ASPECTS OF TENDERS FOR CONSTRUCTION CONTRACTS

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The University of Cape Town

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CONTENTS

PREFACE

The author chose to write a thesis on this particular subject with the prime intention of acquainting himself with some aspect of the Construction Industry. This was because he felt that, after obtaining a four year undergraduate degree in the theory of Civil Engineering, he was insufficiently prepared to enter the field of Construction.

Furthermore, there are vast areas of application for Operations Research methods in Construction work. Apart from the Critical Path Method, and similar scheduling techniques, the present writer considers that insufficient use has been made of Operations Research up to the present time.

This has possibly been caused by the absence of a comprehensive literature on the applications of statistical methods to Construction. The main reason for this is undoubtedly the reluctance of companies successfully using these techniques to divulge information which might be of use to their competitors.

The fact that not much work had previously been done on this thesis topic made it a challenging one.

In conclusion, the author wishes to acknowledge his debt to several people and institutions for their kindness to him.

His year of study was made financially possible through the award of the Andrew Roberts Scholarship by the South African Federation of Civil Engineering Contractors and through a grant by the Council for Scientific and Industrial Research. The author is indeed grateful to both these institutions, for without their help, this thesis could not have been written.

Next, the author wishes to express his sincere thanks to certain members of a local firm of contractors. Not only were they always available to discuss points about which the author had little or no experience, but they allowed him to observe their tendering methods at first hand. Furthermore, the firm supplied data on past tenders which proved invaluable in the latter parts of this thesis. Unfortunately, since this data is of a semi-confidential nature, the firm's name cannot be mentioned.

For typing the manuscript, the author is very grateful to Mrs. Elsie Chapman. Her patience in deciphering a nearly illegible handwriting was most commendable.

But most of all, the author is indebted to his thesis supervisor, Professor A.D.W. Sparks, both for the refreshing discussions held with him and for his encouragement in supporting a thesis on Construction. Without his subtle guidance, the author would certainly not have learned as much about the subject as he did-

PART 1

FACTORS TO BE CONSIDERED WHEN TENDERING

CHAPTER 1. - CHOOSING THE CONTRACTOR

Section 1.1 - General :

Before considering in detail that portion of the cost of a Civil Engineering project associated with the employment of a contractor, one should take an overall look at the total cost of an average project.

This would usually include the following items :

a) cost of the land on which the project was to be built;

b) legal expense incurred in drawing up conditions of contract, etc.,

c) financial expense including interest on bank loans or the cost of issuing bonds;

d) cost of construction itself;

e) cost of employing consulting engineers to design and supervise the project;

f) loss of interest that could be earned by capital tied up during the construction period;

g) contingencies.

It is clear that while construction costs do not constitute the complete cost of a project, they nevertheless form a very large part. Hence, once the consultants have been appointed, they theoretically expend a great deal of time and energy in choosing an optimal design in close co-operation with the promoter.

Figure 1.1 gives an indication of a typical pre-contract programme for a reasonably large project. This flow diagram ends with the tendering phase, and it is upon

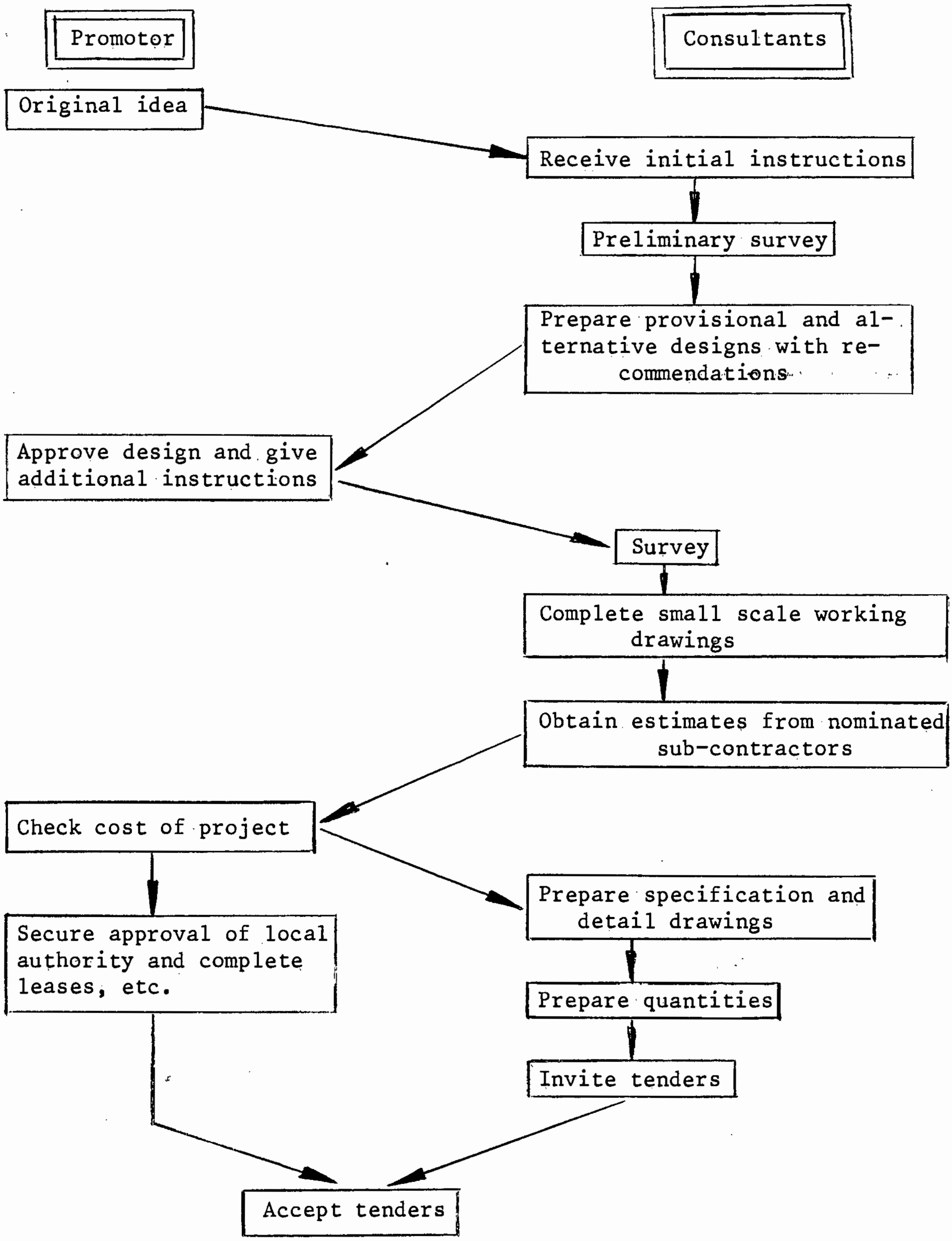

Promotor
Consultants
Original idea
Receive initial instructions
Preliminary survey
Prepare provisional and al-ternative designs with re-commendations
Approve design and give additional instructions
Survey
Complete small scale working drawings
Obtain estimates from nominated sub-contractors
Check cost of project
Secure approval of local authority and complete leases, etc.
Prepare specification and detail drawings
Prepare quantities
Invite tenders
Accept tenders

Figure 1.1

this that the remainder of this thesis will be concentrated.

Section 1.2 - Types of Tender :

Obviously there are many ways in which the contractor for a project can be chosen. However the best approach generally depends upon particular circumstances, such as the type of job, size of project, time available for completion, etc. The various types of tender used at present are described in the following sub-sections.

1.2.1 - Open Competition. In this method, the promoter or his agent advertises for tenders from any interested contractor. Generally these tenders are for the whole contract price. There are two main objections to this type of tendering.

a) The essence of the method is that the lowest bid should be accepted. Hence anybody willing to chance a low bid will get the contract, and so it could possibly be awarded to an incompetent contractor.

b) The better contractors might not bother to tender seriously if they feel that their chances of losing the award to an incompetent firm was high.

At first glance at the tender results, one would obviously be attracted by the lowest price, but only after estimating the additional cost of delays and in extreme cases the cost of bankruptcy of the contractor, would the true cost emerge. Hence promoters should try and avoid open unrestricted tendering wherever possible.

1.2.2 - The Selected List. In this system, the promoter or his agent invites certain contractors to tender for the proposed project. The contractors may be selected in two ways :

a) A list of "approved" contractors is kept and a short list of at most eight contractors is selected from it for a particular contract. Good practice is to change the short list for each job so that all the contractors have equal tendering opportunities, though the present writer doubts if this can always occur in practice. The approved list is changed periodically by removing the names of unsatisfactory contractors and inviting others to join.

b) Should such a list not be kept, then contractors might be invited by advertisement to have their names considered for a short tender list for a particular project. The promoter then decides to which contractors he will send the tender documents.

The main objection to selective tendering is its use by public bodies where there will always be complaints that the list has been unjustly complied.

A model form of invitation (19a) requires the following information to be given in the letter of invitation to the contractor.

a) The name and address of the promoter and his professional engineer.

b) The name of the quantity surveyor and any other consultants.

c) Details of the form of contract to be used.

d) A description of the extent and nature of the works.

e) The proposed starting date and completion time.

f) The time allowed for preparing the tenders.

g) A reminder to the contractor that he is legally bound not to disclose his tender price to any other contractors before all the tenders have been received.

h) The period of time for which the invitation will be open for acceptance.

<u>1.2.3 - Based on Overheads and Profit Only</u>. Such a tender is also done from a selected list of contractors. This method is usually adopted when there is insufficient time to prepare firm bills of quantities. The contractors generally submit prices in the form of percentages of the project cost for overheads and profit, and their percentages might also be required to include design and site supervision charges. The information given to the contractors will include the following :

a) Conditions of contract (especially penalty clauses, defects liabilities, etc.);

b) The project programme as envisaged by the promoter;

c) The approximate anticipated value of the job;

d) The way in which the remainder of the contract price is to be paid.

<u>1.2.4 - Based on Technical and Management Proposals Only</u>. This also is done from a selected list and would be relevant

when the construction of the project is likely to be of such magnitude and difficulty that the price of the contract would hinge on the method of construction. The contractor would be required to submit the following information :

a) The proposed method of construction together with a description of the main technical features;
b) The proposed system of organisation for the job;
c) A programme for the job including the date when work would begin;
d) Budget prices with their degree of accuracy and a list of exclusions with reasons;
e) The proposed extent of sub-contracting;
f) Any queries about the general and special conditions of contract as suggested by the promoter.

1.2.5 - Negotiations. In this case, the promoter selects a single contractor with whom to negotiate. While it would appear that the price offered by a single contractor would be higher than the lowest of several tender bids, after completion and the totalling of the final construction cost a negotiated contract should be cheaper. Indeed, if at the outset the project seems to be of such a nature that there is no reason why the tender price should not be the final price (i.e. no additional claims are likely to be made by the contractor), then negotiation should not be adopted. On the other hand, should there be only one contractor qualified to complete the proposed project, then there is no alternative but to negotiate. Trying to convince the contractor that he is tendering in a competitive environment would probably have disastrous results and destroy any confidence the contractor might have in the promoter.

At the outset, an agreed programme for the contract must be drawn up. It should cover the period from the start of negotiations to the completion of the construction, and it would usually include the following steps :

a) Agreement on the general contract conditions;
b) The preparation of an estimate by the contractor in the same manner as if it were a contract for tender;
c) Agreement between the promoter and the contractor on quantities and unit prices;
d) Agreement on margins for overhead and profit.

During the negotiation it is important to leave very little room for future disagreements. Hence a careful note is made of whether any variations are to be allowed in material prices, whether such prices include transport and handling costs, and whether trade discounts have been deducted. Also, a reasonable allowance is made for contingencies. It is agreed in some quarters that overhead charges should not include expenses which are not connected with the job in some way; for example, the cost of motor cars used by engineers working on other jobs. However, this would seem to be unreasonable, as the contractor is only in a position to negotiate at all on account of the experience gained by his organization as a whole. If the promoter wishes to make use of this experience, then he should surely pay for it.

1.2.6 - Two - Stage Tendering. This may be done to ensure a measure of competition before negotiations proceed with a single contractor. Preliminary drawings and specifications, probably in note form, are distributed to the potential contractors who are asked to submit tentative material prices and labour and overhead rates as well as information about their plant capacity, site organization and other relevant details. From these reports, and possibly after interviews with the contractors in question, one particular firm is chosen and the job proceeds as a normal negotiated contract. This procedure would seem to have most application when extensive design work is to be incorporated in the contract.

1.2.7 - Package Deals. These are also known as "Turn-Key" contracts. A contractor may form a consortium with consultants and perhaps with other contractors who are better equipped to perform certain specialized work, so that he may offer a price to cover the whole cost of a project. On the one hand it is argued that this will result in savings to the promoter because he will avoid the separate cost of consultants, and also the design will be executed keeping in mind the plant available to the contractor. However, on the other hand it is held that the consultants are being paid in any case, and also that the contractor's equipment and resources limit the feasibility of an otherwise excellent design, which could be executed for a considerably reduced price by another contractor.

Another argument advanced against package deals is that they are undesirable from the professional engineer's point of view. It is felt that a loss of professionalism will result if the engineer shares in the profits of the contract.

a) His supervision of the work in progress will not be as it should.

b) Indirectly, he might indulge in self-laudatory advertising.

c) He will be offering his combined services with the contractor in a competitive enviornment.

d) It is possible that he might have to undertake a contract without the remotest possibility of making a profit, to avoid having the contractor's organization lying idle.

<u>1.2.8 - Serial Tenders.</u> These are applicable where there is a number of very similar projects to be constructed. The first contract is put out to tender in the normal way and the remainder of the contracts are negotiated using the original tender as a basis. Obvious advantages are that special equipment which might have to be purchased for the first contract will be assured of continued employment, and also that experienced and efficient construction teams will be formed on account of the repetitive nature of the work. This type of contract is especially applicable for industrialized building where a large initial outlay has to be made.

Section 1.3 - Types of Contract.

There are several basic types of contract that may be used for Civil Engineering construction projects. Individually, these broad types of contract may have different conditions of contract associated with them. These conditions will be dealt with at a later stage, though (Chapter 3).

<u>1.3.1 - Lump Sum Contracts.</u> These provide for the contractor to be paid an agreed sum of money for the completion of the project according to the drawings and specifications. The agreed sum may be varied only under special circumstances and these will be dealt with in the discussion on conditions of contract. This type of contract is most popular with promoters for several reasons :

a) The cost of the project is fairly well established at an early stage and thus aids financial planning;
b) The contractor is provided with a good incentive to keep his costs down and to hasten his progress;
c) The promoter does not need to employ quantity surveyors to keep a close eye on the amount of work that has been done each pay period.

<u>1.3.2 - Unit Price Contracts.</u> These provide for the contractor to be paid an agreed amount for each unit of work he completes. Obviously, this is done when there is doubt as to the exact quantity of work in the project. The tender documents include a bill of quantities which is priced by the contractor to provide a tentative contract sum on a basis of which the contract might be awarded, and more important, it provides the unit prices by which the remeasured quantities are valued to pay the contractor. Unit price contracts may have several variations :

a) The contractor may be asked to price the items without being given even an approximate idea of the quantities involved;

b) The promoter may have filled in the prices opposite respective items and the contractor is asked to make percentage adjustments on which the tender award might be based. This method was used in the United Kingdom during the Second World War because prices were subject to extreme fluctuation. It was known as "Tendering on Basic Rates".

<u>1.3.3 - Cost Reimbursement Contracts.</u> These are contracts paid for by calculating the actual amount of money that was used to construct the project. This type of contract is used when speed is all-important and also when aspects of the project are open to alterations during the construction stage. In such cases the final cost of the contract is very likely to be substantially higher than the original tender price after all the contractor's claims for extra payment have been settled. The problem with this type of contract is that the contractor has to be paid enough money to cover his overhead costs that are not associated with the job, as well as a management fee, or profit margin. This might be done by paying the contractor an agreed percentage in addition to the total direct cost of the project. However, this is quite impracticable as the contractor is provided with no incentive whatsoever to complete the job quickly or efficiently. In fact, the less efficient he is, the more profit he will make. A slightly better method is to agree on a fixed amount to be paid to the

contractor on completion of the project to cover his overheads and profit. While being an improvement this still is not all that good a method as the contractor is limited in the amount of profit he can make.

<u>1.3.4 - Target Cost Contracts</u>. These are basically cost reimbursement contracts in which an attempt has been made to provide some incentive to the contractor. This is done by agreeing on a "target cost" for the contract before construction begins and then sharing any savings or excesses (depending whether the final cost is under or over the target) between the contractor and the promoter. The target cost itself will usually include an amount for contractor's overhead and profit and it is generally slightly flexible to take into account variations in labour rates and some material prices. The contractor's percentage share in the difference between the actual and target prices will increase, the larger is this difference. In other words, the greater the savings he makes, the more of these savings are his, and the more inefficient he is, the greater quantity of the additional cost does he bear. The very nature of this type of contract implies that the final project will not differ overmuch from its original plan. Hence it is questionable whether this type of contract is of much use as an alternative to straight-forward selective tendering when the promoter has a choice of contractors for his project. One answer to this is that in theory the promoter will pay less as tenderers will not have to inflate their prices to cover contingencies. This writer envisages this type of contract being of real use only when plans for the project have been fully prepared and there is only one contractor prepared or qualified to do the work. These are severe limiations.

CHAPTER 2 - ELEMENTS OF THE TENDER PRICE

Section 2.1 - General :

Estimating should not be confused with tendering. In the present context, estimating may be defined as the calculation of the quantities and costs of all the various separate items involved in constructing a project. When a contractor prepares an estimate, he does not make an allowance for his own profit margin. After sufficient deliberation, he decides on a suitable profit amount and adds it to his estimated price to make up his tender price. Hence, tendering includes the profit margin while estimating does not.

The job of preparing an estimate is naturally an important one in a construction firm. Only those men who have had fairly extensive experience are generally allowed to prepare estimates. Usually estimators work together with the men who will supervise the project, should the tender prove successful. Such a link at this stage is invaluable as site management will have nobody to blame but themselves if they build the project for a higher price than the estimate.

Apart from an accurate knowledge of the output of both labour and plant, the estimator must have a practical mind and be able to plan the construction properly and visualize exactly how it will be carried out. Though the estimator seldom actually produces data such as the cost of labour and plant per unit of production, yet he must have an extensive knowledge of such costs to be able to select the most economical methods of construction.

When preparing an estimate of the cost of a typical project, the estimator has first to become thoroughly acquainted with the drawings and specifications. Site meetings are often held at which the firms competing for the tender are represented and any queries relating to the drawings and specifications may be put to the promoter or his representative (usually the consulting engineers). The site meeting is also important as the estimator has to have first hand knowledge of the local conditions. He needs to appraise the physical site conditions so that he might form an idea of what plant is needed and how efficiently it will be able to work, as well as the likelihood of sub-surface conditions being different from those indicated in the tender documents. He must also decide what services such as water and electricity must be provided as well as what the local labour situation is. It could seriously influence the cost of labour if workers have to be imported to the work site and accommodated there. Another factor that is to be watched, especially if large quantities of concrete are to be cast, is the proximity of sources of supply of aggregates. General access to the site is also important because double handling of materials and supplies is costly.

Once the estimator is fully conversant with the requirements of the project and the conditions under which it is to be constructed, he has to draw up a detailed plan. Here a practical mind and an eye for economy are all important. Decisions have to be made on how much plant is to be used and where it is to be placed on the site. These decisions can only be made if the estimator has at hand an accurate knowledge of the various types of equipment available at the time and their working capacities. For instance, he will build up an idea of the required rate of concrete production from the time allowed for the contract, an examination of the drawings and his assessment of site conditions. The size of the batching plant is then set and space requirements for the storage of aggregates and access roads for trucks can be determined. The rate of concrete production also dictates the method of placing (such as by wheel barrows or dump trucks, or by crane hoisted skips or concrete pumps). Once all similar considerations have been taken into account, the price of a cubic meter of concrete may be determined on this particular job.

In such a manner, all the items in the bills of quantities are priced from a break down into the cost of plant, labour and material. Certain items do not appear in the bills of quantities such as electricity, accommodation for the contractor's site staff, telephone bills, and other overhead items. Such costs have to be distributed among the unit prices of the bill items or else they may be included in the P & G bill as a lump sum together with management fees.

A practical method used to distribute both overheads and profit is to mark up each bill item by a certain percentage and then make the final adjustment to the total price for the job by altering a lump sum item in the P & G bill. This permits late adjustments to be made at any time right up until the tender is submitted. This does, however, "unbalance" the tender price to some extent, but this topic will be dealt with later.

The above description is of a detailed estimate. In many cases it is not necessary or practicable to form such an accurate picture of the cost of a project. For example, during the feasibility study stage of a project, only the approximate cost is called for. Rough estimates may also be used by contractors when planning their future operations, i.e. when deciding whether to make a serious bid for a project or not. Approximate estimates may also be used to check more detailed estimates.

The easiest way of making an approximate estimate is to compare the project with a completed one of known cost, making adjustments for any differences in prevailing labour and material costs or in the structure itself.

Slightly more detailed methods include the following :

a) Unit of floor area method. The total floor area of the building is determined and this is multiplied by the past cost per unit of floor area of buildings of the same type;

b) Unit of volume method. This is essentially the same as the previous method except that the total volume of the building is determined. This method is generally more accurate than the unit of floor area method;

c) Panel method for buildings. The building is split into different types of "panels" (e.g. certain wall or floor elements). The cost of one of each type is measured and this is then multiplied by the number of such panels to obtain the total cost of the building;

d) Bay method for buildings. This method is useful for factory buildings or warehouses comprising of several similar bays. When totalling the individual costs, due allowance must be made for features such as end walls and windows.

It is noticeable that the above methods apply exclusively to buildings. Civil engineering projects might be classified into kilometers of roadway, cubic meters of reservoir capacity or length of pipeline, but physical conditions dominate to such an extent and are so variable from project to project, that approximate estimates are almost meaningless and if considered, should be looked at with extreme scepticism.

It is important to be systematic when preparing an estimate of any type. Checklists are invaluable in reducing the likelihood of omitting any item of cost. Estimators generally check their work against actual costs whenever possible. This feedback of information from the site is useful both to the estimator and for controlling actual construction costs, though when comparisons are made, the estimator's plan of construction must be borne in mind as any differences from the actual method of construction would provide price differences. If the site management was not present during the estimating stage of the project, then decisions and observations made concerning the method of construction would have been communicated to them together with the cost estimates and tentative program. Hence the construction will in most cases proceed along the lines originally envisaged.

Another way the estimator may check his work if the tender is unsuccessful is to determine the cost of the project from the other tender prices. A good approximation may be obtained if the tender bids are averaged without considering the lowest or highest of them. An expected profit margin should then be subtracted and the estimator has a reasonable price with which to compare his own.

Section 2.2 - Bills of Quantities :

Bills of quantities describe every item of labour and material which goes into the work, and also list the contractor's obligations with respect to temporary work, liabilities for defects, insurances etc. The estimator has first of all to check that the quantities entered opposite each of these items are correct and then he calculates the unit prices or lump sums relating to each item.

Two distinct types of bills are usually included in the tender documents. These are the "Preliminary and General" (P & G) Bill and the "Measured" Bill.

The Preliminary bill includes items that cannot be measured easily such as allowances for setting out, temporary site offices, dewatering, etc. It also includes an allowance for contingencies to cover unforseen occurences. This lump sum may also be used to adjust the final total tender price as explained previously. It is even conveivable that this or any other item in the Preliminary bill could have no sum of money attached to it, depending on the opinion of the contractor.

The Measured bill is made up of a detailed schedule of the work involved in the project. Each item is carefully described and the quantity involved is stated. In the most usual type of contract involving bills of quantitites, the contract is awarded to the lowest total tender price after which the unit rates entered in the bills of quantities are used to calculate the actual quantity of money due to the contractor when he has completed part of the work. These unit rates are multiplied by the number of units of work actually done, which might often be different to the billed quantity.

The bills of quantities will often also include two special items. These are "Prime Cost" items and "Provisional Sums". The promotor has a fixed sum of money entered opposite these items and no work needs to be done on them by the contractor's estimator. These sums are however included in the total tender price.

Prime cost items cover materials that are to be obtained by the contractor under the specific directions of the promotor's representative. The contractor has no right to choose the supplier or the price of such items. Should the cost of these items differ from the sum appearing in the bills of quantities, then an adjustment is made and the contractor is fairly reimbursed.

Provisional sums are allocated in the same way for work not yet finalised at the time of tender. Such work may have to be done by either the contractor himself or else by sub-contractors. Naturally, payment is made only for the work done and not for the sum shown in the bill.

The present form of bills of quantities is under severe critisism in the United Kingdom at present. It is felt that the form in use at the moment is ill-suited for use on any contract where equipment like cranes, concrete mixers, compressors electricity generators, etc. are used to complete more than one item of work. The problem is to distribute the cost of such plant fairly. In point of fact, bills of quantities were originally used on labour intensive projects, but with the advance of technology in the construction industry, more mechanical equipment is now used, the cost of which forms a large part of the project construction cost. In addition, the bills of quantities in use at present are poorly suited for processing by computer to facilitate easier and faster estimating and cost control.

Essentially, separate bills are required for the major portions of the work of a different nature. Also the ideal bill of quantities should separate the labour, plant, material and indirect costs and also give an indication of the respective difficulty of the different parts of work. Several new types of bills have been suggested, among which are :

a) Operational and Activity Bills. These both set out the quantities in the same logical order in which the construction will be executed. Operational bills split the work items up into plant, material and labour requirements, while Activity bills keep to the conventional format. Both these bills turn out to be longer than usual, but this difficulty is overcome by the use of computers to process them.

b) Component Bills. These identify the individual cost of items of work that are prefabricated and keeps separate the cost of fixing them. An obvious area of application is industrialised building.

Section 2.3 - Job Planning :

Job planning has been mentioned before, but as this is such a critical part of being able to offer the lowest construction price, it shall be examined in greater detail.

Before the contractor's estimator ever sees the tender documents, the time available for completion of the job will have been assessed together with its affect on the project as a whole. Time is an important factor in deciding whether to put the contract out to tender or to negotiate a price with a particular contractor. Also it will have a bearing on the actual design of the project, for instance whether industrialised building methods should be used rather than conventional methods.

But time is perhaps most important during the construction stage of the project. Direct costs such as those of labour and plant tend to rise with less available time, but on the other hand most indirect costs such as supervision and office overhead drop. Figure 2.3.1 shows the effect of decreasing the time to construct a project on the total cost of the project. It is noticeable that the optimum time for completion of the construction is in general somewhat less than the normal rate of working.

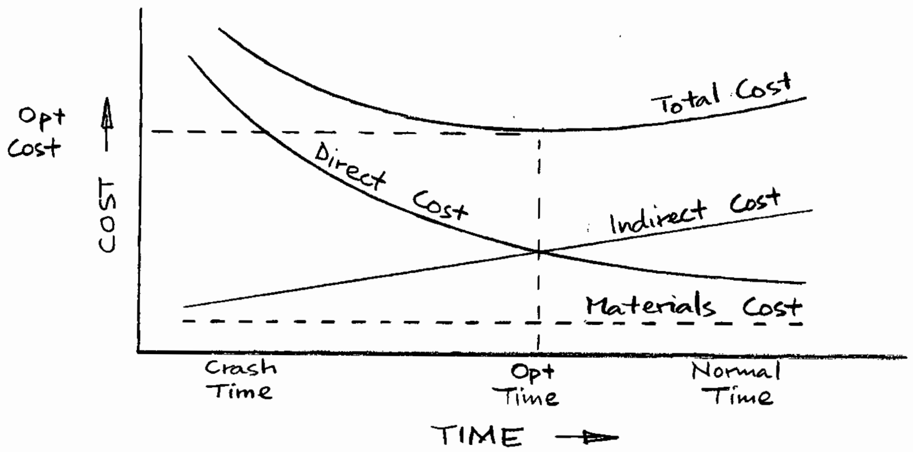


Figure 2.3.1

However, in most practical situations, the time for the contractor to complete a project is set by his client's requirements and by the fact that he will be hard pressed to meet them with the resources at his disposal. No contractor has unlimited resources.

Once the time is known, efficient job planning involves deciding the quantity of plant or labour to use that will minimise the time during which these resources will be lying idle while still getting the job finished on time. For instance, the size of cranes to be used on the job is important. Large cranes can handle large loads but will seldom be working to capacity, while smaller cranes able to lift only lighter loads will probably be in action all the time. This could also affect among other things, the size of shuttering panels for concrete formwork. All this involves a detailed appreciation of precisely what has to be done during each stage. As has been explained before, only practical men of experience are really qualified to plan a job effectively.

Another important aspect of job planning is deciding which parts of the job should be sub-contracted and defining clearly the limits of responsibility of each sub-contractor. Time is well spent on this during the planning of a job to avoid any alterations later.

The use of network techniques such as CPM or PERT is becoming widely used on large projects at the present time, but their use at the tender stage is severely limited by the lack of time available for their preparation and they are only being drawn up after the contract has been awarded. However, in the United States and Australia, more time is being allowed to tender for Government contracts and, indeed in some cases the submission of a network is a prerequisite to the tender documents. It is hoped that such will become the case in South Africa, as networks are invaluable in locating potential areas of difficulty in a construction project.

Section 2.4 - Materials :

The costs of materials to be used in the project are relatively simple to estimate. It should be noted however that such costs must include the total costs incurred up until the materials are delivered on site. This includes the price paid to the manufacturer, transport, handling and insurance costs until they arrive on site, and inspection and testing costs where applicable. Variations in price must be taken into account since dealers usually only give fairly short options on prices which are subject to fluctuation. This problem becomes more difficult when the project is likely to last a long time.

The best sources of information on prices are quotes from manufacturers coupled with adequate past personal experience of price variations. However, it is conceivable that published data may be used after adequate adjustments have been made to take into acount local conditions. The most important South African publication is that by Merkel (24). The main problem with this method is that the best estimating information is generally kept secret. Some firms quote low costs for publication as they do not wish to disclose their inefficiencies while others might possibly even quote high costs to try and discourage low bidding by competitors. In any event, published data is more often than not classified differently from the manner in which the estimator uses it. Also adjustment for local conditions is seldom very easy.

The wastage of materials should not be overlooked when estimating their cost. Percentages vary from job to job and certainly depend on the method employed to fix the material. The ordering of standard lengths of steel reinforcement should be co-ordinated with the length of bars to be used in the structure, for instance. Also, concrete wastage is reasonably high when batching is done on strength criteria, but it drops when volume methods are used. These and other factors should all be kept in mind by experienced estimators. Blatant mistakes in the placing of material are of course not considered.

Section 2.5 - Labour :

The cost of labour to perform any particular task is found by multiplying the number of man hours required to do that task by a relevant wage rate.

This wage rate varies with the type of labour needed to perform the task. Artisans are paid more than crane drivers who are paid more than ordinary labourers. Furthermore, wages vary from place to place in South Africa. Also, it is important to include the total cost to the contracting company when calculating wage rates. The cost of welfare and pension fund contributions as well as holiday bonuses, etc. must not be overlooked. Hence the hourly wage rates used for estimating will be considerably higher than the amount handed to the men on payday.

Additional labour costs will be incurred if labour has to be imported to the work area from other parts of the country. A discussion of the present situation in the Western Cape is presented in Appendix A.

The wage rates determined as above have to be multiplied by the relevant number of manhours to complete a part of the work. This will depend on the production of the labour which in turn is dependant upon working conditions. The nature of the site is important as well as the quality of supervision. In this regard the choice of foremen and engineers on the job will have a marked effect on the total construction costs, and when estimating, allowances should definitely be made for the quality and cost of supervision available for the project.

Further variations in labour production rates are caused by the state of the labour market as a whole. In an inflationary envirorment when jobs are plentiful and wages are high, production tends to drop. The reverse is also true, and when there is a slight recession in the construction industry, production rises. Variations of this type are not usually considered by the estimator, though top managemet might well, and indeed should take them into account when deciding on the final allowance to be made for profit.

Generally, when calculating the quantity of manhours required to complete a portion of the work, estimators make use of tables and diagrams relating production to various factors. These production rates are obtained from records prepared on site to show the amount of work done, the number of workers used (classified into ordinary labourers, operators, artisans, etc.), and the time taken over the work. Any conditions likely to affect the rate of production are carefully noted down, and the records themselves cover short time intervals only, so that the conditions do not vary.

The total duration of the project could also be taken into account when deciding on production rates. At the start of a job, production tends to be relatively low until the men adjust themselves to the project and to the supervision. The job only starts going smoothly after some time, and the more repetitive work there is, the more pronounced is the efficiency. Also, if there is only a small amount of work of a particular nature, such as laying bricks, the production rates used for estimating should be lower than usual. However, in practice this is difficult to assess.

Section 2.6 - Plant :

The term plant includes machinery, tools and temporary buildings and other structures that are not included in the permanent works. Another important item of plant is shuttering, but its cost is generally included in the material rates.

Temporary works such as site accommodation, electric light installations and water tanks are usually estimated in detail and entered in the P & G bill. Others such as scaffolding and timber to provide access to parts of the structure may be estimated and then distributed into the concrete or formwork prices.

The cost of items of machinery such as cranes, compressors and concrete mixers must include the following :

a) Depreciation. This is the cost of the equipment less its salvage value divided by its life in hours or in units of production.
b) Investment. This is the cost of having capital tied up in an item of equipment. If the contractor had to borrow money to buy the machine then it is equal to the interest he has to pay on that sum of money, and if he used his own money, then it is the interest he could have been earning with it.
c) Insurance, taxes and licencing. These costs might vary with the area in which the equipment is used.
d) Repairs and maintenance. Such costs will vary extensively with the conditions under which the machine is put to work.

The use of past data is essential in estimating these costs.

e) Fuel, oil and tyres where applicable. These costs will also vary with operating conditions.

f) Operators. Their rates are obtained in the same way as for other labourers. It must be remembered that some items of equipment require more than one man to operate them; for instance labourers to keep the site clear for easy operation of a crane or greasers to keep the crane lubricated.

g) Transport, erection, moving and dismantling. These costs vary considerably with different types of equipment and of course with site conditions and location.

The costs of equipment mentioned above may be distributed amongst the items in the bills of quantities in proportion to the amount of output consumed by each item, but this is quite difficult to estimate in some cases. Another way is to distribute the cost in proportion to the estimated total material and labour cost of the items or else in proportion to the labour cost alone. Alternatively, the equipment costs may simply be included in the P & G bill as job overhead, but this will unbalance the estimate somewhat, as explained previously.

When estimating the cost of tools and other small items such as nails, survey pegs etc., it is common practice to apply a small percentage to the estimated total cost of the works, or else to make additions to the labour cost of artisans, once it has been decided how many will be necessary on the job.

Section 2.7 - Overheads :

By definition, overhead or indirect costs are costs which cannot be attributed to any particular item in the bills of quantities. However, this depends on how the costs are collected. For instance when the job is underway, the costs of an electric generator can easily be distributed if meters are installed to measure the quantity of electricity used at every draw-off point. But when estimating, and in most cases in the field, this cannot be done.

Such indirect costs may be split into two categories. On the one hand there are Job Overhead costs which can be charged to a particular construction project, but which cannot be included under materials, labour or equipment. Such costs include the salaries of engineers, foremen, timekeepers, etc., temporary buildings; legal and professional services; testing of concrete; progress reports; protection of work such as lighting and watchmen; computer services, and many others.

On the other hand there are General Overhead costs which cannot be accurately associated with any particular project. These include the costs of running a head office and paying for the staff to fill it; advertising costs, etc.

It is impossible to draw any definite line between job and general overhead costs. For example, the cost of running motor cars for engineers might be considered as general or job overhead. Also typists spend certain amounts of time processing work for a particular job, but it is difficult to keep track of such a cost. Firm guide lines should be set by top management to decide which costs should be included under what category and this will affect the tender prices quite considerably in some cases.

If rather more indirect costs are collected under general overheads, then small projects will bear somewhat less than their fair share of such costs and the price of large jobs will be higher. Therefore if the company policy is to obtain the larger contracts, an accurate and detailed distribution of costs should be achieved.

Job overhead costs are usually estimated in detail, but a percentage obtained from past experience may be applied to the estimated combined cost of materials, labour and plant, or else to the labour cost alone. This percentage will depend on the nature of the job, its size, the probable difficulties that will be encountered, previous experience on that type of job, etc.

General overhead costs may be distributed among jobs according to their total estimated cost or their estimated cost of labour alone, or else according to their relative durations. An example of the distribution of general overhead costs is as follows :

Average annual value of construction

= R 3 000 000

Average annual cost of general overhead

= R 90 000

Rate to be applied to each project

$$= \frac{90\ 000 \times 100}{3\ 000\ 000} = 3\%$$

On very small projects, it is even possible that the two types of overhead may be combined into one and a single percentage applied to the estimated cost.

Section 2.8 - Contingencies :

Estimates can never be made with complete certainty. This is caused by the very nature of construction, and it is this perhaps that makes contracting a stimulating occupation to nearly all who undertake it. Unfortunately, human nature tends to underestimate potential difficulties, and this is why careful consideration should be given to areas of the estimate where information is incomplete.

Of particular importance is data concerning subsoil conditions. Should this appear to be particularly scanty, the contractor might even conduct pre-tender tests at his own expense. The more usual approach though, is to estimate the amount of money necessary to overcome any likely adverse conditions, and add this to the P & G lump sum item for contingencies.

The term contingency applies to future occurrences which cannot be predicted with any reliability. More specifically, it applies to occurrences which will cost the contractor an additional amount of money. For this reason, the lump sum is set aside in the bills of quantities.

The exact quantity of money that should be set aside is decided by the estimator from his practical experience, and by his being able to recognise potential trouble spots.

Aspects of the project likely to influence the size of the contingency sum, apart from subsoil conditions already mentioned, include any natural hazards such as icy conditions, floods or ordinary rainy weather. Also variations in the market situations of labour or materials should be anticipated as far as possible, and adequate financial provision made.

The nature of the project itself might also warrant the inclusion of a financial safety factor. For example, if an estimate was being made for a reservoir, the cost of repairing any leaks might be taken into consideration, especially if working conditions were difficult. This leads on to another point. If the conditions of contract (to be dealt with later) include severe penalties for overrunning a time limit and the estimator considers it to be a fairly difficult one to meet, then a sum might be included with the contingencies.

Of course, it must be appreciated that the larger the sum of contingencies, the smaller will be the probability of winning the tender in competition with other contractors. Therefore a really careful and thorough examination of the estimate by competant construction men is necessary.

Section 2.9 - Profit :

Business concerns may be broadly defined as mechanisms for increasing the value of their input resources by transforming them into output products of higher value. The difference in monetary amount is known as profit. Construction firms are no exception to this description.

The amount of profit for any particular job is usually expressed as a percentage of the estimated cost of the job. This percentage might in some cases include the allowance for overheads, but it is better practice to separate the two when tendering. Instead of being entered in the bills of quantities as a lump sum, some contractors apply a fixed percentage to material costs to cover profit and then add different percentages, which will vary from job to job, to labour and equipment rates.

A "normal company profit policy" might be to decide on the profit amount for a job in much the same way as overheads are determined. For instance, the annual dividend paid to ordinary shareholders might be distributed amongst the firm's contracts in proportion to their estimated cost. This is not a very good method in the opinion of this writer as no allowance is made for company growth. A rather better method would be to base the profit percent on the budget for the forthcoming year. The projected profit for the year should simply be divided by the anticipated turnover for the year to yield a percentage value.

However, most contractors work on a rule of thumb whereby 10% is considered a normal margin to cover both profit and overheads, and it is altered depending on the circumstances of the project.

Such alterations may depend upon some of the following factors :

a) The Competition. Obviously the more competitive the tendering situation, the less will have to be allowed for profit so that the contractor has a better chance of securing the job.

b) The Risk. This is particularly important when tendering for earthworks. Although an amount of money may be set aside for contingencies, if there is a chance that the contractor might lose badly on a job, a higher profit margin is usually required.

c) The Job location. If the project site is fairly removed from the contractor's usual sphere of operations he will require more profit on the job to induce him to extend his area of activity.

d) The Duration of the job. If the job is a long one and will provide a certain source of employment for the contractor's resources, a decrease in profit for the job is usually considered a reasonable price to pay for increased security. Conversely, if the job is a short one, a higher profit is generally sought.

e) The Size of the job. Generally speaking, the smaller the job, the higher the percentage profit considered worthwhile by contractors. The only possible justification for this is much the same as that concerning job duration, namely security. Another possible reason is that smaller jobs make smaller contributions to office overheads.

f) The Firm's need for the job. Less profit will be required on jobs when the contractor is likely to have some of his resources lying idle if he does not win the tender. Also, if top management has decided to branch into a new field of construction, contractors might even be prepared to suffer losses to obtain experience which will eventually boost long term profits.

g) The Type of supervision to be expected. If the contractor has had previous experience with the supervisory consulting engineers or local authority and has found their critisisms to be unrealistic and unhelpful in the past, then he will increase his estimate by a larger profit percentage than usual. The opposite is also true. He will decrease the profit margin if he has enjoyed a pleasant relationship with the promotor's representatives.

h) The Quality of the estimate. If the contractor knows the estimate to be a good one, he will not mark it up by as large a percentage as if he knew it to have been prepared in haste without overmuch attention to detail.

In general then, the percentage addition made to the estimate for profit is at present decided almost entirely intuitively. The contractor simply decides upon the profit for which he considers the undertaking of the job to be worthwhile and then he adjusts this slightly to conform to what he believes are the current market conditions. This writer considers that considerable improvements may be made to this method by adopting operations research techniques, and a large portion of this thesis will be devoted to that end.

Financial aspects are also important when profit is considered. For instance, if a contractor proposes to buy special equipment for a particular job, and intends using a loan to finance it, his banker will take a very close look at the profit the venture seems likely to make before giving his approval. Also, the potential profit on the capital expenditure necessary for a job should be compared with the interest and security that might be gained by soundly investing the money.

Finally, certain considerations about profit margins are peculiar to negotiated contracts. It must be clarified at the outset whether the allowance for profit is to include overhead costs or not. Also, it is important to agree exactly on which sum the profit percent is to apply. Obviously, the inclusion of overheads into the basis will increase the profit amount, but whether the percentage is to be applied to the cost of the construction to the contractor, or to the promotor also will have quite an effect on the monetary amount. An elementary example is given in figure 2.9.1 to clarify this.

Cost of materials, labour, plant and overheads = C

Profit percentage = P

If the profit margin is to be applied to the cost of the project to the contractor :

$$\text{profit} = \frac{PC}{100}$$

But if it is to be applied to the cost of the project to the owner :

$$\text{profit} = \frac{PC}{100} + C \cdot \frac{P}{100}$$

The second amount is greater than the first.

Figure 2.9.1 - Profit Example

Section 2.10 - Accuracy and Mistakes :

As has been mentioned before, it would be a very rare occurrence indeed if the final cost of a construction project were to be exactly the same as the estimated cost.

The most important factor affecting the accuracy of an estimate is the availability of cost data. Time and money are well spent in developing an effective feedback system from the site to the estimator's office. Accuracy and accessibility of cost information also depends to a large extent on the accounting system used and the company secretary always considers the estimator when deciding how to collect and store information from the sites. The availability of cost data will also depend upon the number of past jobs that have been completed which are similar to the proposed project. For this reason, more accurate information will be available for conventional building jobs than for roadways if the contractor is city based and has generally specialised in buildings, for example.

Another factor that helps the accuracy of the estimator is the degree to which the job has been split up when the bills of quantities were prepared. To this end, the new operational bills mentioned previously (Section 2.2) should be of advantage.

The concept of accuracy as used above in no way should be confused with mistakes. These are results not of inaccurate cost data (the collection of which is not usually the province of the estimator) but rather of carelessness in ordinary arithmetic, or in leaving out an item in the bill of quantities. The use of check lists should avoid the occurrence of the latter, and the former may usually be avoided by having two people total the estimate separately.

However, mistakes conceivably might still escape the notice of the contractor. Should this be the case, and the mistakes are only noticed when the tenders are under scrutiny by the promotor or his representatives, the tender is usually altered in such a way that the total amount remains the same.

The following example should clarify this :

Preliminaries	R 5 000
Earthworks	R45 000
Bridgeworks	R20 000
Roadway construction	R30 900

Assume that the contractor had totalled this to R100 000 instead of the correct amount of R100 900 - i.e. his total was R900 too small.

The procedure in common use is to apply a percentage reduction to the measured items. Note that preliminary items and prime cost or provisional sums are not adjusted. This is because the contractor does not apply his profit percentage to these amounts.

The measured items total R95 000, of which R900 is 0,95%. This is the reduction made to the measured items. The revised amounts are as follows :

Preliminaries	R 5 000
Earthworks	R44 600
Bridgeworks	R19 800
Roadway construction	R30 600
Total	R100 000

However, should the error be detected only after the award of the contract, then no alterations are usually made. If the contract is based on unit rates, then the total price is disregarded and the given rates are deemed to apply. If the contract is based on a lump sum, then the total as submitted by the contractor is held to apply.

Should the error in this case be to the contractor's disadvantage and if it can be proved that the owner knew of mistakes in the tender before the contract was signed, then the contractor might take the case to court and a charge of fraud would probably be upheld. Naturally, it would be extremely difficult to provide adequate evidence in support of such a charge.

Section 2.11 - Unbalancing :

Tenders are unbalanced when the contractor purposefully alters his unit rates from those he has estimated to be the most likely ones that will apply to the bill items. Obviously this will only apply to unit price contracts.

The main reason that contractors unbalance their tender bids is that they feel that the quantities shown in the tender documents will prove to be different when the job is actually underway. Consider the following example.

A contractor might be estimating the cost of excavation for a construction project, and the following quantities might be given in the tender documents :

Rock	2 000 m^3
Soil	1 000 m^3

The normal prices that he would quote for excavating in rock and in soil might be R2,00 and R1,00 per m^3 respectively. Thus, his price for the whole excavation would be R5 000.

But let us imagine that this particular contractor had previously done a large amount of work in the area adjacent to the site, and that only one third of his excavations had been in rock. Furthermore, he was reasonably certain that this would also be the case this time. In other words, these quantities would apply :

Rock	1 000 m^3
Soil	2 000 m^3

Should this turn out to be the case, and he had quoted his normal prices, he would only receive R4 000 for the work.

There are now two courses of action open to him. On the one hand he might reduce his contingency allowance for the tender by R 1 000, while still quoting R2,00 for rock and R1,00 for soil excavation. This would reduce the total price of his tender and give him a greater chance of winning the contract over his competitors while the actual profit he finally receives on the job is no different.

Alternatively, he could alter his rates so that he would receive more for the excavation after their final measurement than if he left the rates as they were. This could be done by quoting R1,50 for both rock and soil excavation. In this case, the total for excavation appearing in the bills of quantities would be R 4 500, while if the quantities turned out as he anticipated, the contractor would receive R 4 500. In this way he would have increased his chance of winning the contract as well as increasing the amount he would be paid in the end.

He could even improve on this if he quoted R1,00 for rock excavation and R2,00 for soil excavation. His tender price for the excavation would then be R 4 000 while the actual price he would be paid, assuming his assumption of quantities was correct would be R 5 000. At his normal rates he would have been paid R 4 000 and so he would be making R 1 000 extra for no additional work.

Practical limits are of course set on this since a price for rock excavation lower than that for soil would be viewed with considerable suspicion when the tenders are under scrutiny before the award of the contract. In fact, a tender may be rejected completely if it is felt that it is too badly unbalanced, though this is an extremely difficult decision to make because of normal variations that will be present in the rates quoted by different contractors.

Naturally, the contractor would be at a considerable disadvantage if conditions should not be as he predicted. His decision whether or not to unbalance his prices would take this into account.

Further reasons for unbalancing would be to disguise true costs from competitors if the complete tender results were to be published, and also to ensure early payment for parts of the contract. If the prices of bill items that will be completed towards the beginning of the contract are inflated slightly while later ones are decreased, the contractor will receive more cash sooner than normal, and he would be able to use this for financing later parts of the project. This will result in monetary advantages because he would not have to keep as much capital tied up in the project.

Operations research techniques may be used with advantage when deciding how to unbalance a tender bid, and more will be written about this topic later (Appendix H).

CHAPTER 3 - CONDITIONS OF CONTRACT

Section 3.1 - Legal Aspects :

An important point is that a contract can be legally binding even though it has not been formally signed before appropriate witnesses. Exchanges of letters, or even telephone conversations may constitute contracts, but there are obvious practical difficulties.

The basis of any contract is agreement. This is reached when an offer has been made by the one party and it has been accepted by the other. These concepts of offer and acceptance are of prime importance.

Invitations to tender are rarely offers in themselves. This would only be the case when the employer has included words to the effect that the lowest of the tender prices will definitely be accepted. This does not often happen. It is rather the contractor's tender bids themselves that are the offers. However, this would not be the case if the contractor should insert words like "subject to contract" which would imply that his prices would only become firm when the contract was signed. This would probably reduce the desirability of the tender, though, and so the usual procedure is for the offer to originate from the contractor and the acceptance to come from the employer.

From this, it may be seen that no contract is in existence when the contractor makes his offer, and so he has to bear the cost of his estimate. However, should he be able to prove that the employer invited him to submit a tender without ever intending to consider it for acceptance, then the contractor would be able to charge the employer with fraud and claim the costs of the estimate from him.

An offer may be withdrawn at any time before it is accepted. The exact timing, however, is important. The revocation takes effect only when it is received by the person to whom the offer was made, and not from the time the offeror decides to revoke. Thus, if the notice of withdrawal of the offer is sent by mail, it takes effect when it is received and not when it is posted. On the other hand, if the contractor had specified that acceptance of his tender was to be posted to him, his offer would be accepted at the time the employer actually posted his letter and not when the contractor received it. In most cases, though, the tender bids are opened publicly in the presence of the contractors, and after their appraisal by the employer, he gives his formal acceptance to the contractor in person.

In some cases, disputes arise as to the meaning of certain clauses in the contract. Should legal action be taken, the courts either adopt the meaning of the wording of the contract if it is clear, or else they try and ascertain the meaning that both parties intended at the time of signing. This is an important basis of contractural law in South Africa.

Finally, in all conditions of contract in general use for Civil Engineering projects in South Africa it is important to note that there is no contract between the owner and the sub-contractors. This means that the main contractor is fully responsible for the work and other actions of his sub-contractors.

Also, there is no contract between the contractor and any architect or engineer representing the employer. This implies that the employer is liable for all the acts of his representing engineer and is himself responsible to the contractor for any negligence on the part of his engineer. The contractor may not sue the engineer or architect.

Section 3.2 - General Remarks :

In this and the following sections, we shall consider the conditions of contract that are most generally used for construction in South Africa.

The terminology that contracts are made between the "employer" and the "contractor" is generally used in these conditions and shall be adopted in the following discussions.

Conditions of contract are used primarily to define the relationship between the employer and the contractor and to set out the procedure to be followed should this relationshio be disturbed for any reason.

The author obtained copies of and studied several sets of Conditions of Contract in use in South Africa, and a list of these appears below :

a) "General Conditions of Contract and Forms of Tender, Agreement and Bond for Use in Connection with Works of

Civil Engineering Construction", approved by the South African Institution of Civil Engineers, the South African Association of Consulting Engineers and the South African Federation of Civil Engineering Contractors.

b) "Agreement and Schedule of Conditions of Building Contract", approved and recommended by the Institute of South African Architects, the Chapter of South African Quantity Surveyors and the Building Industries Federation (South African).

c) Conditions of Building Contract used by the Department of Public Works.

d) "Conditions of Contract (International) for Works of Civil Engineering Construction" as recommended by the Federation Internationale des Ingenieurs - Conseils (F.I.D.I.C.), Federation Internationale des Enterpreneurs Europeens de Batiment et des Travaux Publics (F.I.E.E.B.T.P.) and the International Federation of Asian and Western Pacific Contractors Associations (I.F.A.W.P.C.A.).

e) "Cape Provincial Administration Department of Roads - General Conditions of Contract for Construction of Roads and Bridges and Supplementary Works".

f) "City of Cape Town - Contracts for Civil Engineering and Building Works - Conditions of Contract".

These present a general cross-section of conditions in use in South Africa at the present time. The last two may be considered typical of conditions of contract used by local authorities, while the first three are in more general use.

A comparison of the important clauses of these conditions is presented in summary in Appendix B. These clauses will be more fully discussed below.

Section 3.3 - Summary of Clauses :

In this section, a discussion will be given of the main clauses of the conditions of contract mentioned above. Not all of these clauses will have a direct influence on the contractor's estimate, but they are included to present the complete picture of his responsibilities during the construction period of the project.

3.3.1 - Assignment and Sub-contracting. Such clauses require that neither the employer nor the contractor may assign the whole or any part of their responsibilities to somebody else without the consent of the other. Also, these clauses usually provide that the contractor may not sub-let the whole of the works, and that he is responsible for everything done by his sub-contractors. The contractor usually has to submit a list of his probable sub-contractors at the tender stage, and this is confirmed when the contract is awarded. It is important that the contractor should impose the same liability for defects (Sub-section 3.3.11) on his sub-contractors as has been imposed on him, otherwise he might find himself in some difficulty. Finally, some conditions of contract provide for the employer to pay the sub-contractors directly, should the main contractor default. Should this not be the case, it is legally possible for the sub-contractor to claim "unjust enrichment" from the main contractor, should the latter have been paid for the sub-contracted portion of the work, and the sub-contractor had not completed it himself yet.

