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Nowadays, a project-winning environment is very competitive. In order to be successful and make profit, a contractor should start planning in advance and decide about what projects to bid. A prominent contractor should bid on projects for which his chances of winning are good enough or on projects for which the profit is high enough such that bidding would be worth consuming the resources needed for preparing the bid. The chances of winning bids are related to many factors but among all, degree of eminence (previous works) and price are the most important. In this thesis we have developed an optimization model that maximizes an index that takes both of these factors into consideration. Genetic Algorithm is used to solve this optimization model. The output of this model is the most beneficial set of projects and their respected optimal bid markups that will help the contractor make the most intuitive selection which, in return, benefits him/her the most at present and in the future.

BIDDING ON PROJECTS BASED ON PREVIOUS WORKS AND EMINENCE, A CONTRACTORS' VIEW POINT

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Dedication

To my mother and father for the unconditional support they have always provided

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Chapter 1: Introduction and Problem statement

Contracting firms are project-oriented firms. They have to do projects to assure their survival. Projects are like the blood of a contracting firm. The profit of a contracting firm is related to the number of projects awarded. For each project available, there are usually many contracting firms that are competing with each other over that project. Because of the competitive environment, contractors have to be wise in selecting projects for bidding. They have to pick a portfolio of projects which benefits them the most for bidding.

1.1 <u>Project bidding and selection</u>

The contractor has to make up his or her mind and choose a specific number of projects to bid on. There are several reasons behind not bidding on all projects, some of which are:

1-Resource limitations: each contracting firm has a limited resource. Hence, if the contractor bids on as many projects as are available and ends up wining them all, due to the cap on his or her resources, they will face work overload. Because of the work overload, and since each contractor has a limited amount of resources, they have to either procure more resources and assign more human resource to manage all projects, or subcontract those projects to other contractors, if permitted in the contract. In both cases, the actual cost of the project will exceed the forecasted (estimated) cost of the project that was used for preparing the bidding documents. In the case of hiring and purchasing resources, since this acquiring is based on project needs (i.e., they are project based) the costs are more than the already available resources to the contractor. The same reason stands for the subcontracting case.

2-The cost of preparing bids: Even by assuming that bidding on different projects is not constrained by resource limitations and the contractor has an infinite amount of resources; bidding on every project still is not a reasonable effort. Bidding on projects is in itself costly. Especially when, as Lin et al. have observed: "the development of a comprehensive proposal for a large project should itself be treated as a project for a project-oriented business" (Lin & Chen, 2004).

3-The negative effect on reputation: In addition to the monetary cost of blindly bidding, bidding on lots of proposals and not winning many of them has a negative effect on the firm's reputation (Gido & Clements, 1999).

Due to the reasons mentioned above, contractors have to bid on projects wisley. This is the reason why portfolio management is of high importance. Contractors bid on projects that have two characteristics:

1-The projects satisfy their incentive of doing it.

2-There is a good chance of winning them.

For finding the incentive, throughout the process that builds up to the bid/no-bid decision, contractors have to ask themselves what are the incentives that they have for doing a project. Some may want to be helpful to the society and profitability is of least importance for them. However, this applies only to a small group, if any at all. Monetary terms and financial profitability have always been the major incentives for doing projects. Some projects may have been done that have had less profit in order to pave the road for getting more profitable projects in the future. This kind of decision-making, which considers the future, is strategic decision-making. The project that the contactor decides to bid on has to be consistent with the strategic goal of the company/organization.

Contractors tend to bid on projects for which their chance of winning is high. The chances of winning projects are related to the evaluation criteria an owner/client has while evaluating tenders.

The profit of a contracting firm is highly correlated to the amount of projects awarded and the profit of each project. In the following subsections these factors are explained.

