help him make more consistent decisions in his work and possibly also to enable him to delegate responsibility to subordinates while being sure that they will behave similarly to him.
QUESTIONNAIRE

We shall give you a series of questions regarding your decisions in several hypothetical investment choice situations. As far as possible you should answer each question as if it were a real world situation and feel free to ask questions anything seems unclear.

1- What is the usual size of projects you bid on?
   (Give a range)

   Answer: $200,000 TO $2,000,000

2- How would you describe your company's present economic conditions:
   *
   Liquidity position (this concerns the availability of funds for you and the cost of such funds.)
   Better than normal ☐ Normal ☑ Lower than normal ☐

   *
   Availability of work:
   Do you think that the average number of contractors bidding on a project is:
   Higher than normal ☑ Normal ☐ Lower than normal ☐

   Do you think that the number of projects available is:
   Higher than normal ☐ Normal ☐ Lower than normal ☑
3- What is the type of work in which you are involved?

Answer: BUILDING CONSTRUCTION

It is available today? Yes ☑ No ☐

Have you decided or started to switch to another type of work?

Answer: NO

4- What are the goals of your firm:

- To expand as much as possible ☐
- To keep a fixed share of the market ☐
- To expand only to keep up with inflation ☑
- To reduce the amount of work ☐
- Others

5- What kind of profit goals are you following for the company:

- Long term ☐
- Intermediate term ☑
- Short term ☐

Has it changed lately? Yes ☐ No ☑
6- Assuming actual times, suppose that you are offered a $400,000 job on a cost plus fixed fee basis, what would be the minimum profit and home office overhead for which you would consider accepting the contract.

- Answer: $20,000
Now, you have to decide between two projects: (you can only take one)

a- A job under a unit price arrangement where the final monetary return is uncertain.

b- A job on a cost plus fixed fee basis where a certain profit level is guaranteed.

Assume first that you have a $400,000 job with two uncertain outcomes: $60,000 markup or $20,000 with a 50-50 chance of occurrence (this is similar to the flip of a coin: heads you get $60,000, tails you get $20,000) and a similar cost plus fixed fee contract for a $400,000 job (assume the same resources: capital, equipment, manpower are required for either jobs) where you would be guaranteed a fixed profit.

The unit price arrangement is represented for convenience by

```
\begin{tikzpicture}
  \node {$60,000$} child {node {$50$} child {node {$60,000$}} child {node {$50$} child {node {$20,000$}}}};
\end{tikzpicture}
```

What would be the minimum profit and home office overhead for which you would prefer the cost plus fixed fee contract?

- Answer: $25,000
8- Assuming actual times, suppose that you are offered a $1,000,000 job on a cost plus fixed fee basis, what would be the minimum profit and home office overhead for which you would consider accepting the contract.

- Answer: $35,000
9- Now, you have to decide between two projects: (you can only take one)

a- A job under a unit price arrangement where the final monetary return is uncertain.

b- A job on a cost plus fixed fee basis where a certain profit level is guaranteed.

Assume first that you have a $1,000,000 job with two uncertain outcomes: $150,000 markup or $35,000 with a 50-50 chance of occurrence (this is similar to the flip of a coin: heads you get $150,000, tails you get $35,000) and a similar cost plus fixed fee contract for a $1,000,000 job (assume the same resources: capital, equipment, manpower are required for either jobs) where you would be guaranteed a fixed profit.

The unit price arrangement is represented for convenience by

\[ \frac{\text{\$150,000}}{50} \cdot \frac{\text{\$35,000}}{50} \]

What would be the minimum profit and home office overhead for which you would prefer the cost plus fixed fee contract?

- Answer: \$50,000
Assuming actual times: (you have eight to ten competitors on a project)

You have to bid on a project with uncertain final cost: the final cost cannot exceed $430,000 and cannot go below $370,000. You have an equal chance of spending $430,000 or $370,000 on it. We will represent it by

\[
\begin{align*}
\text{\$430,000} & \quad \frac{\text{.50}}{} \\
\text{\$370,000} & \quad \frac{\text{.50}}{}
\end{align*}
\]

What would you bid on this project. Include profit and home office overhead. Keep in mind that if you bid too high you will lose the contract.

- Bid: $440,000
Similarly you have to bid on a project with two uncertain final costs: $1,075,000 and $925,000 (maximum and minimum costs). There is an equal chance of spending $1,075,000 or $925,000.

What would you bid on this project.

- Bid: $1,103,000
12- Assuming normal times, suppose that you are offered a $400,000 job on a cost plus fixed fee basis, what would be the minimum profit and home office overhead for which you would consider accepting the contract.

- Answer: $30,000
Now, you have to decide between two projects: (you can only take one)

a- A job under a unit price arrangement where the final monetary return is uncertain.

b- A job on a cost plus fixed fee basis where a certain level of profit is guaranteed.

Assume first that you have a $400,000 job with two uncertain outcomes: $60,000 markup or $30,000 with a 50-50 chance of occurrence (this is similar to the flip of a coin: heads you get $60,000, tails you get $30,000) and a similar cost plus fixed fee contract for a $400,000 job (assume the same resources: capital, equipment, manpower are required for either jobs) where you would be guaranteed a fixed profit.

The unit price arrangement is represented for convenience by

```
          $60,000
          /     \
         .50   .50
        /     /   \
       $60,000  $30,000
```

What would be the minimum profit and home office overhead for which you would prefer the cost plus fixed fee contract?

- Answer: $40,000
14- Assuming normal times, suppose that you are offered a $1,000,000 job on a cost plus fixed fee basis, what would be the minimum profit and home office overhead for which you would consider accepting the contract.

- Answer: $45,000
15- Now, you have to decide between two projects: (you can only take one)
a- A job under a unit price arrangement where the final monetary return is uncertain.
b- A job on a cost plus fixed fee basis where a certain profit level is guaranteed.

Assume first that you have a $1,000,000 job with two uncertain outcomes: $150,000 markup or $45,000 with a 50-50 chance of occurrence (this is similar to the flip of a coin: heads you get $150,000, tails you get $45,000) and a similar cost plus fixed fee contract for a $1,000,000 job (assume the same resources: capital, equipment, manpower are required for either jobs) where you would be guaranteed a fixed profit. The unit price arrangement is represented for convenience by

\[
\begin{array}{c}
\$150,000 \\
\frac{50}{50} \\
\$45,000
\end{array}
\]

What would be the minimum profit and home office overhead for which you would prefer the cost plus fixed fee contract?

- Answer: $58,000
16- Assuming normal times: (you have three to four competitors on a project)

You have to bid on a project with uncertain final cost: the final cost cannot exceed $430,000 and cannot go below $370,000. You have an equal chance of spending $430,000 or $370,000 on it. We will represent it by

```
<table>
<thead>
<tr>
<th>0.5</th>
<th>$430,000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
</tbody>
</table>

|     | $370,000 |
```

What would you bid on this project. Include profit and home office overhead. Keep in mind that if you bid too high you will lose the contract.

- Bid: $455,000
Similarly you have to bid on a project with two uncertain final costs: $1,075,000 and $925,000 (maximum and minimum costs). There is an equal chance of spending $1,075,000 or $925,000.

What would you bid on this project.

- Bid: $1,448,000