3.3.2 - Arbitration. Litigation is both expensive and time consuming, and so such clauses are included to provide for the appointment of an umpire. The arbitrator is usually either the head of the relevant Institution approving the conditions of contract, some other prominent person, or else some one agreed upon by both parties either before the contract is signed or when a dispute arises. The arbitrator can decide on most disputes, but he does not have jurisdiction to decide whether a contract is void or whether he himself in fact has jurisdiction upon any question, should this be challenged. These points have to be referred to a court of law.

3.3.3 - Bankruptcy. Should the contractor be declared insolvent, then the employer has several courses of action open to him :

a) He may terminate the contract and only pay the contractor the balance of any money due to him after the employer's expenses have been deducted.
b) He may allow the contractor's liquidators or sureties to complete the contract.
c) He may allow the original contractor to complete the project, should this be possible.
d) He may employ another contractor to complete the contract and deduct any additional expenses from any money owing to the original contractor.

The original contractor is only paid at the end of the contract (i.e. after the maintenance period), if at all.

Should the employer be declared insolvent then the contractor has first to remove his plant and equipment and any unfixed materials from the site and shall be paid any money due to him, in addition to money for any losses he might incur from the determination of the contract. However, it would be very unlikely that any payment would actually be received, and so a careful inspection of the employer's financial state of affairs obviously is advisable before the contractor enters into a contract.

3.3.4 - Certificates and Payment. Such clauses will be discussed later together with other financial conditions (Chapter 4).

3.3.5 - Completion and Delays. The time for completion and the amount of "liquidated damages" for any delay beyond this time are usually set out in the tender documents. Extensions to this time are possible should written requests for such extensions have been submitted to the engineer at the time of any unforeseen delays. The date of completion is marked by the issuing of a certificate by the engineer, and these may also be issued when individual sections of the work are ready for use by the employer. Should this be the case, the amount for liquidated damages will be reduced by an appropriate amount. The completion date set out in the tender will cease to apply when any alterations or omissions are made to the quality of work, and in such cases, a new date has to be agreed upon. Should the contractor exceed his time limit, then the agreed amount of money for damages that he owes shall be deducted from any money due to him from the employer, and due allowances for such damages might be made in the contractor's bid, should the time restrictions appear tight.

<u>3.3.6 - Contractor's default.</u> The remedies that the employer might have against the contractor are set out in these clauses and they are the same as those given in connection with the bankruptcy clauses. The situations in which such remedies come into effect are also given, and in general these are when the contractor has abadoned the contract or has not started work within a reasonable time of the agreed date, or else has ignored the engineer's written instructions concerning any disregard the contractor has shown for any of the conditions of contract.

<u>3.3.7 - Vesting of the Contractor's Equipment.</u> Such clauses are not always included in the conditions of contract. They require that ownership of any equipment or materials brought on site by the contractor passes to the employer until the works have been completed, or until the contractor has been allowed to remove them. This latter usually may not be done without the permission of the engineer. The purpose of these clauses is to provide the employer with some security against any default by the contractor, in which case the employer may use the equipment and materials to complete the project, or else sell them to help pay for any losses.

<u>3.3.8 - Contractor's Representatives and Workmen.</u> These clauses require that the contractor should supply adequate supervision as well as competent workmen for the project. The

engineer is given the power to dismiss from the works any workman who are unacceptable for one reason or another, and his written approval of the contractor's site agent is required. Adequate wages and housing have also to be provided for labourers and data concerning the number employed and their wages, etc., is to be provided to the engineer on his request.

3.3.9 - Damage to property and injury to persons. Until the certificate of completion, the contractor is completely responsible for the care of the works and for any damage to persons or property resulting from his or any of his subcontractors' negligence, and he is required to indemnify the employer against any claims for such damage. The contractor is not responsible for certain "excepted risks" such as riot, war, etc., causes due to the employer's use of completed portions of the work; or causes due to faults in the engineer's design of the works. The contractor also does not have to indemnify the employer against claims arising from the permanent occupation of land for the works or from any actions by the employer or his representatives. Any alterations to the general aspects of this clause are usually included in the tender documents. Should the works appear to involve considerable risk to the contractor, it is conceivable that he will raise the price of his bid as a measure of protection.

3.3.10 - Drawings. This clause is inserted to ensure that the contractor is kept supplied with drawings and other information concerning the work, and any delay caused by his not having them will be attributable to the employer through the engineer. In some cases, the contractor might be required to submit "as built" drawings. The engineer is also permitted to revise any submitted drawings prior to the construction of the relevant piece of work.

<u>3.3.11 - Defects liability.</u> This clauses outlines the responsibility of the contractor for any defects that might become apparent in the works after the completion certificate has been signed. The period for which the contractor is responible is usually set out in the tender documents, though some conditions of contract include set periods of maintenance. As a security measure, the employer usually retains a certain percentage of the contract price until the completion of the maintenance period, at which time a certificate is issued and the contractor is paid in full. The details of retention money will be discussed in full at a later stage (Chapter 4). Should any defects become apparent during the period of maintenance, and should the engineer decide that they were caused by faulty work on the part of the contractor, then the latter is required to rectify them at his own expense. Should the contractor fail to do this, then the engineer may employ somebody else to do the work and deduct the expense from the retained amount that is due to the contractor.

<u>3.3.12 - Engineer or Architect.</u> The contractor is obliged to comply with any decisions made by the engineer or his representative, unless provided for under the Arbitration clause. This clause implies that any instructions will be

given by the architect or engineer after the tender has been accepted, and not by the employer himself. It seems possible that under certain circumstances, this could become important, and this writer feels that the conditions should be made more specific on this point.

<u>3.3.13 - Execution of the Work.</u> The contractor is required to complete every portion of the work in strict compliance with the specifications, and where any part of the work is not expressly provided for, the contractor has eventually to provide a structure which complies with the engineer's specification.

<u>3.3.14 - Faulty Work.</u> This clause allows the engineer to reject any work that he feels is not in accordance with the specifications, and the contractor is required to remedy the defect to the satisfaction of the engineer. Should the contractor refuse to do this, the engineer may employ somebody else to rectify the work and charge the contractor for any additional expense or delay. Some conditions of contract make particular reference to the covering up of work such as footings or retaining walls. The contractor is not allowed to do this before the engineer has approved the work, and if he does so, the engineer may order the work to be uncovered at the contractor's expense.

<u>3.3.15 - Fluctuations in Price.</u> In some conditions of contract, subsequent variations in the prices of materials brought about by changes in import duties or railage charges are allowed.

Also, changes in the price of cement and reinforcing steel and other materials of controlled manufacture and supply are sometimes permitted, as well as variations in the legal minimum wages payable to workers in the area of the works. The prices quoted for these items in the contractor's tender will not correspond to the ruling market prices, because overhead costs will have been included. Hence, adjustments are made which correspond to the changes in the market rates. This clause is obviously an important one to consider at the tender stage, especially if conditions are such that prices are liable to considerable fluctuation at any time.

3.3.16 - Inspection and Testing. The architect or engineer is allowed to inspect and test if necessary any part of the works either when they are in progress, or when they are finished. The cost of any test is to be borne by the contractor if allowance has been made in the tender documents, but should this not be the case, the contractor has to pay only if the work is shown to be defective on account of his negligence.

3.3.17 - Insurance. Usually, the contractor is obliged to insure himself against any risks for which he is liable, as set out in the above section on damage to property and injury to persons (Sub-section 3.3.9). In some conditions, this is not a specific requirement, though it would obviously be to the contractor's advantage. The cost of insurance has to be included in the contractor's tender price, and so an accurate assessment of adequate insurance coverage must be made at the tender stage.

3.3.18 - Patent Rights. Though this clause is not always included, it is occasionally used to protect the employer against claims and against having to pay royalties on account of the contractor making use of patented methods or materials on the works. The contractor is required to indemnify the employer against any such actions.

3.3.19 - Provisional and Prime Cost Sums. This clause sets out the procedure to be followed when the engineer decides to make use of any provisional or prime cost sums, a description of which appears in section 2.2. Important points to note are that work done that was originally included in the bill of quantities as provisional is paid for in the same way as ordinary variations to the work (Sub-section 3.3.25), and goods or materials included as prime cost items are paid for without allowing any margin for profit or overheads. However, the contractor is usually allowed to take advantage of cash discounts when purchasing prime cost items. Also, when sub-contractors for provisional work are nominated by the employer, then the contractor is allowed to receive a percentage on their work. However, in the case of both provisional and prime cost sums, the contractor has to prove that he has himself paid for the work or materials before he may receive any money from the employer. Should the employer have nominated any sub-contractors for work originally included as provisional, then the contractor may object, and if his objections are reasonable, the employer is usually obliged to reconsider his nominations and apoint other sub-contractors in their place. Thus the contractor is not usually obliged to work with sub-contractors who have been difficult to work with in the past. In the long - run, this will be to the advantage of the contract as a whole.

<u>3.3.20 - Security for Performance.</u> This clause, when used, requires the contractor to provide the employer with a performance bond or bank guarantee usually to the value of 10% of the total contract price. The purpose of this is to guarantee that the contractor will carry out his obligations and that the employer will be paid any money he might otherwise lose if the contractor should default in any way. This writer is of the opinion that if securities of this nature are required by the conditions of contract, the amount of retention money (see Sub-section 3.3.11) should be considerably reduced, if not omitted altogether. It would appear that the employer would be receiving double security, and this should hardly be necessary, especially if the contractor's reputation and financial situation had been considered before the contract was awarded.

<u>3.3.21 - Possession of Site.</u> This clause ensures that the contractor is given adequate access to the site, so that he might perform his duties as quickly and safely as possible. The clause also requires the contractor to allow the engineer to be admitted to any part of the site he might wish. In addition, the contractor is also obliged to give access to any other contractors that might be working on the same site. This is an important consideration, especially when confined spaces make working difficult. On completion of the work, the contractor is usually required to make good any damage that might have been done to fences, shrubbery, etc.

3.3.22 - Statutory and other Regulations. In this clause, the contractor is required to conform with any regulations concerning the running of the site, whether they are made by the Government, or by any local authority. Also, the contractor has to pay for any notices or lighting, etc., that might be required, unless such items had been included in the tender documents. Usually, the contractor is able to claim from the employer if any regulations are changed during the construction period and involve him in extra expense.

3.3.23 - Sufficiency of Tender. Legally, this is an important clause as it states that the contractor must have taken into account any possible element of cost or uncertainty when calculating his tender price. This means that the contractor is not allowed to plead ignorance if he is involved in any unforseen expense, nor will any mistakes or omissions be tolerated in his tender price, though this aspect is discussed more fully in section 2.10. However, usually the contractor is allowed to claim for any unforseen expenses if the engineer is convinced that they could not reasonably have been anticipated by a competent contractor. This part of the clause is advantageous to the employer as well, since the contractors are able to reduce their allowances for contingencies, resulting in generally lower tender prices.

3.3.24 - Suspension and Delays. The contractor is required to stop work if the engineer decides that it is unwise to continue until a later date, and he is usually allowed to claim his extra costs in such a situation, unless the tender documents had made specific provision for delays of that type.

3.3.25 - Variations to the Work. The problem of an employer changing his mind about aspects of the project when it is already under construction is a rather difficult one. Without exception, the conditions state that the contract is not vitiated (rendered useless) by any variations, though these must obviously be kept to a reasonable level. This means that the contractor has to carry out any variations that might be ordered, though exactly how much is to be paid is left open to agreement. If agreement cannot be reached, most conditions then allow the variations to be carried out on a daywork basis. This means that the contractor is paid the cost of the materials and labour, excluding supervision, plus a percentage addition to each for overheads and profit. The usual additions are 10% to materials and $33^{1}/3$% to labour,

3.3.26 - Special Clauses. The clauses mentioned above cannot cover every eventuality on every contract. Therefore employers often include clauses to cover specific conditions peculiar to the project in question. For example, the Department of Public Works insists that public transport is used for providing materials to outlying sites. Because of traffic congestion, trucks may only be allowed access to urban sites during off-peak periods. Another example is the blocking of rivers or railway lines. This may only be allowed for specific short periods of time.

The above list of items covered in a set of conditions of contract is certainly not exhaustive of the subject, but it is hoped that a general description of the legal responsibilities of a contractor has been given. Such responsibilities have certainly to be considered at the tender stage.

CHAPTER 4 - FINANCIAL ASPECTS OF TENDERING

This chapter provides a brief introduction to the financial considerations that have to be borne in mind when tendering for a construction contract.

Section 4.1 - Cost Control in Construction :

The term "cost control" should never be confused with book-keeping. Book-keeping is essentially an historical activity. It will inform a contractor whether he has made a profit on a contract after it has been completed, but it can never enable him to analyse and control the cost of his labour or plant while the contract is underway.

Cost control has three main functions in a construction company.

The first of these is obviously the pinpointing of operations which are being carried out uneconomically. Information provided by the cost control system in use must be such as to enable the supervisor to make a timely decision on how to remedy the situation. One possible course of action might be for the contractor to speed up production on certain parts of the job or to slow down on others. In this regard, cost control is closely linked with the time control system (such as the Critical Path Method) used on the contract.

The second main purpose of a cost system is to feed information back to the estimator. The main information from the site will concern the costs of labour and equipment, but another most important item is data concerning wastage. An example of this might be information regarding concrete used for blinding. The specification for the project might have required a minimum of five centimetres under each footing of a large number of columns. The estimator has to assess the actual quantity of concrete necessary, keeping in mind the fact that unevenness in the depth of the excavations for the footings will cause the thickness of the blinding layer to vary. The percentage of extra concrete which the estimator feels is necessary might involve a considerable sum of money, and so accurate information from similar contracts will be invaluable.

The third function of a cost control system is to provide information concerning variations in the prices of certain materials and in the wages payable to labourers from the billed rates. If such variations are allowable in the conditions of payment for the contract, the contractor may claim extra money provided that he can produce adequate proof of the variations.

Traditionally, contractors have taken less advantage of cost control systems than their associates in the production engineering industry. Possibly this is because conditions change from contract to contract and the details of a system have to be set up anew with each fresh contract undertaken. This has caused the smaller contractor to feel that an adequate cost control system is not worth the time and money to him. A frequent result of this is that when some contractors eventually find out that they have lost money on a contract, they submit claims for extra payment, more often than not based on illegitimate grounds. Often the size of the claims will be determined by what the contractor has lost on the project.

Before a cost control system is set up for a contract, the required amount of detail necessary for its handling must be decided upon. This will naturally vary from situation to situation. The following four methods of cost control may be used, depending on conditions.

a) By comparison with cost standards such as the estimated costs at the tender stage.
b) By comparison with the amount paid for work done at monthly or other intervals.
c) By costing only certain parts of the work which are likely to prove unnecessarily expensive if not controlled properly.
d) By combining the cost control activities with other functions such as bonus incentive schemes or labour utilization schemes.

The most important point to be kept in mind when designing a cost control system is its simplicity and ease of understanding. Site staff are notoriously wary of excess bookwork, and so this should be kept to a minimum. Furthermore, if they are easily able to see the purpose behind what they are doing, they will co-operate better.

Experience indicates that the best way of collecting site costs is for the foreman or charge-hand to allocate costs daily. This might be done by completing a printed form on which the details concerning labour and plant working under him are entered. Such details will include the names and numbers of each labourer and a brief description of the work done by each as well as the hours taken. A description of the equipment used will also be given as well as the work performed and time taken working and standing idle. Another important entry on the form is a short description of site conditions such as the weather. As they will affect production, they are important to the estimator when preparing new estimates of unit costs to be used for other tenders.

These completed forms are then sent to the accounting department who produce periodic summaries for the use of management. A computer might be used to advantage at this stage, though more conventional methods might be both faster and cheaper.

From these summaries, trouble spots should become apparent in good time to take corrective action where necessary; also, more realistic rates will be available for use in the estimating department of the firm.

Section 4.2 - Conditions of Payment :

Perhaps the most important clause in any set of conditions of contract is that relating to the payment of the contractor.

First of all, a certificate has to be issued by the owner's representative before any payment may be made to the contractor. This is generally done at monthly intervals while the work is being carried out. The general procedure is for the contractor to submit a claim for payment for the work that he has completed since the previous certificate was issued. This is then checked by the owner's representative, and when he is satisfied, the certificate of payment is issued.

Also included in the certificate of payment is an amount for materials brought onto the site, but not yet used in the work. The contractor might have to provide proof of ownership of such materials, such as invoice from the supplier. Often, only a certain percentage (e.g. 75%) of the cost of such materials will be paid to the contractor before they are used. The contractor is thereby effectively forced to guard against the loss of such materials, though other conditions of contract such as those relating to the delivery of materials and the passing of property also bind him to do this.

Other important certificates issued by the owner's representative are those at the beginning and end of the maintenance period, relating as they do to the payment of any retention money that might be required by the owner.

Retention money is a term describing money that is not paid to the contractor immediately it becomes due to him, but which is retained by the owner as security against any default by the contractor. Bankruptcy and the failure to make good any repairs necessary during the maintenance period are the most important misdeeds of the contractor considered.

The amount of money retained by the owner usually takes the form of a percentage of the value of the work completed up to that time. Upper limits are often set on the amount of money retained and these are described in Appendix C of this thesis. A common amount is 10% of the total value of the contract.

The quantity of retention money for a contract is important when preparing the estimate. This is because the contractor will have to provide this amount of extra working capital for the project. This capital might be earning a useful return if it was invested elsewhere and this lost amount of return should be included in the estimate as an "opportunity cost". More will be written about this topic in the following sections of this chapter.

Most conditions of contract allow repayment of half of the retention money when the last certificate is issued at the start of the maintenance period. The balance is paid at the issue of the final certificate.

Some conditions of contract allow the contractor to be paid interest on the retention money. This should naturally be taken into account when the estimate is being prepared by the contractor.

Interest usually has also to be paid by the employer if he is slow to pay the contractor after a certificate has been issued.

The reader is referred to Appendix C where this and other clauses appearing in Conditions of Contract used in South Africa are compared.

Section 4.3 - The Time Value of Money :

In this section, an introduction will be presented to the effect of time on a decision involving cash flows.

A cash flow is a sum of money that changes hands when a businessman makes a capital investment. The cash flow is termed positive if it is paid in to the investor and negative if it is paid out by him.

Consider the example of a contractor purchasing a bulldozer. The negative cash flow is the money paid by the contractor to the dealer for the bulldozer. The positive cash flows are the sums of money earned by the bulldozer while working on contracts awarded to the contractor. It is important to note that at the end of each year of the economic life of the bulldozer, the contractor will show a depreciation cost in his annual income statement. This is not a cash flow, as no money actually changes hands.

When the contractor takes the decision to buy the bulldozer, he must be certain that the positive cash flows from his investment will exceed the negative cash flows. The important point here is that the cash flows will take place at different times. Furthermore, a Rand earned at any particular time will always be worth more than a Rand earned at any time later. This is because the original Rand could have been invested at a certain rate of interest so that it would have increased by the time the second Rand was earned.

Decisions concerning capital investments such as the buying of a bulldozer are usually made by comparing the values at any given time of the positive and negative cash flows resulting from the investment. The time chosen is usually the present - i.e. the time at which the decision is being taken - and hence the term "Present Value Method" is often used. Another common term for this type of analysis is "Discounted Cash Flow".

The reader will appreciate that if an amount of x Rand is invested at a rate of return i per year, then after n years it will have grown to :

$$x\ (1 + i)^n \qquad \ldots\ldots(4.3.1)$$

Alternatively, an amount x paid n years hence will have a present value of :

$$\frac{x}{(1 + i)^n} \qquad \ldots\ldots(4.3.2)$$

Values given by these formulae are widely tabulated and so present value calculations are easily performed once the cash flows and their dates have been established.

It then becomes a matter of choosing the investment yielding the highest present value.

Section 4.4. - Cash Flows During a Construction Project :

Figure 4.4.1 shows diagramatically the cash flows at various times of a construction contract. The curves of cumulative income and expenditure may be derived from a bar chart

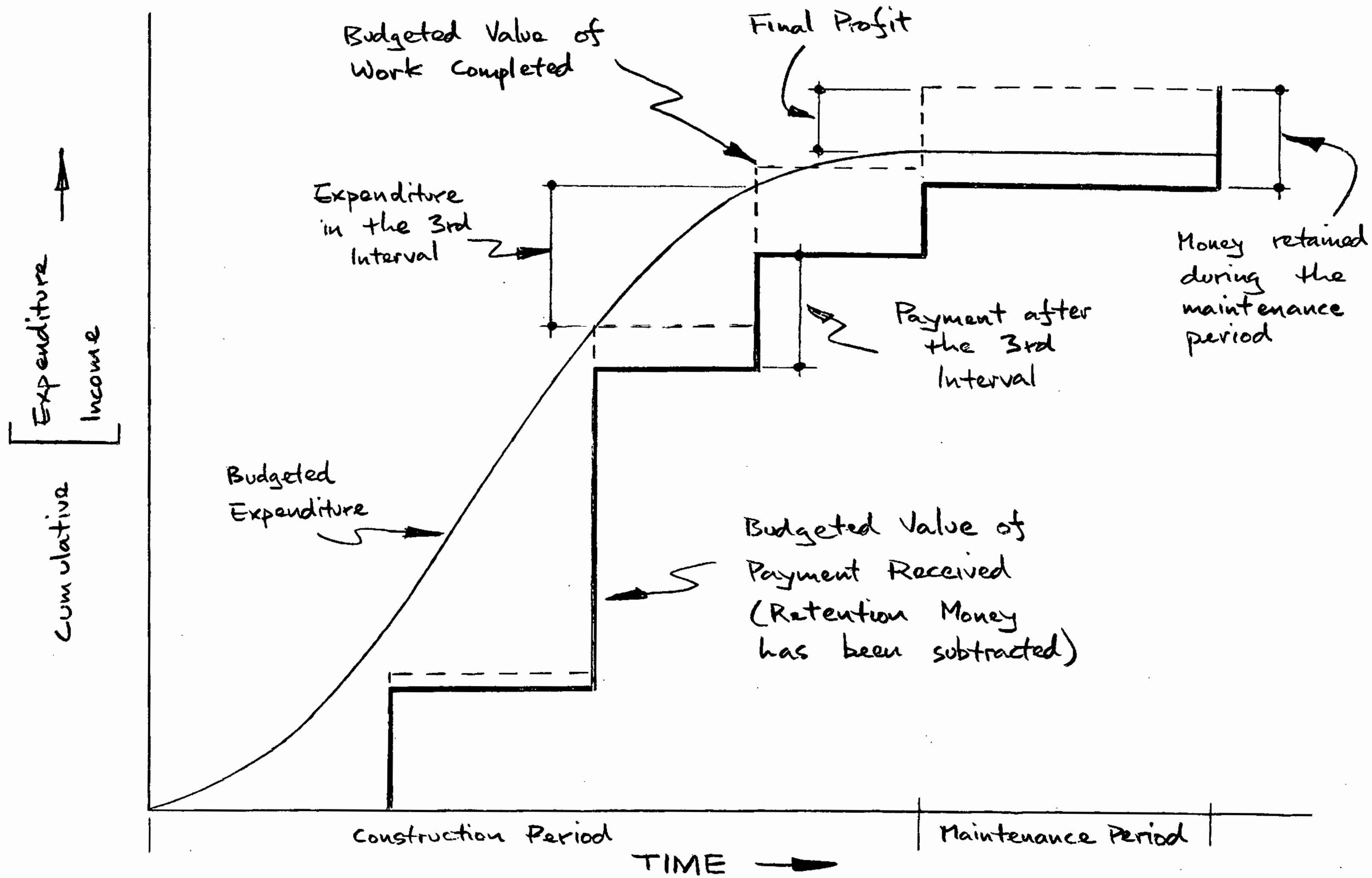


Figure 4.4.1 - The financial progress of a contract

or network drawn up at the tender stage to show when each activity of the work is to be performed. Naturally, such a plan will not normally be very detailed before the contract has been awarded, but nevertheless it would give an indication of the sizes and times of the cash flows to take place over the duration of the contract.

By calculating the net present values of all the cash flows relating to a particular plan of performing the work, the contractor is able to compare it with other plans, whose associated net present values have also been calculated.

Also, should the contractor be forced to decide which of two tenders to bid seriously when a lack of resources prohibit him from being able to accept both contracts, a comparison of the net present values of the cash flows likely to be associated with each contract will provide an excellent criterion on which to base his decision.

In conclusion it should be pointed out that the results of this method of deciding between ways of performing a contract, or between different contracts, should not be accepted at face value. They are obviously dependent on the estimates of times and costs on which the analysis is based. However, this method does take into account the effect of time which would otherwise be impossible, and also, the person making the comparison is forced to consider his motives more carefully than normal.

CHAPTER 5 - CERTAIN SUBJECTIVE FACTORS RELEVANT TO THE TENDER BID

When the contractor has completed his estimate of the cost of a project, his tender is not yet ready for submission. This is because he has still to consider the amount of profit he requires from the job. The concept of profit has already been discussed in Section 2.9, and it was mentioned that certain factors influenced the amount of profit that will make a job seem worthwhile to a contractor. The effect of conditions of contract has been dealt with (Chapter 3). Generally speaking, a contractor will increase his price if the conditions of contract to be used on a job appear unusual, or in any way unfair to him. Other factors (dealt with in Chapter 4) are the financial aspects of a tender and in particular, the time value of money. In this chapter, a discussion will be given of certain other factors which must be considered if the contractor is to ensure that he has made his best possible bid for the job.

Section 5.1 - Competition :

The competition he is likely to encounter from his fellow tenderers is perhaps a major factor influencing the contractor's decision on how much profit allowance to add to his estimate. It is here that experience, not only in general contracting, but in contracting in the particular locality of the project will count most. The state of the contracting industry varies from place to place, as well as from job type to job type. Also, when there are fewer jobs open for tender, competition will force all the tenderers to lower their profit margins, while if there is an excess of jobs and contractors are working close to capacity, all the prices received when a job is put out to tender might be higher than usual.

There can be no certainty associated with a contractor's assessment of his competitor. The methods he might use vary from the simple "hunch" to elaborate opertions research techniques, involving the use of information obtained from past tenders. Contractors also find the maintenance of personal contacts in the industry of use. These might include suppliers of equipment or materials who might be able to provide some information on the degree of interest shown by other contractors in a particular tender.

It is hoped that the following chapters of this thesis will be able to provide a contractor with mathematical models which might be used together with conventional methods to assess the likelihood of winning a contract and to choose an optimum bid amount.

Section 5.2 - Risk :

It has been mentioned before that it would be extremely improbable for the final price of a contract to be the same as the contractor estimated it at the tender stage.

Human nature is such that potential difficulties are usually under-estimated. Figure 5.1 shows how a probable frequency distribution of the ratio between the final price of a contract to the estimated price is generally skewed to the left. For this reason the contractor has to be aware of the care with which his estimators have prepared their

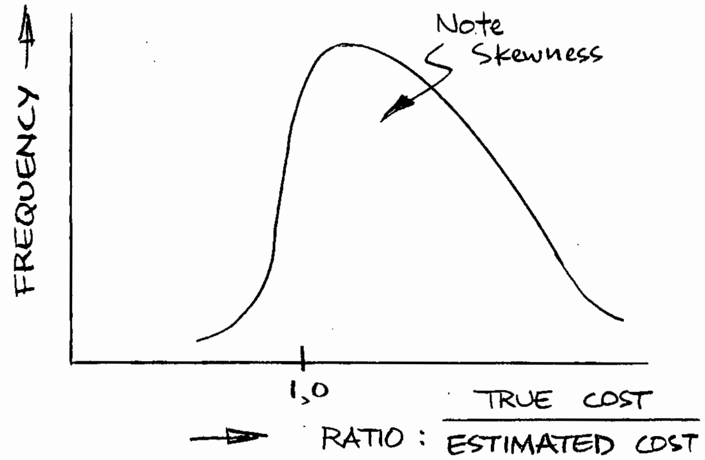


Figure 5.1 - Distribution of True Cost

information. This is usually done at a meeting between management and the estimators at some time just before the tenders are due. The estimates are then read thoroughly and management attempts to pinpoint any weaknesses that might become apparent. Such a meeting could take from 15 minutes to several days, depending on the complexity of the project. The contractor's confidence in the estimate will influence the amount of profit he will seek.

Another element of risk will be the number of natural hazards that could be encountered on the job. The most common of these are unexpected sub-surface conditions and the effect of adverse weather. This is where the contractor's past experience of local conditions is obviously most valuable at the tender stage. Competent contractors are seldom prepared to gamble, and so unknown factors generally extend their profit requirements.

Should the conditions of contract not allow any variations in the price of materials purchased by the contractor for the project (see section 3.3.15), then such variations should be considered a potential risk by the contractor, and he should consider this when deciding on his final bid price.

Finally, the contractor must make a careful estimate of the financial stability of his intended client. This is especially important if the job is to be of long duration. Not only should the contractor try to obtain copies of the employer's balance sheets and income statements for a few preceeding years, but he should also consider the effect of the current project on the client's business. In spite of any conditions of contract designed to protect the contractor against bankruptcy of the employer, there is no doubt that he will lose heavily if this ever happens. If there should be any real risk of this, it might be better for the contractor not to submit a tender than simply to increase his prices somewhat, as this might only aggrevate the situation.

<u>Section 5.3 - Company Size</u> :

The size of the contractor's company will provide a very obvious limitation to the amount of work he might undertake. Of particular importance is the number of men that can be used.

A contractor would be foolish to underestimate or ignore his manpower requirements. In fact, if a client was to present him with a very attractive cost reimbursement contract, the contractor might even have to refuse it if the work was such that he would have to increase his labour force by a large amount.

His decision to turn down the contract would be a good one if a recession was forecast in the construction industry. Having gone to a great deal of trouble and expense to comply with Government regulations concerning the importing of labour from other parts of the country (see Appendix B), the contractor might find himself in the position of having too many labourers for his needs.

Men can hardly be laid off whenever they are not needed and so the contractor's costs per unit of labour production would show a considerable increase. This might possibly offset any advantages that would be gained from the presentation job.

The size of the company also has an important bearing on the overhead costs that have to be borne by each job it undertakes. The more contracts there there are in hand at any particular time, the lower will be the proportion of office overhead costs to be borne by each individual job. It follows that during a recession, when there is a scarcity of work, a higher proportion of the revenue from each job will go towards the cost of overheads, unless these are reduced in some way. It is important for a contractor to be able to forecast his requirements so that he might anticipate changes in office expenditure where possible.

Also, the size of his company will dictate the amount of risk a contractor is willing to undertake on any particular job. If his company is small, a loss on a single job could bankrupt his organisation, while large companies should be able to withstand the effect of unforeseen losses. This will have an overall effect on the caution with which each contractor sets his margin for profit, part of which may be considered as a margin for error.

Section 5.4 - Planning :

When tendering for a contract, the contractor has to consider the impact his execution of the job will have on his future.

It is possible, for instance, that the job will provide the contractor with experience that will be of use in the future. Here again, the contractor's judgment is important. It is pointless to acquire specialised knowledge for a particular contract when in all probability, jobs of such a type will not be constructed again in the contractor's area of operations. However, such experience might prove invaluable, and the contractor has to decide whether this will be the case. In this context, experience covers more than the simple acquisition of knowledge by personnel. It also includes the purchasing (and paying for) specialised equipment and other things such as computer programmes.

The contractor might also bid purposefully low to be given an opportunity to work for a particular client. Should the client be planning an extensive expansion programme, of which a particular job is but the first part, then the contractor would be well advised to make a favourable impression so that he might be approached by the client to negotiate further contracts. Naturally, the contractor should not bid too low on the job, because the client would hardly be impressed with the capabilities of the contractor if he knew that he was losing money.

Section 5.5 - Past Experience :

Naturally, a contractor will be able to produce a more accurate estimate for a job when he has had previous experience either of the job type, or of working in the vicinity of the job site. Here again, experience of the job type includes both knowledge and the ownership of specialised equipment.

Experience in working in the vicinity of the job site means that the contractor will have a reasonably good idea of sub-surface problems, as well as a knowledge of local labour and transport conditions. His supply lines should also have been established and should be ready for use. This is important in outlying areas.

A contractor with little or no experience would have to estimate his costs higher to be certain of not getting into difficulties, and so would be at an obvious disadvantage from the start.

Section 5.6 - Alternative Designs :

Occasionally, the tender documents make specific provision for the submission of tenders based on alternative designs by the contractor as well as on the original designs. However, even if this is not the case, it might be of advantage for the contractor to suggest certain alterations to the design, while ensuring that the use to which the completed structure is to be put is in no way impaired. The purpose of such alterations would be to reduce the cost of the project by making it easier for the contractor to construct by using other materials etc. This will also decrease the time spent on construction.

An objection to the submission of an alternative design might be that it would damage the relationship between owner and contractor. The former might get the impression that the contractor is just trying to be clever and might think that the effort of checking the alternative would be wasted. Also, the engineer might take it as a personal criticism if his design is altered. The contractor should take these relationships into account when deciding whether to submit an alternative. Also, he should not waste his own time and money in seeking alterations when they would most probably be rejected outright.

Should his alternative be accepted, the contractor and the client usually share the monetary advantages in some agreed manner between themselves. It is important that the contractor should take care in planning his submitted alternative designs, as the client could be tempted to take advantage of the new design by adopting it as the basis for a new set of tenders. However, this would hardly be an ethical procedure.

PART 2

STATISTICAL APPROACHES TO TENDERING

CHAPTER 6 - INTRODUCTION TO STATISTICAL APPROACHES TO TENDERING

Section 6.1 - The Objectives and limitations of Mathematical Models :

A model may be defined as a representation of a system. It may be a physical representation such as a perspex scale model of a proposed new bridge, or it may be an abstract representation such as a mathematical equation used to calculate the flow of water through a pipeline under different pressures.

The particular model to be developed in the remaining chapters of this thesis is one to represent the competitive bidding situation that occurs when a construction contract is put out to tender.

The purpose of a model is to predict. It is used to predict the outcome of various changes to the system which it represents.

The model is manipulated rather than the real-world system because it is easier and cheaper to do so. Indeed it is often impossible to manipulate the original system. For example it is impossible to place actual loads on a bridge which has not yet been built.

Models are set up in order to make decisions. In this regard, they do not have to represent every single aspect of a system. They have only to provide the information necessary to make a correct decision.

Chapter 9 of this thesis includes recommendations for the integration of professional judgment with the predictions made by the competitive bidding model developed and tested in Chapter 8.

Section 6.2 - The Expected Value Concept :

There are many processes whose outcomes cannot be predicted with certainty. The tossing of a coin is a prime example of such a process.

Each outcome of the process has a particular probability of occurrence. For example, if the coin is unbiased, the probability of it landing heads is 0,5.

These processes are termed "probabilistic" as opposed to "deterministic" processes, the outcomes of which can be predicted in advance.

This concept of a probabilistic process or system is important in this thesis because a competitive bidding system falls into this category. Each contractor tendering for a project cannot predict with certainty whether he will be awarded the contract. The best he can do is to assign a value to the probability that his tender will be the lowest. Even if his tender is the lowest, the contract might still be awarded to somebody else.

When dealing with probabilistic processes, the expected value of the random variables (outcomes) of these processes is an important concept.

Repeated use will be made of this concept in the following chapters of this thesis and so it will be given a brief introduction in this section.

The expected value of a random variable may be defined as the weighted average of all the possible values of the variables, each weighted by its probability of occurrence.

The important point to realize is that this is identical to the arithmetic average.

Let us return to the tossing of a coin. Consider a situation in which a person is given R10 if the coin lands heads. If the coin lands tails, he is given nothing. The expected value to him of the tossing of the coin is calculated as follows.

The probability of his obtaining R10 is 0,5 (assuming the coin is unbiased), and the probability of him obtaining nothing is also 0,5. The expected value of the random variable (his gain) is given in equation 6.2.1.

$$\text{Expected Value} = \frac{(10 \times 0{,}5) + (0 \times 0{,}5)}{(0{,}5 + 0{,}5)} \quad \ldots(6.2.1)$$

This reduces to R5.

It is important to note that this is the average amount he will receive each time if the coin is tossed a large number of times.

It must also be appreciated that the expected value is not an actual amount of money which the person will receive after the coin has been tossed. He will receive R10 or nothing.

In general then, the expected value is not a real value assumed by a random variable. Rather, it may be considered to be the average value of the random variable when a particular process is repeated often.

This concept will be expanded upon in section 8.1 where the criterion on which to base the optimal bid amount for a construction tender is discussed.

CHAPTER 7 - A SURVEY OF PUBLISHED LITERATURE CONCERNING TENDER ANALYSIS AND DECISION TECHNIQUES.

The literature contains relatively few papers on competative bidding in the construction industry, and it is of interest to note that those available all originated in the U.S.A. This chapter contains summaries of the more important work done on bidding strategies to date, and where possible the present writer has attempted to rephrase the statistical passages in order to make them more readable by a contractor with little or no knowledge of the principles of statistics. However, this has not always been possible owing to the dependence of decision theory on statistics.

Section 7.1 - Friedman :

This author's paper (12) was first presented in 1955 and was published a year later. As such, it is generally recognised (4,25,40a,42) as the first appearance of literature on competitive bidding, though as Friedman himself remarks : "Unfortunately details of the successful applications of operations research to the development of bidding strategies cannot be made public for reasons of industrial security". The present writer considers this still to be a problem at the moment.

The bidding situation considered by Friedman is one common to the construction industry, though he made no specific reference to this application. Each competitor submits a closed bid, or tender price, to the client who publicly opens them all at a prescribed time. Generally the contract is awarded to the lowest bidder.

Friedman remarks that each tendering company could have one or more of several objectives in submitting a bid.

a) Maximization of total expected profit.

b) Gains of a certain percentage of the market.

c) Minimization of expected losses.

d) Minimization of the profits of competitors.

e) Keeping production going, even if the contract is won at a loss.

These objectives will naturally affect the strategy to be adopted by the company and Friedman chooses the first - maximization of total expected profit - as the basis for his strategy.

Before the mathematical part of Friedman's model is described, one should consider this concept of expected profit maximization. It is important to note that the great majority of jobs for which a contractor tenders are essentially different from each other in many respects - the site location, the sub-soil conditions, the availability of labour, the supervision available for the job, the state of the company's finances, etc. Is one justified in using the expected profit to make a decision concerning a particular job? As previously pointed out (Section 6.2), the expected profit is not the actual excess of revenue over expenditure that will result from completing the contract. Further it is the average profit that would be made if that particular contract was tendered for a large number of times.

The use of expected values in making decisions in "one off" situations like a construction tender, i.e. situations that are unique and will not recur, is receiving considerable attention at the moment (24a), and though the present writer can profess no specialised knowledge on the subject, this aspect will be discussed at a later stage (Section 8.1).

Friedman begins his mathematical presentation by recognising that the true cost of the contract is invariably different from the estimated cost - a point neglected by several later writers on the subject (13,15,25,40a), let c be the estimated cost of the contract. If enough past data is studied, a relative frequency distribution of S, the ratio of the true cost to c may be constructed. Friedman suggests that it might take the form shown in figure 7.1.1.

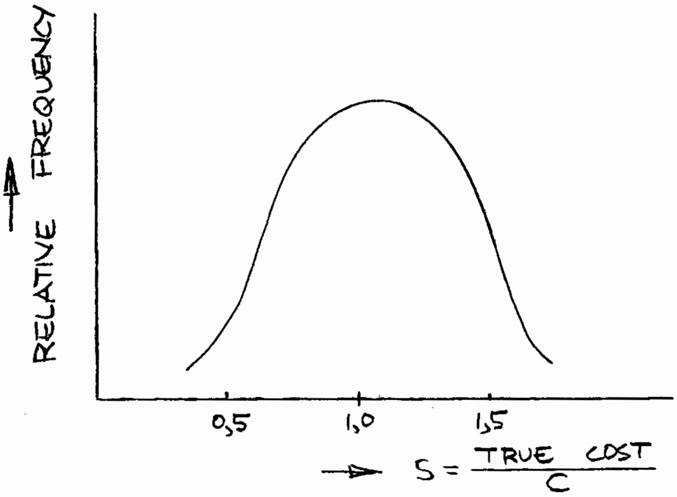


Figure 7.1.1 - Reliability of the Cost Estimate

If h(S) is considered to be the probability density function of S, then the probability that S lies between S and S + dS is h(S)dS. It follows that the expected cost of completing the contract is given by :

$$\text{Expected cost} = \int_0^\infty SC\ h(S)dS \qquad \ldots\ldots \ (7.1.1)$$

If the contractor's bid is b, his profit will then be :

$$\text{Profit} = b - \int_0^\infty SC\ h(S)dS \qquad \ldots\ldots \ (7.1.2)$$

But this amount will only be realised if the contractor actually wins the contract, i.e. if his bid is the lowest. Hence this quantity must be multiplied by the probability P(win) that the contractor wins with bid b, to give his expected profit for the contract E.

$$E = P(win) \left[b - \int_0^\infty SC\ h(S)dS \right] \ldots\ldots \ (7.1.3)$$

Friedman refers to SC h(S)dS as "The estimated cost corrected for bias". This concept that the cost of performing the work is a random variable (i.e. cannot be predicted with certainty) is an important one, and more will be written about this subsequently (Section 9.1).

Friedman then gives a sketch of the move of E vs. b (figure 7.1.2) and suggests that the bid yielding the maximum value of E should be used.

Perhaps the crucial part of Friedman's model is that introduced by his statement that "The difficulty in determining the expected profit lies in determining P(win), the probability of winning as a function of the amount bid".

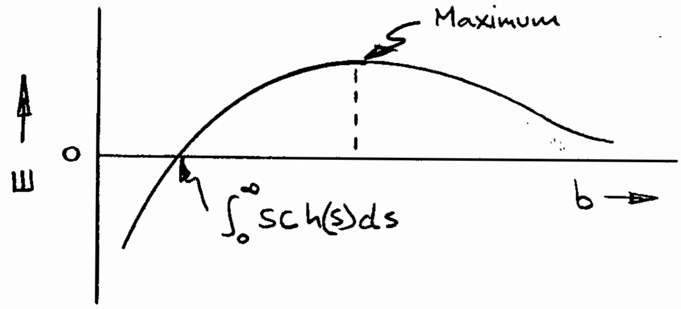


Figure 7.1.2 - Expected Profit Curve

Essentially, Friedman suggested that if the probability that a particular contractor would bid lower than competitors A;B and C were respectively P(A), P(B) and P(C), then the probability that he would win is given by :

$$P(win) = P(A)\ P(B)\ P(C) \qquad .....(7.1.4)$$

Also, if the probability of beating the average competitor in the market was P(ave), and if there were on average n competitors per job, then the probability of winning would be :

$$P(win) = n\ P(ave) \qquad .....(7.1.5)$$

This implies that the probability of the contractor bidding lower than competitor A is statistically independent of the probabilities of his bidding lower than competitors B or C. This has been contested by Gates (14), and is dealt with in detail later (Section 8.2).

Friedman suggested that the probability of submitting a lower tender price than a particular competitor may be assessed by setting up a relative frequency distribution of the ratio

R(A) of that competitor's bid to the contractor's cost estimate :

$$R(A) = \frac{\text{Competitor A's Bid}}{C} \qquad \text{.....(7.1.6)}$$

Such a distribution is shown in figure 7.1.3. The shaded area to the right of X, the ratio of the contractor's bid to his cost estimate, represents the probability of the contractor bidding lower than competitor A.

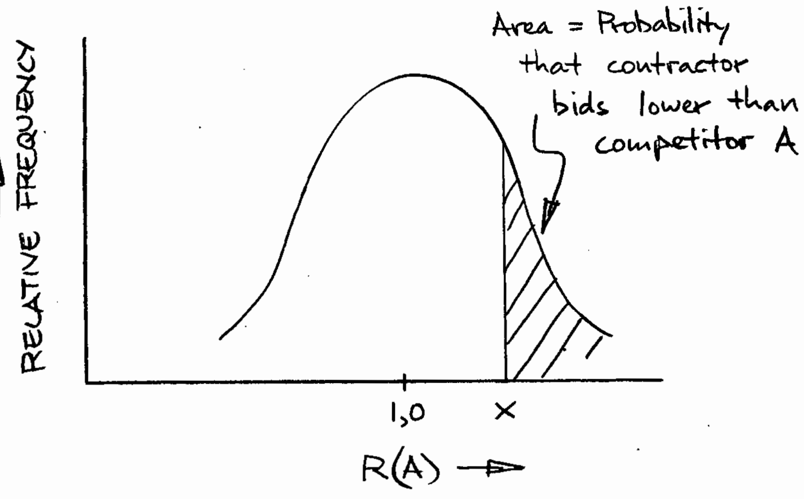


Figure 7.1.3 - Relative Frequency Diagram for Competitor A

Friedman continues to say that the "average competitor's" bid ratio (obtained by averaging all the competitors' bids for a past contract and then dividing this value by the contractor's cost estimate for that job) is gamma distributed. The present writer has not found this to be the case on the data he has studied (Section 8.3). The normal distribution fits the data closely.

However, as Friedman states, the number of contractors tendering for a construction contract is Poisson distributed. He then extended equation 7.1.5 to take into account the random number of competitors :

$$P(win) = E(N)\ P(ave) \qquad \text{.....(7.1.7)}$$

where E(N) is the expected value of N, the (random) number of competitors for the contract.

By using the Poisson and Gamma distributor's respectively for E(N) and P(ave), Friedman showed that P(win) evolved as the cummulative of the Poisson distribution. The mathematics will not be presented as the present writer feels that the use of the Gamma distribution is unjustified. Friedman then suggested that freely available tables of the cummulative Poisson distribution could be used to give the probability of the contractor defeating n "average" competitors for the lowest bid.

Finally, Friedman proposed that the number of bidders on any particular contract should be related to the contractor's cost estimate for the job, A regression analysis could then be made to find the relationship between these two variables. Unfortunately, the present writer did not find this to be the case (Section 8.7). The only way to predict the probability of encountering a certain number of competitors on a particular project is to make use of the fact that that number is Poisson distributed.

Section 7.2 - Gates (A) :

In his paper (15), Gates adopted a completely different approach to the problem. Indeed, it seems that he was unaware of Friedman's paper (12) from the absence of any reference to it in his work.

What Gates did was to establish a relationship between the size of a contract and the "spread" or difference between the lowest and second lowest bids. He selected certain road construction tenders whose results were published in the press at the time. He was careful to exclude any unusual jobs that were "not representative of the usual highway projects encountered". Gates then classified the contracts according to the value of the lowest bid and computed the geometric mean of the spread for each job in the group. He then took the geometric mean of the job values in each group and plotted the pairs of co-ordinates so obtained on log-log paper. He found a linear relationship to exist.

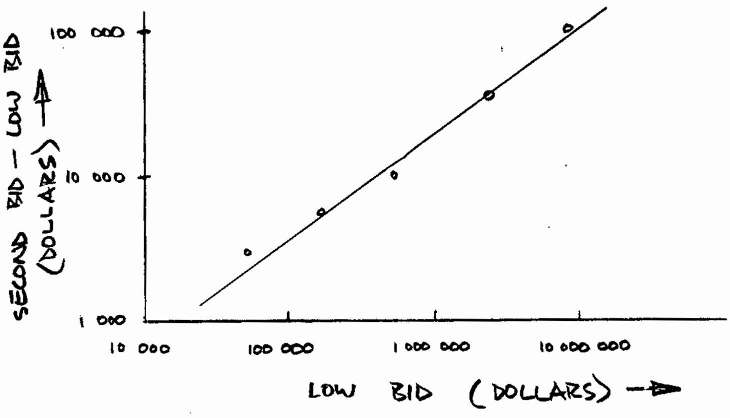


Figure 7.2.1

Gates then constructed a diagram relating the size of the contract (as given by the lowest bid) to the probability of the spread being a certain amount. The probabilities were obtained from an observation of the scatter of the actual spreads on jobs of particular size about the predicted spread given by the regression equation.

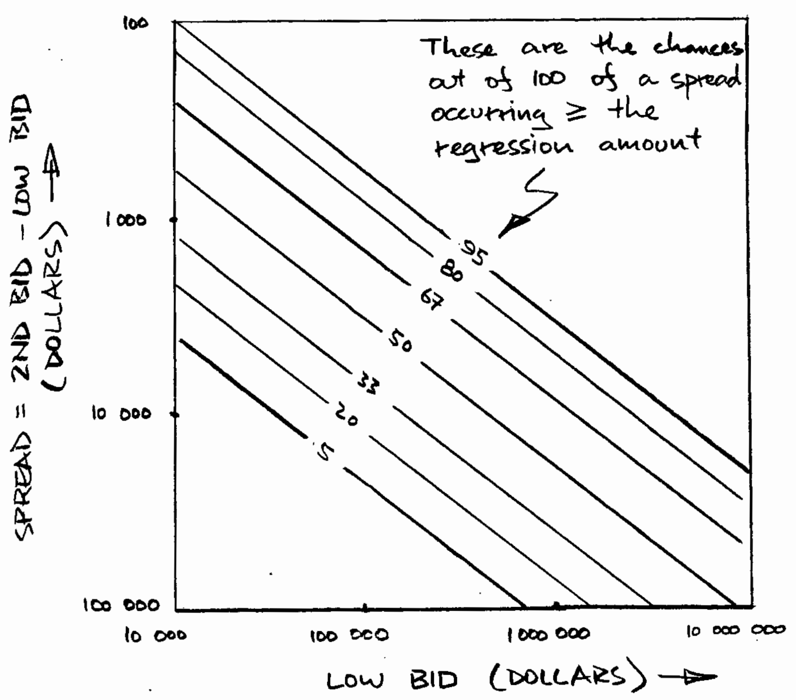


Figure 7.2.2

The analysis in the form of this diagram was then applied in various ways, the first of which was to the problem of determining whether the lowest bidder had made a gross mistake. Gates assumed that if there was less than a 3% chance of the spread on a job being as large as it was, then a "rare" event had taken place, and the lowest bidder had made a gross mistake. He suggested that a client should allow the lowest bidder to withdraw his bid without penalty in such a case, should he wish to do so. Naturally, the fact that the spread was in fact so large did not mean that the lowest bidder had in fact made a mistake, and the decision to withdraw should be left in the hands of the contractor.

The present writer consider this to be a most practical use of the analysis as no contract will ever be completed satisfactorily when the contractor knows that he cannot avoid making a loss.

However, as a corollary to this, it would seem that if the lowest and second lowest bids were so close that there was less than a 3% chance of the spread being so small, the client should assume that there had been collusion between these bidders and disregard them both. The present author is of the opinion that in practice this would be a very difficult step to take.

The next application of the analysis that Gates made was to the matter of the "bid guarantee". This is the amount of money to be paid by the contractor should he be awarded the contract and then withdraw. Gates proposed that the amount should correspond to the limiting spread beyond which there would be a mistake in the bid - i.e. the probability that the spread would be less than this amount would be 0,97. This was because it was the limiting amount of extra money that the client would have to pay should he have to accept the second lowest bid.

Bid guarantees are seldom if ever required in South Africa as the cost of making the estimate is considered to be sufficient waste of money by the contractor to deter him from withdrawing from the contract. However, a case could be made for the American practice since it does protect the client from the financial loss that he himself would sustain. In the event of bid guarantees being required, Gates' method of setting their amount does seem logical.

Gates thereupon turned his attention to the use of average unit prices in the bid. He reasoned that the size of the spread was closely related to the precision of the estimate. Since approximately one third of the contracts had spreads above the average, it was concluded that the same proportion of each estimate could be made up of "going" prices obtained from trade journals. Gates suggested that minor items should be chosen for estimation this way and that even if more effort was expended in producing accurate assessments of the costs of such items, little or no extra precision would result in the total estimate.

The logic behind the adoption of Gates' analysis in this way does seem rather loose, but the present writer discussed this point with a prominent local contractor (40b) who agreed in principle with Gates' conclusion.

Gates then turned his attention to bidding strategies by which a contractor might make use of his analysis. The first of these he termed the "Method of Constant Work". If the contractor requires to win n jobs per year to keep his company optimally loaded with work, and from past experience he is able to evaluate his average probability of success at tendering as p%. then the optional number of jobs for which he must tender a price each year is :

$$N = \frac{100 \quad n}{p} \qquad \ldots\ldots(7.2.1)$$

Gates proposed that the contractor could increase his profits by making use of a spread analysis. This is done by first assuming that b, the bid he has prepared, is 100% certain to win the contract. If he adds on amount b' to b the contractor will increase his profit if he is still the lowest bidder, but he will naturally reduce the probability that his bid is the lowest. From a spread analysis, the contractor may assess his new probability of being the low bidder as q. This is done by entering the diagram relating job size to the probability of the spread being a particular size with b. The probability of the spread being greater than b' is read off and this is assumed to be the probability q that the contractor will still win the contract.

In this way, if the contractor decides to add a constant percentage ($\frac{100\ b'}{b}$) to all of his tender prices, he should bid on :

$$N = \frac{100\ n}{pq} \qquad \ldots\ldots(7.2.2)$$

contracts per year - assuming that he is confident that such an amount of jobs will come up for tender.