1.2 Elements of project profit

The profit of each project is one of the main elements that affect the bidding prices, which is usually equal to the cost of the project plus a markup. Each of them has a series of characteristics:

1-Project Cost: The cost that is measured at the beginning of a project is just an estimate of the actual cost. It has two elements: direct cost and indirect cost. Direct costs are those that are related directly to the project. Indirect costs are those portions of costs that are allocated to projects. They are costs that are not due to the direct labor or material or equipment of the project.

2-Project Markup: The markup is the amount by which a contractor multiplies the costs of the project to calculate his or her bidding price. It usually consists of: general overhead, profit, and contingency, which are expressed in percentages (Lee & Chang, 2004).

The contingency factor exposes the inaccuracy of the cost estimate and the risk it may have. Therefore, depending on the nature of the project and the accuracy of the auction material (the plans, etc.) it can vary. Thus, the reasonable markup differs and the nature of the work may have a significant effect on the markup percentage. For example, Lee et al. have focused on developing the markup for micro tunneling projects (Lee & Chang, 2004). Since the bids are competitive, a contractor has to outbid his or her opponents while still keeping a reasonable profit.

There are many other factors that affect the overall price of the project. Many works have been executed to address those factors, one of which is the contract type and the effect it has on the price of the project. Paul and his colleague, have considered the effect the type of the contract (fixed price or cost plus) on the expected procurement cost. They have looked at the bidding problem from the owner's viewpoint and have declared that in the case that the contractors are risk neutral, the smallest expected procurement cost for the owner will be from a fixed price contract (Paul & Gutierrez, 2005). There are still more attributes that affect the price, but these are outside of the scope of this research.

The profit has an effect on the probability of winning. There is a reasonable profit that results in a reasonable probability of winning the auction from other competitors. In order to come up with the probability of outbidding other competitors, a contractor has to have some historical data about the other competitors' bidding behaviors. In other words, a historical distribution of the markup of the competitors is usually required. Assuming that the costs for different companies are more or less the same, which is valid when the different companies have almost the same experiences, the bidding price distribution for each project could easily be derived from the markup distribution for each opponent contractor.

1.3 Project awarding Mechanisms

Owners provide projects to contractors using mainly two mechanisms: Granting a project by assigning to a contractor; granting the project by holding an auction.

Projects could be just assigned without any competition and challenge. This actually happens when the contractor is a large enough contractor and has the perfect relationship with an owner. The owner leans towards contracting with a contractor with whom he or she already has enough experience and believes that the contractor's price and quality of work suits him or her the best. Not much research has been done on this type of project assignment.

The other type of winning a contract is through an auction or tender process. Giving projects through auctions has many benefits, including fairness and the competitive situation that leads to a better price for the client.

When the bids are received, the auctioneer, who is usually the client (owner) of the project itself or a representative of the client, evaluates the bids and awards the project to the bidder, who from his or her point of view is the best among all other bidders. The criteria that are considered in evaluating the bidders are known as the evaluation criteria.

1.4 Tender Evaluation criteria

When an auction is held, there are always criteria that are used for evaluating tenderers. These criteria may vary from one client to another. They can be anything. Sometimes these criteria are known at the time of bidding and sometimes they are not. The weight of each criterion is largely dependent on the preferences of the client. The evaluation criteria can be categorized into two groups: monetary evaluation criteria and non-monetary evaluation criteria.

1.4.1 Monetary Evaluation Criteria

Monetary criteria are among the major criteria to which the previous literature has paid attention. The main monetary criterion is the bidding price. The bidding prices are evaluated depending on the type of auction. For instance, in the sealed-bid lowest price auction, the project is awarded to the bidder with the lowest price. So, the chance of winning the bid is equal to the probability of having the lowest bidding price. The sealed-bid price auction is a very popular method in public procurement auctions.

Only considering the bidding price used to be the most popular method for evaluating tenderers. However, it was found that considering only monetary terms and only the lowest bidding price would not necessarily lead to a successful project that would meet the budgeted time and cost. In fact, many of the projects that were awarded based on the lowest bidding price have had huge amounts of cost and time overruns (Conti & Naldi, 2008). These unsuccessful projects are usually a result of an anomalous bid. There is a positive correlation between the increase in bidding price and the decrease in the risk of projects not meeting their planned deadline and costs. In order to prevent time and cost overruns, different kinds of auctions and methods have been introduced that do not necessarily award the project to the lowest bidder. Some of these auctions consider the bidding price of all of the tenderers. Some samples of considering only monetary criterions and also eliminating anomalous bids are:

- Awarding the project to the average bidder: The bidder that has the average price among all competitors is chosen as the winner of the auction.

- Using the average submitted bid to eliminate the anomalous bids: As said before, this prevents the bad effect an anomalous bid has on procurement auctions. Conti and Naldi (2008) have proposed a method that is based on average submitted bid to detect the anomalous bids and put them aside in order to improve the performance of the project. In another effort to eliminate non-competitive bids, Skitmore (2002) has stated that in the case that the bids have a normal distribution; bids that are 1.47 times the standard deviation more than the mean are not competitive. Hence, clients and owners should not investigate them.

Because of many problems of this kind, many owners consider other criteria in addition to the bidding price to evaluate the bidders. They take into account different capabilities of the contractors to come up with a winner that can lead the project towards its goal with the minimum risk. These additional criteria that might be added to the monetary criteria to build a set of evaluation criteria that are important for an owner are called non-monetary criteria. These criteria could be any characteristic that the client (owner) believes are among the most important a bidder should have.

1.4.2 Non-Monetary Evaluation Criteria

Non-monetary criteria are criteria that are not related to the proposed bidding price and owners use to evaluate different bids in an auction. As mentioned before, these criteria arose because of the lack of performance, which was a result of only considering monetary criteria when awarding projects. These criteria are widely used in different countries.

For example Lai, Liu, & Wang (2004) have noticed that in Beijing, the criteria to which points are assigned for project evaluation are: "(1) Degree of response to the bid document; (2) Construction organization design; (3) Firm's honor and competence; (4) Bid prices and the amounts used of three materials (steel, cement and lumber); (5) Range for reducing cost; and (6) Comprehensive evaluation and examination". In order to define each of these criteria Lai and his colleges have described each of them separately and have assigned points to each of them.

Padhi & Mohapatra (2010) have collected some countries' evaluation criteria for selecting construction contractors and have saved them in a table as shown in Figure 1-1.

Modeling approaches to the problem of construction contractor selection.

Author	Country	Selection attributes used	Modeling approach
Kumaraswamy (1996)	Hong Kong	Financial status, technology offered, and experience in handling similar types of projects.	Performance-based scoring
Holt (1998)	UK	Quoted cost, quality of work, and completion time	Cluster analysis
Hatush and Skitmore (1998)	UK	Quoted bid price, financial soundness, technical ability, management capabilities, safety performance, and reputation.	Multi-attribute utility theory
Deng (1999)	Australia	Quoted cost, technical capability, services and references of the government officials.	Fuzzy-AHP
Al-Harbi (2001)	UAE	Experience in handling similar types of projects, financial stability, quality performance, manpower resources, equipment resources, and current workload.	AHP
Topcu (2004)	Turkey	Quoted cost, quality of work, and completion time	AHP
Lai et al. (2004)	China	Contractor organization structure, firm honor and competence, quoted bid price, and amount of materials used.	Multi-attribute analysis
Missbauer and Hauber (2006)	Austria	Bid price	Integer programming
Lambropoulos (2007)	Greece	Quoted cost, quality of work, and completion time	Multi-attribute utility theory
Wang et al. (2006)	Taiwan	Conversion of all the attributes to price	Unit-price based
Padhi and Mohapatra (2009)	India	Quoted bid price, financial status, available physical resources, amount of work done, service during warranty period, co-operation and coordination offered, meeting of completion time, value of work done in each of the past projects, and pollution control measures.	Fuzzy-AHP-SMART

Figure 1- 1- Different Selection attributes used in different countries (Padhi & Mohapatra, 2010)