The present writer is of the opinion that there are several points of doubt in this application of Gates' work.

a) n, the optional number of jobs per year for the contractor to win has little meaning in the context of civil engineering contracting where the nature of each job and its duration determines the quantity of the contractor's resources to be used.
b) p, the probability of success at tendering varies considerably from job to job, depending as it does on many factors which have been ennumerated elsewhere in this thesis (Appendix A).
c) The assumption that the contractor's bid is the lowest before the increase is applied is hardly likely to be correct in most cases. Should it not be the lowest, then the probability associated with any increase in the bid will be incorrect and this will lead to an invalid conclusion.

Gates termed his next application the "Method of Maximum Income". If the contractor had prepared his bid including an amount of profit a (the "anticipated profit") the problem is to determine the amount he should increase this bid so that the probable gain minus the probable loss is a maximum, i.e. :

$$qb' - a(1 - q) = \max \qquad \text{.....(7.2.3)}$$

where b' is the increase in the bid amount and q is the probability of still winning the contract after adding b'.

Once again, the present writer considers this to be fallacious in that to use the Gates analysis of spread probabilities the contractor must assume that his bid will be the lowest. The only other way of determining p is by means of the method Friedman proposed, of which Gates makes no mention.

Finally, Gates extended the "Method of Maximum Income" to the "Method of Maximum Profit". He recommends this method to contractors "if work is plentiful and past experience indicates that it is not practical to attempt to estimate the net profit from a bid". It follows directly from the previous method, the only difference being that the sole input required is the contractor's cost estimate. The spread analysis is used to decide upon the final addition for profit.

The present writer is of the opinion that the same argument is applicable here as was to the "Method of Maximum Income" - the probabilities given by the analysis could be considerably wrong.

It seems then that the value of Gates' paper lies mainly in its use to clients in assessing tender bids received for a particular job. Its contribution to this problem is considerable, in the opinion of the present writer. Gates' suggestions to apply this type of analysis to the contractor's problem of deciding on an optimum markup, while appearing somewhat misdirected, did however attempt to place that subject on a logical basis in the construction industry.

Section 7.3 - Gates (B) :

In a later paper (14), Gates treats the subject in considerable depth. He proposes several different strategies to be used by the contractor in various circumstances depending mainly on the contractor's knowledge about his competition. He carries Friedman's work further and also discusses the application of game theory to competitive bidding, and the unbalancing of bids.

The first situation considered by Gates is one where the contractor finds himself the only tenderer for a contract. In this case, the contractor should model his bid on what Gates terms the "Lone Bidder Strategy". It is essentially for adoption by the contractor against his client. In it the contractor makes subjective estimates of the probability of the client accepting his tender price with various amounts of markup for profit. The contractor then chooses the markup that would give him the maximum expected profit - his profit allowance times the probability of his bid being accepted.

This strategy does appear to be sound in theory, but the present writer is of the opinion that the probability assignments are of such a subjective nature and are unable to be substantiated by historical data, that perhaps a direct estimate of the best allowance for profit will be just as effective.

Published discussion on this strategy centred around the problem of how the contractor was to know whether he was in fact the only bidder and what the "engineer's estimate" was. In his closure, Gates countered the first problem by suggesting that a few minutes before the deadline for submission of the tenders, the contractor should be able to find out how many tenderers there were, and an item such as one in the P & G bill could have been left blank for filling in at the last moment.

The present writer has seen this done in practice - indeed there is usually an item entitled "fees" in the P & G bill.

With regard to the problem of determining the "engineer's estimate", Gates pointed out that in the United States, for every project on which such an estimate was kept a secret, there was one for which it was actually published. The present writer has discussed this problem with a local consulting engineer (19a), and it seems that there is no reason why the consultant's estimate should be kept a secret.

Gates thereupon presented an application of game theory to a situation where there were only two tenderers for a contract. A brief description of the elements of game theory is given elsewhere (Appendix D) and it is sufficient to note that Gates' application is rather artificial.

The possible actions described in the game are given below.

a) Both tenderers do not increase their bids because they are the only competitors for the contract.
b) Both tenderers do increase their bids.
c) The one tenderer does increase his bid while the other does not.
d) Vice versa.

The payoff matrix consisted of the expected profits from one of the bidders point of view. These were evaluated from subjective estimates of the probability of winning in each situation. The resutling two person, zero-sum, two by two game conveniently produced a saddle point to provide each competitor with a grand strategy. As pointed out in Appendix D, this is a rare occurrence and tends to highlight the possible over-simplification adopted by Gates.

The next strategy presented by Gates was one which he recommended for use by contractors when competing against many competitors. Essentially, the method of maximizing expected profit as presented in Friedman's paper was used. The difference was that Gates considered only the lowest competitor's bid for each past tender in deciding on the probability of winning related to various profit allowances. Unfortunately, possibly because of industrial security, Gates did not use the actual contractor's cost estimate in determining the competitor's bid to cost ratio for each job. Instead, he assumed that the contractor had adopted a steady 5% markup on each job. This detracted somewhat from the analysis, but nevertheless showed the method clearly enough.

Gates next discussed the application of Friedman's method to a situation where the contractor knows exactly which competitors he is going to meet when competing for a particular tender. Relative frequency distributors were to be set up as before, but the important advance that Gates made was in the combination of the probabilities of beating each of the competitors to yield the probability of winning the contract. It will be recalled that if P(A), P(B), P(C) are the probabilities of beating competitors A, B and C respectively, then Friedman suggested that the probability of beating all of the competitors together was given by :

$$P(\text{win}) = P(A)\,P(B)\,P(C) \qquad \text{.....(7.1.4)}$$

However, Gates refuted this and suggested that the probability be given as :

$$P(\text{win}) = \frac{1}{\frac{1-P(A)}{P(A)} + \frac{1-P(B)}{P(B)} + \frac{1-P(C)}{P(C)} + 1} \qquad \text{..(7.3.1)}$$

Unfortunately, Gates did not offer a proof of this in his paper, beyond stating that it was "the mathematical model of a 'coloured balls in the urn' problem".

The present writer supports the use of equation 7.3.1 and its proof appears subsequently (Section 8.2).

Gates then presented the "least spread strategy". This was the same as the method given in his previous paper (15) and has already been described in Section 7.2. of this thesis.

The next strategy Gates gave was that of "unbalancing" the bid. This can only be employed for unit price tenders. It consists of the contractor altering the unit prices in such a way as to keep the total tender price constant while increasing the ultimate monetary benefit accruing to the contractor.

The following situations could warrant unbalancing of the bid.

a) The contractor might not have enough capital on hand to meet the needs of the project. By inflating the unit prices of items that will be completed early in the contract, the contractor will receive extra money that might be used to finance the remaining items of the project.

b) If the contractor believes that the quantities of certain items are in doubt, he might alter the unit prices of such items to his advantage. For instance, if he believed that there was less rock and more earth in the excavation for a substructure, the contractor would be sensible to increase the unit price of earth excavation and decrease that of rock excavation, while keeping his tender price for the whole excavation a constant.

Naturally there is a varying degree of risk attached to such practices, a fact not to be taken lightly by any contractor.

The present writer envisages the best application of unbalancing bidding to be the maximization of the present value of the cash flows associated with the contract. This is presented in detail in Appendix H.

Finally, Gates presented various topics from probability theory that might be used in association with bidding strategies. These included a short discussion on the binomial, Poisson and normal distributions.

<u>Section 7.4 - Ortega Reichert</u> :

In his report (27), Ortega Reichert examines several different bidding processes from a game theoretic point of view. of the various types of auction he considers, the single stage closed bidding process is of interest to us, as this is the type most commonly used for construction tenders in this country.

Ortega Reichert considered the following facts to be relevant to his analysis :

a) uncertainty about the reliability of the bidder's information concerning the exact nature and amount of the work;

b) uncertainty about the actual profit the bidder will make if he is successful and is awarded the contract;

c) the bidder's uncertainty about his opponents' strategies if they have particular cost estimates;

d) uncertainty from the bidder's point of view about the cost estimates on which his opponents will base their bids.

Ortega Reichert developed several bidding strategy models.

a) Each of the bidders was assumed to have perfect information about his own cost and uncertainty about his opponent's cost. Only two bidders were considered (the contractor versus the rest), and the objective was for each to maximise his expected profit. A differential equation was set up and solved to yield the bidding strategy to be adopted by each competitor as a function of his cost. The optimal strategies were found to be in equilibrium. In other words, each competitor should adopt the same strategy.

b) The above model was altered to allow for the optimization of a non-linear utility function instead of the expected profit value.

c) The model was extended to an n-person game and it was observed that the bid resulting from the optimal strategy for a given cost decreased as the number of competitors increased.

d) The model was extended to cover the case where each competitor was uncertain of the number of opponents he has.

e) Model (a) was altered in that each of the two competitors was considered to have differing degree of uncertainty about his cost estimate. The conclusion drawn by Ortega Reichert was that each competitor should assume that his opponent has the same amount of information concerning the project as himself.

Generally, that author endeavoured to produce exact solutions to the differential equations that were set up, though this was only rarely possible. To overcome this difficulty, in one part of the paper he treated model (a) as a "discrete adaptive process". This means that a solution was sought to the differential equations by generating a series of strategies for each competitor. Consider the two opponents A and B. The first step is when competitor A makes a bid following a particular strategy. Then competitor B makes his bid following his strategy, but taking into account A's bid. This process is continued with each competitor obtaining more and more information regarding the other's strategy. Ortega Reichert found this method to be unsuccessful as the process was often unstable.

The present writer noted that throughout this paper, the probability of beating several opponents in competition for the lowest bid was assumed to be that given by equation 7.1.4. As pointed out in the previous sections of this chapter, the use of this equation is in doubt, and this will have an effect on several of Ortega Reichert's models, though not all.

Furthermore, the present writer noted that the successful solution of the differential equations that were proposed involved considerable simplifications which generally reduced the equations to those which Friedman presented in his paper(12). The advantage of such a game theoretic approach as adopted by Ortega Reichert is therefore questionable.

Section 7.5 - Morin and Clough :

A description of a general computer program, OPBID, for use by contractors when deciding on the optimal markup to apply to their cost estimates for construction tenders is presented by the authors (25). The program is designed for use by contractors with no previous experience in operations research techniques.

The opinion of the present writer is that previous experience - if not expertise - in such matters is a prerequisite for their successful use. It seems that the untrained use of OPBID or any similar program could lead a contractor seriously astray.

The model takes cognizance of five factors :

a) cost estimate;

b) true cost;

c) number of competitors;

d) identity of competitors;

e) nature of the work.

Essentially, Friedman's model is adopted with several slight alterations.

Firstly, Morin and Clough disregard the distinction between the true cost and the estimated cost. They state that on the jobs which they studied, the mean of the ratios between the true and estimated costs tended to 1,0 and the standard deviation was of the order of 0,02. The present author has not had the opportunity of studing similar data under local conditions, but such a situation does seem to be somewhat idealized, especially for civil engineering projects where there is always a varying amount of uncertainty with regard to site conditions.

The probability of bidding lower than several competitors was given as in equation 7.1.4, following the Friedman model. Gates (14) has shown this to be incorrect and he reiterated his formula in the discussion on this paper by Morin and Clough.

In OPBID, the probability of beating any particular competitor is determined from a discrete distribution of the ratio between the competitor's bid and the contractor's cost estimate. The present writer favours the use of a continuous rather than a discrete probability distribution, and more is said about this later (Section 8.3).

Also in OPBID, only certain competitors were considered significant enough to warrant the construction of a probability distribution of beating them alone. Part of the input to the program was a "key competitor factor" which was a number between zero and ninty. Only if a competitor had been met on a larger proportion of past jobs than that factor, was a distribution constructed to assess the probability of beating him individually. The bid ratios of all the other competitors were collected into one "average" distribution.

With regard to the number of competitors for any particular job, OPBID used the average number met on past tenders. The authors refute Friedman's suggestion that the number is a function of the monetary size of the job, a fact that has not been supported by the results of work done by the present author either (Section 8.7).

In OPBID, Morin and Clough considered differences in the nature of the work (i.e. pipelines or road bridges) to be significant. Discrete probability distribution were set up for each type of job and only the ones corresponding to the type of project in hand were used to assess the contractor's chances of bidding lower than any particular competitor. Theoretically this is sound, but in practice one meets the problem of not having enough data to draw up reasonably accurate distributions for each type of job. The relation between accuracy and the number of data is presented later in this thesis (Section 8.3).

Finally, Morin and Clough felt that recent data should be given more importance than older data because the relative position in the market of a construction company changes with time. An exponential weighting scheme was adopted :

$$q = K \exp(-K't) + c \qquad \text{.....(7.5.1)}$$

where q is the relative weight given to any particular bidding data; K,K' and c are constants;

t is the time difference in days between the date of the tender from which the bidding data was taken and the tender under consideration.

The experience of the present writer indicates that the relative positions of civil engineering contracting companies in a particular market depend mainly on the amount of work each has in hand and there is not a smooth change in positions with time. Had Morin and Clough clarified the evaluation of the constants in the weighting equation, they might have shed more light on this particular problem.

Section 7.6 - Benjamin :

In his report (4) Benjamin expounded at length on the elements of the competitive bidding problem.

Firstly, he considered factors having an effect on the cost of performing the work (as distinct from the cost estimate), which he took to be a random variable and hence to have a probability distribution associated with it. He ennumerated several factors influencing the uncertainty in the cost estimate, all of which have been dealt with in the first part of this thesis (Section 5.2).

Benjamin then presented three methods of developing the probability distribution of the ratio of the true cost of the project to the estimated cost.

a) By performing a multiple regression analysis to determine the relative influence of each of its elements on the total cost of the project. The uncertainties associated with each of these regression equations should then be summed to give the parameters of the distribution of the total cost estimate. This will be a normal distribution because of the process of addition involved in its construction. Benjamin did not elaborate on this method, but it seems similar to the way Gates (15) set up his spread probabilities (Section 7.2).

b) By giving three prices for each item of the cost - the most pessimistic, the most likely and the most optimistic. These three prices are used to form subjective beta distributions for the cost of each item and their sum is a normal distribution of the total cost of the job. This method is the same as that used in PERT network analysis to develop the probability of completing a project by a given date.

c) By obtaining historical ratios of actual to estimated cost and combining these into a distribution in the same way as probability distributions of bid ratios, as previously demonstrated by Friedman.

Benjamin then went on the enumerate various factors that bear an influence on the amount of profit that a contractor would seek for any particular job. The first of these proved to be of interest. Benjamin termed it "intensity" - the ratio of the duration of the project to its cost. He suggested that the relationship between required profit and intensity should be as shown in figure 7.6.1.

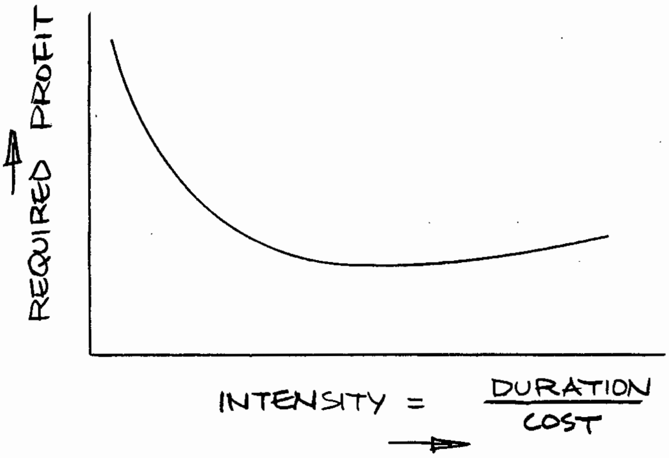


Figure 7.6.1 - Effect of Job Intensity

That author pointed out himself that intensity should not influence the profit requirement if office and job overheads have been included in the cost estimate.

The shape of the curve may be explained by the fact that if the contractor has to keep the job to a very tight schedule and if there are penalty clauses for late completion - i.e. if it is of high intensity - he will need to manage the project very carefully. This will be expensive and so the job overheads will rise. On the other hand, Benjamin does not explain why low intensity jobs require a high amount of profit. The present writer imagines that this is because the cost of tying up capital in the job for a relatively long duration is high. The money could probably earn a higher rate of return elsewhere.

The present writer is also of the opinion that this curve becomes superfluous when job overheads and financial costs are properly included in the total cost estimate, as they should be. Nevertheless, this concept of intensity is an unusual and interesting one, and the present writer has not seen any other reference to it.

The remaining factors that Benjamin mentioned as having an influence on the amount of profit that a contractor would require are all related either to the risk involved in undertaking the work or to the overhead cost of the job.

That author then proposed that all the above factors could be used in a regression model to assess the probability of winning with different bids. Unfortunately he did not carry this idea further.

Benjamin thereupon entered the mathematical phase of his dissertation. He began by considering the competitive bidding problem as a "two stage lottery". The prize of the first stage was the opportunity of actually undertaking the work, and of the second stage was making a profit on the job - i.e. having a lower final cost than the amount bid for the contract.

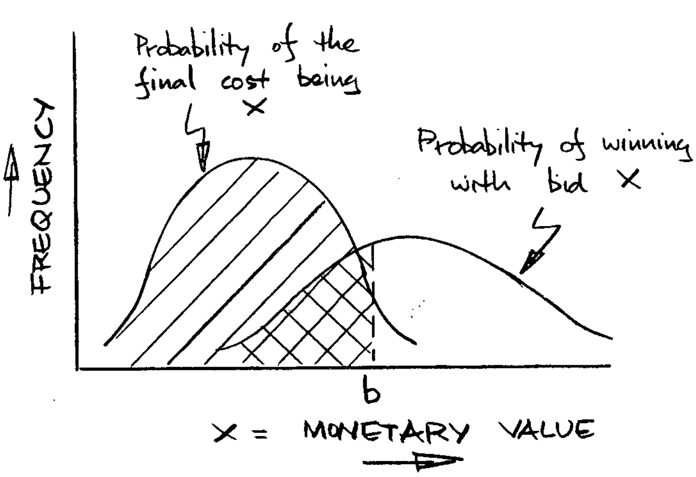


Figure 7.6.2 - Two Stage Lottery

the probability of actually making a profit on the job is the product of the probability of the actual cost of the job being less than the bid amount and the probability of the bid amount being the lowest tendered. In fact, this is exactly the same approach as Friedman took, only Benjamin's terminology is more contemporary.

Benjamin then considered the maximization of the contractor's expected utility instead of expected profit, as most previous authors had done. He considered two types of utility functions - the bilinear and the exponential, both of which are shown in figure 7.6.3.

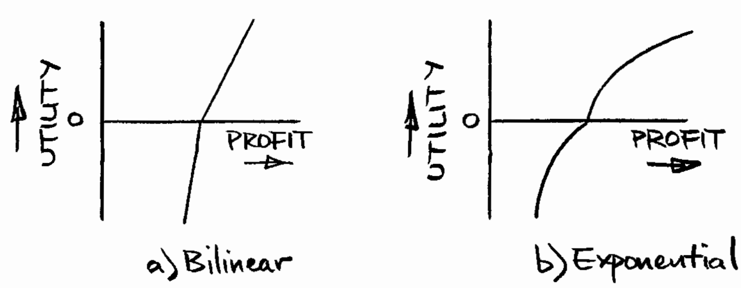


Figure 7.6.3 - Utility Functions

It is regrettable that Benjamin did not mention any method by which the contractor might establish his utility curve apart from in an empirically subjective way. This is a very serious problem if his model is to be of any practical use at all.

Benjamin combined several different distributions of the probability of being the successful bidder and of making a profit on the job with these two types of utility functions. He found that there was no "closed form solution" to the equations giving the optimal bid and suggested that successively larger bid amounts should be taken; the expected utility calculated at each step, and the bid corresponding to the highest expected utility value taken as optimal. Benjamin therefore discarded Ortega Reichert's approach of forming differential equations to solve for the optimal bid (27).

The present writer considers that Benjamin's work would have been of more value if the methods he presented had been demonstrated on actual data, an appendix of which he did in fact include.

Section 7.7 - Shaffer and Michaeu :

In their paper (40a), the authors investigate the use of various models to predict the optimal markup to apply to the estimated cost of a project for which a price is to be tendered in open competition.

The models used are given below.

a) The "One-distribution" model. Here, the ratios of the bids of every competitor met on each past job, to the contractor's cost estimate are combined to form a normal distribution, from which the probability of winning with any particular profit allowance may be determined. The process of choosing the optimal expected profit is the same as in the Friedman model (12).

b) The "Multidistribution" model, in which each individual competitor's past bid ratios are combined into a normal distribution and then, when the opponent's for the particular job under consideration have been identified, their distributions are combined into one normal distribution. From this point onwards, the model is the same as the previous one.

c) The "Low bidder" model, which uses a single normal distribution formed of the lowest bidders' bid ratios to predict the probability of winning. Otherwise it is the same as the two previous models.

d) The OPBID model (25), as described in Section 7.5.

Data on 50 previous jobs was used. Information on each tender included the contractor's cost estimate and all the bids submitted, together with the (fictitious) identities of the bidders. The contractor's tender price was included as well.

The authors used each of the models in different ways. The low-bidder model was used with the lowest, second lowest and third lowest bids on each tender, both including and excluding the contractor's own bids. Furthermore, different amounts of input were used - all the previous jobs, only the 40 immediately preceding jobs, only the 30, only the 20 and only the 10 previous jobs. The One-distribution and Multidistribution models were both used without considering the contractor's own bids, and they were also used with varying amounts of information as with the low-bidder models. The OPBID model was used with different key competitor factors.

Using each of these models on each of the past jobs in turn (the data had been kept in chronological order), the authors calculated the number of times the contractor would have been the lowest bidder if he had used a particular model, the number of times he would have been the second lowest bidder, the profit margin as a percentage that he would have made and the volume of work that he would have undertaken. They then used these results to establish a "lower" and an "upper bound" for the contractor to base his bid on. These were limits, somewhere between which the contractor should bid, depending on his own subjective appraisal of his competitive situation.

Shaffer and Michaeu set the lower bound as the price obtained from the model which yielded the highest number of lowest bids and the greatest monetary volume of work. The upper bound to the bidding was the price obtained from the model giving the second lowest bid most often, as well as the highest profit margin.

Their conclusion was that the lower bound was given by the low-bidder model using information from the 40 immediately preceding jobs. The second lowest prices were used and the contractor's own bids were included. The upper bound was given by the low-bidder model using the third lowest bids on the 20 immediately preceding jobs. The contractor's own bids were again included.

Shaffer and Michaeu then tested these models on four more tenders simultaneously with the contractor who bid on them using his usual informal method. The model yielded the low bid twice and came second on the remaining two tenders. In actual fact, for these four tenders, both upper and lower bounds were the same, and so no subjective decision had to be made by the contractor. If the two bounds are able to coincide, the present writer wonders whether the upper bound model chosen in this way might not in some cases yield a lower bid price than the lower bound model.

In fact, the authors seem to have disregarded theoretical considerations altogether in their choice of models - an unwise thing to do when dealing with operations research techniques.

Firstly, the inclusion of the contractor's own bids as data input for the models seems theoretically unjustifiable. The present author is of the opinion that the contractor's main purpose is to beat his opposition. The inclusion of his own bids in determining his probability of winning seems to be unduly conservative. He does not have to beat himself as well.

Also, the present author considers that the use of the second and third lowest bids in drawing up distributions to determine the optimal bid will in the long run yield the bid that is most likely to be the second or the third lowest. The use of this bid seems little more than a "formally informal" method of choosing the optimal price.

Finally, the use of such small numbers of data in chronologically using data only from the jobs that have preceded the tender under consideration will cause very unstable probabilities of winning as the process continues. This instability will be most apparent at the beginning. The present writer's observations of such a process are presented in Section 8.6.

Probability distributions are notoriously dependent for their accuracy on the number of data used as input. Little confidence can be placed in those distributions using as few as 10 or 15 pieces of information. In fact, the mean and standard deviations of the ratios of the lowest prices to the contractor's cost estimates were respectively 100,6% and 6,4%. Using all 50 lowest ratios, at the 10% level the confidence interval for the mean was ± 1,5%. This means that the mean was anywhere between 99,1% and 102,1%, and this could conceivably have a noticeable effect on the optimum bid prediction.

The present writer has studied this particular problem and his work appears later (Section 8.3).

CHAPTER 8 - ANALYSES MADE BY THE PRESENT WRITER

Section 8.1 - Criteria on which to Base the Optimal Bid :

When a contractor submits a tender price, he might adopt one of several possible strategies. Gates (14) has given a comprehensive list and his mathematical strategies have been described and discussed in Chapter 7. The other strategies which he listed are as follows :

a) Collusion among the competing contractors to control the price and to decide on who is to be awarded the contract;
b) Collusion between a contractor and the owner's representative to give the contractor information not available to the other tenderers, thus enabling him to lower his tender price;
c) "Tieing up" of all economical sources of material for the project by buying or leasing quarries, brickfields, etc.,
d) Finding a way to make money from waste materials such as excess excavation resulting from the job;
e) Guaranteeing to purchase vital materials or equipment from certain suppliers if they quote higher prices to the other contractors tendering;
f) Including the price of some items in the tender at below cost and then sub-contracting them out to an inexperienced businessman at this price after the tender has been won;
g) Sending the other competitors alterations to the tender documents on the owner's letter-head to cause them to raise their bids;
h) Where no borings have been made on the site, digging test

pits and adding rock or water to make the sub-soil conditions appear more difficult then they are.

Gates himself remarks that:"Not all (these strategies) are ethical or even legal", which is indeed an understatement. However, they do have one essential point in common; namely that the contractor is endeavouring to maximise his profit should he be awarded the contract.

The concept of profit bears elaboration. Accountants define it as the "excess of revenue over expenditure" (1a) and this may be more simply explained as the difference between the amount of money paid for a product or service and the amount used to produce it. However most investors are interested in the profit yielded by the amount of capital used. It is the percentage yield that is important. Therefore in this chapter, the term profit will be used to mean the percentage profit.

Most workers in the field of competitive bidding adopt the profit as a percentage of the total cost estimate of the project, including all overhead costs. Strictly speaking though, the profit percentage should be based on the money that is invested in the contract in the form of plant, working capital, and often retention money. After the initial setting up stage, certificates of payment start being issued and the money received is used to cover further expenses such as wages, etc. Therefore, the total cost of the contract actually far exceeds the capital investment made by the contractor.

Hence if the profit is calculated as a percentage of the total cost of the project, it will be considerably smaller than if it had been based on the actual amount of the contractor's money tied up in the contract.

This is a subtle point and is one that has been universally overlooked in the literature up to the present time. In fact it makes no difference to the optimal bid values predicted by the models that have been proposed (see Chapter 7). This is because the two values differ by a multiplying factor :

$$\frac{\text{profit}}{\text{capital invested}} = \frac{\text{profit}}{\text{cost estimate}} \times \frac{\text{cost estimate}}{\text{capital invested}} \qquad \ldots\ldots(8.1.1)$$

In other words, the bid that is optimal when considering the profit based on the capital invested will be the same as the optimal bid from the point of view of the profit based on the total cost estimate. Only the two profit values will be different.

It follows that comparison between optimal bidding techniques are meaningful if based on the profit calculated as a percentage of the total cost estimates of all the work undertaken (i.e. contracts won).

As explained in Chapter 7, bidding models up to the present time all concentrate on optimizing the expected values of the profit or utility associated with the bid values. The expected value concept has been explained in section 6.2. The expected profit associated with a given bid is the product of the actual profit that would be made if the bid was successful and the probability of that bid being successful, i.e. of the contract being awarded. Similarly, the expected utility is the probability of winning the contract with a particular bid times the utility to the contractor of being awarded the contract at that bid price. The concept of utility is expanded upon below and in Appendix E.

There are many factors that influence the amount of profit for which a contractor considers a particular contract to be a fair undertaking by his company. These have been described in detail in Part 1 of this thesis. Certainly, the amount of profit to be won is seldom the only consideration when deciding on the final tender price. It is here that utility theory might be used to advantage, though there are undeniable practical difficulties in its useful application by a contractor.

Formal utility theory is briefly described in Appendix E of this thesis, and so the present discussion will be confined to a more practical and possibly more meaningful description for the non-specialist in decision theory.

For our present purposes, a utility function may be described as a relationship between the monetary profit that would result from undertaking a contract and the (probably non-monetary) value or utility of that profit amount to the contractor. Naturally, this function will be different for different contractors, different types of work, different times of the year, etc., and it will alter together with the contractor's work load, financial position, the availability of labour and many other factors enumerated in Appendix A.

Figure 8.1.1 shows a sketch of a possible utility function for a contractor tendering for a construction contract.

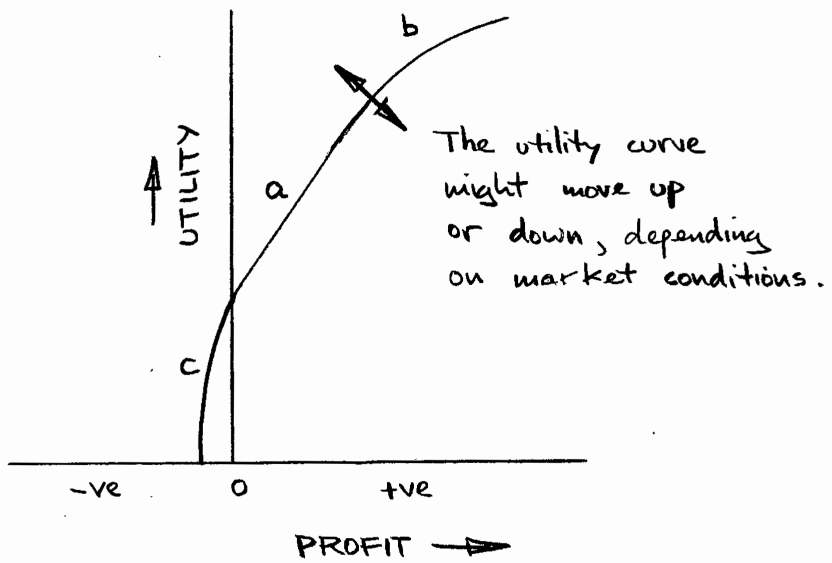


Figure 8.1.1 - Utility Curve

The first point to be noticed is that a bid yielding zero profit has a positive utility value, i.e. is of use to the contractor. The present writer considers this generally to be the case as the contractor will at least be contributing towards his overhead costs (assuming that they have been included in his cost estimate, as they should have been). Furthermore, by winning the contract, he will have secure employment for his resources. This is an important consideration when work is scarce, but as the market changes to one in which there are many work opportunities, so the utility value of zero profit will drop. The stage might even be reached when a small positive profit will have zero utility to the contractor. The important point is that each project that comes up for tender will have a different utility curve for the contractor.

At section a of the curve shown in figure 8.1.1, the utility generally increases in a direct proportion to the profit amount, however as this amount increases, the slope of the utility curve tends to drop as shown at section b. This is caused by the difference between profits of 29 and 30 percent, say, being less important to the contractor then the difference between profits of 3 and 4 percent. These utility differences do of course vary with the conditions surrounding the tender, and once again this highlights the fact that the curve will be different for each tender and for each contractor.

At section c of the curve the slope steepens appreciably. Technically, this is termed "risk aversion" (from the way in which the curve is evaluated in practice). As the profit becomes more and more negative, the contractor has increasingly less utility for it. There is generally a profit allowance below which the contractor will not undertake the work. This value is said to have zero utility to the contractor. Should the contractor attach positive utility values to negative profit values (i.e. he is willing to undertake the contract at a loss - possibly to keep production going) he will usually be less concerned with differences between -1 and -2 percent say, than with differences between -9 and -10 percent. A 10 percent loss could deal a crippling blow to his company. Hence the curve tends to dip more sharply as the profit values become more and more negative.

As pointed out previously, such a utility curve is exceedingly difficult to draw up in practice. The method generally used is to pose a series of questions to the contractor when the cost estimate has been prepared and from his answers, the curve is constructed. The present writer feels that most local contractors would lack the patience to answer such a set of questions before each tender price is submitted and would rather make a subjective appraisal of their best bid for the contract. Furthermore it has been impossible to attempt a practical trial of this method under business conditions. However one trial was performed, though not in a contracting context, and it is described in Appendix E.

A possible set of questions that might be put to the contractor are listed below.

a) What percentage of your cost estimate would you pay for the privilege of bidding for this contract if you knew for certain that a price including a 50% profit margin had a 50:50 chance of winning this contract? Imagine you lose nothing if you don't get the contract.

b) Imagine that you are to be awarded the contract under the following conditions. There are two possible outcomes - either you make 50% profit, or else the contract costs a certain amount more than your tender price, and so you lose. If these outcomes are equally likely to happen, what percentage of the cost estimate would you be prepared to lose under these probability conditions?

c) What percentage of your cost estimate would you be prepared to pay for the privilege of bidding if you knew for certain that you would be awarded the contract under the following conditions? Either you make 50% profit or else you make the percentage you gave as answer to question (a). Each of these outcomes has a 50:50 chance of occurring.

d) Now what percentage of your cost estimate would you pay for the privilege of tendering when you knew for certain that your price would either win the contract giving you a percentage profit equal to your answer to question (a), or else would not win the contract, both outcomes being equally likely to happen?

e) What percentage of your cost estimate would you have to be paid to tender a bid when only the following two outcomes were equally likely to happen? Either you make zero profit on the work, or else you lose a percentage equal to your answer to question (b).

f) Finally, if you had to pay 50% of your cost estimate just to be allowed to submit a tender, and once again there was a 50:50 chance of your either being awarded the contract and making a certain percentage profit x, or else of not being awarded the contract and losing only the 50% of the cost estimate you paid to tender, what percentage profit x would make such a situation worhtwhile for you?

These questions are extraordinarily cumbersome and would obviously try the patience of the most enlightened contractor. Also they are very difficult to simplify without making them appear somewhat frivolous. These are overwhelming practical difficulties.

The reader will appreciate that another approach to this problem is for the contractor to quantify all the abstract factors affecting his tender decision in monetary terms and to include these in his cost estimate. Once again, this would usually be a lengthly and difficult task in practice. Indeed, utility theory was developed to avoid having to do this. However, the present writer is of the opinion that there are certain circumstances when the contractor can successfully apply subjective alterations to his cost estimate and hence avoid the utility function rigmarole.

In the remainder of this chapter, the bidding techniques developed are based on the optimization of expected profit values rather than expected utility values. This is because meaningful utility values were unobtainable by the present writer and so comparative evaluations of the models would have been impossible. However, the models developed may be easily adapted to handle utility functions.

The expected profit value criterion is open to criticism from the point of view of its use in making a decision about a single tender. The size and nature of the contract together with all the relevant factors affecting it will never be exactly duplicated again. Hence, the use of an expected value is open to attack, being as it is, an "average" value. The reader is referred to Section 6.2 for a detailed discussion of the expected value concept.

However, the models described in Chapter 7 and developed later in this chapter all use data from past tenders in evaluating the expected value of the profit resulting from a particular bid. This means that the "average" is based on contracts which are all individually different to a greater and lesser extent. In other words, the expected profits used are the average profits that will be made in the long run on contracts of different size, nature, etc. Hence the situation is incorrectly viewed as being unique (i.e. never to be repeated), and the use of expected profits (or utilities) is justified.

Finally, as pointed out by Friedman (12) and described in Section 7.1, the cost estimate is itself a random variable. This means that the contract might be won with a bid including a healthy profit margin on the contractor's cost estimate, and yet he might still lose money on the job if his estimate has been too low. This uncertainty in the cost estimate should be considered when evaluating the expected profit, and this may be done by means of the following equation :

$$E = P(win)\ (b - c^1) \qquad \ldots\ldots(8.1.2)$$

where E is the expected profit

P(win) is the probability of winning with bid b

c^1 is the most likely cost.

The practical difficulty lies in determining c^1. Benjamin (4) has suggested three methods and these are described in Section 7.6. The present writer favours the use of the beta distribution as used in PERT network analysis to evaluate the probability of completing a project by a certain date.

For each item on the bill of quantities three costs are given - the most likely, the most optimistic (lowest) and the most pessimistic (highest). Naturally, it is probable that these three prices will coincide if the cost of the item is known with certainty. If m, a and b are these costs respectively, the expected cost (c) for that item is given as :

$$c = \frac{a + 4m + b}{6} \qquad .....(8.1.3)$$

The reader is referred to Richmond (35) or any PERT computer package manual for justification of this equation.

The total cost estimate is then given by the sum of the expected costs of each bill item given by equation 8.1.3, and this total amount is substituted for c^1 in equation 8.1.2.

This method does have the advantage that the estimator will have to consider carefully the possible variations in price of an item, and this closer attention should improve his approach to estimating in general.

Unfortunately no data was available to the present writer and so this point was persued no further.

Section 8.2 - The Probability of Submitting the Lowest Tender Bid :

In the previous section it was decided to choose the bid amount which yielded the maximum expected profit value - the product of the bid and the cost multiplied by the probability of winning the contract with that bid.

In this section, a method of evaluating the probability of winning the contract will be developed.

The methods described in Chapter 7 all used distributions of the ratios of an opponent's bid to the contractor's cost estimate on past tenders. From these distributions, the probability of beating any particular opponent could be evaluated, and this was described in Section 7.1.

However, the authors differed on how the probabilities of beating individual competitors could be combined to give the probability of winning the contract - i.e. being the lowest bidder. Friedman (12) suggested that it be given by the product of the probabilities of beating each individual opponent, while Gates (14) proposed a formula connecting the different probabilities.

Friedman's formula is illustrated by figure 8.2.1. This figure diagramatically represents a competition between three

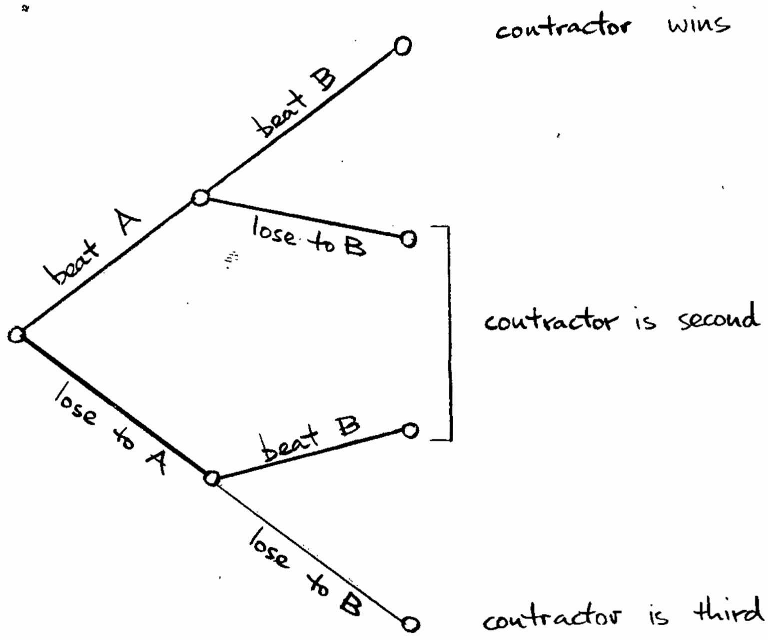


Figure 8.2.1 - Proability Tree (1)

tenderers for a construction contract. They are denoted by "the contractor", A and B. It is seen that for the contractor to win, he will have to bid lower than both A and B. This means that the probability of him winning will be

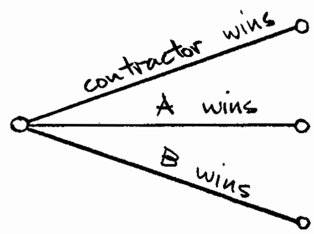
$$P(win) = P(A)\,P(B) \qquad .....(8.2.1)$$

Where P(A) and P(B) are the probabilities of beating competitors A and B respectively. These probabilities are assumed to be independent of each other - i.e. whether the contractor has beaten competitor A or not had no bearing on the probability of his beating competitor B.

The fallacy in this representation of the situation is that the contractor is considered to compete first against Competitor A and then against competitor B, or else the other way around.

If the analogy is drawn with taking coloured balls out of an urn, each competitor having a different amount of balls of a particular colour representing his chance of beating the others this representation means that there are two urns - one representing his probability of beating competitor A and one that of beating competitor B. To win the contract his coloured balls have to be drawn out of both urns simultaneously.

The competitive situation should rather be described by one urn with different amounts of differently coloured balls representing the probabilities of each competitor winning the contract. Only one ball is drawn to decide the winner. This is represented in figure 8.2.2.



w = prob. that contractor wins

a = prob. that A wins

b = prob. that B wins

Figure 8.2.2 - Probability Tree (2)

If the probabilities that the contractor, A and B win are respectively w, a and b, and if P(A) and P(B) are the probabilities that the contractor beats competitors A and B respectively we have the following equations :

$$w + a + b = 1 \quad .....(8.2.2)$$

$$P(A) = \frac{w}{w + a} \quad .....(8.2.3)$$

$$P(B) = \frac{w}{w + b} \quad .....(8.2.4)$$

Equations (8.2.3 and (8.2.4) are both given by Baye's Rule, a fundamental probability theorem. They may also be seen intuitively by means of figure 8.2.2.

These equations may be combined into the form :

$$w \left(1 + \frac{1 - P(A)}{P(A)} + \frac{1 - P(B)}{P(B)} \right) = 1 \quad .....(8.2.5)$$

and if w is replaced by the previously used notation P(win), we have :

$$P(win) = \frac{1}{1 + \frac{1-P(A)}{P(A)} + \frac{1-P(B)}{P(B)}} \quad .....(8.2.6)$$

This equation may readily be expanded to cover the case of any number of competitors, and is the formula used without derivation by Gates (14).

This is the formula used throughout this chapter as representing the probability of beating any number of competitors.

Section 8.3 - The Distribution of Historical Bidding Data :

In Section 7.1 it was remarked that Friedman (12) had proposed that the ratios between an opponent's bid and the contractor's cost estimate for past contracts were gamma distributed. The present writer disputes this, and in this section it will be shown that the Normal distribution adequately describes these ratios.

This is theoretically justified by the Central Limit Theorem of Statistics. Benjamin and Cornell (3a) state it as follows :

> "Under very general conditions, as the number of variables in the sum becomes large, the distribution of the sum of random variables will approach the normal distribution".

It seems reasonable to assume that the ratio of a competitor's bid to the contractor's cost estimate is made up of the sum of a large number of random variables. This is because the final cost estimate is made up of the sum of the estimates of the cost of each of the bill items. Therefore the use of the normal distribution to describe the bid ratios seems justified.

In support of this assumption, the present writer plotted the cumulative relative frequencies of several sets of data on normal probability paper. It was found that straight lines resulted, thus justifying the use of the normal distribution.

Normal probability paper is a special graph paper on which the ordinates are scaled in such a way that the normal cumulative distribution function plots as a straight line. Hence if the cumulative frequency polygon (or ogive) of the data is plotted on this paper, and turns out to be a straight line, it may be deduced that the data is normally distributed. Furthermore, the mean and standard deviation may be read directly from the plot.

The data is prepared for plotting by first of all ranking the data from lowest to highest. The ordinate to be plotted on the paper is then calculated for each piece of data. It is given by :

$$\frac{2n - 1}{2m} \qquad .....(8.3.1)$$

where n is the rank of the data point and m is the total number of data points. This value corresponds to the centre of the cumulative frequency polygon "step" occurring at the data value. This will be clarified by referring to figure 8.3.1.

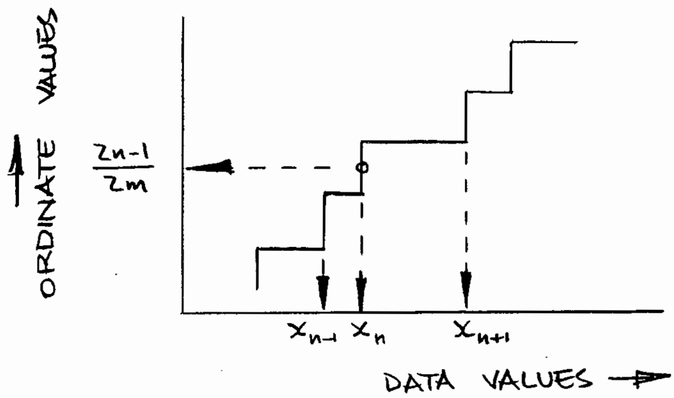


Figure 8.3.1 - Cumulative Frequency Polygon

Another advantage of the use of probability paper is the ease with which the Kolmogorov-Smirnov goodness of fit test may be performed. This test compares the largest difference between the theoretical (normal in this case) and the observed cumulative frequency functions with a tabulated statistic. If the largest observed difference is less than the tabulated statistic, the data is assumed to conform to the theoretical distribution at the confidence level for which the statistic was tabulated.

If the straight line best fitting the data is plotted on the probability paper, the confidence limits may easily be plotted relative to it, and any points lying outside these limits may be seen at a glance.

The reader is referred to Benjamin and Cornell (3a) for a more complete discussion of this and other statistical topics.

The following three sets of data (listed in Appendix K) are plotted in figures 8.3.2 to 8.3.4.

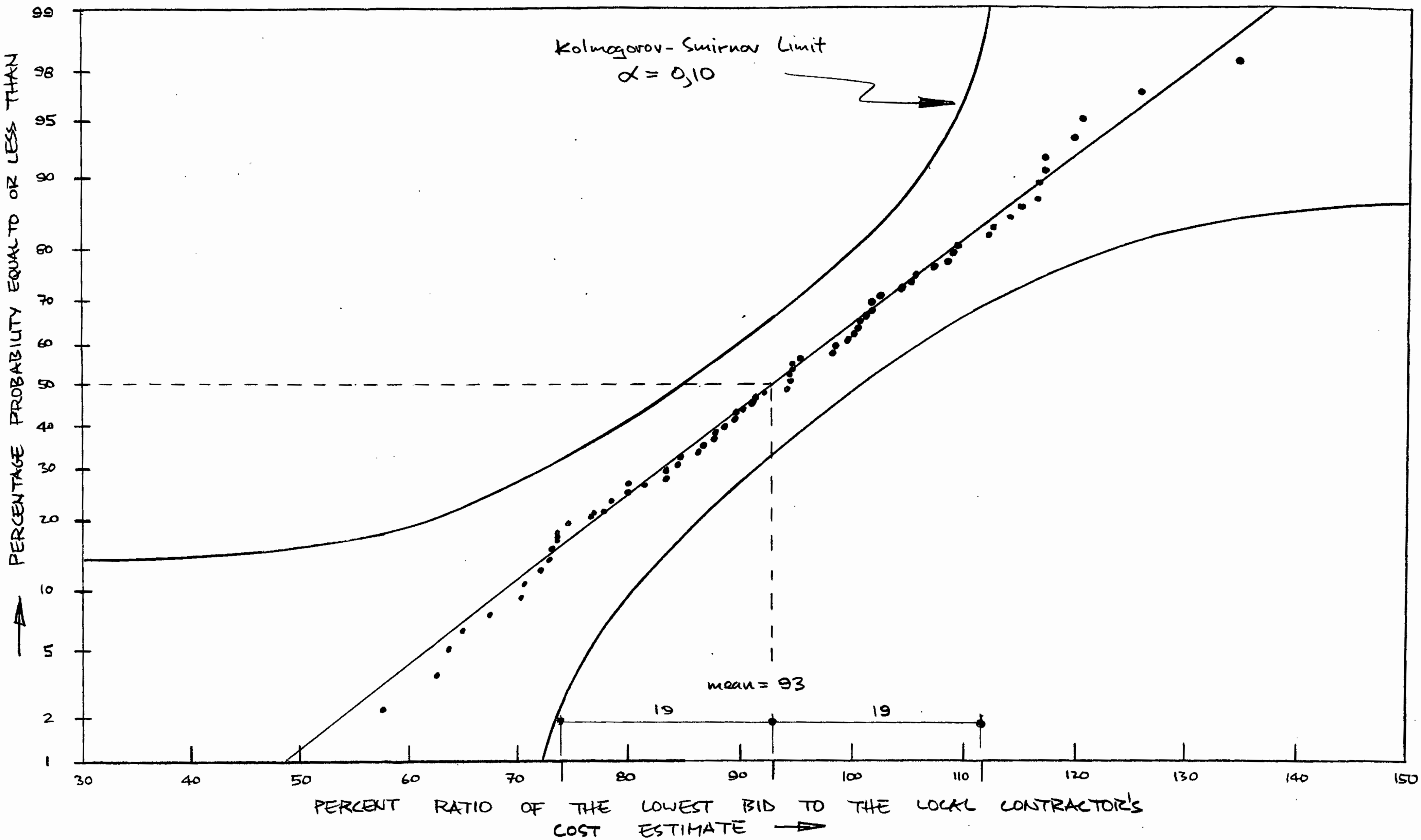

Kolmogorov-Smirnov Limit
α = 0,10
mean = 93
19
19
PERCENTAGE PROBABILITY EQUAL TO OR LESS THAN
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
30
40
50
60
70
80
90
100
110
120
130
140
150
PERCENT RATIO OF THE LOWEST BID TO THE LOCAL CONTRACTOR'S COST ESTIMATE

Figure 8.3.2

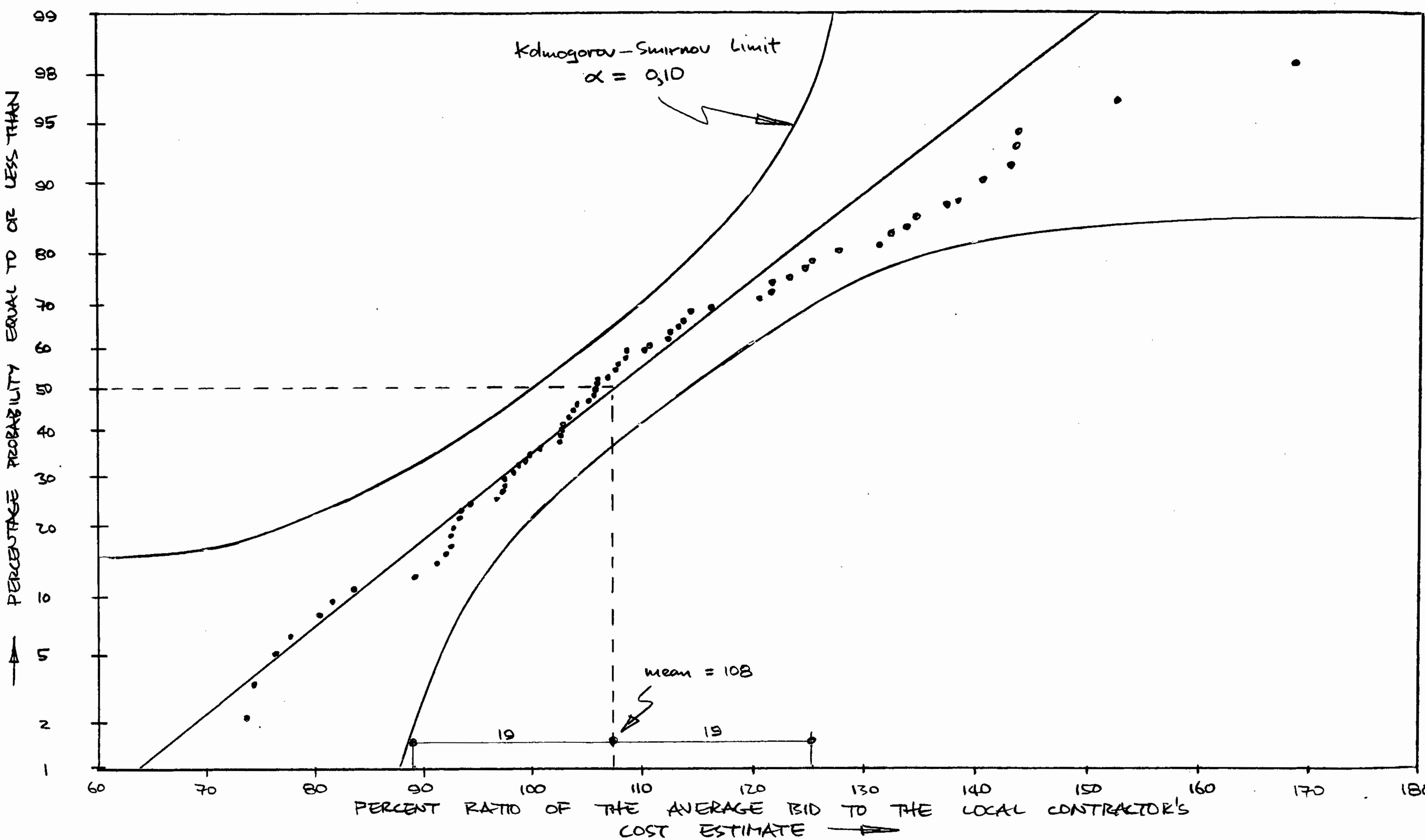

Kolmogorov – Smirnov Limit
α = 0,10
mean = 108
19
19
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
60
70
80
90
100
110
120
130
140
150
160
170
180
PERCENTAGE PROBABILITY EQUAL TO OR LESS THAN
PERCENT RATIO OF THE AVERAGE BID TO THE LOCAL CONTRACTOR'S COST ESTIMATE

Figure 8.3.3

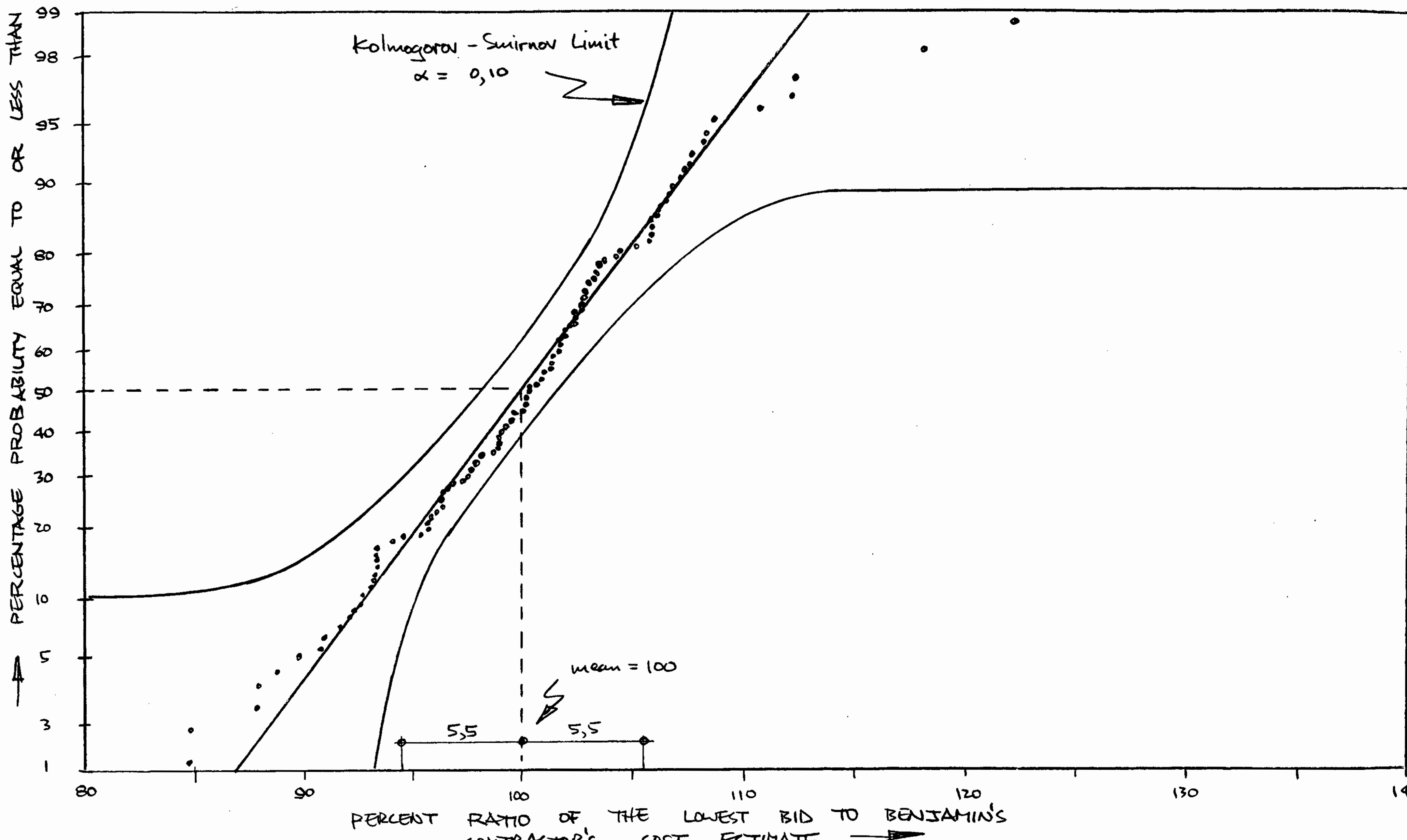

Kolmogorov - Smirnov Limit
α = 0,10
mean = 100
5,5
5,5
PERCENTAGE PROBABILITY EQUAL TO OR LESS THAN
99
98
95
90
80
70
60
50
40
30
20
10
5
3
1
80
90
100
110
120
130
140
PERCENT RATIO OF THE LOWEST BID TO BENJAMIN'S CONTRACTOR'S COST ESTIMATE

Figure 8.3.4

a) The ratios of the lowest bids to the contractor's cost estimates from historical data on 70 tenders supplied by a local contractor.

b) The ratios of the average of the bids to the contractor's cost estimate on each of the above tenders.

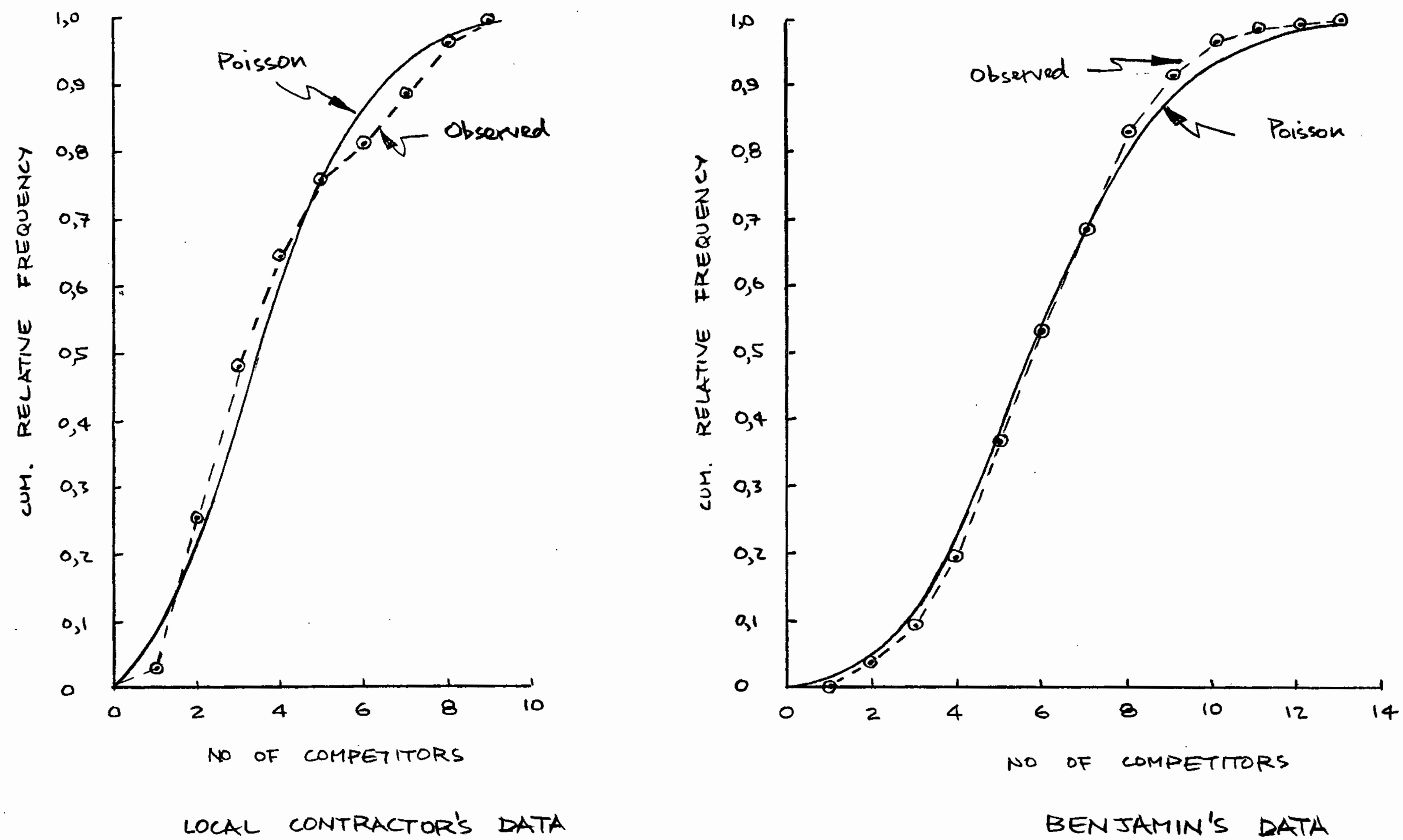
c) The lowest bid ratios of a set of data on 130 tenders listed by Benjamin (4).

Without exception, all of these sets of data conform to the normal distribution. It is therefore assumed in the remainder of this thesis that the ratios of any opponent's bid to a contractor's cost estimate are normally distributed.

The present writer also examined the distribution of the number of competitors met on each contract for the above sets of data. Tables 8.3.1 and 8.3.2 list the results of the Kolmogorov-Smirnov goodness of fit test based on the assumption that the numbers of competitors were Poisson distributed. The results are presented graphically in figure 8.3.5.

For the contractor's data, the maximum difference was 0,088 while the critical K.G. statistic was 0,146; and for Benjamin's data the maximum difference was 0,038 while the K.G. statistic was 0,107.

Both of the Kolmogorov-Smirnov statistics were given at the 10% confidence level. This means that the data fitted the Poisson Model exceptionally well.



CUM. RELATIVE FREQUENCY
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Poisson
Observed
0
2
4
6
8
10
NO OF COMPETITORS
LOCAL CONTRACTOR'S DATA
CUM. RELATIVE FREQUENCY
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Observed
Poisson
0
2
4
6
8
10
12
14
NO OF COMPETITORS
BENJAMIN'S DATA

Figure 8.3.5

Table 8.3.1 - Contractor's Data (Mean = 4,17)

No. of Competitors	Actual Freq.	Cum. Freq.	Cum.Rel. Freq.	Poisson Cum.Freq.	Max. Difference
1	2	2	0,029	0,080	
2	16	18	0,257	0,212	
3	16	34	0,486	0,398	0,088
4	11	45	0,643	0,591	
5	8	53	0,757	0,757	
6	4	57	0,814	0,870	
7	5	62	0,889	0,938	
8	6	68	0,971	0,970	
9	2	70	1,000	0,989	

Table 8.3.2 - Benjamin's Data (Mean = 6,40)

No. of Competitors	Actual Freq.	Cum. Freq.	Cum.Rel. Freq.	Poisson Cum.Freq.	Max. Difference
1	0	0	0	0,012	
2	5	5	0,039	0,044	
3	7	12	0,092	0,118	
4	13	25	0,192	0,230	0,038
5	23	48	0,369	0,370	
6	21	69	0,530	0,530	
7	21	90	0,692	0,677	
8	18	108	0,830	0,795	
9	11	119	0,915	0,880	
10	7	126	0,969	0,935	
11	2	128	0,985	0,968	
12	1	129	0,992	0,984	
13	1	130	1,000	0,993	

Section 8.4 - The Concept of "Spread" and Results Achieved

In Section 7.2 reference was made to a paper published by Gates (15) in which that author examined the relationship between the lowest price tendered for a construction contract and the difference between this price and the second lowest price. Gates termed this monetary difference the "spread".

This method by Gates has been described in detail, and with one notable difference, the present writer performed the same calculations on local data.

Information was obtained from tender results published in the journal "Construction in Southern Africa" from June 1966 until August 1971.

Data on contracts of a civil engineering nature was carefully separated from that concerning building projects. The former category was taken to include earthworks, pipelines, roads and bridges, while housing schemes, blocks of flats, offices and industrial buildings fell into the second category. Maintenance work was excluded from both these groups, but major alterations were included among the contracts listed.

The contracts were also grouped according to the areas in which they were situated. The two regions considered were the Cape Peninsula and the Eastern Cape. This latter region was taken to include Port Elizabeth, Uitenhage and Grahamstown, and the areas surrounding these towns. These regions were chosen because of their familiarity to the present writer.

Each item of data used is listed in Appendix K of this thesis.

After being separated into four groups according to job type and location, the contracts were split into sections according to the lowest tender bid. The limits of these sections were chosen to conform approximately to the geometric progression 2^n where n is the group number. However, some sections were combined to contain at least 10 items of data. The section limits are listed in table 8.4.1.

The geometric mean was then taken of the lowest prices and the spreads in each section. The geometric mean was chosen for reasons that will become apparent as the analysis proceeds.

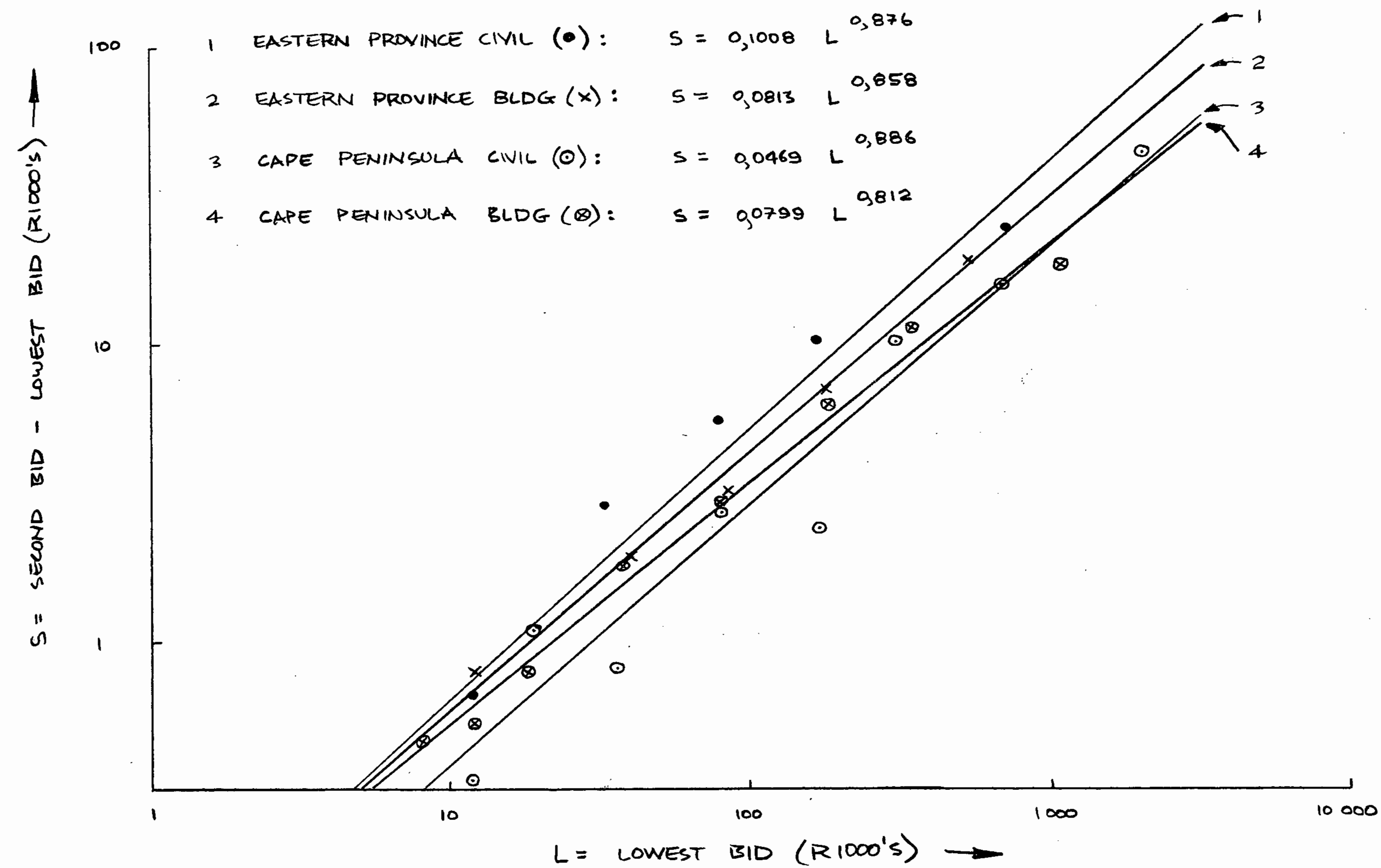
The results shown in table 8.4.1 omit any contracts on which the spread was greater than twenty percent of the lowest bid. This was done because the lowest bidders on contracts with spreads larger than this were generally contractors whose names appeared only once or twice in the tender results published by "Construction in Southern Africa". From this it was deduced that these were contractors of little or no experience who were probably not awarded the contracts in any case. Approximately 10% of the total number of the listed contracts were omitted in this way.

The results are plotted in figure 8.4.1. It was seen that the results plotted linearly when logorithmic scales were used.

This use of logarithmic rather than arithmetic scales was the reason for initially taking the geometric mean of the lowest bids and spreads falling in each group.

Table 8.4.1 - Spread Analysis Results

Job Type and location	Low Bid Group limits (R1000's)	G.Mean Low Bid (R1000's)	G.Mean Spread (R1000's)	No Jobs in Group
Civil engineering Cape Peninsula	1 - 15	10,17	0,33	9
	15 - 25	19,64	1,10	8
	25 - 50	35,97	0,80	20
	50 - 125	79,74	2,67	34
	125 - 250	175,09	2,40	24
	250 - 500	309,42	10,03	16
	500 - 1000	679,14	15,65	15
	1000 - 8000	1988,08	43,34	8
Building Cape Peninsula	1 - 10	8,11	0,45	13
	10 - 15	12,19	0,51	13
	15 - 25	18,25	0,78	14
	25 - 50	37,18	1,76	22
	50 - 125	79,28	2,86	35
	125 - 250	181,71	6,10	47
	250 - 500	348,71	11,36	29
	500 - 8000	1076,75	17,87	21
Civil engineering Eastern Province	1 - 25	12,13	0,66	9
	25 - 50	32,38	2,85	10
	50 - 125	79,02	5,41	24
	125 - 250	164,81	10,03	18
	250 - 8000	709,72	24,31	15
Building Eastern Province	1 - 25	12,30	0,79	6
	25 - 50	40,00	1,84	12
	50 - 125	84,04	3,12	27
	125 - 250	175,59	6,92	16
	250 - 8000	531,37	18,67	16



1 EASTERN PROVINCE CIVIL (●): S = 0,1008 L 0,876
2 EASTERN PROVINCE BLDG (×): S = 0,0813 L 0,858
3 CAPE PENINSULA CIVIL (⊙): S = 0,0469 L 0,886
4 CAPE PENINSULA BLDG (⊗): S = 0,0799 L 0,812
S = SECOND BID - LOWEST BID (R1000's)
100
10
1
1
10
100
1 000
10 000
L = LOWEST BID (R1000's)
1
2
3
4

Figure 8.4.1

The regression lines corresponding to each set of data points were obtained by the least-squares method of curve fitting. The computer program used is listed in Appendix L of this thesis.

Since no significant difference between the four lines was apparent, a regression was then performed on all of the data points disregarding both location and job type. The resulting equation is

$$S = 0{,}0745 \; L^{0{,}854} \qquad .....(8.4.1)$$

where S is the spread (difference between the second and the lowest bids) and L is the lowest bid. S and L are given in units of 1000 Rand. This equation plots as a straight line when logarithmic scales are used for both axes.

The present writer then adopted a common assumption when dealing with regression analysis. This assumption concerns the random distribution of the logarithm of the actual spreads corresponding to the logarithm of a given low bid value (see figure 8.4.2). The mean of this distribution is given as a (linear) function of the log of the low bid value. This function is the regression equation.

Furthermore, the distribution of the logs of the spreads about this mean is assumed normal with a constant standard deviation. Reference to figure 8.4.2 will help to clarify this point.

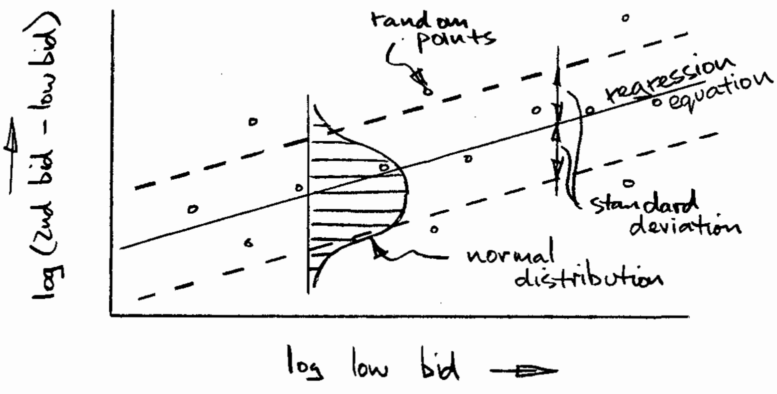


Figure 8.4.2 - Assumed distribution

For each individual value of the logarithm of the low bid, the logarithm of the spread has the distribution sketched in figure 8.4.2.

It should be noted that this distribution is only normal because of the linearity of the regression equation. This is why logarithmic values were used.

The present writer found the above standard deviation to be 0,65256.

A series of lines was then drawn parallel to the regression line. They were each drawn a given number of standard deviations away so that the probability of the spread being greater than or equal to the amount given by that line would be a particular percentage. The calculations were based on tabulated cumulative values of the normal distribution. The chart is presented in figure 8.4.3.

NOTE: The lines represent the chances out of 100 of the spread (S) being greater than or equal to the amount given by the regression equation:

$$S = 0{,}0745 \quad L^{0{,}854}$$

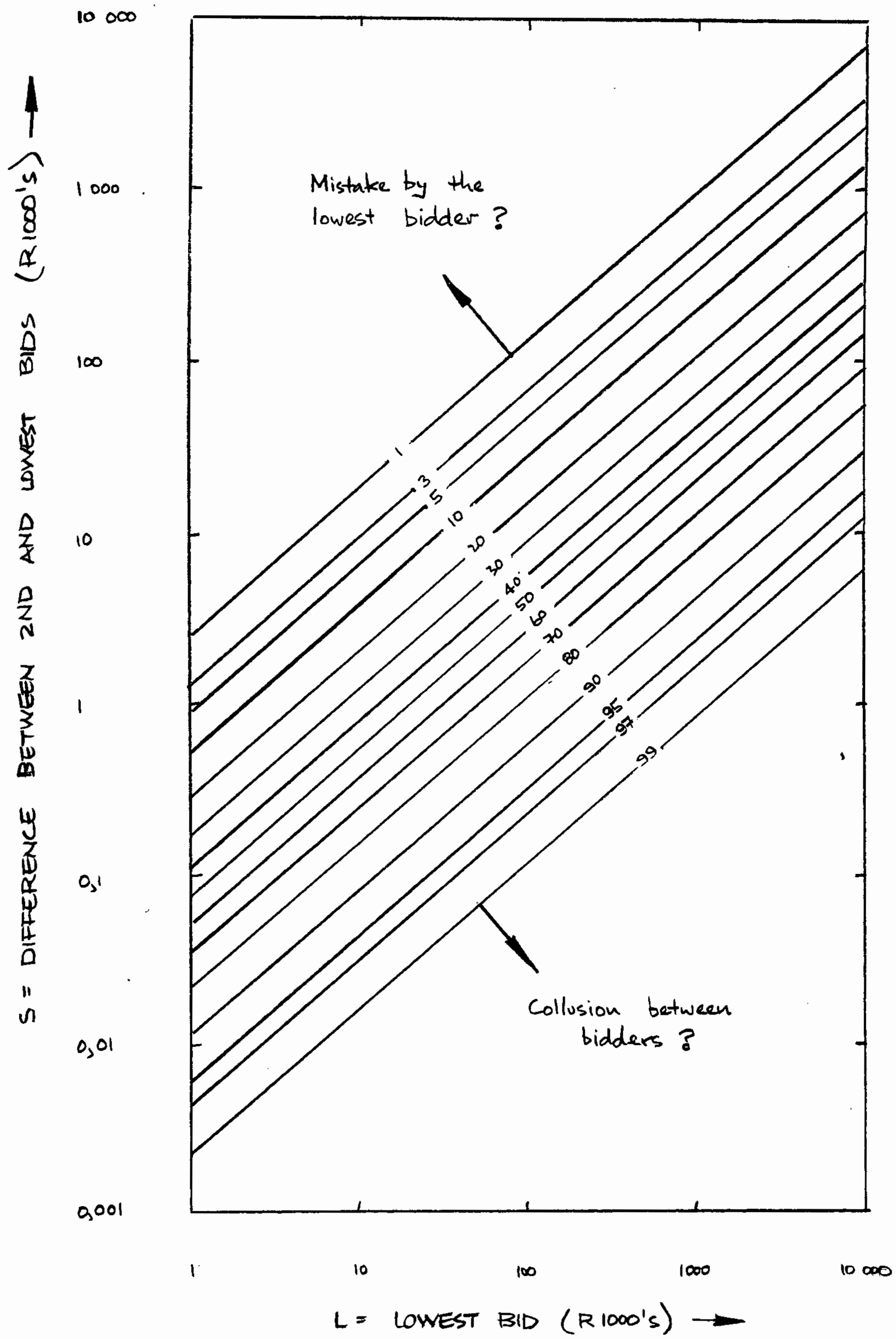


Figure 8.4.3

Gates did not use the normal distribution in his analysis, but rather calculated the probabilities from his observed cumulative distribution of the spread values about the regression line. Reference to figure 8.4.1 convinced the present writer that no bias was apparent in the total distribution of all the spread values used and that the normal distribution was a reasonable assumption to make.

The reader is referred to Section 7.2 where possible uses for this type of chart were enumerated. The present writer considered that its best use was in determining whether the lowest bidder had made a mistake.

Because 10% of the listed contracts were discarded by the present writer as having spreads greater than 20% of the lowest bid, the present writer is of the opinion that spread amounts having a probability occurring of less than or equal to 1% should be considered significantly large or small. Gates used the 3% limit, but very few of the contracts which that author considered had spread amounts greater than 20% of the lowest bid.

As explained in Section 7.2, if the spread amount was so large that there was less than a 1% chance of it being that size, the lowest bidder should be regarded as having made a mistake, and should be given the opportunity of withdrawing his bid.

Alternatively, if the spread amount was so small that there was less than a 1% chance of it being that amount, collusion should be suspected amongst the bidders, and appropriate action should be taken by the promotor.

This subject is dealt with in detail in Section 7.2.

Section 8.5 - The Use of Simulation to Compare Three Optimum Bidding Techniques :

8.5.1 - Introduction.. An artifical tendering situation was stimulated on the computer wherein four "contractors" competed against each other for the award of a large number of "contracts".

Each of the "contractors" was considered to be using a different bidding technique, each of which is described below. The Monte Carlo technique was adopted in that each imaginary contractor was assgiend a semi-random cost estimate of the project. These costs were drawn from normal distributions, bearing in mind the results of market analyses given in Section 8.3. These normal distributions were given a common mean of 100 and had different standard deviations. A pseudo random number generator was used to draw values from the distributions and this method is described in Appendix G. Different standard deviations were used to study their effect on the bidding patterns produced by the techniques.

8.5.2 - Models Used. Three of the optimal bidding techniques used were based on the method of maximising the expected profit value, but each used a different way of predicting the probability of winning the contract. The fourth technique was one suggested by Gates (15) and described in Section 7.2, but which the present writer has rejected as being indefensible. The reasons for this were set out in Section 7.2.

There follows a more detailed description of the techniques.

a) The first technique used the probability of winning the contract as the probability of bidding lower than the lowest other competitor. A distribution of the ratio between the lowest other bid and the contractor's cost estimate was set up from historical data as suggested by Friedman (12) and described in Section 7.1 of this thesis. The technique then consisted of a method of choosing the percentage profit allowance which yielded the optimum expected profit value.

b) The second technique was similar to the first, but the probability of winning the contract was considered to be the product of the probabilities of bidding lower than each of the other competitors. In Section 8.2 it was shown that this method lacked theoretical justification, but it is included in the comparison to observe the effect is using a conservative estimate of the probability of winning the contract. It is reasonable to suppose that this method would yield a lower optimum bid and hence should win more contracts.

c) The third technique was again similar to the previous two, but the probability of winning the contract was given by equation 8.2.6. This estimate of the probability is considered by the present writer to be theoretically correct (see Section 8.2.), and was expected to yield the highest percentage profit.

d) The fourth technique was based on the assumption that the contractor's cost estimate would be the lowest bid for the contract if it was submitted without any addition for profit. A distribution was set up of the percentage differences between the second and the lowest bids on each of the past contracts and from this, the probability of the difference being greater than or equal to a given percentage was able to be calculated. In this technique it was assumed that if a percentage allowance for profit was added to the cost estimate, the bid would still be the lowest only if the difference between the lowest competitor's bid and the cost estimate was greater than this profit allowance. The probability of this happening was then the probability of the contractor winning the contract, and so the familiar expected profit maximization method could be adopted.

The objection to this final method has previously been pointed out as the unlikelihood of the contractor's original assumption (that his cost estimate would be the lowest bid) being true. The reader is referred to Section 7.2 for a full discussion on this. The present writer nevertheless has used this technique to simulate the effect of a contractor using an informal bidding method based on a subjective appraisal of the market situation.

<u>8.5.3 - Probability Distributions Used.</u> Several optimum bidding techniques described in Chapter 7 employed discrete distributions to predict the probability of winning the contract with a given bid (see Sections 7.3, 7.5 and 7.7). An example of a discrete cumulative relative frequency diagram

is presented in figure 8.5.1(a). Figure 8.5.1(b) shows the resulting relationship between expected profit and bid amount.

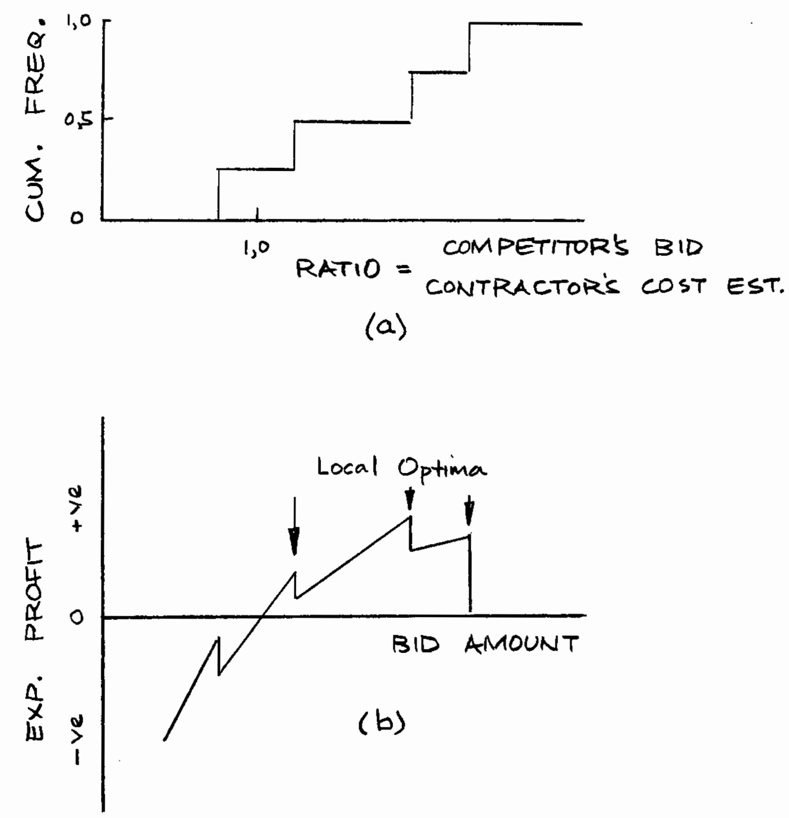


Figure 8.5.1 - Discrete Proability Distribution

In their OPBID model (which used a discrete probability distribution), Morin and Clough (25) employed a "uniform search technique" to arrive at the optimum bid amount. That is, they evaluated the expected profit at a large number of bid amounts spaced at regular intervals (1% of the cost estimate in their case). They then chose the optimum bid as the one yielding the highest expected profit value.

However, most of the effort involved in this method can be avoided by choosing the points where the optimum must obviously lie. Three such points are shown in figure 8.5.1(b). These correspond to the historical ratios of the competitor's bid to the contractor's cost estimate, from which the cumulative relative frequency polygon was constructed. This method was adopted in the simulation.

Further reference to figure 8.5.1 will convince the reader that the use of such discrete distributions will hardly result in very accurate results until a large number of past bid to cost ratios have been studied. The optimmum bid is too dependent for its "smoothness" on the number of individual values of the ratios used to construct the frequency diagram.

The present writer then ran the simulation with the first three optimum bidding techniques making use of continuous rather than discrete frequency diagrams. The fourth model was left unchanged, being indeed, as it was, merely to simulate a contractor using an informal bidding technique. The method in which the highest expected profit value was sought is presented in Appendix F of this thesis.

The present writer expected more stable values of optimmum allowances for profit to be predicted by the models using continuous distributions. Also they should yield higher profits as percentage of the value of the work undertaken.

8.5.4 - Program details. Flow-charts of the main program and of the sub-routines representing the four models are presented in figures 8.5.7 to 8.5.11. The complete program is listed in Appendix L.

Standard deviations of 5, 10, 15 and 20 were successively used for the normal distribution from which the random costs were drawn. The mean was 100 in each case.

An initial number (or "seed") was read from a data card, and using this, sufficient random costs were generated for 100 "tenders". After they had been "bid", and the results had been calculated, a new initial number was read and the process was repeated. This was done 10 times for each standard deviation, using both discrete and continuous probability distributions.

It was decided to use 10 sets of 100 tenders rather than 1000 tenders from the same initial random number, so that inaccuracies in the pseudo random number generation would be neutralized. Further remarks are made in Appendix G in this concern.

Furthermore, the efficiency of these techniques under conditions of relatively little historical information was examined by restricting the number of past tenders to 100. This is important to a contractor using these methods for the first time.

8.5.5 - Results. The results considered relevant from each technique were _

a) The total profit made;

b) The profit made as a percentage of the work undertaken;

c) The optimal profit allowance (markup) predicted after 100 "tenders".

Of these, the present writer considered (b) to be the most significant result for reasons explained in Section 8.1.

The average results obtained from the 10 greater cycles are presented in tables 8.5.1 and 8.5.2.

In these tables, the following figures are given for each model.

a) The standard deviation of the normal distribution with mean 100 from which each imaginary contractor's cost estimate was randomly drawn.

b) The cumulative profit made by the imaginary contractor using that particular model. The units are the same as those used for the cost estimates.

c) The above profit as a percentage of the value of the contracts on which that particular model had yielded the lowest bid (i.e. the sum of the contractor's estimates of the costs of those contracts).

d) The optimum percentage allowance for profit, or markup, yielded by that model for the 100th tender.

Table 8.5.1 - Using Discrete Probability Distributions:

Model	Std. Dev.	Total Profit	Profit %	Markup %
(a) Based on lowest other bid	2	43,98	2,175	2,322
	10	229,94	12,693	14,075
	15	355,51	18,172	20,464
	20	440,60	22,266	24,814
(b) Based on product of probabilities	2	50,17	1,562	1,510
	10	269,25	9,088	9,645
	15	400,76	14,271	14,911
	20	468,10	18,109	18,241
(c) Based on equation 8.2.6.	2	39,19	2,084	2,086
	10	212,82	11,247	12,221
	15	284,23	17,090	19,779
	20	325,50	22,365	25,263
(d) Based on Gates' spread proposal	2	46,67	1,826	1,855
	10	244,47	11,200	10,796
	15	335,02	17,154	18,942
	20	403,10	20,897	22,329

Table 8.5.2 - Using Continuous Probability Distributions:

Model	Std. Dev.	Total Profit	Profit %	Markup %
(a) Based on lowest other bid	5	108,3	4,792	5,077
	10	230,0	10,059	10,926
	15	336,7	15,67	17,599
	20	439,9	22,11	25,75
(b) Based on product of probabilities	5	125,6	3,988	3,865
	10	249,4	8,851	8,511
	15	374,1	13,750	13,943
	20	492,2	19,890	20,630
(c) Based on equation 8.2.6.	5	89,2	5,596	5,635
	10	173,0	11,030	12,367
	15	271,9	17,940	20,174
	20	338,4	23,390	29,050
(b) Based on Gates' spread proposal	5	110,8	4,501	3,955
	10	220,2	10,416	9,671
	15	324,9	15,450	14,589
	20	444,6	20,660	21,250

These results are shown graphically in figures 8.5.2 and 8.5.3.

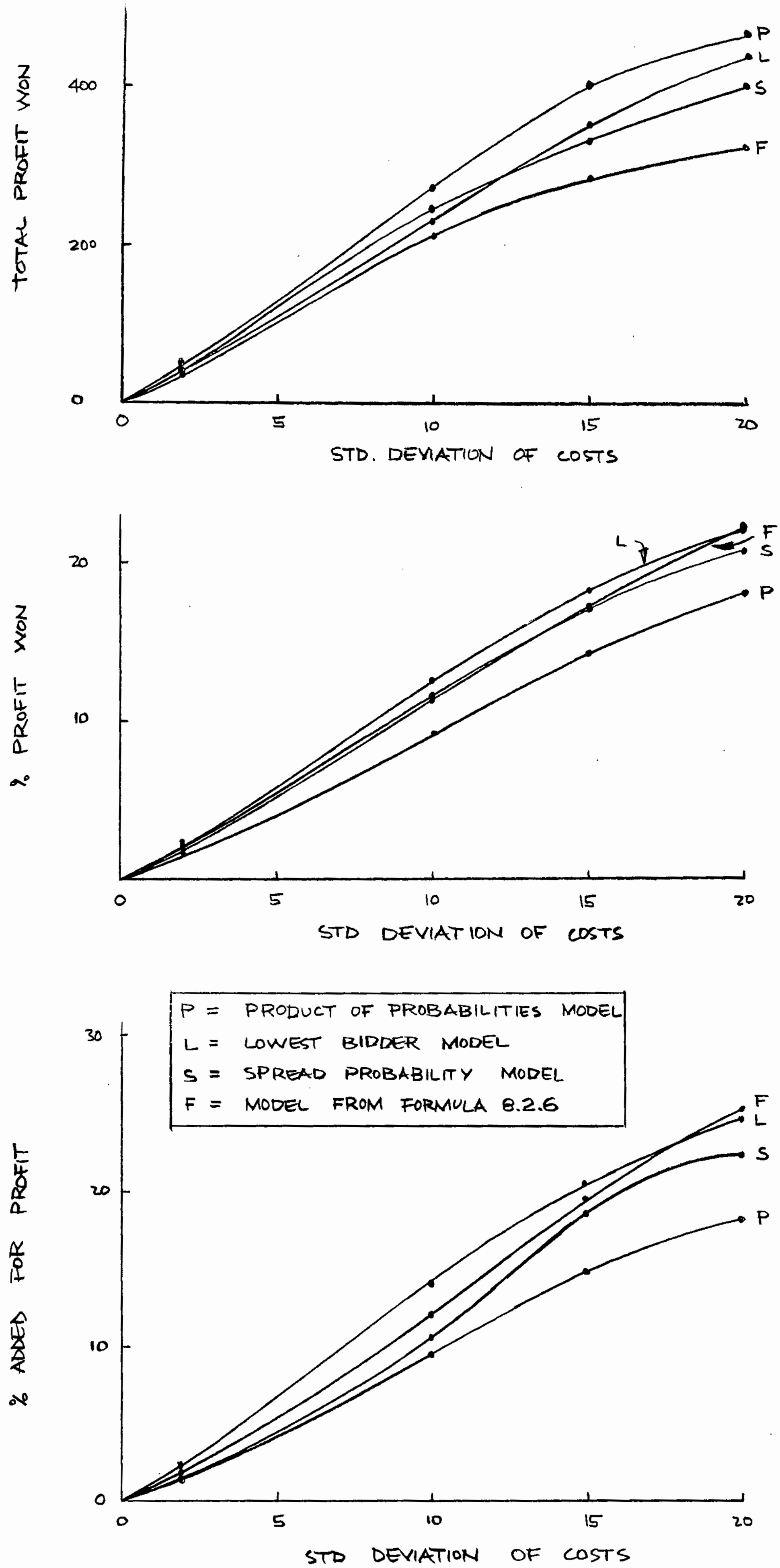


Figure 8.5.2 - Discrete Distributions

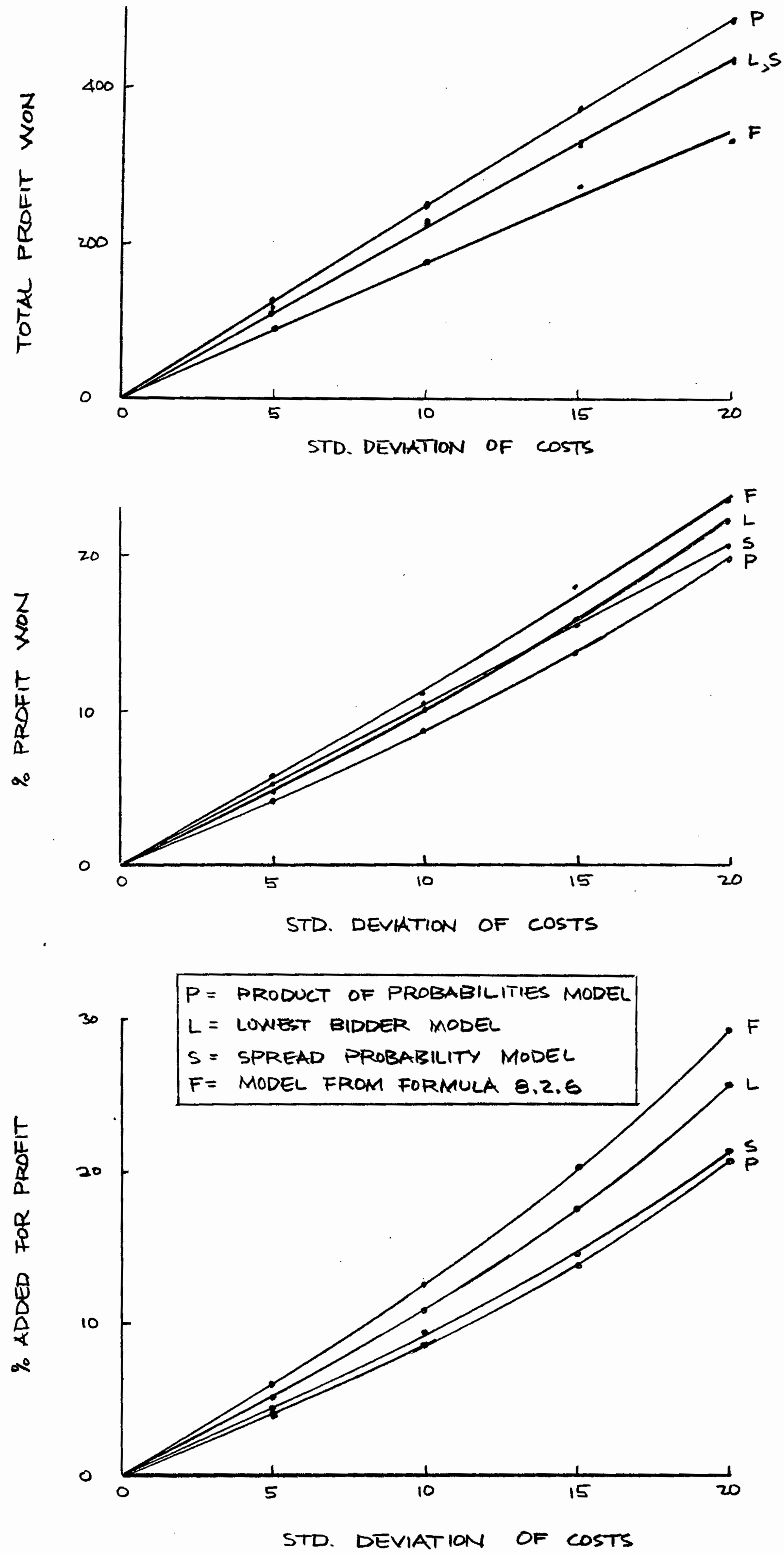


Figure 8.5.3 - Continuous Distributions

In figure 8.5.2 where the results from the use of discrete distributions presented in table 8.5.1 were plotted, it was observed that each set of points showed a tendency to fall along an S-shaped curve. This type of curve was therefore used, in spite of there being relatively few points. The present writer would not have assumed such a curve if this tendency had not been repeated by every set of points to a greater or lesser degree.

More points would have been plotted had the simulation not taken an average of 15 minutes per run (i.e. 10 cycles of 100 tenders analysed by 4 techniques) on the UNIVAC 1106 computer in use at the Universitu. At normal hire rates, this would have cost R75 for each point.

<u>8.5.6 - Conclusions.</u> The conclusions reached after studying these curves are given below.

First of all, the highest total profit values were always obtained when the probability of beating three competitors was taken to be

$$P\ (win) = P(A)\ P(B)\ P(C) \qquad .....(8.5.1)$$

making use of the notation of Section 8.2.

As previously pointed out, this is a conservative estimate of the probability of winning the contract and so this formula resulted in a lower optimal profit allowance than the correct formula given in equation 8.2.6. It was clearly apparent from the curves that this formula yielded lower percentage profit allowances than the other three techniques.

In turn, this meant that more contracts were awarded to the imaginary contractor using this model than to the others.

Hence it would be argued that this model should be used by a contractor when he is in need of work to keep his organization occupied.

However, the present writer is of the opinion that use of this formula is unjustified as it was not developed specifically to optimize the total amount of profit won on a large number of contracts, but rather to optimize the profit won as a percentage of the cost estimates of a large number of contracts.

It is possible that a regression type of analysis comparing the total profit made on each contract and the contractor's cost estimate for that contract could be used to develop a technique to optimize the total profit. Such an analysis would be similar to the one carried out in Section 8.4. However, the present writer did not approach the problem from this angle.

The next conclusion reached was that the formula

$$P\ (\text{win}) = \frac{1}{1 + \frac{1-P(A)}{P(A)} + \frac{1-P(B)}{P(B)} + \frac{1-P(C)}{P(C)}} \qquad \ldots(8.5.2)$$

for the probability of bidding lower than 3 competitors (using the same notation as in Section 8.2) yielded the highest cumulative profit as a percentage of the cost of all the work undertaken, as well as the highest percentage profit allowances for the 100th tender.

This was apparent both when the probability of beating the lowest competitor alone was considered to be the probability of winning the contract and when the probability of beating each of the three other competitors separately was considered.

Using the notation of Section 8.2, the formula reached to

$$P\ (win) = P(A) \qquad .....(8.5.3)$$

when only one (the lowest) competitor was considered.

Furthermore, this conclusion was reached when the results of using both continuous and discrete distributions were considered.

It should be noted that when discrete probability distributions were used, formula 8.5.3 yielded curves that were generally more predictable, but when continuous distributions were used, formula (8.5.2) yielded higher cumulative percentage profits. However formula (8.5.3) yielded higher cumulative total profit values in both cases.

The third conclusion drawn from a study of figures 8.5.3 and 8.5.4 was that the use of continuous distributions appeared to yield more consistent results than when discrete distributions were used. By this it is meant that the points obtained conformed better with general trends - i.e. smooth curves could easily be drawn through them.

Moreover, when discrete probability distributions were used, the slope of every curve in figure 8.5.2 decreased for standard deviation values greater than 10. This appears to indicate an upper limit to both the total cumulative profit and the percentage cumulative profit that might be won using these techniques when discrete distributions are employed. Such a tendency was not displayed when continuous distributions were used.

The final conclusion does not concern which technique to use, but rather the effect on all the results of different standard deviations of the distribution from which the imaginary contractor's cost were drawn.

One point to note in this regard is that every curve passed through the origin in figures 8.5.2 and 8.5.3. This means that if all the competitors had identical cost estimates for every contract tendered, the use of these techniques would yield zero profit allowances. In consequence each competitor would make zero profit amounts even though they would win contracts by having the lowest cost estimate.

Furthermore, as the standard deviations of the costs increased, both the total and the percentage profit amounts won by each imaginary contractor increased.

The reason for this is that the larger the standard deviation, the "flatter" will be the probability distributions of the ratio of a competitor's bid to the contractor's cost estimate. This in turn is caused by the wider variation in the contractor's cost estimates. The reader is referred to figure 8.5.5.

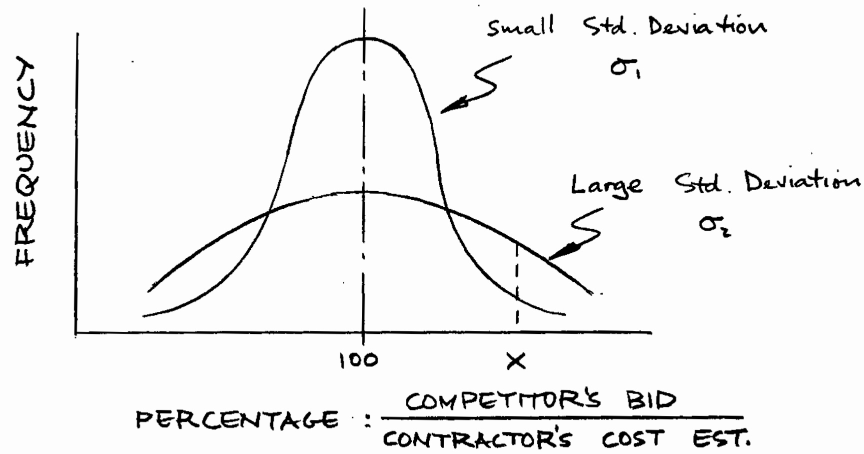


Figure 8.5.5 - Frequency Distributions

Now, the expected profit value is the product of the probability of winning the contract and the profit that would be made if the contract was won. Also, when the higher profit allowances are considered (say for bids greater than x above), the flatter distribution will yield higher probabilities of winning the contract (given by the area under the curve to the right of x). Hence it is reasonable to suppose that the expected profit curves take on the relative forms shown in figure 8.5.6.

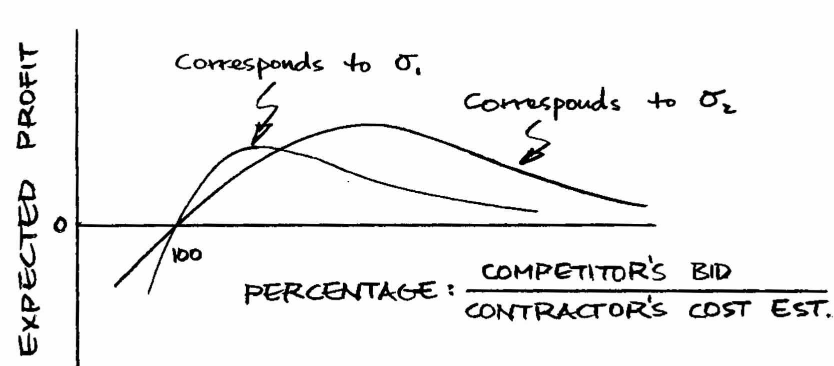


Figure 8.5.6 - Expected Profit Curves

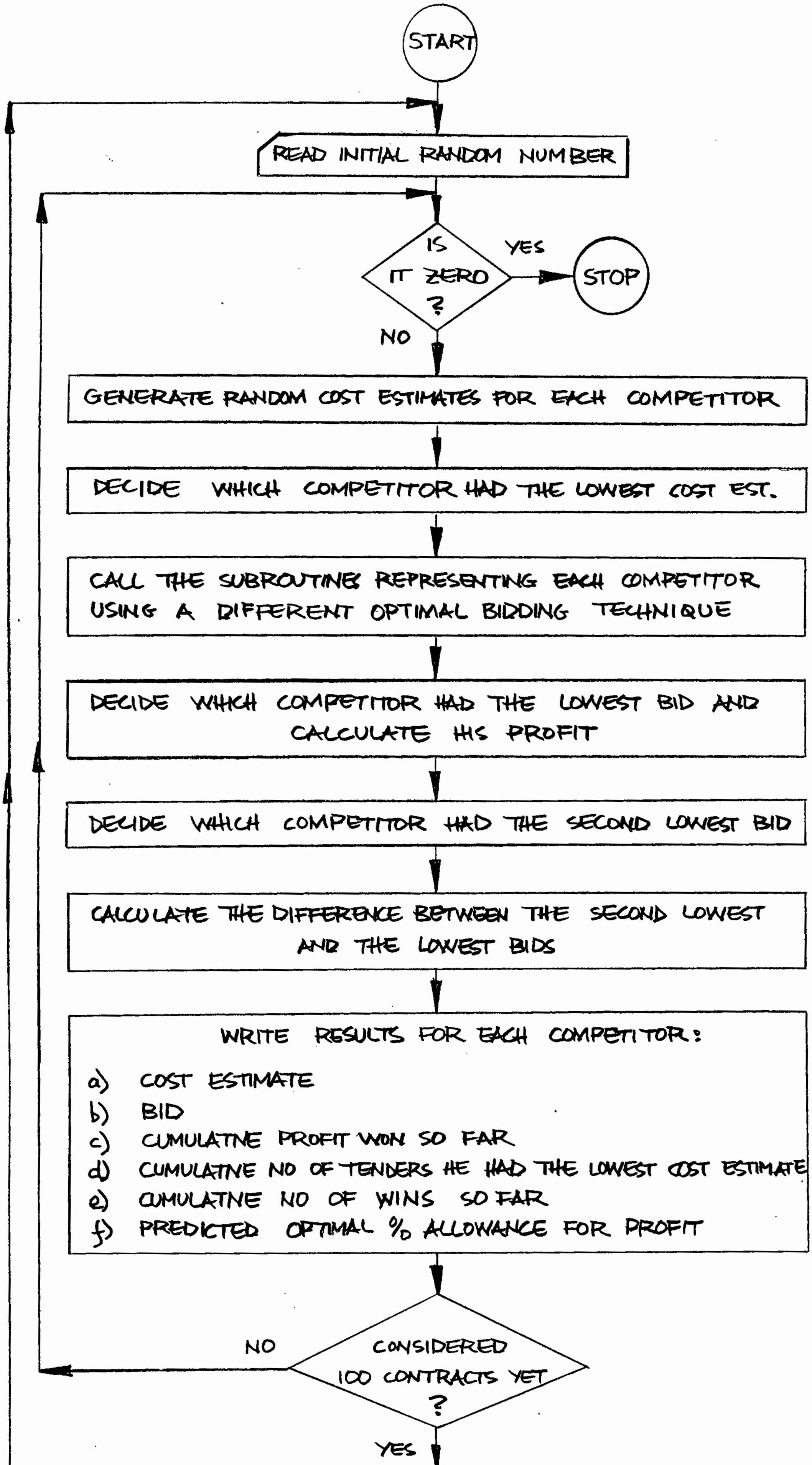


Figure 8.5.7 - Main Simulation Program

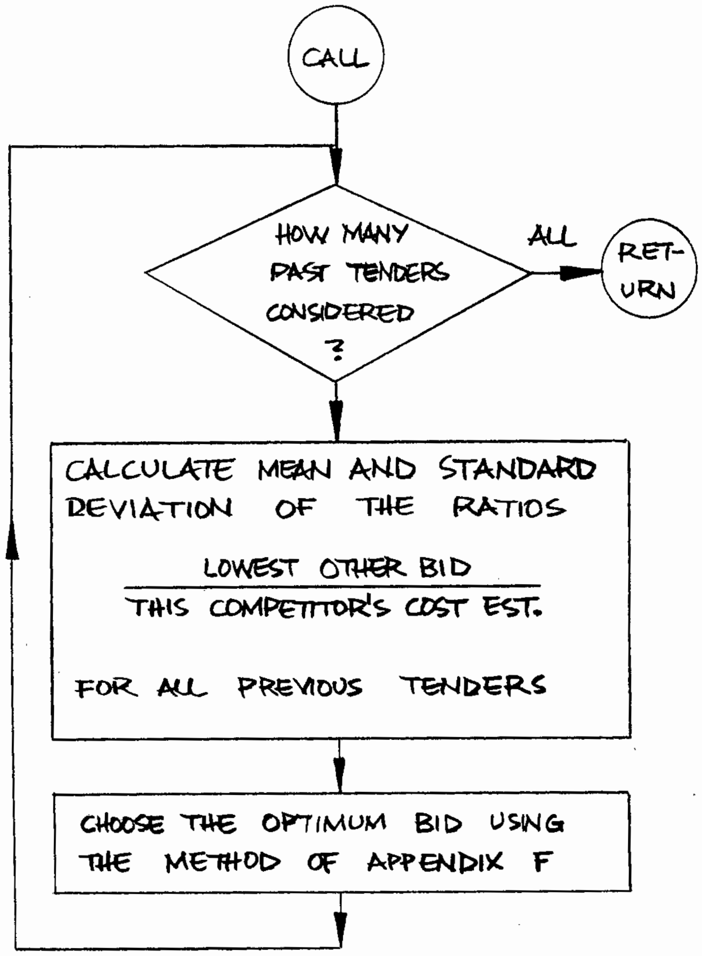


Figure 8.5.8(a) - Technique based on the probability of beating the lowest other bidder (continuous distribution)

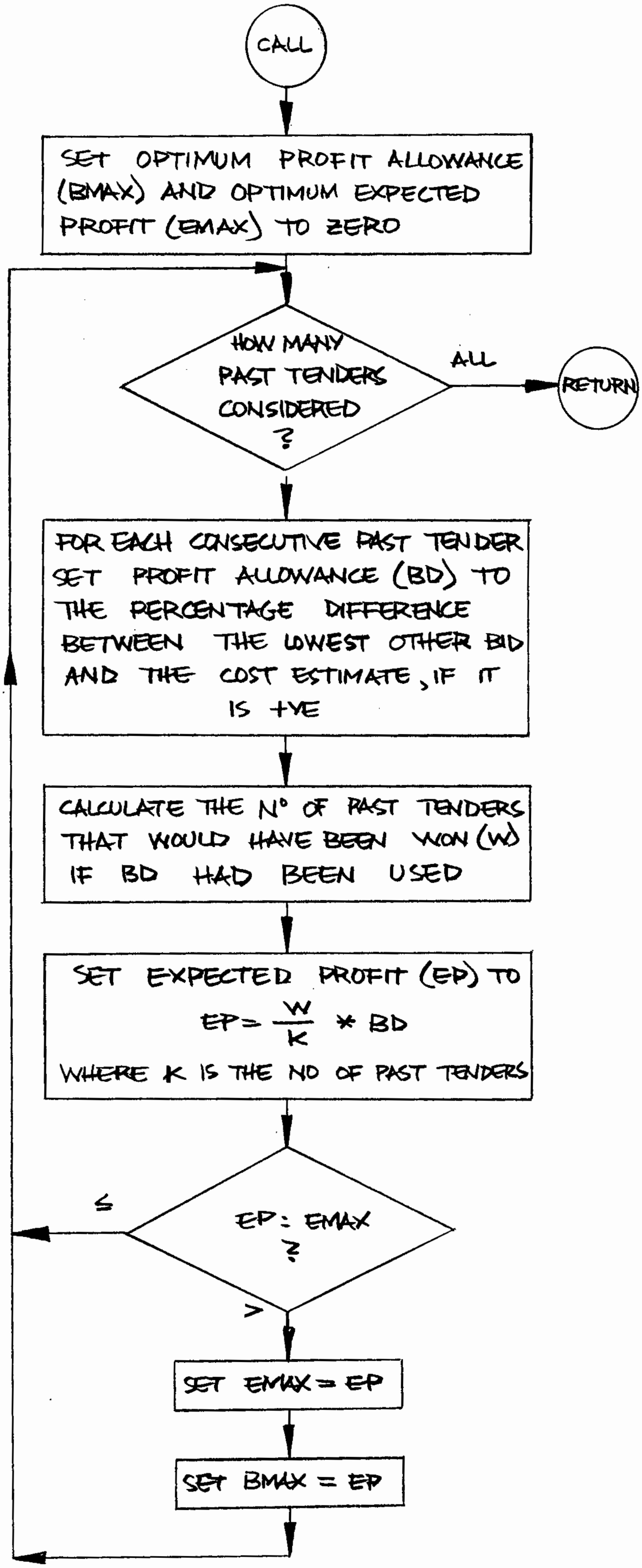


Figure 8.5.8(b) - Technique based on the probability of beating the lowest other bidder (discrete distribution)

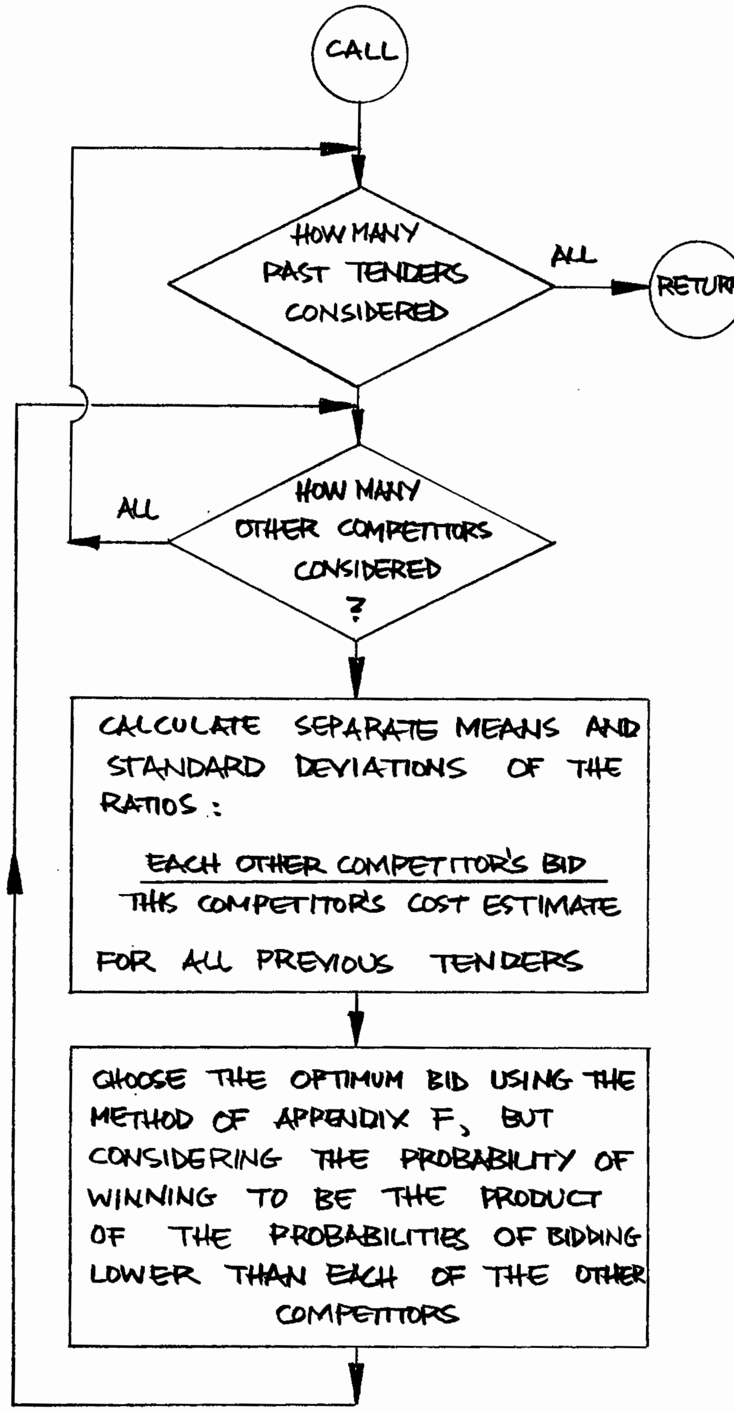


Figure 8.5.9(a) - Technique based on the product of the probabilities of beating each other bidder (continuous distribution)

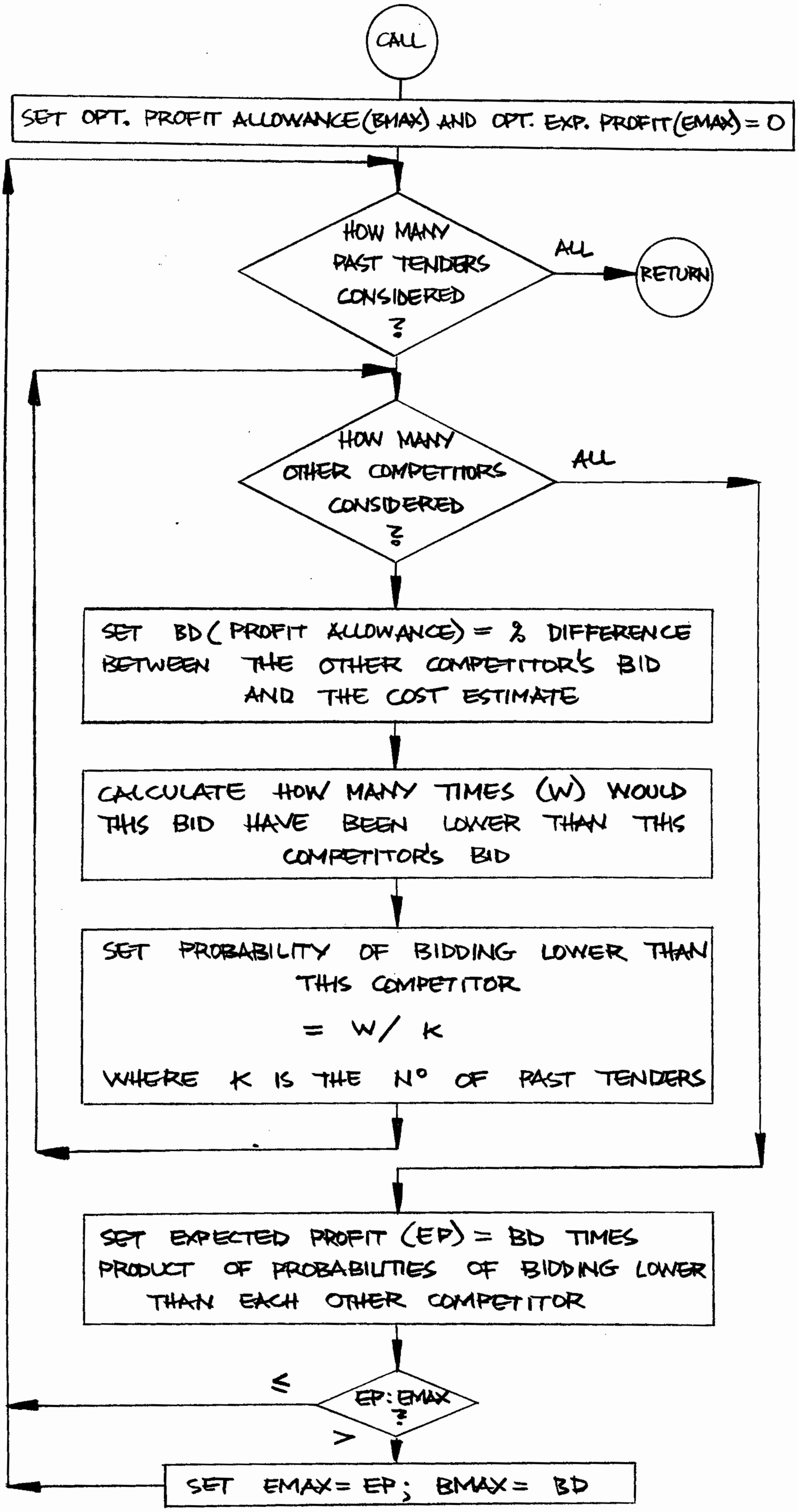


Figure 8.5.9(b) - Technique based on the product of the probabilities of beating each other bidder (discrete distribution)

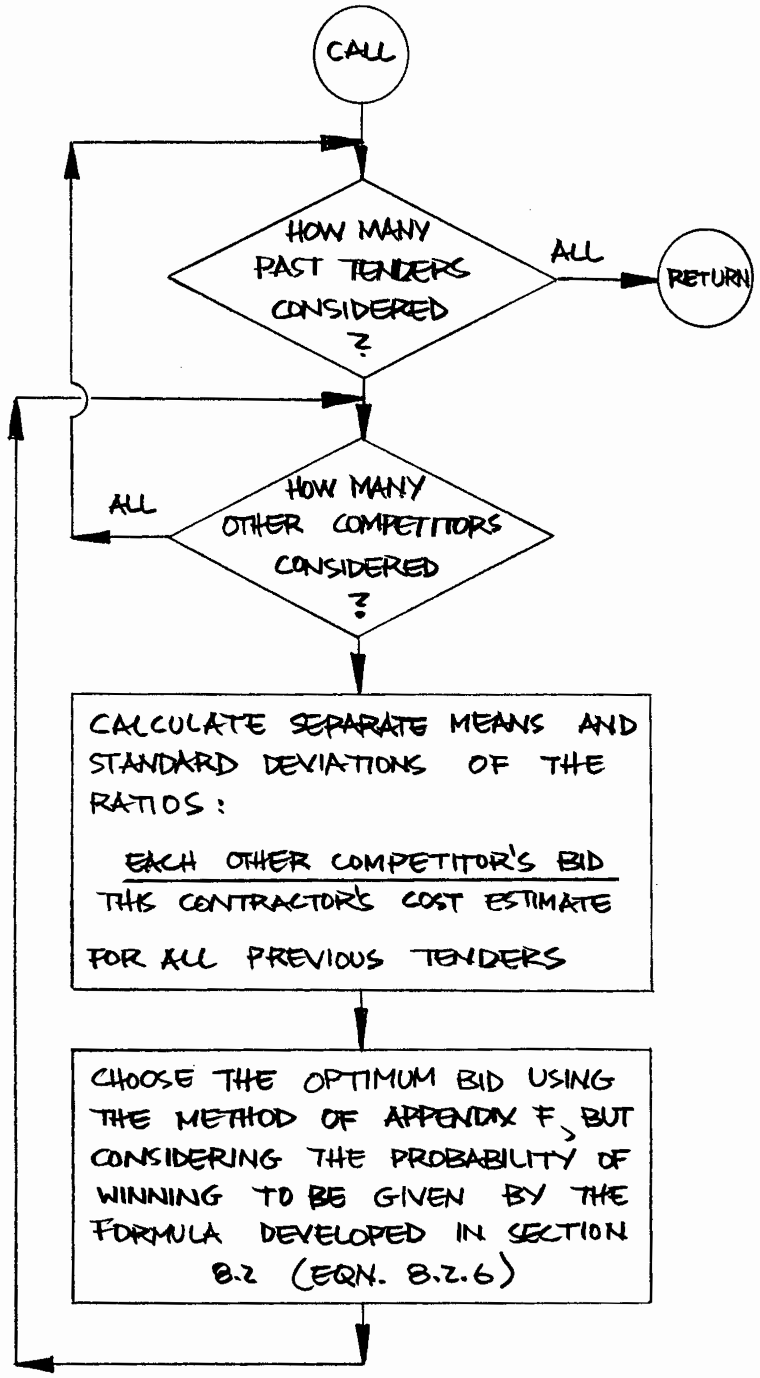


Figure 8.5.10(a) - Technique based on equation 8.2.6 giving the probability of being the lowest bidder (continuous distribution)

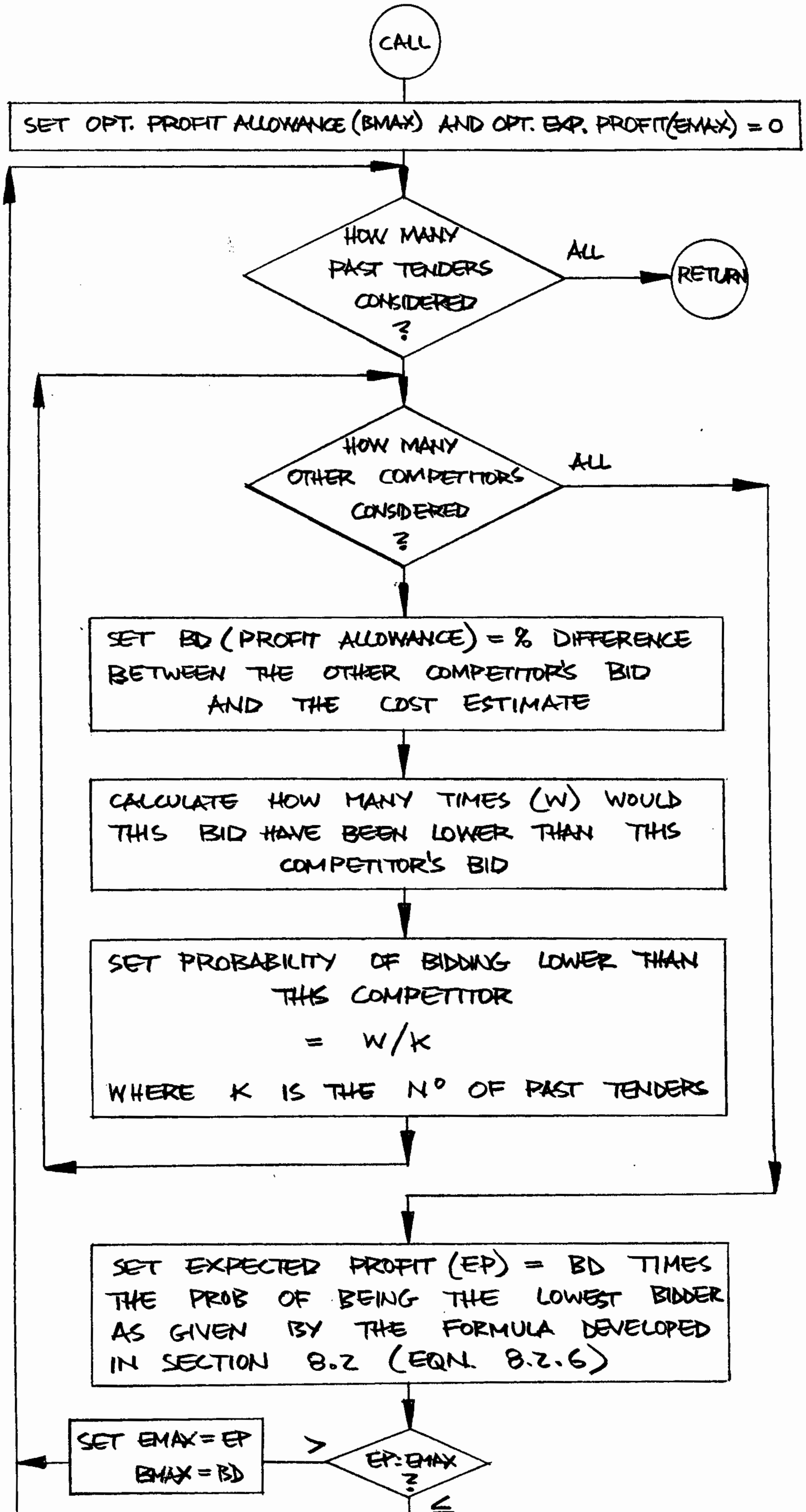


Figure 8.5.10(b) - Technique based on equation 8.2.6 giving the probability of being the lowest bidder (discrete distribution)

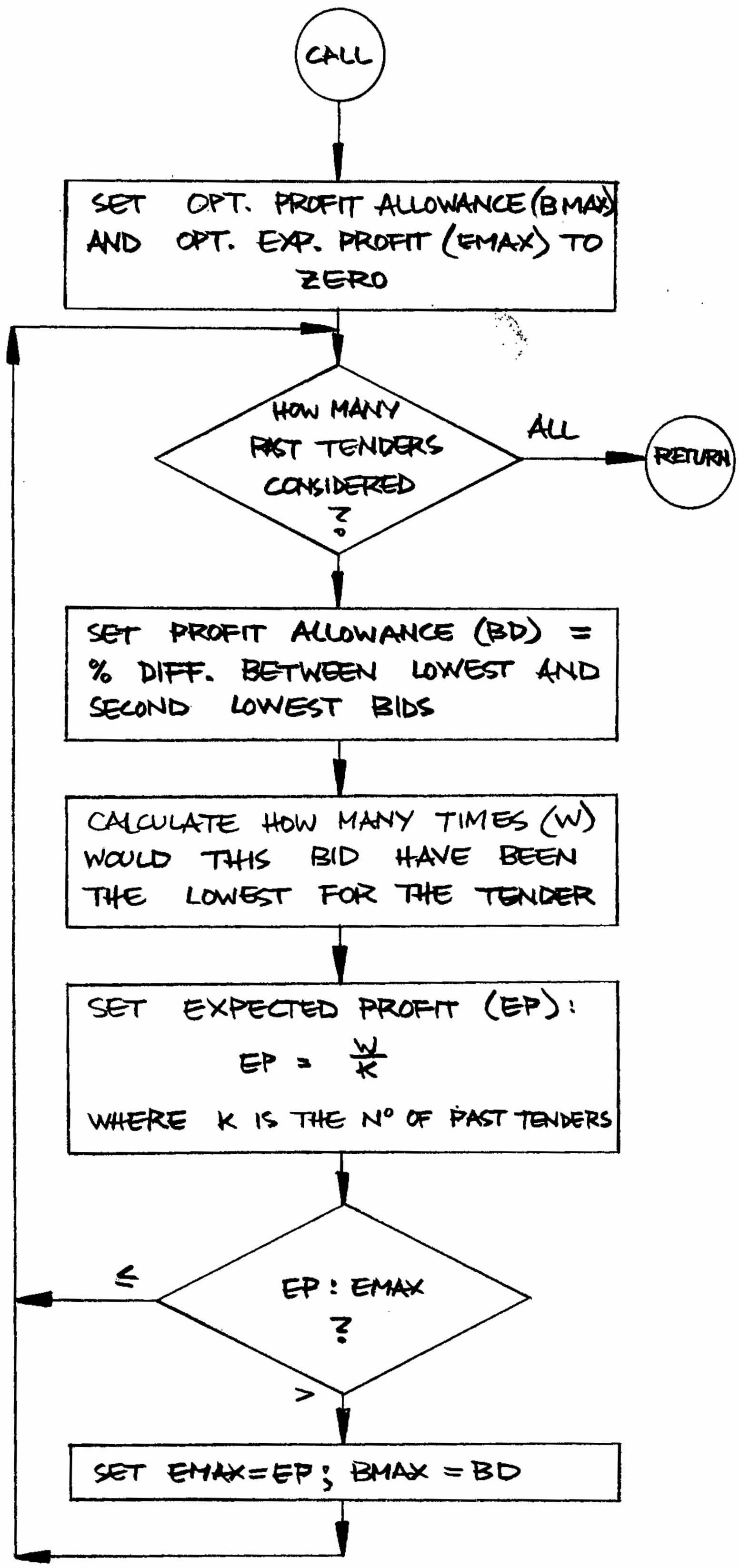


Figure 8.5.11 - Technique proposed by Gates to predict the optimal bid from spread probabilities.

Since the optimum expected profit occurs at a higher allowance for profit in the case of the flatter distribution, higher profits will be made when the market situation can be described by such a distribution.

Note that no significance is attached to the relative values of the optimum expected profits.

This general conclusion implies that contractors would be will advised to seek markets where there is a wide variation in the prices submitted for each tender. They should be able to make higher profits in such markets.

This result is intuitively supported when one considers the reasons behind wide differences in the tender prices. These must be caused by the contractors lacking the experience or ability necessary to be able to estimate accurately the cost of a contract. Hence a competent contractor should be able to fare well in such a market.

In conclusion then, the general results of this analysis as given in tables 8.5.1 and 8.5.2 and in figures 8.5.2 and 8.5.3 were as expected. Therefore it is deduced that the use of the probabilistic model derived in Section 8.2 is justified.

It remains to test the model against "real world" data.

Section 8.6 - Parallel Comparison of the Models with Actual Results :

In this section, the profits that would have been yielded by two optimal bidding techniques presented in Section 8.5 are compared with the profits actually made by two contractors.

In this context, the profit is considered to be the difference between the bid amount and the cost estimate for the contract. A profit can only be made if the tender is awarded to the contractor.

Both of the techniques used predict the bid amount that will give the maximum expected profit value.

In the first one, the probability of winning the contract is considered to be the probability of bidding lower than the competitor submitting the lowest other bid for the contract.

$$P\ (win) = P\ (lowest) \qquad \ldots\ldots (8.6.1)$$

where P (win) is the probability of winning the contract and P (lowest) is the probability of beating the lowest other competitor.

P (lowest) is calculated by setting up a cumulative relative frequency distribution of the ratio of the lowest other competitor's bid to the contractor's cost estimate for a number of past tenders.

In the second technique, the probability of winning the contract is considered to be the following :

$$P\ (win) = \frac{1}{1 + n \dfrac{1 - P(Ave)}{P(Ave)}} \qquad \ldots\ldots (8.6.2)$$

where P(Ave) is the probability of beating an "average" competitor and n is the number of other bidders for the contract.

P(Ave) is determined from a cumulative relative frequency distribution of the ratios of the average of all the competitors' bids to the contractor's cost estimate for a number of past tenders.

The ratio for one particular tender is given in equation 8.6.3.

$$R = \frac{\frac{a + b + c + \ldots}{n}}{CE} \qquad \ldots\ldots(8.6.3)$$

where a,b,c,.... are the bids of every other contractor competing for the contract, n is the number of these competitors, and CE is the contractor's cost estimate for the work.

The concept of an "average" competitor is therefore an imaginary one.

Both these techniques have been fully described in Section 8.5, so no further description is necessary here.

In setting up the probability distribution, bids greater than 1,5 times the contractor's cost estimate were discarded as not being seriously submitted.

A flow-chart of the computer program used is presented in figure 8.6.7, and it is listed in Appendix L.

The first set of data used was obtained from a local contractor. 70 past tenders of a civil engineering nature in the Western Cape Province were included. The reader is referred to a detailed listing in Appendix K to this thesis.

The second set of data was given by Benjamin in an appendix to his report (4). It includes 130 tenders for building construction contracts in the U.S.A. This data is also fully listed in Appendix K.

The present writer would have preferred to have used local data on building tenders, but this was unfortunately not readily available.

In the comparison, the ratios of both the lowest and the "average" competitor's bids to the contractor's cost estimate were considered to be normally distributed. The reasons for this appear in Section 8.3.

The probabilities associated with these distributions were calculated by the method described in Appendix G.

Initially, only information on tenders that had chronologically preceded the one being bid was used by the techniques. This means that the frequency distributions used to calculate the probability of winning the contract were drawn up from an ever increasing number of data.

An interpretation of this is that the optimum bidding techniques "learned" more and more about the particular construction markets as the results of more tenders became known. This placed the actual contractor at an unfair advantage since he always had the results of a large number of past tenders on which to base his judgment of the best bid for each new tender.

The results of this comparison are presented graphically in figures 8.6.1 and 8.6.2 for the local contractor's data, and in figures 8.6.3 and 8.6.4 for Benajmin's data.

The results were not tabulated as it was felt that a graphical presentation would make comparisons easier.

It should be mentioned at this stage that a point was plotted whenever one of the techniques, or the actual contractor, submitted the lowest tender. These points were then connected by straight lines. While this does not represent the true profit at any stage, this method nevertheless makes the graphs much easier to follow.

Figure 8.6.1 shows the total profit made when the local contractor's data is considered. No units have been assigned to the total profit values for reasons of industrial security. When the data was collected, an arbitrary monetary unit was used to measure the cost estimate for each tender. This was done in an attempt to disguise the real identity of each project.

No significant difference is apparent in the results obtained after all 70 tenders had been bid. The final profits made were :

Actual contractor	:	11,35 units
"Lowest bidder"	:	11,45 units
"Average bidder"	:	10,61 units.

Figure 8.6.2 shows the profits as a percentage of the work undertaken. Once again, the local contractor's data was

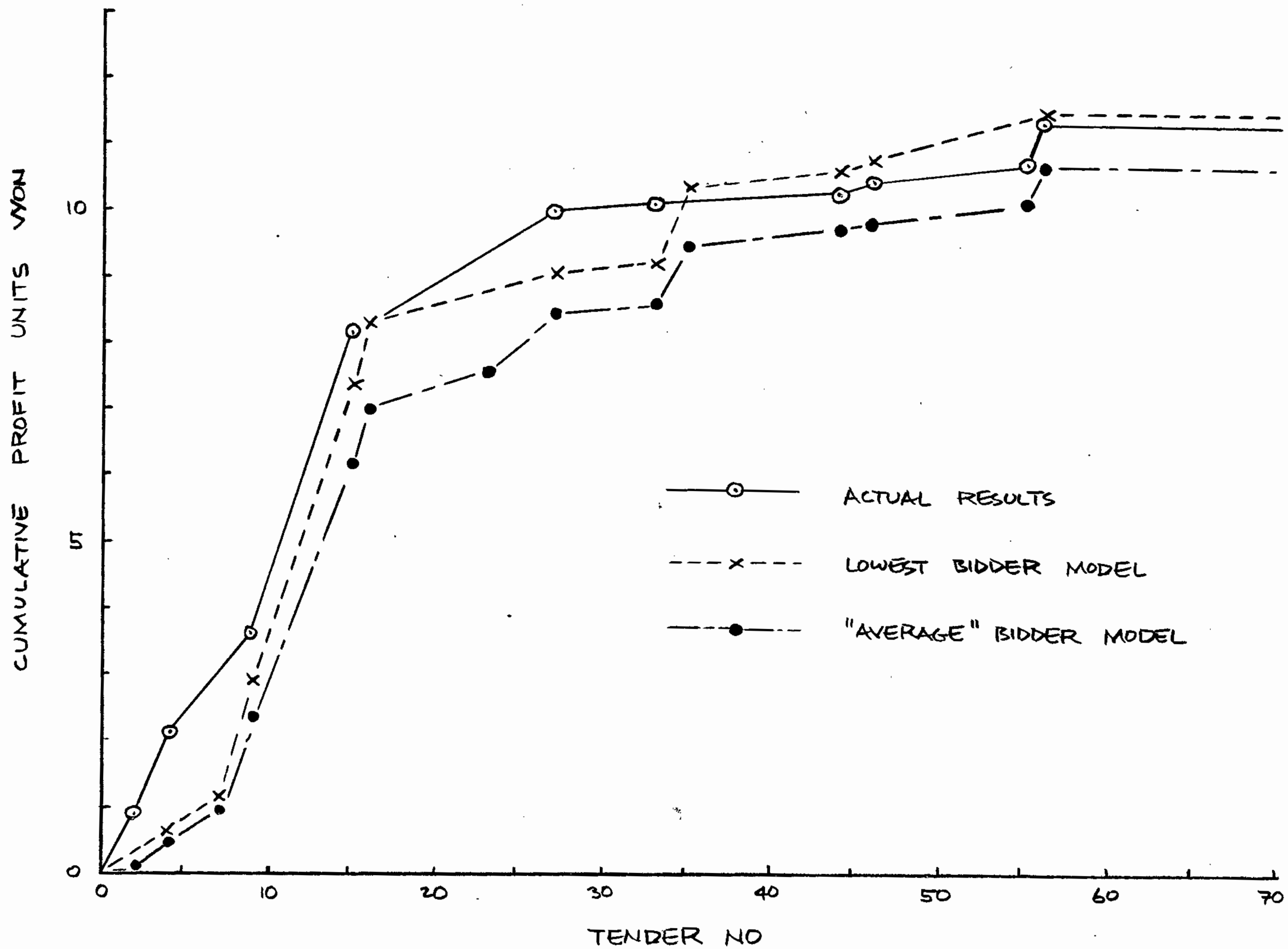


Figure 8.6.1 - Local contractor's data (considering only the previous tenders)

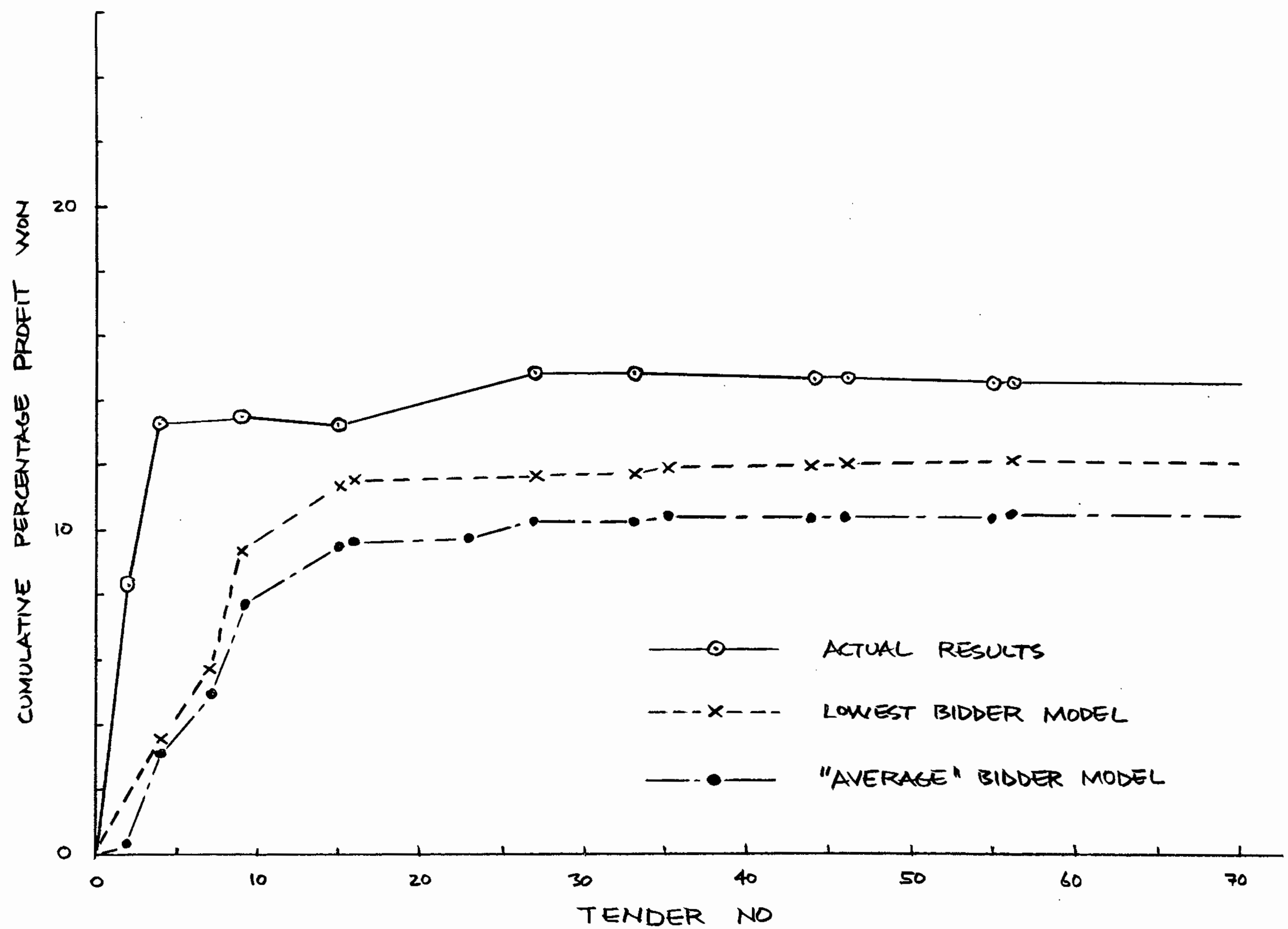


Figure 8.6.2 - Local contractor's data (considering only previous tenders)

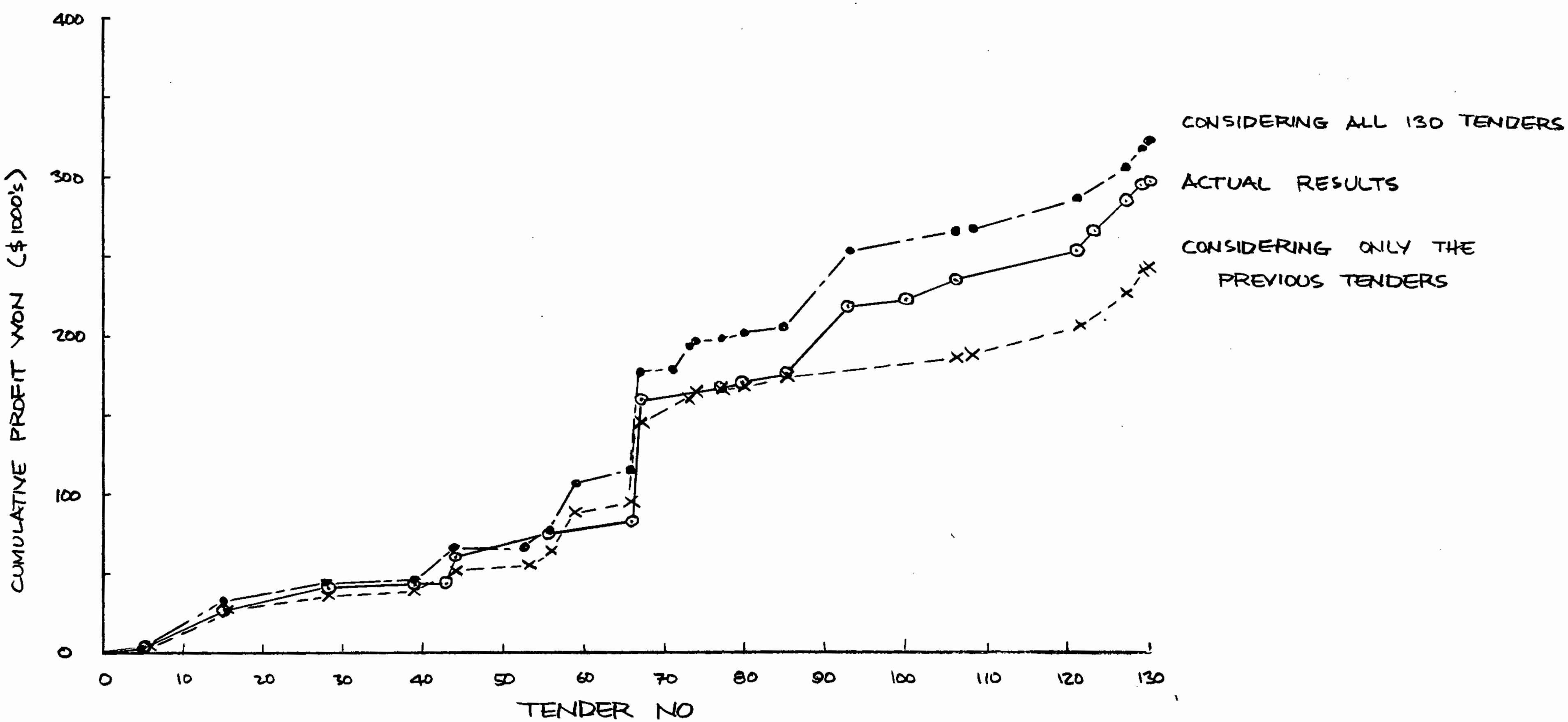


Figure 8.6.3 - Benjamin's Data

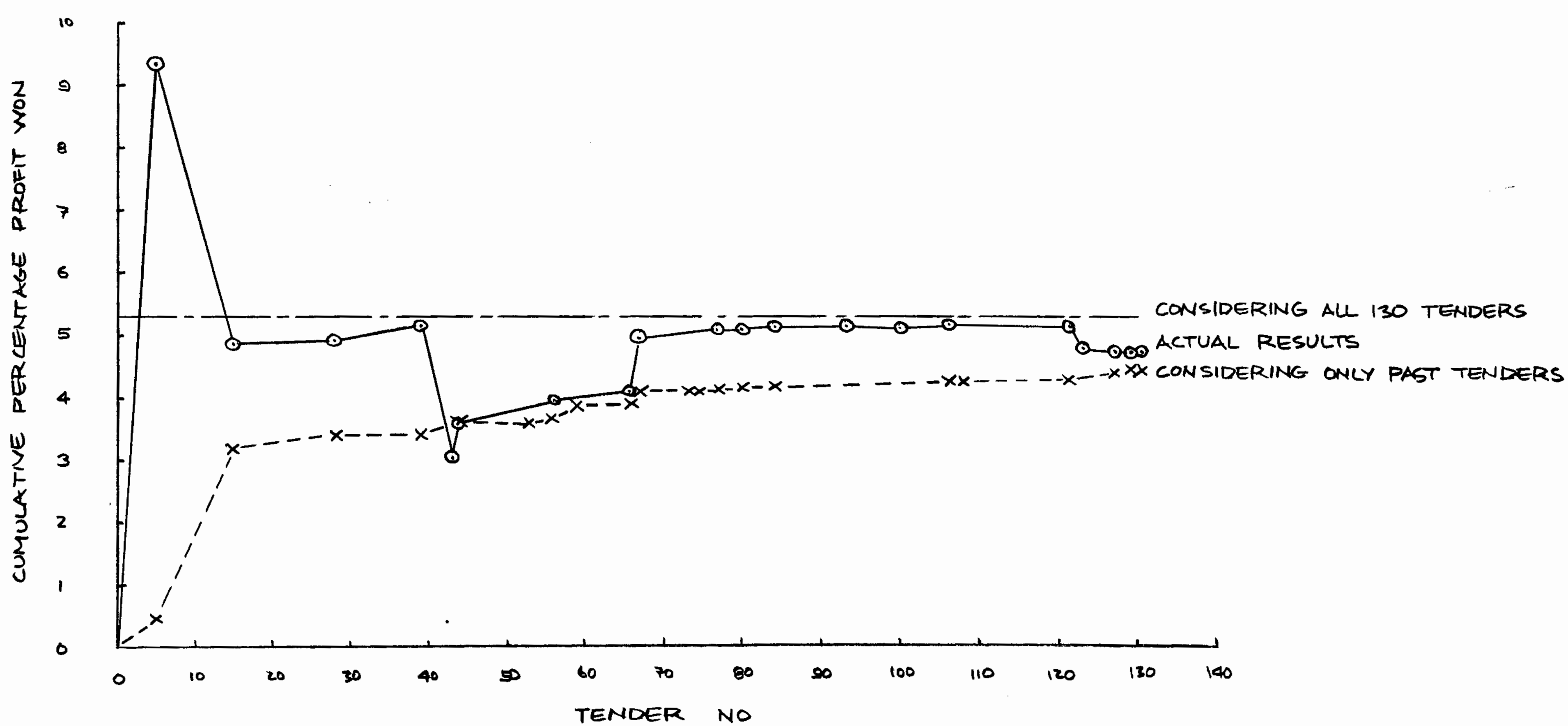


Figure 8.6.4 - Benjamin's Data

used. In this instance, both optimmum bidding techniques proved to be decidedly inferior to the contractor's judgment. The final percentage profits were :

Actual contractor	:	14,56%
"Lowest bidder" technique	:	12,05%
"Average bidder" technique	:	10,40%

The data supplied by Benjamin included information on the lowest other competitor's bid only. Hence the "Average bidder" technique could not be compared with the actual contractor's judgment.

The total profits and percentage profits made by the original contractor and by the "Lowest bidder" technique are presented in figures 8.6.3 and 8.6.4 respectively. Once again, only information from tenders preceding the one being bid are used by the optimum bidding technique.

The final results obtained were :

Actual contractor	: Total Profit :	$296 500
	Percentage Profit :	4,74%
"Lowest bidder" technique	: Total Profit :	$242 090
	Percentage Profit :	4,41%

It was noticed that for both sets of data, the percentage profit yielded by the models always increased, as more tenders were bid, though this increase was hardly noticeable at the end.

This is attributed to the fact that the techniques "learned" more about the market as more tenders were bid. In point of fact, the means and standard deviations of the probability distributions were being estimated more accurately.

The effect of the number of past tenders on the mean of the probability distribution is presented in figure 8.6.5.

This figure shows within how many standard deviations the true mean must lie from the estimated mean for various amounts of data used to construct a probability distribution. This figure applies to any distribution and is drawn up by making use of the statistical concept of "confidence limits".

Essentially, the confidence limits of the mean are the upper and lower limits between which the mean is assumed to lie. However, such a statement cannot be made with absolute certainty. Therefore a percentage probability is associated with any pair of confidence limits. This probability is termed the "confidence level".

The reader will appreciate that as the confidence level rises, so the difference between the confidence limits (the "confidence interval") must increase. This is to increase the probability that the mean lies within these limits. Each curve on figure 8.6.5 represents a different confidence level.

An example will clarify the use of this curve. If the probability distribution has been constructed from information on only 40 past tenders, then the true mean lies within 0,266 standard deviations of its calculated value, at the 90%

When the standard deviation of the percentage ratios :

$$\frac{\text{competitor's bid}}{\text{contractor's cost estimate}}$$

is 20%, the values in the following table apply at the 80% confidence level :

CONFIDENCE INTERVAL(%)	N° PAST TENDERS
1,0	→ ∞
2,0	180
3,4	70
5,0	32
10,0	10

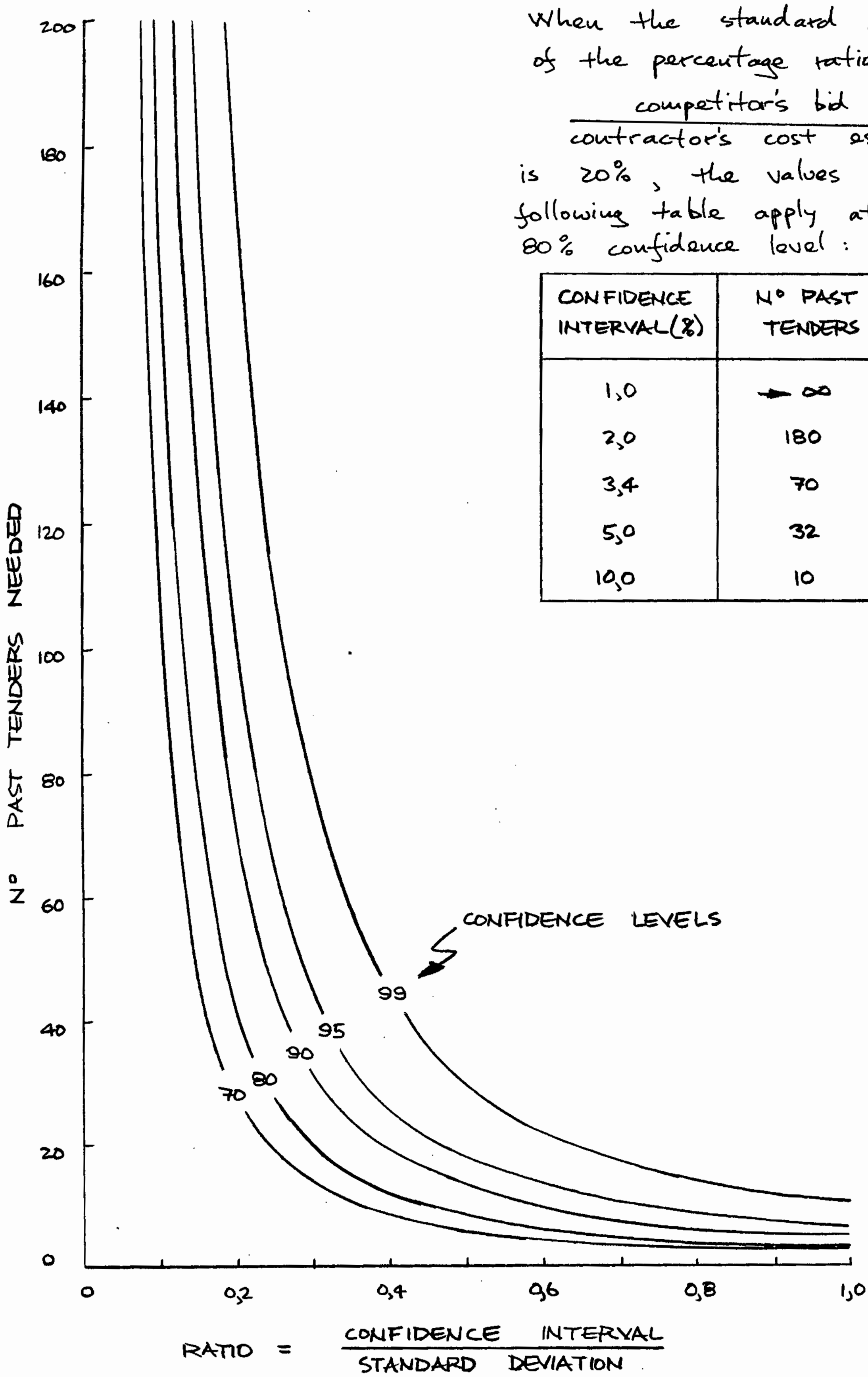


Figure 8.6.5 - Effect of number of previous tenders

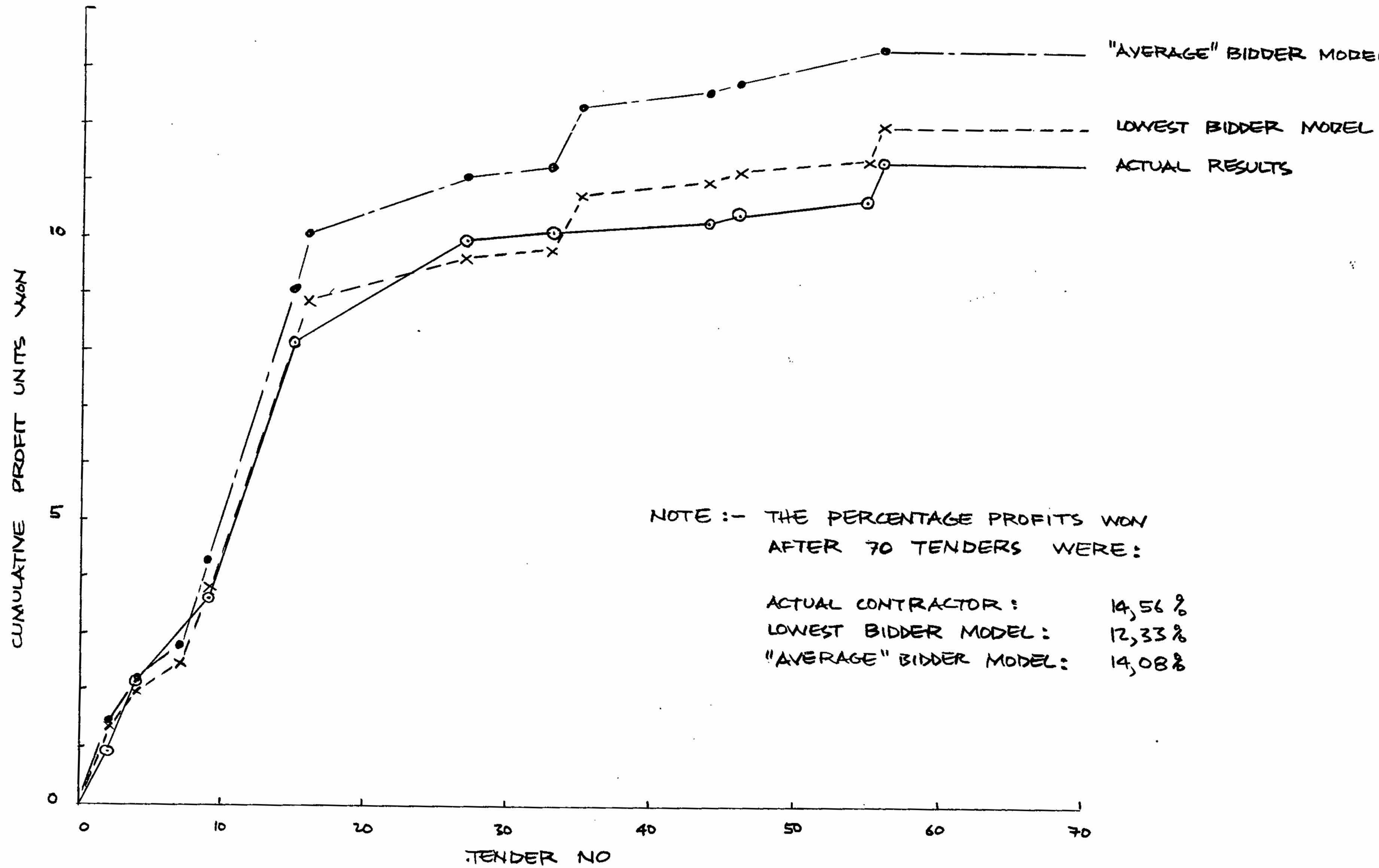


Figure 8.6.6 - Local contractor's data (considering all 70 tenders)

confidence level. If the estimated mean is 100 and if the standard deviation is 20 (typical results obtained from the local contractor's data) then the true mean lies between 94,68 and 105,32 at the 90% confidence level.

This is a fairly wide interval and is one which will have an effect on the optimal bid value predicted by these models. It is not surprising then that the percentage profits yielded by these models are inferior to the actual percentage profits made.

In view of this uncertainty, the techniques were compared once again, only this time the probability distributions were drawn up using all the local contractor's 70 tenders and Benjamin's 130 tenders. The results appear in figures 8.6.6 and 8.6.3.

Both techniques yielded higher total profit values than the local contractor :

Actual contractor	:	11,35 units
"Lowest bidder" technique	:	11,96 units
"Average bidder" technique	:	13,38 units

This was also the case when Benjamin's data was considered :

Actual contractor	:	\$296 500
"Lowest bidder" technique	:	\$321 770

An improvement was also noted in the percentage profit amounts made by the techniques :

Contractor's data :	Actual Contractor	: 14,56%
	"Lowest bidder" technique	: 12,33%
	"Average bidder" technique	: 14,08%
Benjamin's data :	Actual Contractor	: 4,74%
	"Lowest bidder" technique	: 5,28%

The present writer concludes from these results that the optimum bidding techniques used are not significantly superior to the informal methods employed by the two contractors.

However, they are at least as good as the more conventional method and so should prove useful in checking the judgment of a contractor concerning his best allowance for profit when submitting a tender.

A way in which these techniques might be put to practical use is presented in Chapter 9.

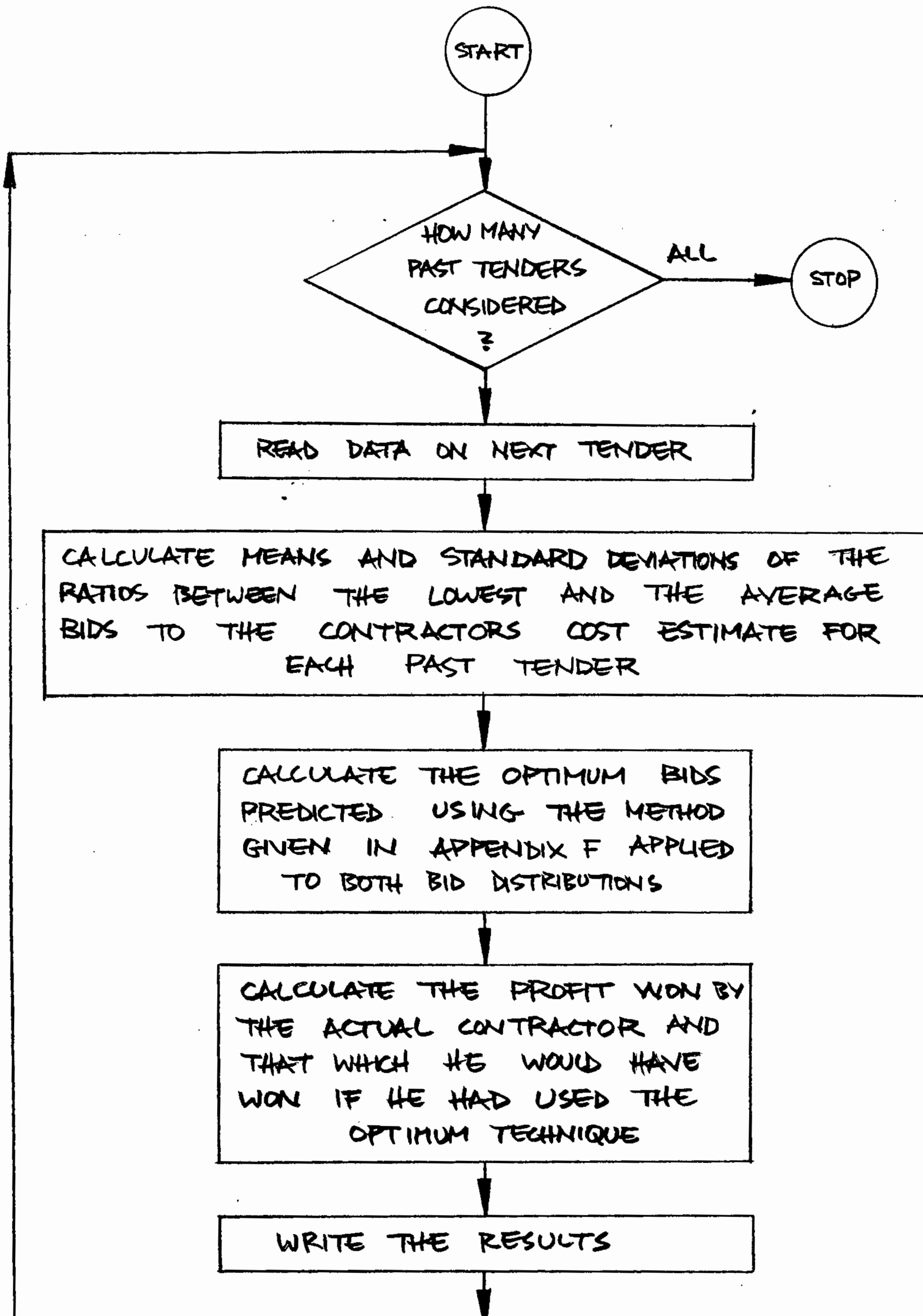


Figure 8.6.7 - Program used to compare the optimal bidding technique with actual results

Section 8.7 - The Correlation Between Suggested Factors Influencing the Tender Bid :

In Chapter 7 it was remarked that Gates (14) and Benjamin (4) had suggested that various factors influenced the amount of profit to be sought by a contractor tendering for a project. These factors included the following :

a) The contractor's cost estimate for the work;

b) The number of competitors to be met when tendering for the contract;

c) The estimated duration of the contract;

d) The amount of the work to be sub-contracted.

The present writer plotted the relevant data listed in Appendix K to try and establish possible relationship between the ratio of the lowest competitor's bid to the contractor's cost estimate and these four factors. One set of data used was obtained from a local contractor and the other set was appended to Benjamin's report (4).

The data was first ranked in ascending order with respect to the ratio between the lowest competitor's bid to the contractor's cost estimate on each past contract. The data was then split into five groups of equal number while maintaining the ascending order.

Thereafter arithmetic means were taken of the following values corresponding to each contract falling in the five groups :

a) The ratios between the lowest competitor's bid to the contractor's cost estimate;

b) The cost estimates;

c) The number of competitors for the tender;

d) The duration of the contract (this data was not available from the local contractor);

e) The percentage of the cost estimate which was to be sub-contracted out (this data also was not available from the local contractor).

The local contractor had supplied data on 70 past contracts, and so the above means were taken from 14 values each, while Benjamin had given data on 130 past contracts, and so the above means were taken from 26 values each in this case.

The reader is referred to figure 8.7.1 where scatter diagrams are drawn to show the results of these calculations. For each group, the average ratio of the lowest competitor's bid to the contractor's cost estimate is plotted on the vertical axis, and the corresponding average value of one of the relevant factors listed above is plotted on the horizontal axis.

From these diagrams, it is apparent that no firm relationships between these factors and the ratio between the lowest competitor's bid and the contractor's cost estimate can be deduced.

The only general trend appearing in both the local contractor's and in Benjamin's data was that the above ratio tended to decrease as the number of competitors increased. It follows from this that the probability of winning a

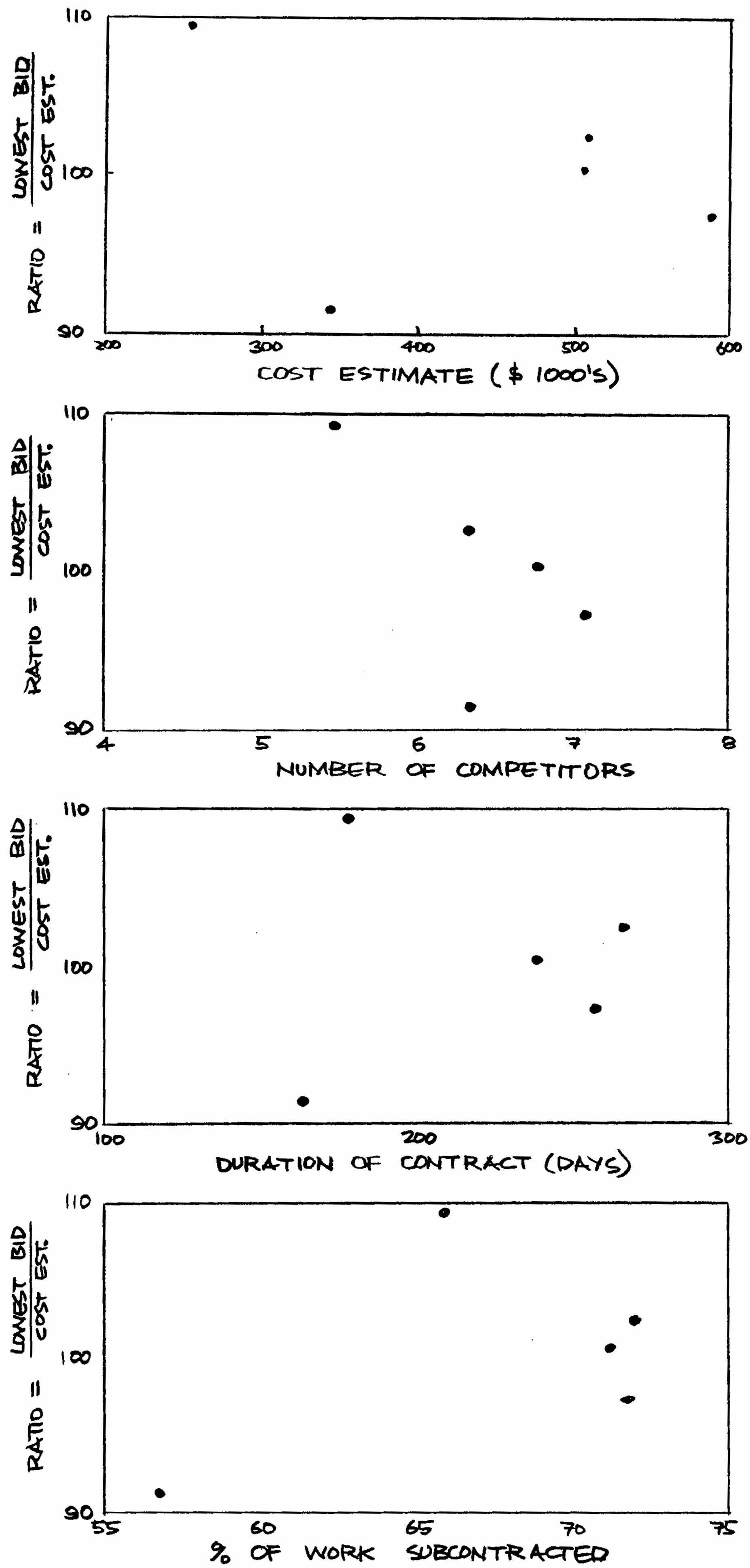
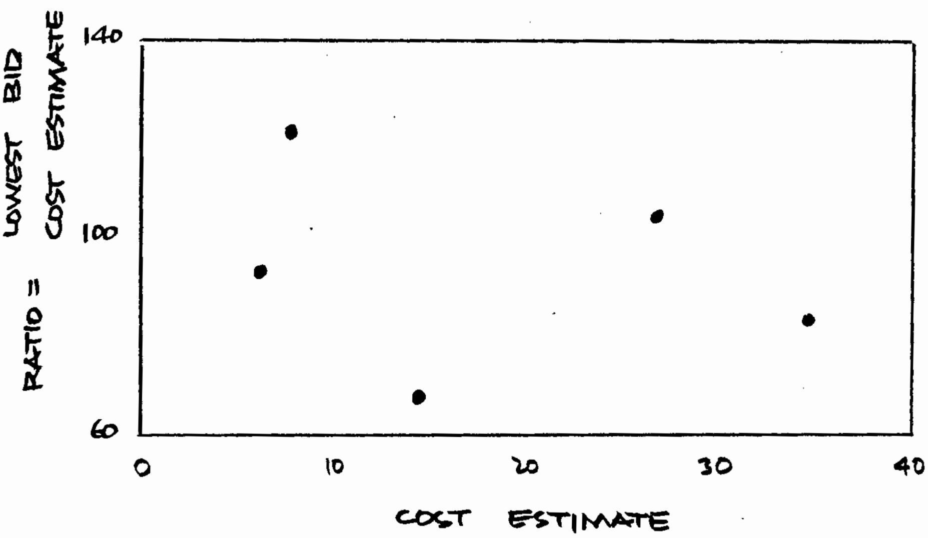


Figure 8.7.1(a) - Benjamin's Data



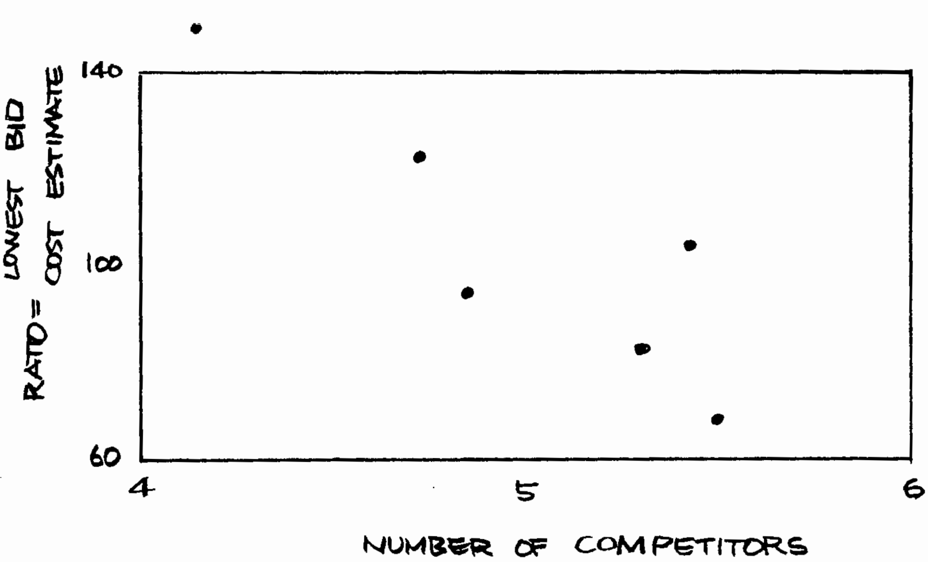


Figure 8.7.1(b) - Local contractor's data

contract decreases with an increase in the number of competitors.

This fact corresponds with the results of Section 8.2 where the following equation was given :

$$P(\text{win}) = \frac{1}{1 + n\,\frac{1-P(\text{ave})}{P(\text{ave})}} \qquad \ldots\ldots(8.7.1)$$

where P(win) is the probability of winning the contract; P(ave) is the probability of beating an "average" competitor, and n is the number of such "average" competitors. The appearance of n in the denominator of this formula indicates that the probability will decrease as n increases.

Generally, the present writer was surprised at the poor results of this analysis and so the same scatter diagrams were drawn on a graph plotter linked to the University computer. However on this occasion averages were not taken of the data values in each group, and each individual item of data was plotted. Such a task would have been most tedious without the aid of a computer.

The results obtained were just as disappointing as when averages were taken and so the diagrams are not reproduced here.

Therefore it must be concluded that though relationships would intuitively appear to exist between the ratio of the lowest competitor's bid and the contractor's cost estimate, and certain factor's listed above, historical data both from South Africa and from the U.S.A. does not support this.

CHAPTER 9 - THE PRACTICAL USE OF AN OPTIMUM BIDDING TECHNIQUE

In this chapter, a way in which an average contractor might make use of an optimum bidding technique is presented.

The particular technique to be considered is that based on equation 8.2.6 for the probability of being the lowest bidder for a construction contract. This technique was developed in Chapter 8 of this thesis and is described therein. No further description will be given of the technique in this Chapter.

The prime requirement for this technique is historical bidding data. The particular items of information that have to be collected for each past tender in which the contractor has participated are as follows :

a) The ratio of the lowest other competitor's bid to the contractor's cost estimate.

b) The average of the ratios of each competitor's bid to the contractor's cost estimate. The contractor's own bid should be excluded, as should any bid greater than 1,5 times the contractor's cost estimate.

c) The number of competitors for the tender, apart from the contractor.

d) Whether the contract was for a civil engineering project or for a building project. The contractor may use his own system of classifying contracts, but he must be consistent in deciding into which category each new tender should be placed.

It is necessary to maintain up-to-date values of the means and standard deviations of the two ratios (a) and (b) above for each past tender falling into both categories of work. This might be achieved by hand, but is easiest done by storing the historical data in a computer file. Only a very brief program is needed to calculate the means and standard deviations, and the cost of computer time will be negligible.

The present writer then recommends the use of charts such as those presented in figures 9.1 to 9.3 to obtain the optimal bid as a percentage of the contractor's cost estimate for the work of each new contract up for tender.

These charts have been constructed making use of the optimum bidding technique developed in Chapter 8. The charts shown are for tenders where 1,5 and 10 other competitors are to be met by the contractor. Other charts are easily constructed to take into account other numbers of competitors.

The contractor might use these charts in one of two ways. Firstly, he might consider only the lowest of the historical bids available to him. In this case, he would enter the chart for one competitor with the mean and standard deviation of the past ratios of the lowest bids to his own cost estimate. It is but a simple matter to read off his predicted optimum bid.

Alternatively, if the contractor knows how many other competitors he will meet on the tender, he might enter the corresponding chart with the mean and standard deviations of

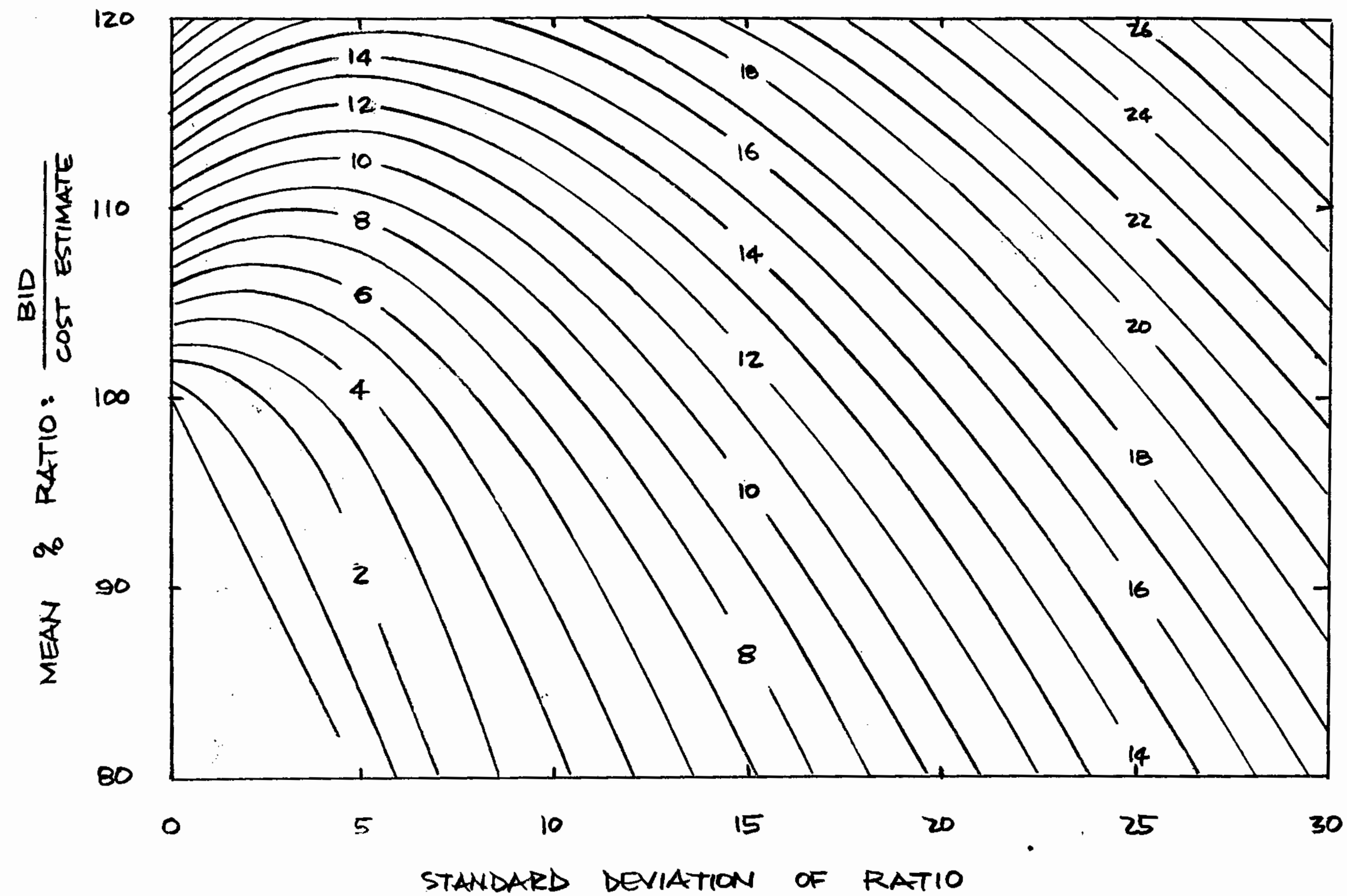


Figure 9.1 - Optimum percentage profit allowances, when competing against 1 competitor

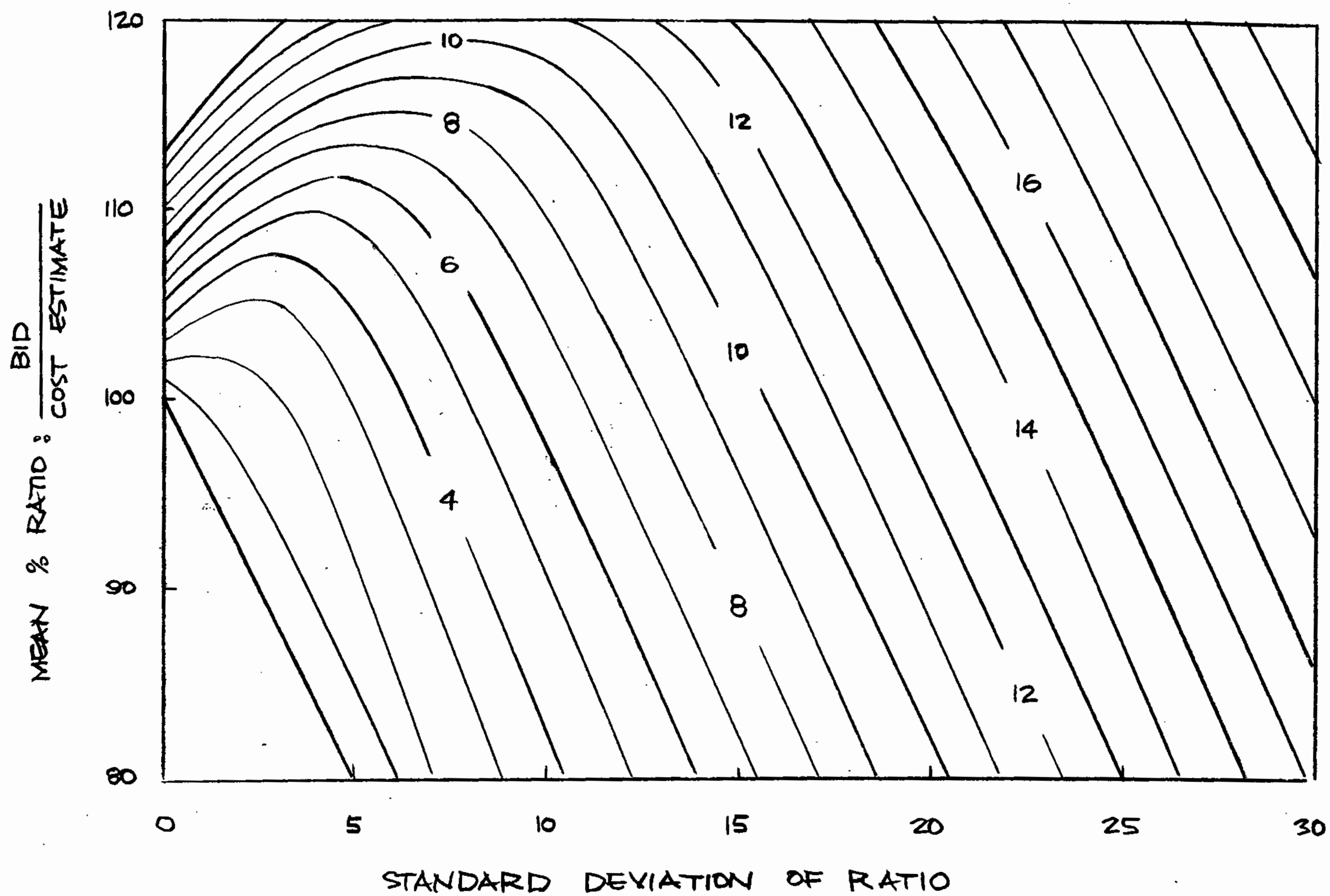
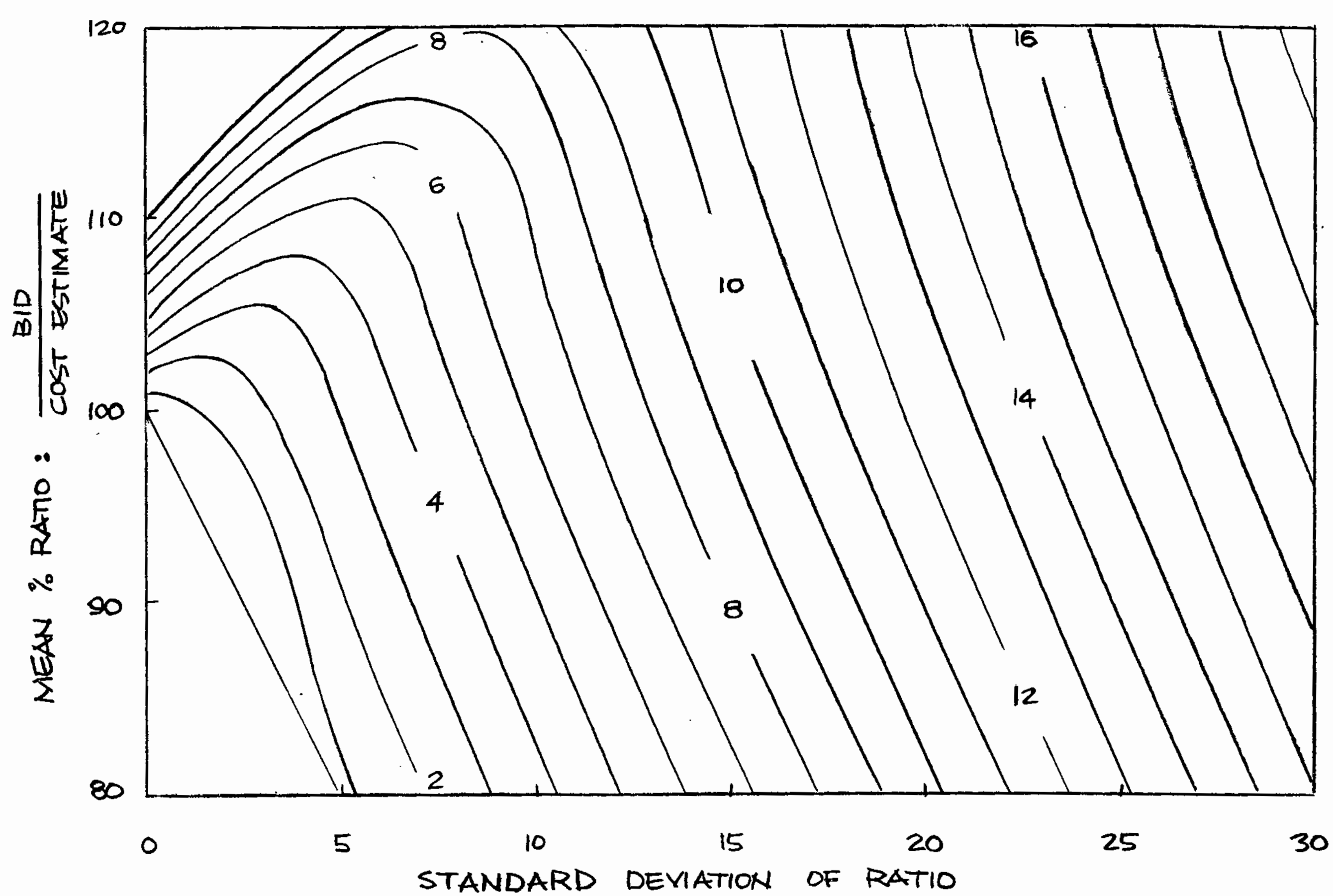


Figure 9.2 - Optimum percentage profit allowances, when competing against 5 competitors



<u>Figure 9.3 - Optimum percentage profit allowances, when competing against 10 competitors</u>

the past ratios of the average other bids to his cost estimates. Once again, the predicted optimum bid is easily read off.

Which of these two methods to use is left to the discretion of the contractor. It was noted, however, that in general, the two bid values that were given did not differ by more than 1%. The local contractor's data referred to in section 8.6 was used to arrive at this result.

In conclusion, it is important that the contractor should not regard this optimum bidding technique as a panacea to his tendering problems. It is of paramount importance that his judgment is integrated with the results obtained.

The reader is referred to figure 9.4 where the suggested bidding system is represented diagramatically.

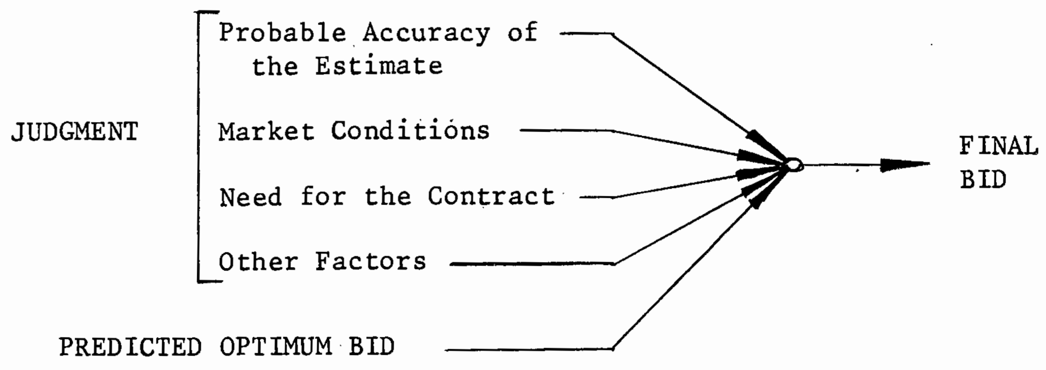


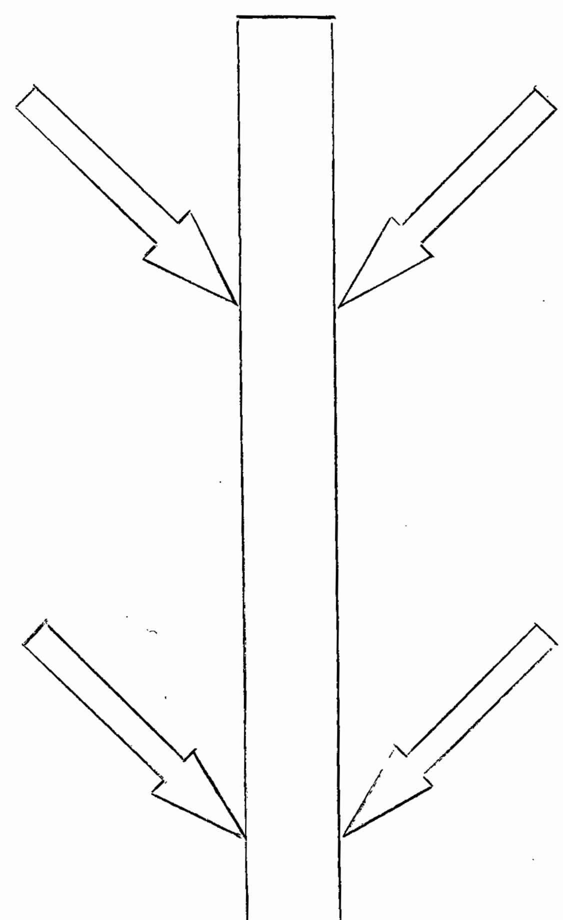
Figure 9.4

The matters upon which the contractor has to exercise his judgment were presented in Part 1 of this thesis, and the optimum bidding technique was developed in Part 2.

APPENDIX A - A DIAGRAMMATIC REPRESENTATION OF SOME FACTORS AFFECTING THE FINAL TENDER PRICE

COMPONENT COSTS

Material?
Labour?
Job overheads?
Office overheads?
How accurate is the estimate likely to be?



CONDITIONS OF CONTRACT

Type of tender?
How long is there to prepare the tender?
Are the contractor's responsibilities clearly defined?
Is completion clearly defined?
Are there penalties for delay?
Are there performance guarantees?
If there are any nominated sub-contractors, are they acceptable?
Are alternative designs acceptable?
Do the conditions of contract place unfair risk on the contractor?
Are sureties or bonds required?
Is there an arbitration clause?

FINANCE

What are the conditions of payment?
How long is the job?
How much money is to be retained?
How large is the required capital investment?
What return on investment is required by the company?
Is bank credit available?
What is the prevailing bank rate?
What are the insurance liabilities?

SIZE OF COMPANY

How large are the overhead costs?
Will it be possible to absorb the possible loss on a risky job?
Is the company large enough to finance the job itself?

PAST EXPERIENCE

Is it necessary to buy special equipment?
Is it necessary to train or hire specialists?

COMPETITION

What was the past bidding performance of likely competitors on similar jobs?
What interest has been shown by likely competitors?
Will this client invite the company to tender in future even if it submits a high price?

WORK LOAD

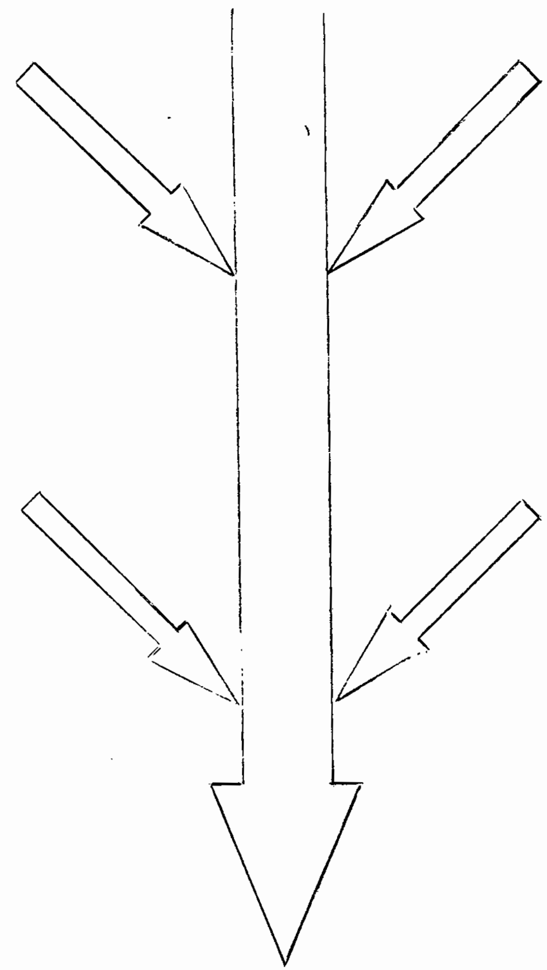
Will the job necessitate an increase in the company labour force?
Will it be possible to maintain or higher work loading level?
Will the job avoid resources lying idle?

RISK INVOLVED

How accurate is the tender information?
What natural hazards might be encountered on the job?
Are severe price changes likely?
Is there a price variation clause in the conditions of contract?
Is there a possibility of future labour difficulties?
Is this client financially stable?

PLANNING

Will the experience gained be of use in the future?
Will the job provide a basis for future client-contractor negotiations?
Is the job of value as an advertisement?



FINAL TENDER PRICE

APPENDIX B - THE EMPLOYMENT OF BANTU LABOURERS IN THE WESTERN CAPE.

The purpose of this appendix is to relate some of the relevant rules and regulations governing the hire and use of Bantu labour on civil engineering (heavy construction) contracts in the western Cape.

The western Cape is legally defined as bounded by the southern and eastern borders of South West Africa up to and including the magesterial district of Gordonia, and then in a south easterly direction to include the magesterial districts of Hay, Hopetown, Philipstown, Colesburg, Middleburg, Graff-Reinet, Pearston, Jansenville, Steytherville, Hankey and Humansdorp. Special regulations govern this area because of the supposed abundance of coloured labour, though this ethnic group appears far inferior to the Bantu in its physical capability for and mental attitude towards manual labour of the type necessary to carry out a civil engineering contract. Perhaps to avoid confusion, it should be noted that actual physical labour is under discussion here. These considerations do not apply to skilled labour such as bricklaying or carpentry.

The Bantu labour Act No. 67 of 1964 forms the legal basis for this discussion, and the points relevant to our discussion are summarized below.

A special "Employers recruiting licence" is required for a contractor wishing to obtain Bantu labour directly from the homelands and not through a labour bureau. However no employers in the western Cape are awarded these licences as will be seen from the way in which contractors actually obtain Bantu labour, as discussed below. On the other hand, such a licence is relevant to contractors living outside the western Cape, and so it will be described briefly.

The licence may not be issued in the name of a company, partnership or other association of persons, and so one individual in such an organisation has it made out in his name. However, provision is made in the Act for the licence to be transferred from one person in a company to another, provided permission is granted by the Director of Bantu labour. Also, licences are issued in respect of a specific recruiting area and cannot be used for any other.

The holder of such a licence may employ "runners" with the permission of the Director of Bantu labour. These are Bantu who are employed to canvass or collect Bantu or to act as a messenger in connection with the recruiting of labour. Such runners may only operate for one licence holder (and) in one area, and furthermore, any runners permits attached to a licence expire with it on the 31st of December each year.

The Act also states that adequate accommodation has to be provided for Bantu labourers near their place of employment and that a Compound Manager has to be appointed for every compound to house more than 50 Bantu.

The Government Gazette Extraordinary of the 3rd of

December 1965 sets out the Regulations pertaining to the above Act (Regulation Gazette No. 581, Government Notice No. R.1892). Some of its relevant points are given below.

A contract of employment betwwen a Bantu labourer and an employer is deemed to be for a period of 30 days and if a Bantu voluntarily continues to work after this period, he is deemed to be employed on a weekly basis if he is paid weekly or on a monthly basis if he is paid monthly. This is not quite the case in the western Cape, though, as will become clear later.

Apart from conditions covering accommodation, those governing licences and permits are also set out in these Regulations. Recruiting is forbidden in Rhodesia, Portuguese Territory or anywhere North of latitude 22^{o}S, as well as in certain areas of Natal for work outside those areas. Also, no recruiting may be done for employment inside a "prescribed area" (as referred to in section nine bis of the Urban Areas Act), and no holder of a labour agents' licence may recruit any non-Bantu.

The practical aspects of obtaining Bantu labour for work with a construction company in the western Cape shall now be considered.

First of all, an application has to be made to the Commissioner of Bantu Affairs for permission to employ a certain quantity of "imported" labourers at any one time. This "quota" is granted subject to the requirements of the company, and to sufficient reasons being given for the importing of labourers from other areas. Of course, the main reason will be the unavailability of coloured labourers, in most cases. From the approval of this application onwards, this quantity of imported labourers may not be exceeded until the quota is altered, as it may be on further application by the contractor.

At any time after the setting of this quota, the contractor may apply to import a certain amount of labourers. However, he has first to prove that there are no coloureds available.

To do this, he has to apply to the Divisional Inspector of the Department of Labour for Coloured labour to fill his vacancies. In this application he has to include the reasons for the vacancies, the numbers of Coloured and Bantu employed by him at the time and the conditions of employment, including the minimum wage and the number of hours to be worked each day.

Assuming that there is no Coloured labour available, the Inspector then issues a certificate stating this fact. This certificate is valid for one month.

Also, before he can import any labour, the contractor has to prove that adequate accommodation is available at the place of employment. The local authority usually provides a limited amount of accommodation, but failing this, the contractor has to find adequate accommodation elsewhere or else build it himself. In the latter case he must comply with the Government Regulations.

The contractor might build hutments varying in size from 18 to 56 bunks. These are built on land leased from the local authority, and should the contractor fail to keep the buildings occupied for some reason, then the local authority may assume the use of them.

Now when the Commissioner for Bantu Affairs is satisfied that labour may be imported, the contractor applies to the Municipal or District Labour Officer in the area from which he wishes to recruit labourers. On the application form, he has to state the particulars of the vacancy, the conditions of employment (including salary, etc.) and he has to enclose a sum of R25. per vacancy to cover the cost of bringing the labourers by train from their homelands to the place of employment, as well as giving them medical examinations etc. The portion of this actually covering the rail fare is recoverable from the Bantu in the form of a weekly wage deduction.

Imported Bantu labourers are obliged to work for one year only and then to return home for a period of at least three weeks. After this period, the contractor once again has to undergo the application process.

Usually a contractor wishes to re-employ a good labourer whom he has spent time training, and this is possible in that specific requests for particular Bantu may accompany the applications. In practice though, this is not always successful.

This procedure for collecting labour is only entered into when the relevant contract has been signed, and so due allowance has to be made for a time lag of approximately 13 weeks when the job is scheduled. It is important to note that there is always a firm labour requirement when such a recruiting compaign is begun and seldom, if ever, is it based on forecasts alone.

When rough forecasts of any type of labour are made they are usually based on an estimate of company growth for the prediction period to be considered. This estimate is generally made by top management.

It is but a simple matter to apply the estimated growth factor to past labour requirements to produce a very rough prediction of future labour requirements. Presumably the method can be improved if one uses different growth estimates for the different spheres of interest of the company (e.g. high-rise buildings, pipelines, roads etc.). These estimates might vary quite considerably.

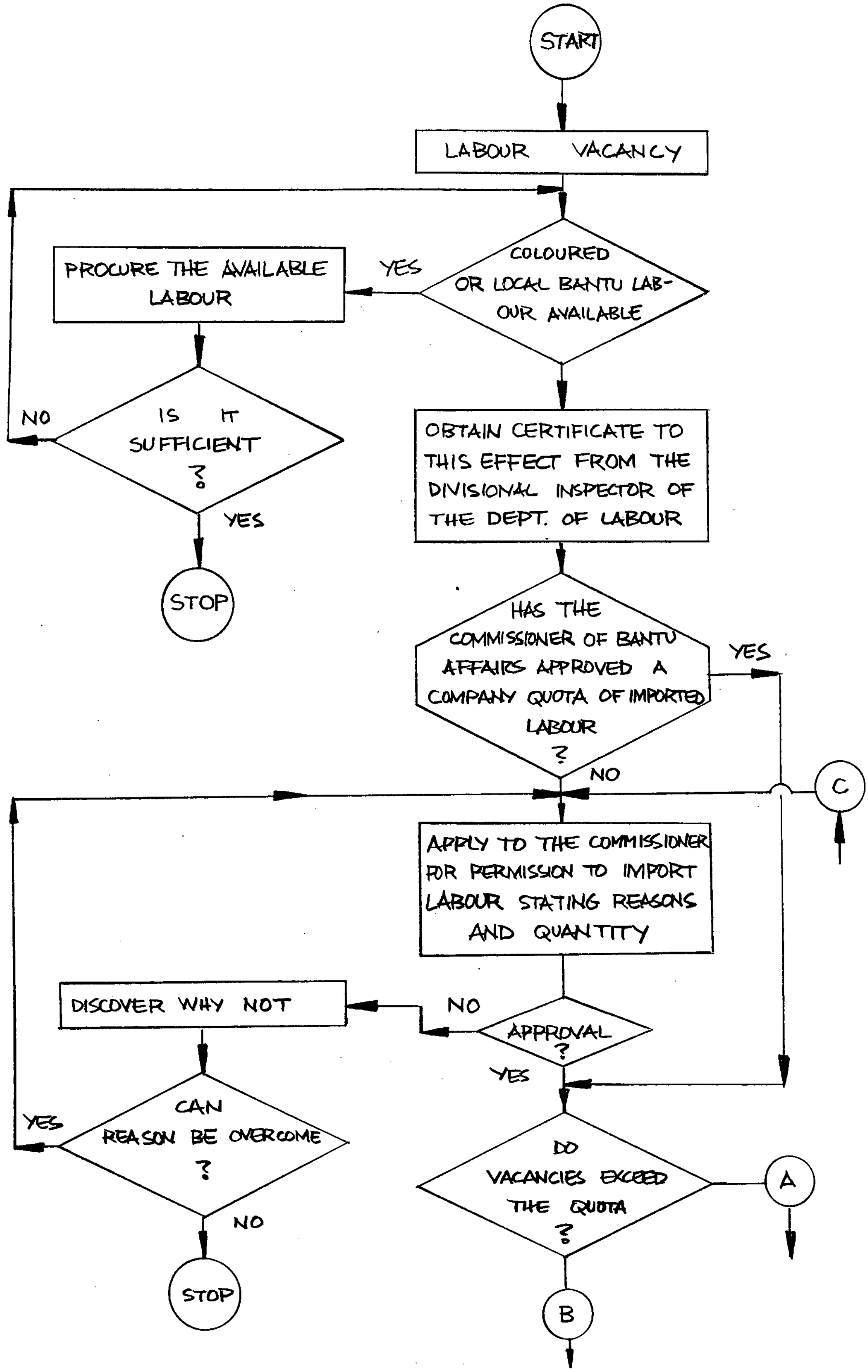


Figure B.1 - The employment of Bantu Labourers in the Western Cape

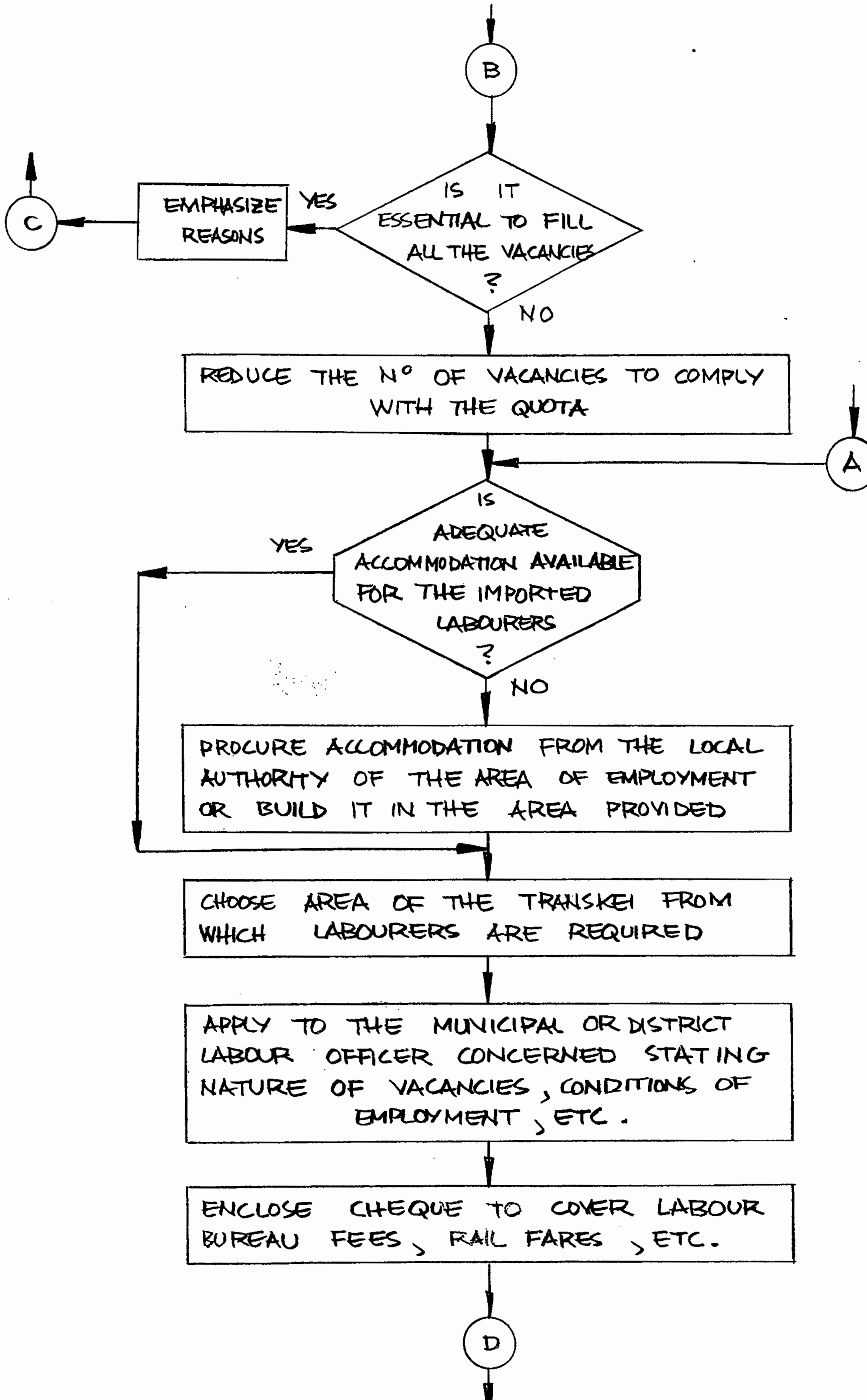


Figure B.1 - (continued)

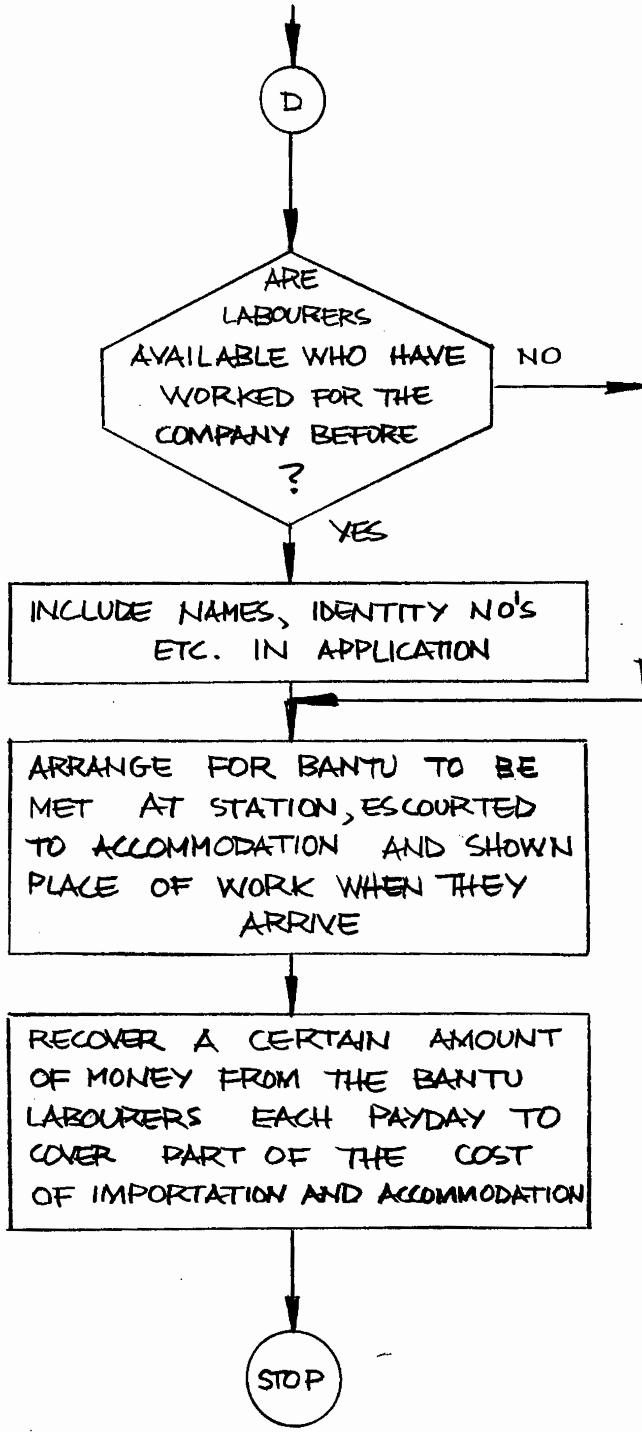


Figure B.1 - (continued)

APPENDIX C - A TABULATED COMPARISON OF SOME CONDITIONS OF CONTRACT IN USE IN SOUTH AFRICA.

In this Appendix, a comparison is made between the clauses of the six conditions of contract listed to in Section 3.2 of this thesis.

The reader is referred to that section for the full titles of these conditions. Hereafter in this Appendix the following abbreviations will be used :

a) The South African Institution of Civil Engineers conditions - SAICE;
b) The Institute of South African Architects conditions - A; see latest Edition March 1971
c) The Department of Public Works conditions - PW;
d) The Cape Provincial Administration Department of Roads conditions - CPA;
e) The Cape Town City Council conditions - CT.

The International conditions were not included in the tabulated comparison as they are almost identical with the SAICE conditions. However, there were a few differences and these are summarised below.

a) There were several clauses relating to the languages to be used on the contract, payment in currencies other than that of the country in which the contract was being executed, and the import and export of plant. In all these clauses, the employer was required to assist the contractor as far as possible.

b) Should there be a major economic dislocation such as the devaluation of a currency or the imposition of import restrictions by the Government of the country in which the works were being carried out, then the employer was to pay any extra costs incurred by the contractor.

c) In the International conditions, ownership of the contractors plant and equipment did not automatically pass to the employer for the duration of the contract.

d) No mention was made of retention money in the International conditions.

In the following tabulated comparison, the first column contains a brief description of the subject of each clause. The next five columns contain the numbers of the clauses relating to each subject in five conditions of contract presently in use in South Africa. Finally, a brief description is given of points on which the conditions differ.

Clauses	SAICE	Architects	Public Works	CPA Roads	Cape Town	Notes
1. Assignment & Sub-contracting	3,4	14	16	8(a)	28,29	PW includes piecework in the provisions of the clause while SAICE & CPA specifically exclude it. A and CT do not mention piecework.
2. Arbitration	67	26	28	5(c)	52	PW refers disputes to Courts of Law while others agree on arbitration. A suggest agreement be reached before signing contract. All except PW & CPA refer to heads of Institutions of Civil Engineers, Architects or Quantity Surveyors.
3. Bankruptcy	63	22(b)	26	8(i)	-	
4. Certificates & payment	60,61 62	25	19	9	33,36,44	CPA require contractor to provide proof of ownership of materials. 10% retained at each payment except for SAICE where amount specified for each job. PW limit retention money to 7½% contract value while CPA limits to R5 000 for roads and R20 000 for bridges. A and CT retain 5% during maintenance period while CPA retain lesser of R5 000 or

Clauses	SAICE	Architects	Public Works	CPA Roads	Cape Town	Notes
						10% of total and PW retain 2½%. A allow interest to be earned on retention money when it exceeds R20 000. CT prohibit this. CPA retain 25% on unused materials in addition to above %. A makes employer liable for 10% interest on late payments while SAICE adopt prevailing bank overdraft rate.
5. Completion & Delay	43,44, 47,48	18,19, 20	17	8(d), (e),(f)	32,33, 34	
6. Contractor's default	63,65	21,22	18	8(i)	39	
7. Contractor's equipment, vesting of	53,54	-	5	-	24	CPA only takes ownership of equipment when contract determined. A does not assume ownership and sells the equipment when the contract is determined, crediting the contractor with the proceeds less the costs. Only the SAICE makes specific mention of hired plant.
8. Contractor's representatives & workman	15,16, 34,35	7	8,12, 13,14	5(f)(g) (h)(i)(j)	13,14, 46	Only A makes no requirements regarding wages and accommodation given to workmen.

Clauses	SAICE	Architects	Public Works	CPA Roads	Cape Town	Notes
9. Damage to property & injury to persons	20,22, 23(3), 24(1)	16	21,24	7(g)(h)(i) (k)	30	CPA makes contractor responsible for obtaining permission to use private land.
10. Drawings	7,8	2	2	5(d)(e)	3,4	
11. Defects Liability	49,50	13	23	9(g)(j) (k)	35	Maintenance period stated in tender documents except for CPA who require 12 months and A who require 3 months for defects other than roof leakage for which 6 months is required.
12. Delivery of materials & passing of property	53,54	6,12	6,20	6(b)	24	A requires that materials only become the property of the employer after they have been taken into account. PW requires the use of government transport when delivering materials.
13. Engineer/architect	1(c)(d) 2	1	1(iv)	1(f), 5(a)	1(b),16	
14. Execution of the work	13,36(i)	1(a)(b) 11	2(i)	4	5,10	
15. Faulty work	39	6	11	5(o)	25	

Clauses	SAICE	Architects	Public Works	CPA Roads	Cape Town	Notes
16. Fluctuations in Price	68	-	14(ii)(iii)	3(b)(c)	46(7),48	SAICE,PW and CT specifically allow variations in labour rates while CPA allows variations in cost of living allowance. SAICE allows fluctuations in ruling market prices of materials and fuels quoted in tender, CPA allows fluctuations in prices of bitumens, fuels and oils, cement, steel reinforcing, and CT allows fluctuations in cement. PW allows no material price fluctuations while A does not mention any fluctuations at all.
17. Inspection & testing	36,37, 38	1(a)(iv) 8	10,11	5(n)	11,15 26	
18. Insurance	21,23, 24,25	17(A) or (B)	22	7(j)	31	SAICE, CPA and CT require contractor to insure. A require contractor to insure for new buildings under construction and employer to insure for old buildings under alterations. PW does not specifically require insurance, and states government to insure against fire.

Clauses	SAICE	Architects	Public Works	CPA Roads	Cape Town	Notes
19. Patent rights	28	-	-	-	12	
20. Provisional & prime cost sums	58,59	24	-	-	40,41,42	
21. Security for performance	10	-	18	1(d) 8(i)	-	PW makes allowance for 10% of contract value to be deposited with the Dept. of Public Works as surety for the work.
22. Site, possession of	42	18	17(i)	8(b)	32	
23. Statutory & other regulations	26	4	25	7(a)(b) (c)(d)(f)	6	
24. Sufficiency of tender	11,12	-	-	2(c)	-	Clauses concerning sufficiency of tender are contained in conditions of tender for A,PW & CT.
25. Suspension & delays	40	20	9,17(ii)	8(c)(f)	38	
26. Variations to the work	51,52	10	3,4	2(b),4(b) 9(c)(d)(e)	19,20,21, 22	A,PW and CT allow 10% on materials and $33^1/_3$% on labour for dayworks while CPA allow 15% on materials, 20% on labour and $33^1/_3$% on approved plant rates. SAICE have %ages entered in contract agreement CT,PW,A allow for losses because of omissions, but SAICE and CPA do not.

APPENDIX D - THE ELEMENTS OF GAME THEORY

The Theory of Games was developed for use in strategic situations. These may be defined as situations of conflict between several decision makers. Such situations include warfare, negotiation between a contractor and the promotor of a property development scheme, or merely haggling between a housewife and a grocer over the price of tomatoes.

The important point is that one decision maker does not know with certainty what the others will do. Hence, every decision maker is uncertain of the exact outcome of any course of action which he might take. He is only able to assign probabilities to several probable outcomes.

Certain terminology is peculiar to Game Theory, and a short list of important terms is given below.

a) A "player" is a decision maker. This could be an individual, a firm of contractors, or a whole nation.
b) A "payoff" is the value (not always monetary) of a particular outcome of the game. Each outcome is the result of a set of decisions by the players.
c) A "strategy" is a pre-determined set of instructions stating what decision should be taken by a player in a certain situation.
d) A "zero-sum" game is one in which the losses of any one of the players are the winnings of the others. None of the players' resources leave the game.

e) A "two-person" game is one where there are only two players. This is the simplest type, and our discussion will be confined to such games.

Consider the two-person zero-sum game whose payoff matrix is given in figure D.1

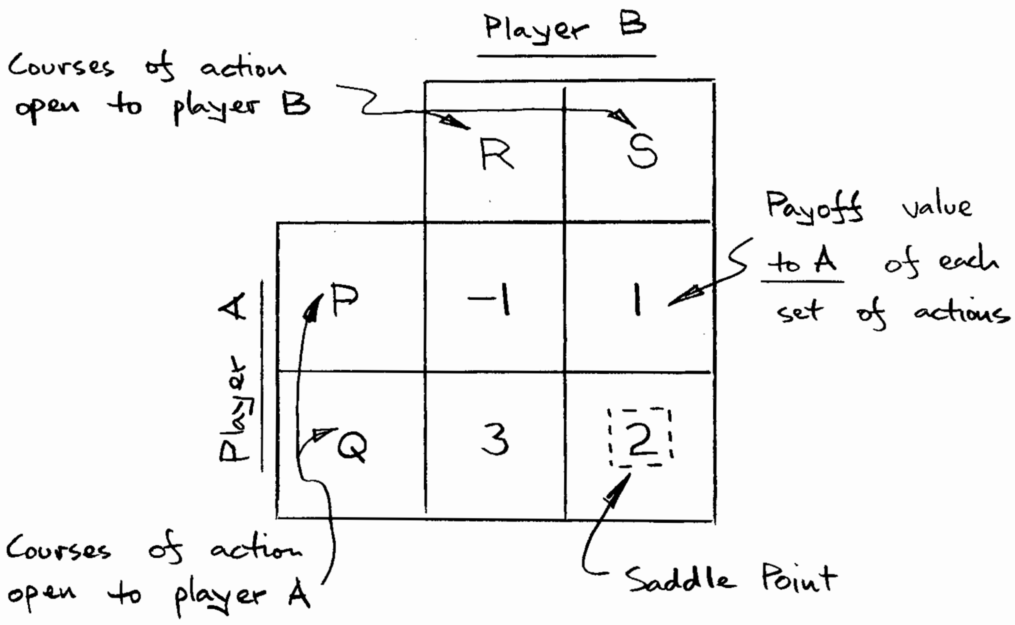


Figure D.1

The players are A and B, and each has two courses of action open to him. A may adopt P or Q and B may adopt R or S.

Consider the possible outcomes if A chooses P. If B chooses R, then the outcome is a loss of 1 unit to A. However, if B adopts S, then A will win one unit.

When choosing his course of action, each player pessimistically assumes that his opponent will select his best counter course of action. Each player therefore chooses his own safest course of action.

The worst outcome for A if he chooses P is that he loses 1 unit. If he chooses Q, the worst that can happen is that he wins 2 units. Therefore his best strategy is to adopt Q as his course of action.

Similarly, if B chooses R, he might lose 3 units, but if he chooses S he will only lose 2 units at worst.

Therefore the two optimal strategies are for A to adopt Q and B to adopt S. Furthermore, the value of the game is 2 units since this is the amount won by A and lost by B when both adopt their optimal strategies.

The element Q-S of the payoff matrix is termed a "saddle point" since it contains the payoff associated with each players' optimal strategy. Unfortunately, it is a significant fact that in practice games with saddle points are rare.

Another point to notice in this game is that A wins what B loses, no matter what strategies are used. This is therefore a zero-sum game.

Now consider the payoff matrix given in figure D.2. This differs from the first payoff matrix in only one element, namely that associated with A adopting strategy P and B adopting strategy S. B now loses 4 units to A instead of 1 as before.

Player B

Player A		R	S
	P	−1	4
	Q	3	2

Figure D.2

From this payoff matrix it is readily seen that B's safest strategy seems to be R and A's safest strategy seems to be Q.

However, if B knew that A was going to adopt Q, he might adopt S instead, and only lose 2 units instead of 3. On the other hand, wily A might anticipate B and choose P. He would then win 4 units from B.

This circular reasoning indicates that the best strategy in fact would be for each player to select his course of action in such a way that the other would be unable to predict what he will do. This is termed a "mixed strategies" as opposed to the "pure strategy" presented above.

The choice between courses of action might be made by tossing a coin, spinning a roulette wheel or by making use of tables of random numbers.

In the case of mixed strategies, the value of a game is determined from a consideration of expected profits or losses. The size of this appendix does not permit this subject to be persued further.

In the opinion of the present writer, the weakness of Game Theory is its severe practical limitations. The two-person zero-sum game described above are hardly representative of everyday situations. When more realistic circumstances are modelled, Game Theory rapidly becomes unmanageable, and the time and money spent on this type of analysis could often be put to better purpose in another sphere.

Furthermore, it is highly doubtful whether any contractor would happily toss a coin to decide on his profit allowance before submitting a multi-million Rand tender!

APPENDIX E - THE ELEMENTS OF UTILITY THEORY

Utility Theory consists of a set of axioms. A decision maker is said to be "rational" if he satisfies these axioms when making a decision.

In this context, a decision denotes a choice between alternative courses of action, each one resulting in a different outcome. The axioms of utility theory concern the decision maker's order of preferences for any particular set of outcomes.

If these preferences comply with the axioms (i.e. the decision maker may be termed "rational"), then a utility function may be used to describe his preferences.

Two of the most important axioms of Utility Theory concern us and they are given below.

a) It is possible to rank the preferences for different outcomes so that if A is preferred to B and B is preferred to C, then A is preferred to C.

b) If outcome A is preferred to B and outcome B is preferred to C, then there is a probability, p, such that the decision maker is indifferent between having outcome B occur with certainty and making a decision whose outcome will be A with probability p and C with probability (1-p).

To illustrate the use of these axioms in constructing utility functions, the present writer conducted an experiment with the co-operation of three of his friends.

They were asked the following questions to establish their preferences for various sums of money. From their answers, functions were constructed to describe their utility for money.

a) If a man offered to toss a coin if you paid him a sum of money, and if it landed heads he would pay you R1000, and tails nothing, then how much would you give him for tossing the coin?

b) If he still said that he would give you R1000 if it landed heads and furthermore that you wouldn't have to pay him anything to toss the coin, then how much would you be prepared to give him if it should land tails?

c) Once again he offered to pay you R1000 for heads, but the amount of money you would have given him in question (a) if the coin came up tails. How much would you pay him just to toss the coin this time?

d) Now he offers nothing for tails and your answer to question (a) if it lands heads. How much would you give him to toss the coin?

e) This time he offers to pay you nothing if the coin lands heads, but you have to pay him the answer to question (b) if it is tails. How much would he have to give you before you would accept the gamble?

f) Finally, if you were to pay him R1000 to toss the coin, how much would he have to pay you if it landed heads, considering that you will get nothing if it lands tails? Or wouldn't your present financial position allow you to take such a chance?

It will be observed that these questions each concern three sums of money. Two are given in the question and the answer is the third.

The tossing of a coin is used to introduce the element of chance, or probability. The second axiom of utility theory, as given above, is then used to determine the utilties of the amounts of money given as answer to the questions by the subjects of the experiment.

Each outcome of the tossing of a coin has a probability of occurrence of 0,5. If a person is indifferent between obtaining an amount B for certain, or else tossing the coin and obtaining A if it lands heads or C if it lands tails, then the amount B has a utility to him equal to the average of the utilities of A and C.

The answers to each of the three participants in the experiment are presented in table E.1.

Table E.1 - Answers

Question No :	(a)	(b)	(c)	(d)	(e)	(f)
ALF	R50	-R100	R100	R10	-R80	No
BEN	R20	-R 20	R 25	R 1	-R18	No
CARL	R100	-R300	R300	R30	-R250	No

These points are plotted in figure E.1 and approximate curves are drawn through them.

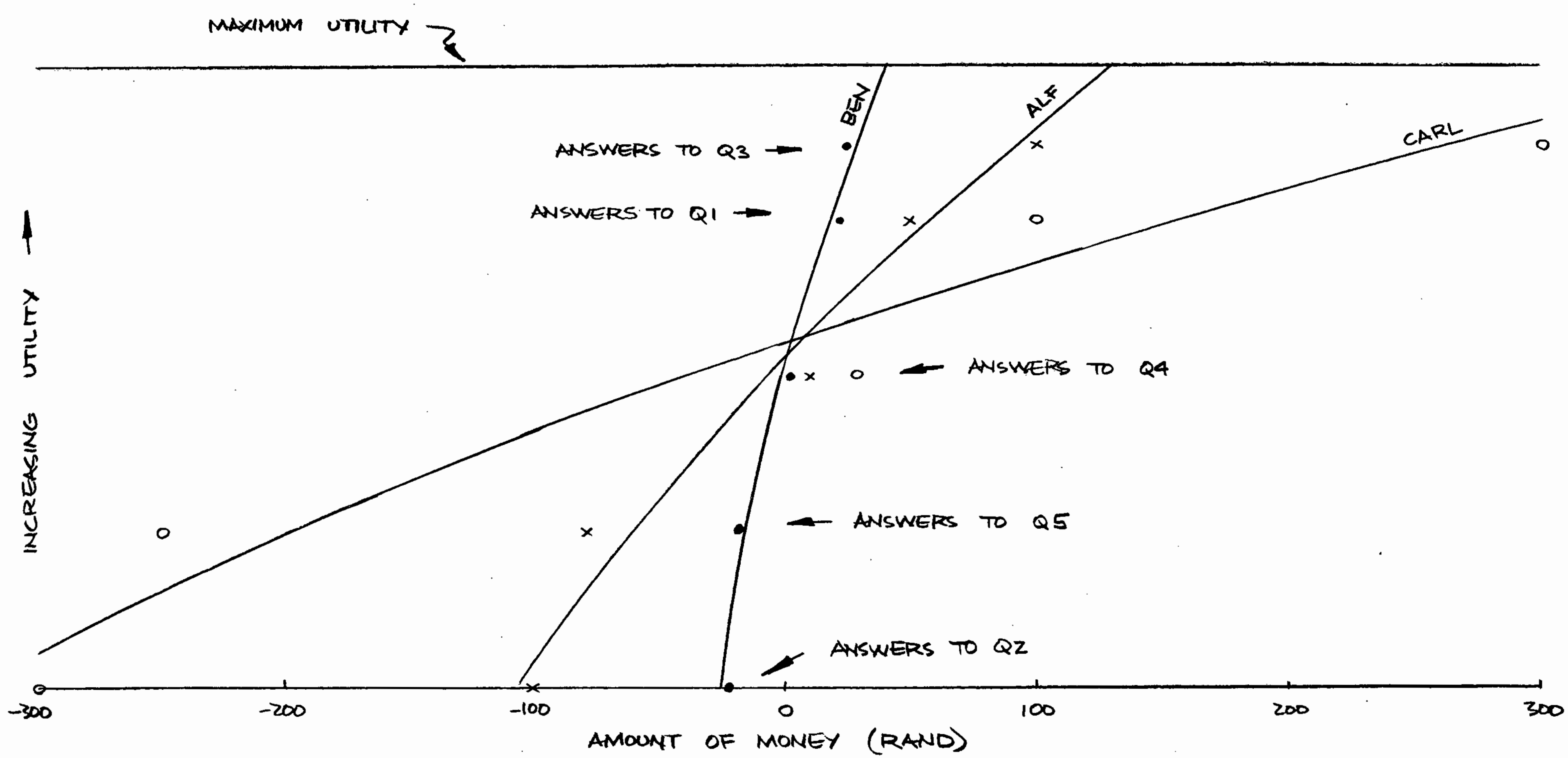


Figure E.1 - Results of Utility Questions

It should be noted that no specific utility values were assigned to the points. Only their relative utilties were plotted.

Utility amounts are completely arbitrary, and are usually chosen to lie between 0 and 1. However, the present writer omitted to do this to emphasize the fact that only relative utilties are necessary when making decisions.

From figure E.1 it is apparent that each of the participants in the experiment had a different attitude towards money.

Money is not very important to Carl, and he likes to gamble, whereas Ben is a thrifty person. Alf's attitude towards money is somewhere between the two.

It is also noticeable that each of the curves tended to decrease in slope as the monetary amount increased. This indicates that an increase from 1 to 2 Rand has more increase in utility than an increase from 101 to 102 Rand. This nonlinear utility of money is a common phenomenon.

Utility theory is an extensive subject, the surface of which has barely been scratched. However, the present writer is of the opinion that its practical application to the competitive bidding problem is severely restricted by the practical problem of setting up utility functions.

The reader is referred to section 8.1 of this thesis for further discussion on this topic.

APPENDIX F - AN OPTIMIZATION TECHNIQUE.

In their book (44a), Wilde and Beightler quote the following Chinese Maxim :

"There are many paths to the top of the mountain, but the view there is always the same".

Very broadly speaking, the "paths" of Optimization Theory may be classified into the three groups described below.

a) Differentiation. Maximum and minimum points may be found by setting the first differential of any function of zero and then evaluating the second derivative at those points. A positive value will denote a minimum point and a negative value a maximum. Of course, this method becomes successively more complicated as the function has more and more variables, and partial derivatives must be used.

b) Elimination. In this method, the function is evaluated at several points, and from the results, the region in which the optimium must lie is reduced. The process is successively repeated until the position of the optimum is known to lie within acceptably small limits. Figure F.1 shows the method diagramatically for a function with only one independent variable and only one optimum point (a one dimensional unimodal function). After the function has been evaluated at the five points, the optimum is known to lie between p and q.

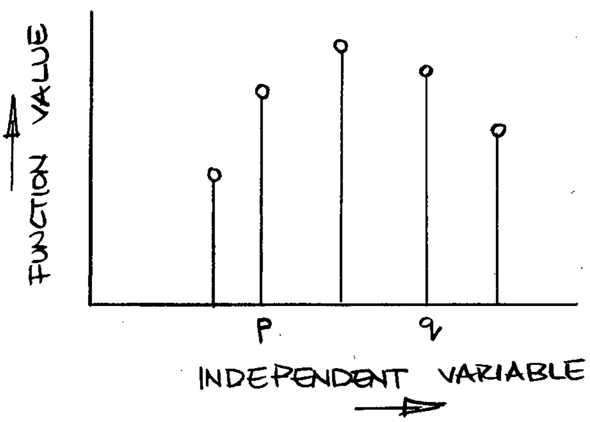


Figure F.1 - Elimination

c) Climbing. This procedure begins with at least two evaluations of the objective function and then the position of the succeeding points where the function is evaluated are automatically chosen so that the function values will improve. The optimum is reached when no further improvement is possible. Reference to figure F.2 should help to clarify this method for a one dimensional unimodal function.

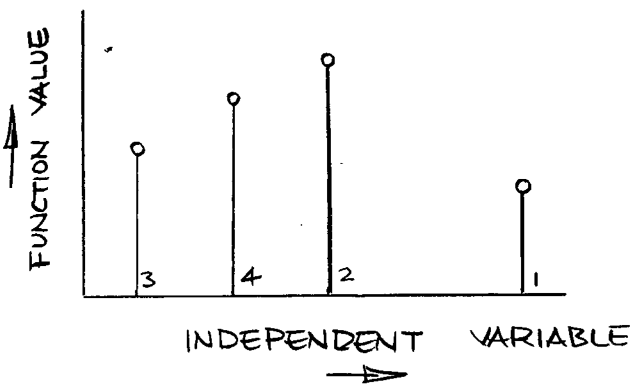


Figure F.2 - Climbing Technique

The points were chosen in the order shown. Note the closer spacing of the points after the "turn".

The optimization technique used in the computer programs of this thesis is actually a mixture of all three of the above methods. The problem of finding the optimum expected profit as a function of the bid amount is a particularly simple one since there is only one peak value and there is only one independent variable.

Successive evaluations of the expected profit were made at two closely spaced values of the bid amount. From these two expected profit values, the slope of the function was determined and the next pair of measurements were made in the "uphill" direction. The reader is referred to figure F.3.

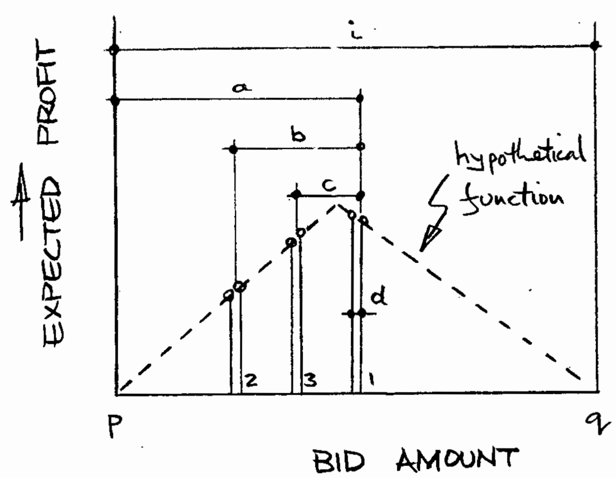


Figure F.3 - Optimization Technique

Initially, the peak is assumed to lie between the two bid values p and q. The initial "region of uncertainty" is therefore i = q - p. The first pair of measurements are made symetrically about the centre of the region of uncertainty, at position 1 in the figure. These two expected profit values indicate that the peak lies to the left and so the region of uncertainty is reduced to a. This procedure is repeated until after three sets of measurements of the expected profit, the region of uncertainty is c.

If d is taken as the interval between the two bid values at each set of measurements, it is easily verified with reference to figure F.3 that the region of uncertainty r is given by equation F.1 after n sets of evaluations.

$$r = \frac{q-p+d}{2n} - d \qquad \ldots\ldots(F.1)$$

The bid values actually used in the computer programs of this thesis were expressed as percentage allowances for profit based on the contractor's cost estimate for the contract. They were as follows :

$$p = 0{,}0\% \ ; \quad q = 30{,}0\% \ ; \quad d = 0{,}1\%$$

If these values are substituted into equation F.1, for

n = 8	r = 0,016
n = 9	r = 0,042

Hence it is seen that eight values are sufficient to reduce the range of uncertainty to 0,03% of its original value.

Figure F.4 shows a flow chart of the Optimization sub-routine.

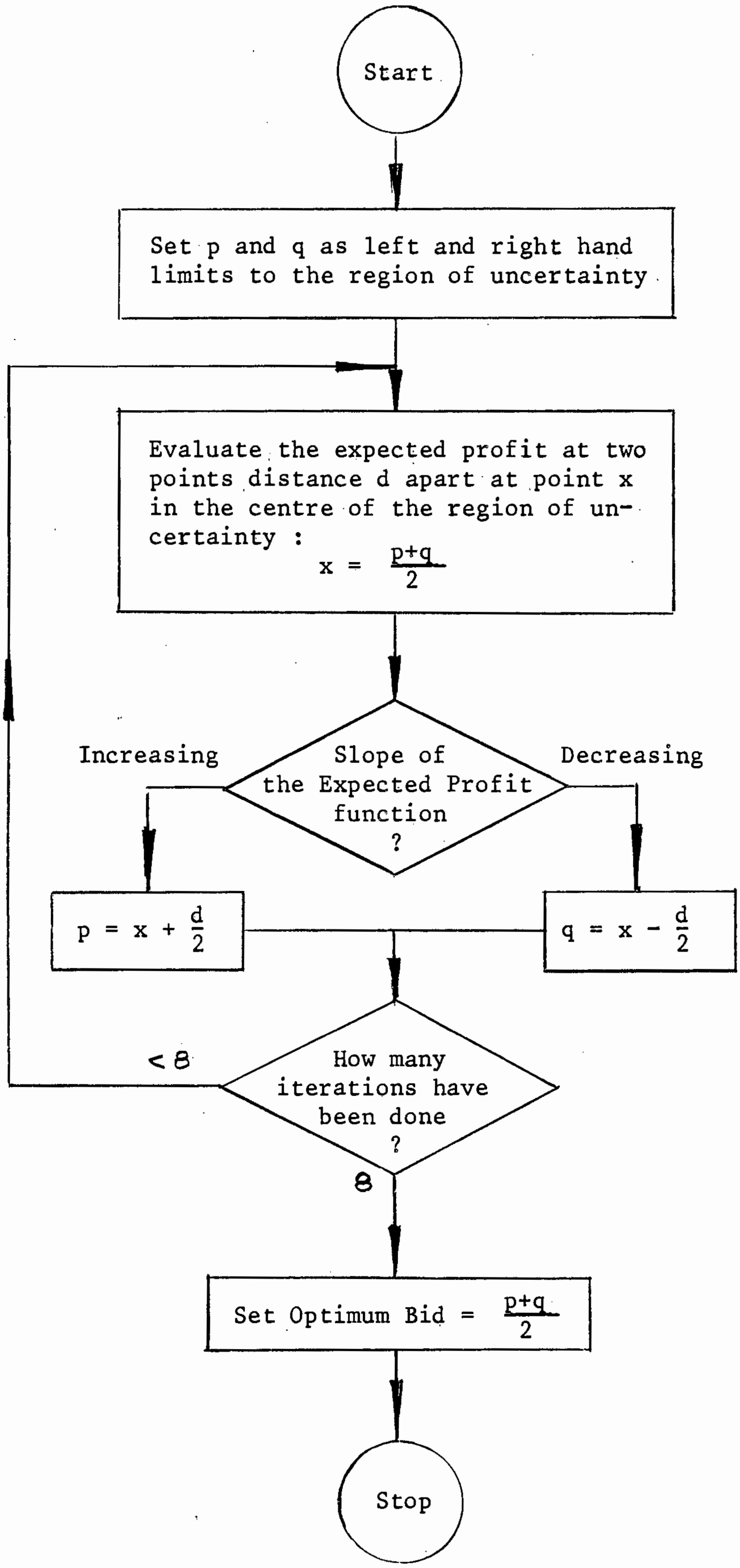


Figure F.4 - Optimization Flow Chart

APPENDIX G - A PSEUDO RANDOM NUMBER GENERATOR

At the time when the present writer was developing the simulation program described in Section 8.5, no effective random number generator was available for use on the University computer. This necessitated a brief investigation into the subject of random number generators and the findings of the writer are set out in this appendix.

The random numbers usually produced by computer program are uniformly distributed over the interval 0 to 1. The random number generator developed by the present writer also followed this pattern.

An initial number or "seed" was used to start the generation process. Using this number, the sub-routine then produced a new random number which was itself used as input for the next one. In general, the (i + 1)th number was generated from the ith number.

The generation method adopted is commonly termed the "congruence method". The input number was multiplied by a constant (P) and divided by another constant (K), leaving a remainder lying between 0 and 1. This remainder was the random number generated.

The value of P used was 109 and the value used for K was 8.

The value 8 was chosen for K as it is a power of 2. Since the computer used the binary number system, division by any power of 2 is performed very efficiently by shifting the binary point to the left.

The value 109 was chosen for P since it was a prime number and hence could have no relationship to the value 8. A lack of correlation between P and K is said to result in very randomly generated numbers.

The seed was a four figure number (i.e. had a value between 0 and 9999) selected from a table of random numbers.

This number was then divided by 10 000 to reduce it to a value between 0 and 1. After this, a sequence of random numbers was generated in the manner described above.

The flow chart of the sub-routine used to generate random numbers is presented in figure G.3. where?

It is apparent that since a computer can only handle a finite number of significant figures, eventually a random number will be generated which will be the same as a previous one. This will cause the series of numbers generated up to that point to be repeated.

It is for this reason that the term "Pseudo Random Number Generator" is used to denote the procedure.

The likelihood of the sequence of numbers being repeated before any required amount of random numbers has been granted is however remote.

In Section 8.5 of this thesis, random numbers were required to be drawn from a normal instead of a uniform distribution. The present writer accomplished this by using a UNIVAC supplied sub-routine.

The uniformly distributed random numbers were considered to be the values of the cumulative normal distribution function. The inverse of this function was therefore required to yield the corresponding normally distributed random value. This process is illustrated in figure G.1.

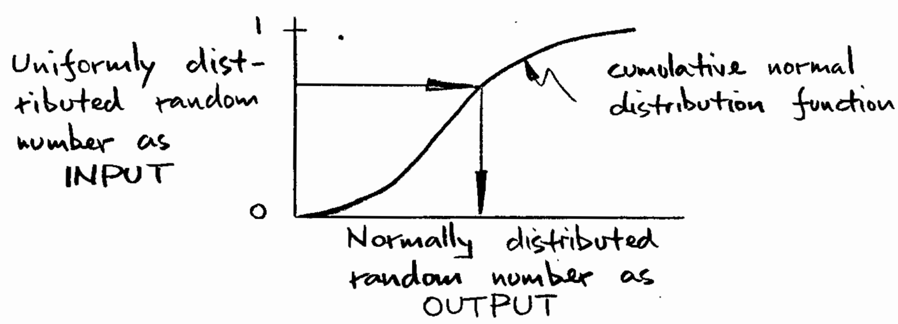


Figure G.1

The inverse of the cumulative normal distribution function cannot be expressed in ordinary matematical terms, and so a numerical approximation was used in the sub-routine. Further details of this method are beyond the scope of this appendix.

Also in Chapter 8, the value of the cumulative normal distribution function had to be evaluated at various points. This was in order to calculate the probability that the value of a normally distributed random variable (an opponent's tender bid) would be less than a certain amount (the contractor's bid in this instance).

Once again a UNIVAC supplied sub-routine was used, and this was also based on a numerical approximation to the cumulative normal distribution function.

In this case, the process shown in figure G.1 was reversed. The reader is referred to figure G.2.

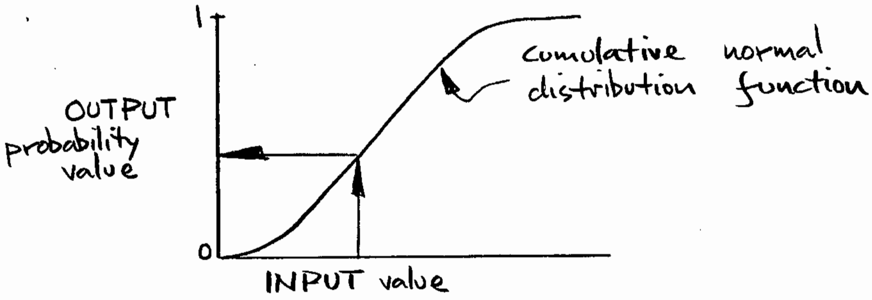


Figure G.2

APPENDIX H - UNBALANCED BIDDING

In this Appendix, the reader is assumed to be partially familiar with the concept of linear programming. However, nearly every computer in use at the present time has software able to solve linear programming problems. Hence, a contractor without a theoretical knowledge of linear programming should nevertheless have little difficulty in making use of the bidding technique outlined in the following pages.

At the outset, it must be explained that this method applies only to tenders for unit price contracts. These form the subject of sub-section 1.3.2 of this thesis. Furthermore, it is assumed that payment for the work takes place at intervals while it is being carried out. The reader is referred to Section 4.2 of this thesis where typical conditions of payment for construction work are described.

Now when the price submitted by the contractor for each item of the work has been calculated without regard for any outside factors bearing an influence on that contract, then the bid is said to be "balanced". As soon as the contractor alters any of his unit rates because of the circumstances surrounding a contract, he is said to have "unbalanced" his bid.

This subject has been introduced in Section 2.11 of this thesis. It is the purpose of this Appendix to describe a technique whereby a tender bid may be optimally unbalanced.

It is senseless to discuss an optimal technique unless a measure of effectiveness is presented to compare different techniques. In linear programming, this measure is known as the objective function.

When unbalancing a bid, the usual objective is to maximise the present value of all the future payments to be received for the work. The present value concept has been considered in Chapter 4.

There are two possible ways of achieving this objective. One is to alter the order in which the items of work are carried out, and the other is to alter the unit prices for each item while maintaining a given schedule for their completion. A dynamic programming technique is needed for the first method while a linear programming method may be used for the second. This Appendix is concerned with the second method.

Obviously, one way to maximise the present value of the payments would be to obtain payment for the work in advance. Since this is seldom possible, it is seen that there is a constraint to the values that might be assigned to the unit rates. These constraints are listed below.

a) The total price. If the balanced price for the contract is P, it is usual to unbalance the bid while keeping this constant. If N_i is the number of units of item i and X_i is the unbalanced unit price of item i, then

$$\sum_{i=1}^{u} N_i X_i = P \qquad \ldots\ldots (H.1)$$

Where P is the total price of the contract and u is the total number of bid items.

b) The allowable prices of each item. The unit price of each item always has to lie within a certain range. For example, a contractor cannot charge R500 for a cubic metre of concrete, nor can he charge nothing. If L_i and U_i are the respective lower and upper bounds to the unit price of item i, then

$$L_i \leq X_i \leq U_i \qquad \text{.....(H.2)}$$

c) The rate at which payment is made. As mentioned above, the contractor can hardly receive payment for the whole contract at the end of the first month. Also, the client might only be able to pay a certain amount at the end of each valuation period. If the amount to be paid at the end of valuation period j is Q_j, and the quantity of item i completed in this period is N_{ji}, then :

$$Q_j = \sum_{i=1}^{u} N_j X_i \qquad \text{.....(H.3)}$$

Finally, if the present value of all future payments for work done on the contract is Z, we have :

$$Z = \sum_{j=1}^{k} \sum_{m=1}^{u} N_{jm} R^j X_m \qquad \text{.....(H.4)}$$

where k is the total number of intervals j at which payment is made and R is the discount factor.

$$R = \frac{1}{1+q} \qquad \text{.....(H.5)}$$

where q is the rate of interest.

It is seen that both the constraints and the objective function Z are linear, and hence a linear programming algorithm may be used to find the optimal prices for each bid item.

The present writer is of the opinion that the correct use of this technique would be of considerable benefit to any contractor.

APPENDIX I - NOTATION

a	most optimistic cost for a bill item (the lowest)
b	most pessimistic cost for a bill item (the highest)
b	contractor's bid for a contract
b'	increase to the contractor's bid for a contract
c	estimated cost of a contract
E	contractor's expected profit for a contract
$h(s)$	probability density function of the ratio of the true cost of a contract to it's estimated cost
i	bill item number
j	valuation period number
L	lowest bid for a contract
L_i	lower bound to the price of bill item i
m	most likely cost for a bill item
n	number of contractors tendering for a contract
N_i	number of units for bill item i in the contract
N_{ji}	number of units of bill item i to be computed in valvuation period j
P	total price of a contract
$P(A)$	probability of bidding lower than competitor A
$P(Win)$	probability of submitting the lowest bid for a contract
q	rate of interest
Q_j	amount of money paid for work done in valuation period j
R	discount factor used to calculate present values
$R(A)$	ratio of competitor A's bid for the contractor's cost estimate for a contract
$R(Ave)$	ratio of the average of the other competitor's bids to the contractor's cost estimate for a contract

R(Low)	ratio of the lowest other competitor's bid to the contractor's cost estimate for a contract
s	ratio of the true cost of a contract to it's estimated cost
S	spread (difference between second lowest and lowest bids for a contract)
U_i	upper bound to the price of bill item i
X	ratio of the contractor's bid to his cost estimate for a contract
X_i	unbalanced unit price of bill item i
Z	present value of future cash flows

APPENDIX J - BIBLIOGRAPHY

The following abbreviations are used :-

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ICE	:	Institution of Civil Engineers
IEEE	:	Institute of Electrical and Electronics Engineers
JCD	:	Journal of the Construction Division

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APPENDIX K - DATA LISTINGS

Errata: In the column headings of the final set of data listed, "BID (%)" should read "LOWEST OTHER BID (%)"

THIS IS THE DATA USED IN SECTION 8.4

ALL BID AMOUNTS ARE IN RAND

THE FOLLOWING AREAS ARE LISTED

1 - CIVIL JOBS IN THE EASTERN CAPE

2 - BUILDING JOBS IN THE EASTERN CAPE

3 - CIVIL JOBS IN THE CAPE PENINSULA

4 - BUILDING JOBS IN THE CAPE PENINSULA

AREA	LOWEST	SECOND	BIDDERS
1	11.7000	12.5000	5
1	131.9000	139.7000	2
1	489.6000	643.8000	2
1	30.7000	32.8000	3
1	49.2000	72.0000	3
1	1416.6000	1486.0000	3
1	140.4000	154.2000	3
1	68.1000	72.6000	2
1	161.1000	175.4000	2
1	240.3000	291.6000	2
1	193.6000	223.1000	5
1	68.5000	69.8000	5
1	364.3000	426.6000	3
1	215.9000	249.7000	4
1	71.1000	80.7000	2
1	7.9000	9.7000	4
1	215.9000	249.7000	4
1	38.6000	53.4000	5
1	249.0000	261.0000	3
1	121.2000	140.9000	3
1	24.2000	25.2000	4
1	36.0000	39.5000	6
1	68.3000	74.5000	6
1	187.2000	243.2000	5
1	14.1000	15.5000	4
1	154.4000	155.4000	5
1	30.3000	35.9000	5
1	20.6000	30.9000	6
1	33.5000	52.8000	5
1	7.6000	7.9000	5
1	89.5000	91.1000	5
1	97.7000	116.9000	4
1	74.9000	81.0000	5
1	143.2000	157.4000	5
1	5.4000	7.3000	3
1	125.0000	141.7000	7
1	64.8000	72.6000	3
1	64.8000	83.4000	3
1	424.8000	431.3000	5
1	330.7000	355.4000	4
1	126.2000	129.7000	4
1	33.5000	39.0000	4
1	92.7000	136.0000	2
1	87.6000	103.3000	6
1	423.5000	433.3000	3
1	91.9000	97.1000	5
1	120.0000	142.1000	3
1	358.5000	362.1000	6
1	497.8000	500.0000	4
1	185.3000	210.0000	7
1	826.3000	836.8000	7
1	158.7000	160.2000	6
1	38.9000	53.6000	5
1	181.5000	191.9000	7
1	1218.8000	1269.7000	3
1	9.5000	13.8000	3
1	16.4000	19.8000	4
1	29.5000	32.9000	4
1	30.0000	31.0000	5
1	68.0000	90.6000	2
1	127.8000	128.4000	5
1	9.1000	11.0000	4
1	78.5000	82.8000	3
1	17.5000	17.8000	2
1	446.0000	456.9000	5
1	32.1000	37.9000	6
1	42.0000	42.8000	6
1	2933.7000	2981.7000	6
1	122.2000	159.1000	9
1	56.0000	60.7000	4
1	10.3000	10.5000	4
1	121.5000	151.3000	8

AREA	LOWEST	SECOND	BIDDERS
1	97.8000	99.6000	8
1	73.0000	75.4000	8
1	144.9000	171.0000	7
1	8.5000	8.8000	9
1	14.9000	17.4000	6
1	[illegible]	735.4000	2
1	71.0000	75.9000	5
1	56.9000	63.8000	8
1	1275.0000	1404.8000	6
1	1795.8000	1929.8000	4
1	84.4000	91.3000	15
1	198.0000	213.1000	3
1	400.0000	600.0000	2
2	287.8000	323.4000	3
2	91.9000	96.7000	3
2	208.9000	235.0000	3
2	784.3000	796.9000	4
2	58.1000	63.5000	2
2	308.1000	333.5000	3
2	13.1000	30.3000	6
2	19.4000	22.7000	3
2	43.1000	59.7000	3
2	91.9000	116.7000	4
2	553.5000	590.0000	4
2	140.6000	145.4000	4
2	103.3000	120.0000	5
2	50.0000	57.5000	7
2	85.1000	99.3000	4
2	316.5000	322.2000	8
2	79.7000	87.3000	3
2	185.5000	191.4000	2
2	59.2000	60.0000	5
2	38.5000	46.3000	3
2	42.5000	48.7000	3
2	20.0000	21.0000	5
2	16.1000	19.6000	7
1	81.5000	82.2000	9
1	8.2000	9.7000	3
1	73.0000	75.4000	8
1	31.0000	33.9000	8
1	52.1000	65.3000	8
1	44.3000	55.0000	12
1	66.6000	76.7000	7
1	195.2000	212.5000	3
1	148.5000	161.6000	4
1	519.4000	561.6000	9
1	93.2000	104.8000	8
1	30.5000	33.9000	6
2	14.6000	19.7000	4
2	86.5000	88.3000	8
2	44.0000	55.8000	4
2	729.9000	789.9000	4
2	807.9000	855.9000	4
2	694.6000	702.1000	5
2	105.3000	111.2000	4
2	766.3000	892.3000	3
2	455.6000	457.5000	5
2	265.1000	266.4000	4
2	71.2000	75.0000	2
2	453.3000	460.1000	2
2	123.0000	167.4000	4
2	12.3000	20.0000	4
2	137.2000	161.8000	6
2	69.6000	76.4000	6
2	266.3000	284.5000	6
2	1156.0000	1398.1000	4
2	42.9000	44.8000	5
2	45.7000	57.3000	3
2	35.5000	42.6000	7
2	25.1000	31.9000	4
2	161.5000	189.0000	9
2	43.3000	45.8000	7

AREA	LOWEST	SECOND	BIDDERS
2	94.3000	103.2000	2
2	5.8000	14.3000	5
2	110.1000	116.8000	3
2	57.8000	60.2000	4
2	153.0000	157.8000	7
2	106.4000	111.6000	6
2	49.4000	51.6000	6
2	124.3000	126.2000	0
2	18.4000	24.6000	5
2	57.5000	57.6000	6
2	11.4000	12.6000	3
2	222.7000	226.4000	8
2	65.1000	69.1000	6
2	29.6000	52.2000	5
2	8462.9000	10378.0000	8
2	40.0000	40.8000	6
2	30.6000	32.2000	4
2	10.0000	11.2000	5
2	299.1000	306.8000	4
2	6512.0000	6598.4000	6
2	26.3000	31.8000	5
2	71.3000	74.9000	3
2	203.3000	212.0000	6
2	245.9000	263.8000	5
2	39.2000	40.3000	4
2	19.8000	30.5000	4
2	114.0000	114.1000	6
3	94.4000	130.8000	2
3	542.8000	553.3000	4
3	10.7000	25.3000	3
3	10.7000	11.8000	5
3	18.5000	21.5000	6
3	25.0000	25.9000	4
3	29.0000	29.5000	7
3	152.9000	189.1000	3
3	28.9000	30.0000	4

AREA	LOWEST	SECOND	BIDDERS
2	33.7000	50.9000	2
2	28.7000	43.6000	4
2	38.2000	45.9000	3
2	144.0000	157.1000	7
2	92.9000	139.2000	2
2	31.4000	32.8000	3
2	10.9000	13.5000	7
2	245.8000	249.9000	4
2	97.4000	98.8000	6
2	69.7000	69.7000	3
2	148.8000	156.1000	5
2	44.3000	44.4000	7
2	46.6000	51.2000	4
2	161.3000	164.5000	10
2	83.0000	90.3000	10
2	8.4000	8.9000	3
2	103.3000	106.3000	5
2	81.6000	83.0000	4
2	340.8000	384.6000	9
2	78.6000	83.7000	4
2	156.8000	160.4000	4
2	9.3000	9.4000	7
2	145.4000	148.8000	5
2	114.7000	121.1000	9
2	33.0000	43.2000	4
2	289.5000	294.4000	7
2	121.8000	122.9000	7
3	631.4000	640.9000	5
3	435.5000	464.8000	4
3	7.9000	8.0000	3
3	343.3000	459.0000	3
3	266.7000	268.0000	4
3	2493.7000	2562.5000	4
3	18.9000	26.9000	4
3	930.9000	939.6000	6
3	302.6000	312.7000	3

AREA	LOWEST	SECOND	BIDDERS
3	200.0000	206.3000	3
3	796.8000	812.6000	5
3	97.9000	113.0000	3
3	112.8000	117.2000	4
3	71.3000	82.3000	3
3	24.9000	27.0000	4
3	53.9000	56.6000	4
3	18.9000	25.4000	2
3	65.6000	72.9000	4
3	136.0000	149.9000	4
3	583.4000	695.8000	3
3	20.3000	20.7000	4
3	11.6000	14.9000	7
3	655.8000	661.7000	3
3	8.9000	11.2000	10
3	871.1000	896.8000	3
3	16.3000	18.5000	4
3	176.7000	179.8000	3
3	274.5000	297.6000	5
3	37.3000	50.3000	3
3	55.8000	56.4000	2
3	393.2000	404.6000	5
3	100.8000	108.7000	2
3	133.4000	134.0000	6
3	305.1000	340.1000	3
3	775.6000	989.6000	3
3	348.8000	355.0000	4
3	25.2000	25.5000	2
3	16.1000	17.7000	2
3	975.5000	1019.1000	4
3	1951.1000	2010.6000	5
3	570.3000	590.2000	3
3	258.3000	263.5000	3
3	109.9000	110.9000	7
3	79.3000	79.8000	8
3	130.4000	130.6000	5

AREA	LOWEST	SECOND	BIDDERS
3	6.9000	7.3000	4
3	139.1000	139.9000	3
3	250.3000	275.3000	5
3	63.8000	71.4000	2
3	58.7000	67.9000	4
3	31.6000	33.1000	3
3	19.6000	19.6000	3
3	38.0000	41.4000	2
3	134.9000	135.6000	2
3	3698.3000	3807.5000	3
3	177.3000	185.5000	4
3	245.0000	256.3000	3
3	98.7000	113.5000	7
3	260.2000	267.5000	5
3	10.9000	15.8000	4
3	402.9000	408.0000	0
3	655.8000	661.7000	3
3	11.1000	11.4000	5
3	107.0000	107.8000	4
3	875.7000	880.1000	4
3	3238.0000	3244.2000	3
3	48.1000	48.3000	5
3	42.6000	42.8000	5
3	41.6000	48.2000	6
3	104.2000	120.9000	4
3	210.8000	214.8000	6
3	14.9000	15.5000	5
3	171.9000	172.0000	7
3	37.0000	37.6000	8
3	181.4000	182.3000	7
3	574.2000	593.9000	3
3	195.4000	205.2000	2
3	318.7000	326.2000	4
3	258.3000	263.5000	3
3	65.1000	66.5000	8
3	196.5000	199.7000	3

AREA	LOWEST	SECOND	BIDDERS
3	39.8000	39.9000	3
3	26.4000	27.5000	4
3	45.9000	47.0000	6
3	50.8000	51.5000	7
3	58.5000	59.0000	7
3	110.2000	120.3000	3
3	206.4000	206.7000	9
3	81.9000	82.0000	8
3	37.4000	38.3000	10
3	10.9000	11.7000	2
3	16.3000	20.8000	4
3	1266.5000	1292.3000	8
3	81.6000	87.5000	7
3	150.3000	154.4000	8
3	210.0000	212.3000	14
3	27.4000	59.5000	3
3	64.9000	64.9000	13
3	14.0000	14.1000	9
3	62.4000	63.5000	8
3	2346.7000	2410.1000	7
3	151.0000	161.1000	5
3	121.9000	124.8000	4
3	46.7000	46.9000	7
3	92.9000	94.9000	8
3	238.9000	246.4000	6
3	26.7000	43.2000	2
3	115.1000	123.5000	2
3	511.6000	572.4000	2
3	40.9000	49.0000	17
3	184.3000	184.7000	8
3	41.3000	49.0000	8
3	296.9000	358.7000	8
4	212.5000	217.3000	3
4	15.2000	15.2000	8
4	9.4000	11.5000	3
4	13.5000	13.7000	8

AREA	LOWEST	SECOND	BIDDERS
3	75.7000	83.4000	3
3	305.1000	305.1000	6
3	1316.6000	1334.0000	9
3	53.4000	55.3000	11
3	221.0000	266.8000	3
3	163.3000	169.5000	3
3	68.7000	70.8000	7
3	56.3000	60.4000	8
3	154.8000	157.5000	3
3	7.7000	7.9000	4
3	653.9000	693.7000	4
3	37.5000	38.4000	10
3	23.4000	23.6000	4
3	75.8000	78.1000	6
3	45.1000	46.0000	12
3	27.1000	27.4000	3
3	10.3000	10.7000	2
3	580.0000	583.3000	12
3	176.0000	178.3000	9
3	318.8000	325.9000	8
3	38.1000	38.6000	10
3	88.9000	93.8000	10
3	100.0000	101.8000	6
3	29.8000	37.4000	7
3	98.7000	101.4000	12
3	229.2000	252.5000	7
3	317.8000	348.1000	2
3	1070.4000	1228.1000	2
3	148.1000	153.9000	11
3	45.8000	61.0000	2
3	39.3000	42.3000	6
4	180.7000	187.2000	3
4	989.5000	996.0000	5
4	23.7000	32.1000	3
4	429.5000	459.8000	4
4	9.9000	10.9000	5

AREA	LOWEST	SECOND	BIDDERS
4	12.1000	13.0000	9
4	174.7000	187.0000	2
4	232.9000	316.3000	2
4	182.5000	185.3000	4
4	16.3000	16.8000	5
4	219.9000	225.5000	3
4	255.2000	305.4000	4
4	185.8000	167.9000	4
4	808.9000	811.7000	4
4	56.2000	56.8000	4
4	168.3000	176.0000	3
4	346.6000	353.8000	3
4	16.7000	25.6000	2
4	17.9000	19.1000	3
4	17.1000	19.0000	2
4	111.3000	115.3000	2
4	318.9000	333.3000	6
4	187.6000	189.5000	6
4	419.2000	425.9000	6
4	322.9000	329.6000	4
4	253.5000	258.9000	3
4	389.9000	399.9000	4
4	848.5000	858.0000	12
4	242.2000	244.4000	4
4	15.3000	15.5000	5
4	28.1000	29.5000	2
4	49.5000	74.0000	7
4	38.7000	44.7000	2
4	9.4000	9.9000	14
4	167.4000	181.0000	2
4	1517.4000	1604.1000	7
4	70.4000	80.2000	2
4	18.2000	19.7000	2
4	118.7000	122.7000	6
4	384.1000	456.2000	2
4	958.5000	969.0000	6
4	166.1000	185.0000	3
4	163.0000	169.2000	3
4	94.1000	95.4000	2
4	23.7000	32.1000	3
4	109.1000	111.6000	5
4	180.0000	180.6000	5
4	186.4000	187.2000	2
4	6.4000	7.5000	7
4	61.5000	65.8000	4
4	284.8000	310.6000	2
4	168.2000	239.9000	5
4	317.7000	385.8000	4
4	14.7000	18.0000	4
4	20.1000	24.9000	4
4	104.6000	109.0000	3
4	814.7000	883.3000	2
4	105.6000	108.2000	7
4	20.7000	29.0000	4
4	29.0000	29.6000	4
4	323.9000	330.8000	4
4	11.5000	12.5000	6
4	413.2000	458.9000	4
4	225.5000	228.5000	6
4	90.4000	93.6000	2
4	359.9000	375.4000	7
4	138.5000	141.2000	5
4	1035.0000	1040.1000	4
4	208.3000	222.3000	2
4	6.9000	7.6000	12
4	161.1000	167.3000	3
4	27.0000	29.5000	4
4	48.7000	55.8000	2
4	7.9000	9.0000	11
4	8.5000	8.6000	9
4	237.7000	265.1000	5
4	248.7000	256.8000	4

AREA	LOWEST	SECOND	BIDDERS
4	7.8000	9.4000	9
4	7.3000	9.8000	9
4	792.8000	843.8000	4
4	11.0000	11.3000	7
4	149.3000	173.5000	4
4	228.7000	233.9000	5
4	27.2000	28.7000	8
4	229.2000	230.2000	2
4	653.6000	778.4000	2
4	229.5000	258.9000	5
4	15.4000	16.9000	7
4	11.4000	11.6000	7
4	291.9000	327.8000	3
4	8.0000	8.8000	6
4	157.2000	189.0000	2
4	180.7000	191.8000	2
4	355.7000	359.9000	4
4	59.9000	60.7000	4
4	969.4000	974.3000	5
4	9.6000	9.9000	6
4	17.4000	17.7000	5
4	10.9000	10.9000	5
4	48.6000	57.2000	4
4	336.0000	344.8000	9
4	107.5000	110.0000	4
4	185.4000	208.3000	2
4	17.4000	19.5000	2
4	77.4000	81.4000	4
4	26.4000	27.5000	2
4	8.0000	8.8000	4
4	49.9000	50.3000	3
4	860.8000	864.3000	9
4	16.8000	17.5000	10
4	30.0000	30.1000	6
4	298.4000	302.3000	2
4	17.2000	20.8000	3
4	7.3000	7.4000	12
4	34.0000	39.3000	3
4	636.5000	649.1000	4
4	92.8000	97.7000	6
4	875.0000	921.2000	4
4	42.0000	43.2000	2
4	283.4000	298.0000	2
4	14.6000	14.9000	5
4	54.5000	56.5000	2
4	6.6000	7.0000	3
4	12.5000	17.8000	7
4	9.6000	11.8000	4
4	24.0000	26.1000	3
4	21.5000	30.0000	3
4	14.6000	15.1000	5
4	137.8000	267.9000	3
4	612.8000	644.8000	2
4	11.3000	11.7000	5
4	162.7000	165.7000	5
4	25.7000	27.3000	2
4	314.8000	318.2000	3
4	336.0000	344.8000	9
4	6383.4000	6416.0000	3
4	10.3000	11.2000	5
4	228.9000	235.0000	3
4	592.0000	603.9000	8
4	47.3000	47.8000	10
4	336.0000	344.8000	8
4	20.2000	28.2000	2
4	1972.1000	1987.7000	5
4	39.7000	41.4000	7
4	58.8000	61.3000	2
4	79.4000	81.7000	10
4	39.6000	44.0000	2
4	203.0000	205.3000	5
4	2886.0000	2896.5000	4

AREA	LOWEST	SECOND	BIDDERS
4	3262.9000	3336.4000	3
4	232.7000	264.8000	2
4	135.3000	139.8000	3
4	102.9000	108.6000	7
4	87.4000	98.7000	5
4	182.7000	190.5000	6
4	98.7000	98.7000	10
4	66.9000	71.2000	6
4	119.2000	123.3000	4
4	106.6000	109.8000	6
4	21.4000	21.7000	5
4	206.0000	224.8000	4
4	263.4000	274.9000	8
4	41.9000	41.9000	17
4	130.0000	141.9000	3
4	99.0000	100.5000	8
4	487.9000	488.3000	6
4	295.8000	311.5000	11
4	83.7000	86.5000	13
4	127.1000	127.7000	6
4	128.9000	131.3000	5
4	15.9000	15.9000	3
4	15.0000	21.5000	3
4	216.4000	218.5000	11
4	125.8000	159.0000	4
4	356.7000	368.9000	14
4	227.2000	240.0000	9
4	12.0000	14.5000	7
4	186.9000	189.0000	14
4	66.0000	73.0000	8
4	129.3000	134.6000	3
4	473.5000	477.2000	9
4	130.2000	139.7000	8
4	46.6000	49.7000	9
4	133.4000	137.7000	3
4	64.6000	66.6000	6
4	222.0000	269.0000	2
4	585.0000	589.4000	9
4	243.4000	249.4000	9
4	12.2000	13.3000	5
4	451.9000	463.0000	17
4	155.4000	174.2000	3
4	13.5000	14.4000	11
4	41.7000	42.2000	13
4	595.0000	605.0000	11
4	24.4000	24.8000	7
4	44.7000	45.8000	6
4	57.4000	61.0000	8
4	95.2000	101.6000	8
4	92.9000	114.2000	6
4	487.0000	492.7000	7
4	50.2000	52.7000	9
4	263.3000	274.0000	10
4	81.5000	85.5000	6
4	9.5000	9.8000	3
4	8.5000	8.8000	11
4	157.8000	173.5000	14
4	11.5000	15.0000	4
4	67.8000	70.0000	13
4	1694.7000	1841.7000	6
4	78.0000	79.3000	10
4	218.6000	232.7000	4
4	11.2000	11.7000	7
4	52.4000	54.0000	6
4	143.1000	153.0000	10
4	48.3000	54.2000	4
4	38.2000	45.2000	6
4	57.5000	58.2000	7
4	11.4000	13.7000	3
4	442.0000	502.2000	9

THIS IS THE DATA USED IN SECTIONS 8.6 AND 8.7

THE FIRST TWO SETS OF DATA WERE SUPPLIED BY A LOCAL CONTRACTOR

THE SECOND SET OF DATA WAS GIVEN BY BENJAMIN (14)

JOB	DESCRIPTION	PRICE UNITS	BIDDERS
1	EARTHMOVING & RETAINING WALLS	6	10
2	MARINE WORKS	11	7
3	DEMOLITION AND R.C. WORK	10	3
4	PIPELINE	5	4
5	MARINE WORKS	6	3
6	MARINE WORKS	67	4
7	EXCAVATION & R.C. WORK	4	3
8	R.C.WORK	1	5
9	EARTHWKS, R.C. WORK, DRAINS & ROADS	11	4
10	R.C. BRIDGES	6	3
11	IRRIGATION WORKS	3	4
12	WATER RETAINING STRUCTURE	6	7
13	ROAD BRIDGE	9	4
14	WATER RETAINING STRUCTURE	4	6
15	R.C. STRUCTURE	34	4
16	PIPELINE	7	4
17	CONCRETE WORKS (ROADS)	53	5
18	IRRIGATION WORKS	7	5
19	ROADS AND SEWERS	14	4
20	RAILWAY SIDINGS	10	3
21	WATER RETAINING STRUCTURE	9	3
22	ROAD BRIDGE	5	4
23	WATER RETAINING STRUCTURE	5	7
24	PIPELINE	6	3
25	SIDING	1	3
26	PIPELINE	5	9
27	PIPELINE	6	2
28	PIPELINE	5	8
29	WATER RETAINING STRUCTURE	5	5
30	PIPELINE	4	8
31	WATER RETAINING STRUCTURE	4	4
32	SIDING	1	3
33	SIDING	1	3
34	PIPELINE	13	8
35	ROAD BRIDGE	8	6
36	WATER RETAINING STRUCTURES & PIPELN	14	10

JOB	DESCRIPTION	PRICE UNITS	BIDDERS
37	ROAD BRIDGES	10	4
38	BRIDGES	7	5
39	BRIDGES	6	9
40	PIPELINE AND PUMPING STATION	3	5
41	PIPELINE	23	9
42	SIDING	6	4
43	ROADWAY AND BRIDGES	233	6
44	PIPELINE	2	7
45	REPAIRS TO CONCRETE STRUCTURE	2	3
46	SIDING	1	3
47	PIPELINE AND EARTHWORKS	1	8
48	BRIDGE	31	5
49	BRIDGE	7	6
50	PIPELINE	3	8
51	PIPELINE	6	4
52	SIDING	1	4
53	SIDING	1	3
54	SIDING	1	4
55	BRIDGE ALTERATIONS	2	6
56	BRIDGE	5	6
57	BRIDGE	4	9
58	BRIDGE	17	3
59	PUMP STATION	28	5
60	SIDING	3	4
61	PIPELINE	11	9
62	BRIDGE	4	2
63	PIPELINE	11	5
64	SIDING	5	3
65	MARINE WORKS	91	6
66	MARINE WORKS	328	5
67	MARINE WORKS	8	6
68	SIDING	1	3
69	PIPELINE	13	9

BID = COMPETITORS BID AS % OF CONTRACTORS COST ESTIMATE

OB	BIDDER	BID	JOB	BIDDER	BID	JOB	BIDDER	BID	JOB	BIDDER	BID	JOB	BIDDER	BID
1	1	73.4	1	2	74.3	1	3	75.0	1	4	101.6	1	5	105.8
1	6	108.8	1	7	109.0	1	8	109.4	1	99	110.2	1	10	115.5
2	99	108.3	2	8	116.3	2	4	120.6	2	10	135.4	2	11	169.8
2	1	406.7	2	12	838.1	3	4	100.1	3	13	104.9	3	99	115.1
4	99	124.0	4	7	125.8	4	4	172.5	4	14	210.2	5	4	94.5
5	9	113.5	5	99	115.6	6	4	83.2	6	8	83.2	6	11	83.2
6	99	119.3	7	17	134.7	7	99	137.0	7	4	151.8	8	15	84.3
8	4	97.1	8	13	111.0	8	16	135.1	8	99	142.2	9	99	114.0
9	4	120.0	9	17	133.8	9	2	157.3	10	14	98.5	10	4	106.9
10	99	133.1	11	15	80.0	11	16	89.8	11	4	108.8	11	99	130.0
12	18	94.2	12	19	109.2	12	16	114.2	12	99	115.2	12	4	128.9
12	13	145.5	12	1	214.5	13	4	98.3	13	16	106.8	13	99	118.9
13	11	132.0	14	20	86.3	14	16	88.5	14	21	93.2	14	19	109.1
14	99	124.1	14	4	134.5	15	99	113.1	15	22	114.1	15	4	122.1
15	13	147.2	16	16	117.3	16	99	122.6	16	4	137.1	16	14	139.1
17	23	104.5	17	10	113.7	17	99	120.8	17	4	127.9	17	24	135.5
18	17	63.6	18	16	64.2	18	15	117.0	18	99	117.7	18	4	123.6
19	17	73.4	19	99	100.0	19	4	100.2	19	19	105.6	20	25	94.7
20	4	104.5	20	99	114.3	21	4	72.0	21	26	83.8	21	99	115.0
22	8	89.5	22	4	104.6	22	15	115.1	22	99	120.0	23	27	112.1
23	99	112.9	23	11	114.5	23	8	125.0	23	23	126.6	23	24	135.4
23	15	138.8	24	4	91.1	24	15	120.2	24	99	125.4	25	25	87.5
25	4	107.1	25	99	116.0	26	15	57.3	26	12	60.9	26	28	61.1
26	16	61.8	26	4	66.4	26	29	68.1	26	27	72.7	26	99	111.8
26	14	141.8	27	99	130.7	27	4	138.5	28	16	62.3	28	5	68.2
28	4	75.2	28	7	81.2	28	12	97.0	28	30	101.0	28	15	102.1
28	99	117.8	29	8	109.8	29	31	110.7	29	99	117.3	29	12	118.0
29	32	190.2	30	12	94.8	30	99	109.1	30	4	116.8	30	16	164.8
30	14	170.1	30	30	203.8	30	7	206.3	30	33	224.7	31	8	109.0
31	99	117.3	31	4	130.6	31	15	130.8	32	25	105.4	32	4	110.4
32	99	115.2	33	99	111.7	33	25	120.8	33	4	122.9	34	16	99.7
34	15	106.6	34	29	107.8	34	27	108.9	34	34	109.2	34	99	111.9
34	4	118.4	34	14	161.9	35	11	117.2	35	99	119.3	35	35	120.9
35	37	137.5	35	16	155.3	35	36	187.7	36	16	100.2	36	4	101.8
36	30	103.0	36	27	107.7	36	28	107.9	36	38	108.1	36	99	109.9
36	19	115.5	36	8	116.8	36	14	133.5	37	39	88.8	37	99	115.0

BID = COMPETITORS BID AS % OF CONTRACTORS COST ESTIMATE

OB	BIDDER	BID	JOB	BIDDER	BID	JOB	BIDDER	BID	JOB	BIDDER	BID	JOB	BIDDER	BID
37	11	122.2	37	4	126.4	38	8	86.6	38	27	88.4	38	23	89.5
38	99	114.1	38	19	129.7	39	27	77.8	39	23	82.8	39	28	97.9
39	8	105.2	39	13	106.1	39	4	112.3	39	99	112.6	39	19	119.4
39	40	120.5	40	4	108.6	40	99	114.6	40	16	141.8	40	14	142.2
40	15	142.6	41	34	43.8	41	28	49.9	41	41	62.6	41	14	80.9
41	16	84.8	41	29	88.9	41	99	111.8	41	4	114.8	41	15	117.8
42	25	95.3	42	4	101.1	42	99	106.2	42	42	119.9	43	37	105.9
43	4	106.7	43	99	107.2	43	43	113.4	43	10	117.9	43	11	123.1
44	99	108.8	44	30	116.8	44	29	129.9	44	4	135.7	44	14	139.7
44	16	193.0	44	44	198.2	45	45	102.4	46	4	110.0	45	99	124.1
45	8	147.0	46	25	101.6	46	99	115.4	47	15	101.3	47	13	101.5
47	14	104.2	47	5	105.0	47	4	105.8	47	99	113.6	47	46	116.4
47	16	124.3	48	43	100.8	48	4	107.2	48	99	112.4	48	11	117.6
48	26	132.0	49	28	84.7	49	13	87.9	49	38	98.4	49	4	98.7
49	19	102.3	49	99	110.0	50	29	107.3	50	99	111.2	50	8	132.7
50	30	134.8	50	15	136.2	50	14	141.0	50	4	157.7	50	16	176.0
51	13	78.4	51	4	95.3	51	14	106.3	51	99	113.9	52	25	94.5
52	47	94.7	52	4	108.4	52	99	109.4	53	25	101.7	53	4	110.0
53	99	113.4	54	25	91.5	54	4	95.1	54	42	108.3	54	99	113.4
55	99	112.4	55	15	112.8	55	14	120.5	55	28	122.0	55	23	125.2
55	4	128.2	56	99	114.2	56	11	115.1	56	4	120.3	56	23	125.5
56	13	170.9	56	28	183.2	57	23	81.4	57	34	82.7	57	4	84.1
57	14	86.4	57	13	90.4	57	28	95.0	57	8	95.7	57	38	96.7
57	99	117.7	58	23	70.5	58	4	77.8	58	99	124.0	59	11	83.2
59	38	85.9	59	8	95.7	59	4	105.8	59	99	108.2	60	25	67.4
60	4	79.3	60	42	82.3	60	99	110.6	61	34	90.1	61	35	92.8
61	48	100.0	61	49	106.4	61	8	107.2	61	99	111.0	61	4	111.3
61	13	117.8	61	16	134.8	62	4	70.3	62	99	109.8	63	29	87.8
63	13	95.3	63	4	100.0	63	99	117.7	63	14	131.4	64	4	73.0
64	25	90.1	64	99	112.3	65	11	72.9	65	38	92.0	65	8	94.8
65	4	98.1	65	99	117.8	65	50	128.9	66	11	76.9	66	99	100.0
66	4	102.4	66	51	104.9	66	43	170.8	67	53	74.3	67	11	103.2
67	99	112.2	67	52	117.7	67	4	118.1	67	8	128.8	68	25	89.8
68	4	93.1	68	99	115.0	69	54	92.3	69	55	94.0	69	16	97.1
69	30	98.3	69	15	99.2	69	29	100.0	69	4	100.7	69	99	111.7
69	14	126.1	70	5	64.9	70	11	81.6	70	4	91.3	70	99	114.9

JOB	BIDDERS	COST($)	SUBC($)	MARKUP(%)	BID(%)
1	5	16.8	6.1	15.34	81.97
2	7	309.5	237.6	5.20	101.77
3	9	239.2	155.3	5.88	96.16
4	3	824.2	746.8	5.05	99.50
5	5	37.9	34.6	9.33	112.90
6	5	11.0	4.3	19.35	105.90
7	4	1377.7	862.9	7.99	99.15
8	5	218.7	182.5	4.33	103.72
9	8	147.6	113.6	5.56	98.83
10	5	391.1	213.3	7.06	104.43
11	9	689.1	580.5	4.25	97.37
12	6	851.2	670.4	4.53	97.51
13	5	298.2	246.6	5.05	102.37
14	4	214.4	180.0	5.03	96.03
15	6	556.2	436.5	4.54	108.30
16	6	236.9	155.9	6.54	101.30
17	6	272.5	196.6	3.94	96.58
18	6	303.3	175.5	7.81	98.86
19	13	365.9	300.0	3.76	94.01
20	5	417.9	298.6	4.90	99.05
21	11	802.2	450.4	5.13	90.57
22	7	1188.2	862.5	4.34	102.75
23	7	505.8	411.4	3.92	100.37
24	7	493.0	288.1	12.70	100.96
25	8	637.7	439.3	4.81	96.29
26	3	75.3	56.6	5.97	101.22
27	6	226.6	196.0	3.43	101.43
28	6	217.4	199.4	5.28	107.61
29	9	154.7	119.9	4.85	97.84
30	6	55.7	47.0	4.36	102.91
31	5	34.5	14.5	9.25	102.80
32	8	1066.5	756.9	5.37	97.40
33	2	50.5	40.8	6.08	101.97
34	3	1246.8	881.2	5.50	103.46
35	5	712.3	573.0	4.83	98.13
36	10	570.0	470.1	4.13	100.13

JOB	BIDDERS	COST($)	SUBC($)	MARKUP(%)	BID(%)
37	4	1307.5	997.8	4.97	103.17
38	7	169.3	157.9	3.61	101.84
39	4	22.9	8.8	12.71	118.18
40	6	1053.0	633.0	7.19	102.73
41	7	56.9	26.3	9.64	95.73
42	7	484.9	344.8	4.82	96.88
43	6	529.9	372.1	-.41	100.01
44	6	345.3	276.0	5.79	105.90
45	10	898.0	657.6	7.13	98.77
46	9	690.2	497.3	4.93	100.98
47	4	1043.6	718.9	4.99	100.61
48	5	1189.2	765.6	5.65	96.28
49	7	185.4	127.2	5.08	101.38
50	5	1219.4	953.3	4.42	88.73
51	6	437.2	276.9	3.94	102.07
52	6	127.4	88.8	6.89	101.21
53	4	12.6	3.3	14.00	107.46
54	6	319.3	223.5	4.93	102.63
55	8	956.9	771.8	5.26	103.35
56	7	207.9	136.4	6.90	112.12
57	7	359.9	216.7	4.11	103.48
58	2	40.7	25.5	14.72	92.25
59	8	614.3	479.0	10.15	105.77
60	9	99.4	43.9	6.36	96.34
61	8	312.2	226.8	5.61	100.59
62	7	129.1	53.8	5.86	92.55
63	8	133.7	83.3	7.48	103.34
64	10	1232.7	886.1	7.75	95.30
65	4	87.4	30.6	10.79	92.61
66	7	122.2	53.7	5.89	106.29
67	5	1215.4	751.2	6.41	106.63
68	3	333.0	182.0	3.20	93.38
69	7	1572.0	962.3	5.32	97.56
70	7	1534.3	985.5	6.38	95.70
71	4	12.3	10.0	29.32	122.96
72	8	685.1	433.6	5.90	102.57

JOB	BIDDERS	COST($)	SUBC($)	MARKUP(%)	BID(%)
73	3	271.0	149.9	8.39	106.58
74	5	69.9	45.1	6.73	105.77
75	6	310.0	236.6	6.11	100.98
76	8	644.8	557.7	2.91	101.57
77	2	33.5	16.9	18.61	137.68
78	5	137.3	125.5	4.66	98.98
79	5	199.3	138.5	4.07	98.82
80	6	38.5	31.5	6.01	106.11
81	6	489.3	377.3	3.95	97.94
82	4	417.4	210.4	6.75	93.16
83	8	409.7	279.0	5.25	100.38
84	7	6.7	1.3	17.02	93.18
85	5	65.0	46.4	7.32	108.74
86	9	15.4	10.7	10.02	93.07
87	8	128.0	94.4	4.60	101.21
88	8	692.0	585.5	4.72	101.61
89	5	288.0	192.9	5.99	101.72
90	3	305.8	227.2	5.15	84.57
91	7	187.1	136.9	3.76	94.54
92	9	9.9	7.0	9.55	90.94
93	11	901.3	664.0	5.13	105.65
94	12	184.0	143.2	4.75	102.43
95	5	123.9	73.1	4.53	102.43
96	9	440.9	296.7	4.05	99.29
97	10	18.5	14.8	7.56	97.70
98	2	399.8	296.9	6.31	100.05
99	8	303.5	208.7	6.27	102.96
100	7	38.0	35.6	2.86	105.15
101	9	109.2	53.2	9.56	93.42
102	8	803.2	627.1	3.65	93.38
103	6	273.1	219.0	6.31	87.88
104	5	40.4	19.8	8.37	91.60
105	7	136.1	96.0	3.87	100.27
106	6	254.2	159.7	5.57	107.54
107	7	247.4	168.9	4.55	99.74
108	2	38.6	30.5	9.44	106.24

JOB	BIDDERS	COST($)	SUBC($)	MARKUP(%)	BID(%)
109	4	22.7	4.4	18.05	95.54
110	4	9.4	3.1	10.82	87.78
111	6	739.8	499.7	3.49	102.40
112	8	1230.0	1039.6	2.30	98.56
113	10	227.5	177.7	4.29	93.46
114	9	899.5	512.7	7.14	99.33
115	7	236.6	135.6	6.25	104.38
116	5	172.2	134.9	4.83	95.62
117	5	1235.9	1061.1	3.92	101.79
118	5	265.1	157.8	3.43	92.04
119	10	1501.1	1065.8	5.10	96.39
120	8	2005.5	1327.0	.22	93.43
121	4	339.0	235.0	4.95	107.18
122	4	9.9	.4	14.62	89.72
123	8	618.8	488.3	2.15	102.75
124	10	469.0	327.0	4.38	99.78
125	9	575.2	322.8	4.00	100.14
126	3	38.6	30.3	6.72	84.73
127	5	420.7	281.0	4.25	106.72
128	7	1307.3	815.8	5.36	100.20
129	8	250.7	156.7	4.38	110.86
130	6	35.0	16.3	6.62	108.20

APPENDIX L - COMPUTER PROGRAM LISTINGS

Errata : In the listings of the simulation program used in Section 8.5, the following changes should be made to the comment statements concerning the subroutine used to optimize the expected profit making use of discrete distributions :

a) Interchange "PROBABILITY OF WINNING GIVEN BY PROBABILITY OF BEATING THE LOWEST COMPETITOR" with "PROBABILITY OF WINNING GIVEN BY PRODUCT OF PROBABILITIES OF BEATING EACH COMPETITOR"

b) Interchange "PROBABILITY OF WINNING GIVEN BY FORMULA DEVELOPED IN SECTION 8.2" with "THIS SUBROUTINE EMPLOYS THE METHOD PROPOSED BY GATES TO PREDICT THE OPTIMAL BID FROM SPREAD PROBABILITIES".

```
      THIS PROGRAM WAS USED IN SECTION 8.4 - THE CONCEPT OF SPREAD
      AND RESULTS ACHIEVED

      DIMENSION IHDG(20),G(20),BL(600),SPRED(600)
         READ WHICH REGION TO CONSIDER
5     READ(8,100)NCODE,(IHDG(I),I=1,19)
100   FORMAT(I1,19A4)
      IF(NCODE.EQ.0)STOP
      XBAR=0.
      YBAR=0.
      X2=0.
      XY=0.
      IN=1
      WRITE(5,200)(IHDG(I),I=1,19)
200   FORMAT(1H1,19A4,//,' GROUP  MEAN LOW BID  MEAN SPREAD',/,32('-'),/
     1/)
         READ GROUP LIMITS
      READ(8,101)G(1)
      DO 1 I=2,9
      READ(8,101)G(I)
101   FORMAT(F10.2)
      IF(G(I))4,4,
      N=0
         READ LOWEST AND SECOND LOWEST BIDS
2     READ(16,102)ICODE,ALOW,SECND
102   FORMAT(I1,14X,F6.1,4X,F6.1)
         DECIDE WHETHER THEY FALL INTO THE GROUP
      IF(ICODE)3,3,
      IF(ICODE-NCODE)2,,2
      IF(ALOW-G(I-1))2,,
      IF(ALOW-G(I)),2,2
      IF(.2-(SECND-ALOW)/ALOW)2,,
      IF(SECND.LE.ALOW)GO TO 2
      N=N+1
      BL(N)=ALOW
      SPRED(N)=SECND-ALOW
      GO TO 2
         CALCULATE GEOMETRIC MEANS OF LOWEST BIDS AND SPREADS FOR
         CONTRACTS IN GROUP
```

```
3     CALL GMEAN(BL,N,GMBL)
      CALL GMEAN(SPRED,N,GMSPRD)
      X=ALOG10(GMBL)
      Y=ALOG10(GMSPRD)
      XBAR=XBAR+X
      YBAR=YBAR+Y
      X2=X2+X*X
      XY=XY+X*Y
      J=I-1
C        WRITE GEOMETRIC MEANS
      WRITE(5,201)J,GMBL,GMSPRD
201   FORMAT(1H ,I3,6X,F7.2,7X,F7.2)
      REWIND 16
1     CONTINUE
4     I=I-1
C        CALCULATE REGRESSION COEFFICIENTS
      B=(XY-XBAR*YBAR/I)/(X2-XBAR**2/I)
      A=YBAR/I-B*XBAR/I
      A=10**A
C        WRITE REGRESSION EQUATION
      WRITE(5,202)A,B
202   FORMAT(1H0,'SPREAD = ',F7.4,' * LOW BID ** ',F7.4)
      N=0
C        CALCULATE MEAN AND STANDARD DEVIATION OF SPREADS ON ALL JOBS
7     READ(16,102)ICODE,ALOW,SECND
      IF(ICODE)6,6,
      IF(ICODE-NCODE)7,,7
      IF(.2-(SECND-ALOW)/ALOW)7,,
      N=N+1
      SPRED(N)=(SECND-ALOW)/ALOW
      GO TO 7
6     CALL AMEAN(SPRED,N,XBAR)
      CALL STDEV(SPRED,N,1.,SIGMA)
C        WRITE MEAN AND STANDARD DEVIATION
      WRITE(5,203)XBAR,SIGMA
203   FORMAT(1H0,'ON ALL JOBS THE MEAN SPREAD IS ',F10.5,'  WITH STD DEV
     1 ',F10.5)
      REWIND 16
      GO TO 5
      END
```

```
      THIS PROGRAM WAS USED IN SECTION 8.5 - THE USE OF SIMULATION
      TO COMPARE THREE MODELS

      THIS IS THE MAIN SIMULATION PROGRAM
      INTEGER C,CW(10),OW(10),CWC(10,500),OWC(10,500)
      COMMON BL(500),COST(10,500),B2(500),BID(10,500),K
      DIMENSION PIOP(10),IWIN(500),SPRED(500),P(10),X(500),CPROF(500)
8     WRITE(5,200)(I,I=1,4),(I,I=1,4),(I,I=1,4)
200   FORMAT(1H1,'JOB',16X,'COSTS',27X,'BIDS',21X,'CUMULATIVE PROFITS',/
     1/,2X,12I8,//,100('-')/)
      READ THE INITIAL RANDOM NUMBER
      READ(8,100)X(1)
100   FORMAT(F10.3)
      IF(X(1).LE.0.)STOP
      DO 12 I=1,4
      OW(I)=0
      CW(I)=0
      CPROF(I)=0.
      DO 12 J=1,100
      OWC(I,J)=0
12    CWC(I,J)=0
      GENERATE THE RANDOM COST ESTIMATES FOR EACH COMPETITOR
      CALL CRANDN(X,400,100.,20.)
      DO 1 J=1,100
      DO 6 I=1,4
      N=J*4+1-I
      COST(I,J)=X(N)
6     BID(I,J)=COST(I,J)
      I=1
      DECIDE WHO HAD THE LOWEST COST
      DO 10 C=2,4
10    IF(COST(C,J).LT.COST(I,J))I=C
      OW(I)=OW(I)+1
      OWC(I,J)=OW(I)
      K=J-1
      IF(K)2,2,
      CALL THE SUBROUTINES USING THE DIFFERENT OPTIMAL BIDDING
      TECHNIQUES
      CALL OPBID1
```

```
      CALL OPBID2
      CALL OPBID3
      CALL OPBID4
2     I=1
C     DECIDE WHO WAS THE LOWEST BIDDER AND CALCULATE HIS PROFIT
      DO 3 C=2,4
3     IF(BID(C,J).LT.BID(I,J))I=C
      IWIN(J)=I
      CW(I)=CW(I)+1
      CWC(I,J)=CW(I)
      BL(J)=BID(I,J)
      CPROF(I)=CPROF(I)+BID(I,J)-COST(I,J)
      I2=I-1
      IF(I2.LE.0)I2=4
C     DECIDE WHO WAS THE SECOND LOWEST BIDDER
      DO 4 C=2,4
      IF(C-I),4,
      IF(BID(C,J).LT.BID(I2,J))I2=C
4     CONTINUE
C     CALCULATE THE SPREAD ON THE CONTRACT
      SPRED(J)=(BID(I2,J)-BL(J))/BL(J)*100.0
      B2(J)=BID(I2,J)
C     WRITE THE RESULTS
9     WRITE(5,201)J,(COST(I,J),I=1,4),(BID(I,J),I=1,4),(CPROF(I),I=1,4)
201   FORMAT(1H0,I3,1X,12F8.2)
1     CONTINUE
7     WRITE(5,202)(I,I=1,4),(I,I=1,4),(I,I=1,4)
202   FORMAT(1H1,'JOB',13X,'ORIGINAL WINS',20X,'FINAL WINS',21X,'OPTIMUM
     1 BIDS',//,2X,12I8,//,10L('-')/)
      DO 5 J=1,100
      DO 11 C=1,4
      OW(C)=OWC(C,J)
      CW(C)=CWC(C,J)
11    BIDP(C)=(BID(C,J)/COST(C,J)-1.0)*100.0
      WRITE(5,203) J,(OW(I),I=1,4),(CW(I),I=1,4),(BIDP(I),I=1,4)
203   FORMAT(1H0,I3,I7,7I8,2X,4F8.2)
5     CONTINUE
      GO TO 8
C
C     THIS SUBROUTINE CALCULATES THE MEAN AND STANDARD DEVIATION OF
```

```
      A SET OF NUMBERS
      SUBROUTINE PARAM(N,BR,XBAR,SIGMA)
      DIMENSION BR(500)
      C=0.
      DO 1 I=1,N
    1 C=C+BR(I)
      XBAR=C/N
      C=0.
      DO 2 I=1,N
    2 C=C+(BR(I)-XBAR)**2
      SIGMA=SQRT(C/N)
      RETURN
      END

      THIS SUBROUTINE CONVERTS MAIN PROGRAM INFORMATION FOR USE IN
      THE BIDDING SUBROUTINES
      SUBROUTINE ALTER1(C)
      INTEGER C
      COMMON BL(500),COST(10,500),B2(500),BID(10,500),K
      DO 1 IJ=1,K
      BL(IJ)=(BL(IJ)/COST(C,IJ)-1.0)*100.0
      B2(IJ)=(B2(IJ)/COST(C,IJ)-1.0)*100.0
      DO 1 I=1,4
      IF(I-C),1,
      BID(I,IJ)=(BID(I,IJ)/COST(C,IJ)-1.0)*100.0
    1 CONTINUE
      RETURN
      END

      THIS SUBROUTINE CONVERTS BIDDING SUBROUTINE INFORMATION FOR
      USE IN THE MAIN PROGRAM
      SUBROUTINE ALTER2(C)
      INTEGER C
      COMMON BL(500),COST(10,500),B2(500),BID(10,500),K
      DO 1 IJ=1,K
      BL(IJ)=(BL(IJ)*0.01+1.0)*COST(C,IJ)
      B2(IJ)=(B2(IJ)*0.01+1.0)*COST(C,IJ)
      DO 2 IQZ=1,4
      IF(IQZ-C),2,
      BID(IQZ,IJ)=(BID(IQZ,IJ)*0.01+1.0)*COST(C,IJ)
```

```
2     CONTINUE
1     CONTINUE
      RETURN
      END
C        THIS SET OF SUBROUTINES GENERATES RANDOM NUMBER USING THE
C        TECHNIQUE OF APPENDIX G
      SUBROUTINE CRANDN(X,N,XBAR,SDEV)
      DIMENSION X(1000)
      CALL CRANDU(X,N)
      DO 1 I=1,N
      Y=X(I)
      X(I)=TINORM(Y,$1)*SDEV+XBAR
1     CONTINUE
      RETURN
      SUBROUTINE CRANDU(X,N)
      DIMENSION X(1000)
      CALL CRAND(X,N)
      DO 1 I=1,N
1     X(I)=X(I)*0.0001
      RETURN
      SUBROUTINE CRAND(X,N)
      DIMENSION X(1000)
      Y=X(1)
      DO 1 I=1,N
      X(I)=Y*109.0
      IX=X(I)/8.
      X(I)=X(I)-IX*8.
1     Y=X(I)*10000.
      RETURN

         THE FOLLOWING SUBROUTINES OPTIMIZE THE EXPECTED PROFIT MAKING
         USE OF CONTINUOUS DISTRIBUTIONS

         THE METHOD IS DESCRIBED IN APPENDIX F

         PROBABILITY OF WINNING GIVEN BY PROBABILITY OF BEATING THE
         LOWEST COMPETITOR
      SUBROUTINE OPBID1
      DIMENSION AX(500)
      CALL ALTER1(1)
```

```
      DO 1 L=1,K
      IF(IWIN(L).EQ.1)AX(L)=B2(L)
      IF(IWIN(L).NE.1)AX(L)=BL(L)
1     CONTINUE
      CALL PARAM(K,AX,XBAR,SIGMA)
      XL=0.0
      XR=30.
      DO 3 L=1,9
      W=(XL+XR)*.5
      X1=W-.05
      X2=W+.05
      Y=(X1-XBAR)/SIGMA
      IF(Y-4.)5,5,
      XR=X1
      GO TO 3
5     EP1=X1*(1.-RNORM(Y))
      Y=(X2-XBAR)/SIGMA
      EP2=X2*(1.-RNORM(Y))
      IF(EP2.LE.EP1)XR=X1
      IF(EP2.GE.EP1)XL=X2
      IF(XR-XL)2,2,3
3     CONTINUE
2     BMAX=(XL+XR)*.5
      BID(1,J)=BID(1,J)*(1.+.01*BMAX)
      CALL ALTER2(1)
      RETURN

         PROBABILITY OF WINNING GIVEN BY PRODUCT OF PROBABILITIES OF
         BEATING EACH COMPETITOR
      SUBROUTINE OPBID2
      DIMENSION AX(500),XBR(5),SGMA(5)
      CALL ALTER1(2)
      DO 1 IC=1,4
      IF(IC-2),1,
      DO 4 L=1,K
4     AX(L)=BID(IC,L)
      CALL PARAM(K,AX,XBAR,SIGMA)
      XBR(IC)=XBAR
      SGMA(IC)=SIGMA
1     CONTINUE
```

```
      XL=0.
      XR=30.
      DO 3 L=1,9
      W=(XL+XR)*.5
      X1=W-.05
      X2=W+.05
      Q1=(X1-XBR(1))/SGMA(1)
      Q3=(X1-XBR(3))/SGMA(3)
      Q4=(X1-XBR(4))/SGMA(4)
      EP1=X1*(1.-RNORM(Q1))*(1.-RNORM(Q3))*(1.-RNORM(Q4 ))
      Q1=(X2-XBR(1))/SGMA(1)
      Q3=(X2-XBR(3))/SGMA(3)
      Q4=(X2-XBR(4))/SGMA(4)
      EP2=X2*(1.-RNORM(Q1))*(1.-RNORM(Q3))*(1.-RNORM(Q4 ))
      IF(EP2.LE.EP1)XR=X1
      IF(EP2.GE.EP1)XL=X2
      IF(XR-XL)2,2,3
    3 CONTINUE
    2 BMAX=(XL+XR)*.5
      BID(2,J)=BID(2,J)*(1.+.01*BMAX)
      CALL ALTER2(2)
      RETURN

         PROBABILITY OF WINNING GIVEN BY FORMULA DEVELOPED IN
         SECTION 8.2
      SUBROUTINE OPBID3
      DIMENSION AX(500),XBR(5),SGMA(5)
      CALL ALTER1(3)
      DO 1 IC=1,4
      IF(IC-3),1,
      DO 4 L=1,K
    4 AX(L)=BID(IC,L)
      CALL PARAM(K,AX,XBAR,SIGMA)
      XBR(IC)=XBAR
      SGMA(IC)=SIGMA
    1 CONTINUE
      XL=0.
      XR=30.
      DO 3 L=1,9
      W=(XL+XR)*.5
```

```
      X1=W-.05
      X2=W+.05
      Q1=(X1-X3R(1))/SGMA(1)
      Q2=(X1-XBR(2))/SGMA(2)
      Q4=(X1-XBR(4))/SGMA(4)
      EP1=X1/(1.+RNORM(Q1)/(1.-RNORM(Q1))+RNORM(Q2)/(1.-RNORM(Q2))+RNORM
     1(Q4)/(1.-RNORM(Q4)))
      Q1=(X2-XPR(1))/SGMA(1)
      Q2=(X2-XBR(2))/SGMA(2)
      Q4=(X2-XPR(4))/SGMA(4)
      EP2=X2/(1.+RNORM(Q1)/(1.-RNORM(Q1))+RNORM(Q2)/(1.-RNORM(Q2))+RNORM
     1(Q4)/(1.-RNORM(Q4)))
      IF(EP2.LE.EP1)XR=X1
      IF(EP2.GE.EP1)XL=X2
      IF(XR-XL)2,2,3
    3 CONTINUE
    2 BMAX=(XL+XR)*.5
      BID(3,J)=BID(3,J)*(1.+.01*BMAX)
      CALL ALTER2(3)
      RETURN

         THE FOLLOWING SUBROUTINES OPTIMIZE THE EXPECTED PROFIT MAKING
         USE OF DISCRETE DISTRIBUTIONS

         PROBABILITY OF WINNING GIVEN BY PROBABILITY OF BEATING THE
         LOWEST COMPETITOR
      SUBROUTINE OPBID1
      CALL ALTER1(1)
      BMAX=0.0
      EMAX=0.0
      DO 4 C=1,4
      IF(C-2),4,
      DO 1 L=1,K
      IF(BID(C,L))1,1,
      IF(BID(C,L)-30.0),,1
      BD=BID(C,L)-0.01
      DO 2 IC=1,4
      IF(IC-2),2,
      W=0.0
      DO 3 IL=1,K
```

```
3     IF(BD.LE.BID(IC,IL))W=W+1.0
2     P(IC)=W/K
      EP=P(1)*P(3)*P(4)*BD
      IF(EP-EMAX)1,1,
      EMAX=EP
      BMAX=BD
1     CONTINUE
4     CONTINUE
      BID(1,J)=BID(1,J)*(1.0+0.01*BMAX)
      CALL ALTER2(1)
      RETURN

         PROBABILITY OF WINNING GIVEN BY PRODUCT OF PROBABILITIES OF
         BEATING EACH COMPETITOR
      SUBROUTINE OPBID2
      CALL ALTER1(2)
      BMAX=0.0
      EMAX=0.0
      DO 1 L=1,K
      IF(IWIN(L)-2),3,
      IF(BL(L))1,1,
      IF(30.0-BL(L))1,,
      BD=BL(L)-0.01
      GO TO 4
3     IF(B2(L))1,1,
      IF(30.0-B2(L))1,,
      BD=B2(L)-0.01
4     W=0.0
      DO 2 IDO=1,K
      IF(IWIN(IDO)-2),5,
      IF(BL(IDO).GE.BD)W=W+1.0
      GO TO 2
5     IF(B2(IDO).GE.BD)W=W+1.0
2     CONTINUE
      EP=W/K*BD
      IF(EP-EMAX)1,1,
      EMAX=EP
      BMAX=BD
1     CONTINUE
      BID(2,J)=BID(2,J)*(1.0+0.01*BMAX)
```

```
      CALL ALTER2(2)
      RETURN
C     PROBABILITY OF WINNING GIVEN BY FORMULA DEVELOPED IN
C     SECTION 8.2
      SUBROUTINE OPBID3
      CALL ALTER1(3)
      BMAX=0.0
      EMAX=0.0
      DO 1 I=1,K
      IF(SPRED(I)-30.0),,1
      BD=SPRED(I)-0.01
      W=0.0
      DO 2 L=1,K
    2 IF(BD.LE.SPRED(L))W=W+1.0
      EP=W/K*BD
      IF(EP-EMAX)1,1,
      EMAX=EP
      BMAX=BD
    1 CONTINUE
      BID(3,J)=BID(3,J)*(1.0+0.01*BMAX)
      CALL ALTER2(3)
      RETURN
C     THIS SUBROUTINE EMPLOYS THE METHOD PROPOSED BY GATES TO PREDICT
C     THE OPTIMAL BID FROM SPREAD PROBABILITIES
      SUBROUTINE OPBID4
      CALL ALTER1(4)
      BMAX=0.0
      EMAX=0.0
      DO 5 C=1,4
      IF(C-4),5,
      DO 1 L=1,K
      IF(IWIN(L)-4),7,
      IF(BL(L))1,1,
      IF(BL(L)-30.0),,1
      BD=BL(L)-0.01
      GO TO 8
    7 BD=B2(L)-0.01
    8 P(1)=1.0
```

```
      P(2)=1.0
      P(4)=1.0
      DO 2 IC=1,4
      IF(IC-4),2,
      W=0.0
      DO 3 IL=1,K
      IF(BD.LE.BID(IC,IL))W=W+1.
3     CONTINUE
      P(IC)=W/K
2     CONTINUE
      EP=BD/(1.0+(1.0-P(1))/P(1)+(1.0-P(2))/P(2)+(1.0-P(4))/P(4))
      DO 4 IC=1,4
      IF(IC-3),4,
      IF(P(IC).LE.0.0)EP=0.0
4     CONTINUE
      IF(EP-EMAX)1,1,
      EMAX=EP
      BMAX=BD
1     CONTINUE
5     CONTINUE
      BID(4,J)=BID(4,J)*(1.0+0.01*BMAX)
      CALL ALTER2(4)
      RETURN

         THIS PROGRAM WAS USED IN SECTION 8.6 - PARALLEL COMPARISON OF
         THE MODELS WITH ACTUAL RESULTS

         THIS WAS THE MAIN PROGRAM
      DIMENSION CE(200),NCOMP(200),CBID(200),ABID(200),BL(200)
      WRITE(5,200)
200   FORMAT(1H1,8X,'CONTRACTOR',12X,'LOWBID',13X,'FORMULA',/,' JOB   ',
     13('BID    PROF    %',6X),//)
      READ(15,100)(J,CE(J),NCOMP(J),I=1,70)
         READ DATA ON PAST BIDS
100   FORMAT(I2,42X,F5.2,5X,I2)
      DO 1 J=1,70
      N=NCOMP(J)
      NC=0
      DO 2 I=1,N
      READ(16,101)M,BR
```

```
101     FORMAT(4X,I2,3X,F6.1)
        IF(M-99)3,,3
        CBID(J)=BR
        GO TO 2
3       IF(BL(J).LE.0.)BL(J)=BR
        IF(BR-200.),,2
           SET UP DISTRIBUTIONS OF THE LOWEST BID RATIOS AND THE AVERAGE
           BID RATIOS
        ABID(J)=ABID(J)+BR
        NC=NC+1
2       CONTINUE
        ABID(J)=ABID(J)/NC
1       CONTINUE
        DO 4 J=2,70
        K=J-1
           CALCULATE THE OPTIMUM BIDS PREDICTED BY THE MODELS
        CALL PARAM(K,BL,XBAR,SIGMA)
        CALL OPBID(93.,19.,OPT,1)
        BLBID=OPT
        CALL PARAM(K,ABID,XBAR,SIGMA)
        N=NCOMP(J)-1
        CALL OPBID(108.,19.,OPT,N)
        FBID=OPT
        X=BL(J)
           CALCULATE THE PROFITS WON BY THE ACTUAL CONTRACTOR AND BY
           THE MODELS
        IF(CBID(J)-X),,5
        CP=CP+(CBID(J)-100.)*CE(J)*.01
        CW=CW+CE(J)
        CPP=CP/CW*100.
5       IF(BLBID-X),,6
        BLP=BLP+(BLBID-100.)*CE(J)*.01
        BLW=BLW+CE(J)
        BLPP=BLP/BLW*100.
6       IF(FBID-X),,7
        FP=FP+(FBID-100.)*CE(J)*.01
        FW=FW+CE(J)
        FPP=FP/FW*100.
           WRITE RESULTS
7       WRITE(5,201)J,CBID(J),CP,CPP,BLBID,BLP,BLPP,FBID,FP,FPP
```

```
201    FORMAT(1H ,I3,1X,3(F6.2,F6.2,F6.2,2X))
4      CONTINUE
       WRITE(5,202)XBAR,SIGMA
202    FORMAT(1H0,2F10.4)
       STOP
       END

          THIS SUBROUTINE CALCULATES THE MEAN AND STANDARD DEVIATION OF A
          SET OF NUMBERS
       SUBROUTINE PARAM(N,X,XBAR,SIGMA)
       DIMENSION X(200)
       C=0.
       DO 1 I=1,N
1      C=C+X(I)
       XBAR=C/N
       C=0.
       DO 2 I=1,N
2      C=C+(X(I)-XBAR)**2
       SIGMA=SQRT(C/N)
       RETURN
       END

          THIS SUBROUTINE CALCULATES THE OPTIMAL BID MAXIMIZING THE
          EXPECTED PROFIT BY THE METHOD OF APPENDIX F
       SUBROUTINE OPBID(XBAR,SIGMA,OPT,N)
       XL=100.
       XR=150.
       DO 1 K=1,10
       X=(XL+XR)*.5
       X1=X-.05
       X2=X+.05
       Y=(X1-XBAR)/SIGMA
       IF(Y-4.)2,2,
       XR=X1
       GO TO 1
2      EP1=(X1-100.)/(1.+N*RNORM(Y)/(1.-RNORM(Y)))
       Y=(X2-XBAR)/SIGMA
       EP2=(X2-100.)/(1.+N*RNORM(Y)/(1.-RNORM(Y)))
       IF(EP2.LE.EP1)XR=X1
       IF(EP2.GE.EP1)XL=X2
```

```
      IF(XR-XL)3,3,1
1     CONTINUE
3     OPT=(XL+XR)*.5
      RETURN
      END

C        THESE PROGRAMS WERE USED IN SECTION 8.7 - THE CORRELATION
C        BETWEEN SUGGESTED FACTORS INFLUENCING A TENDER BID

C        THIS PROGRAM PLACES ITEMS OF DATA ON PAST TENDERS IN GROUPS AND
C        TAKES THEIR MEANS

      DIMENSION BL(200),C(200),N(200),ID(200),S(200),FB(200),FC(200),NF(
     1200),IFD(200),FS(200),FN(50),FD(50)
C        READ THE DATA
      READ(15,100)(FC(J),NF(J),J=1,70)
100   FORMAT(44X,F5.2,5X,I2)
      DO 5 I=1,70
      IDO=NF(I)
      DO 6 J=1,IDO
      READ(16,101)M,BR
101   FORMAT(4X,I2,3X,F6.1)
      IF(M-99),6,
      IF(FB(I).LE.C.)FB(I)=BR
6     CONTINUE
5     CONTINUE
C        RANK THE DATA IN ASCENDING ORDER ACCORDING TO THE LOWEST BID
C        ON EACH TENDER
      DO 1 I=1,70
      MIN=1
      DO 4 J=2,70
      IF(FB(MIN).GT.FB(J))MIN=J
4     CONTINUE
      J=MIN
      BL(I)=FB(J)
      FB(J)=FB(J)+200.
      C(I)=FC(J)
      N(I)=NF(J)
1     CONTINUE
      WRITE(5,200)
```

```
200   FORMAT(1H1,7X,'LOW BID   COST   NUMBER DURATION  SUB  ',/,7X,39('-
     1')//)
C       PLACE IN 5 GROUPS
      DO 2 IDO=1,5
      DO 3 I=1,14
      J=I+14*(IDO-1)
      FB(I)=BL(J)
      FC(I)=C(J)
      IF(C(J).LE.0.)FC(I)=.001
      FN(I)=N(J)
3     CONTINUE
C       CALCULATE THE MEANS
      CALL AMEAN(FB,14,AFB)
      CALL AMEAN(FC,14,AFC)
      CALL AMEAN(FN,14,AFN)
      CALL GMEAN(FB,14,GFB)
      CALL GMEAN(FC,14,GFC)
      CALL GMEAN(FN,14,GFN)
C       WRITE THE RESULTS
      WRITE(5,201)AFB,AFC,AFN
201   FORMAT(1H ,'AMEAN ',3F8.2)
2     WRITE(5,202)GFB,GFC,GFN
202   FORMAT(1H ,'GMEAN ',3F8.2)
      STOP
      END

C       THIS PROGRAM WAS USED TO PLOT SCATTER DIAGRAMS OF VARIOUS
C       FACTORS THOUGHT TO AFFECT THE LOWEST BID

      DIMENSION X(200),Y(200),XNAM(20),YNAM(20)
      DIMENSION NC(200)
C       READ THE DATA
      READ(8,100)N
100   FORMAT(I3)
      MAXX=1
      MAXY=1
      MINX=1
      MINY=1
      DO 1 I=1,N
      READ(8,101)NC(I),Y(I),Z
```

```
101   FORMAT(4X,I3,2X,F6.2,4X,F6.2)
         SET THE SCALES ON BOTH AXES
      Y(I)=Z/Y(I)*100.
      X(I)=NC(I)
      IF(X(MAXX)-X(I))2,3,3
2     MAXX=I
3     IF(X(MINX)-X(I))5,5,4
4     MINX=I
5     IF(Y(MAXY)-Y(I))6,7,7
6     MAXY=I
7     IF(Y(MINY)-Y(I))1,1,8
8     MINY=I
1     CONTINUE
      RANGX=X(MAXX)-X(MINX)
      RANGY=Y(MAXY)-Y(MINY)
      XS=10./RANGX
      YS=8./RANGY
      XO=-4./XS+X(MINX)
      YO=-4./YS+Y(MINY)
      CALL SCALF(XS,YS,XO,YO)
         PLOT THE AXES
      U=1./XS
      NI=RANGX/U+0.5
      CALL FGRID(0,X(MINX),Y(MINY),U,NI)
      CALL FGRID(0,X(MINX),Y(MAXY),U,NI)
      Z=X(MAXX)
      NI=NI+1
      DO 9 I=1,NI
      W=Z+0.1/XS
      V=Y(MINY)-1.7/YS
         LABEL THE AXES
      CALL FCHAR(W,V,.1,.1,1.5708)
      WRITE(7,200)Z
200   FORMAT(F6.1)
9     Z=Z-U
      U=1./YS
      NI=RANGY/U+0.5
      CALL FGRID(1,X(MINX),Y(MINY),U,NI)
      CALL FGRID(1,X(MAXX),Y(MINY),U,NI)
      Z=Y(MAXY)
```