As it can be observed in Figure 1- 1, using non-monetary criteria along with monetary criteria is the widely used case in different countries. Using a combination of these two types of criteria will lead to minimizing the risk of poor performance and minimizing the cost of procurement for the owner. The relative importance of the monetary and non-monetary criteria depends on the owners' preferences. In some cases the owners prefer to just minimize the risk as much as possible. Thus, as mentioned before, they tend to give their projects to some contractors without even holding an auction. This could be interpreted as paying the most attention to non-monetary criteria. In contrast, some owners are willing to take the risk of poor performance and only pay attention to the bidding price. These types often award the project to the tenderer with the lowest price. Their intention is to get the lowest price possible, which satisfies the minimum quality.

One myth associated with paying importance to non-monetary criteria is if a client has some preferences in choosing some contractors over some others, and one of the major evaluation criteria that the client looks at is a non-monetary criterion, the cost of procuring the project will increase for the client. Hence, it is better to not have any preferences and non-monetary criteria. The study done by Hubbard and his colleague (Hubbard & Paarsch, 2009) addressed this myth. While in their research, the preferences are due to political reasons, for example, to support local businesses or small businesses, it is believed that these results can easily be expanded to any preferences of a contractor over another one due to any reason and criteria.

They investigated the effects of having preferences and treating different tenderers asymmetrically. According to them, the common way to implement bid preferences is scaling the bids of preferred firms by a discount factor for just the purpose of evaluation. Further, whenever a bidder wins the auction he only gets what they have bid for. For instance, if the discount for a special contractor is 10% and his or her bidding price is $110,000, for the purpose of evaluation it will be treated as a bidding price of $99,000. If this owner wins the auction, he or she will be awarded the project for $110,000.

They introduced three effects of having preferential bidders on an auction. They are:

1-The preference effect: the preferred bidder will inflate bids and still end up winning the auction. Therefore, the cost of the project will increase for the client.

2-The competitive effect: In order to balance this asymmetry, non-preferred firms will bid closer to their actual costs (choose a lower markup), bid aggressively, and behave more competitively in response to the preferential policy.

3-The participation effect: Although the incentives for preferred and non-preferred bidders are different for participating in an auction with preferential bidders, they still do participate. They stated that the importance of this third effect is small and depends on the distribution of costs.

At the end, they concluded that there is a positive discount number that minimizes the cost of the owner. Having preferential bidders and paying attention to non-monetary criteria is a good method. It can even help reduce the overall expenditure of the owner. These results were valid for four different cost distributions (Weibull, normal, exponential, uniform). It is indeed not an expensive method.

1.5 Main factors in evaluating bids

Assuming the main evaluation criterions for an owner is known, a contractor can increase his or her chances of winning by preparing and having a better performance on those factors compared to other competitors for that project. Since "the choice of one contractor over another is largely dependent on the client's preferences in terms of the evaluation criteria and weightings used, and the trade-offs they are willing to make" (Watt, Kayis, & Willey, 2009), finding these main criteria is of high importance.

In order to have a good sense of what are the main criteria that owners/clients tend to have in evaluating auctioneers, Watt and his colleagues examined the management literature and conducted a survey on contractor selection and tender evaluation. They initially identified 16 mutually exclusive categories. After using a pragmatic and heuristic approach, they concluded that "the preferred criteria for evaluating tenders are those that show the contractors' ability in terms of their management and technical capability, past experience and performance, reputation, and the proposed method of delivery or technical solution." Figure 1- 2 shows the categories of criteria and the number of occurrences of each of them in both literature and survey (Watt, Kayis, & Willey, 2009). As it can be seen, the two major non-monetary criteria that grabbed the most attention were reputation and past performance. Therefore, doing projects for one owner will affect the chance of winning a project at a later auction held by the same owner. During those projects, if the contractor has satisfied the client in all or most of the important and related fields, he will have a higher chance of getting a higher score by that specific client in comparison to other contractors that have had done relatively less successful projects for that client in the evaluation process.

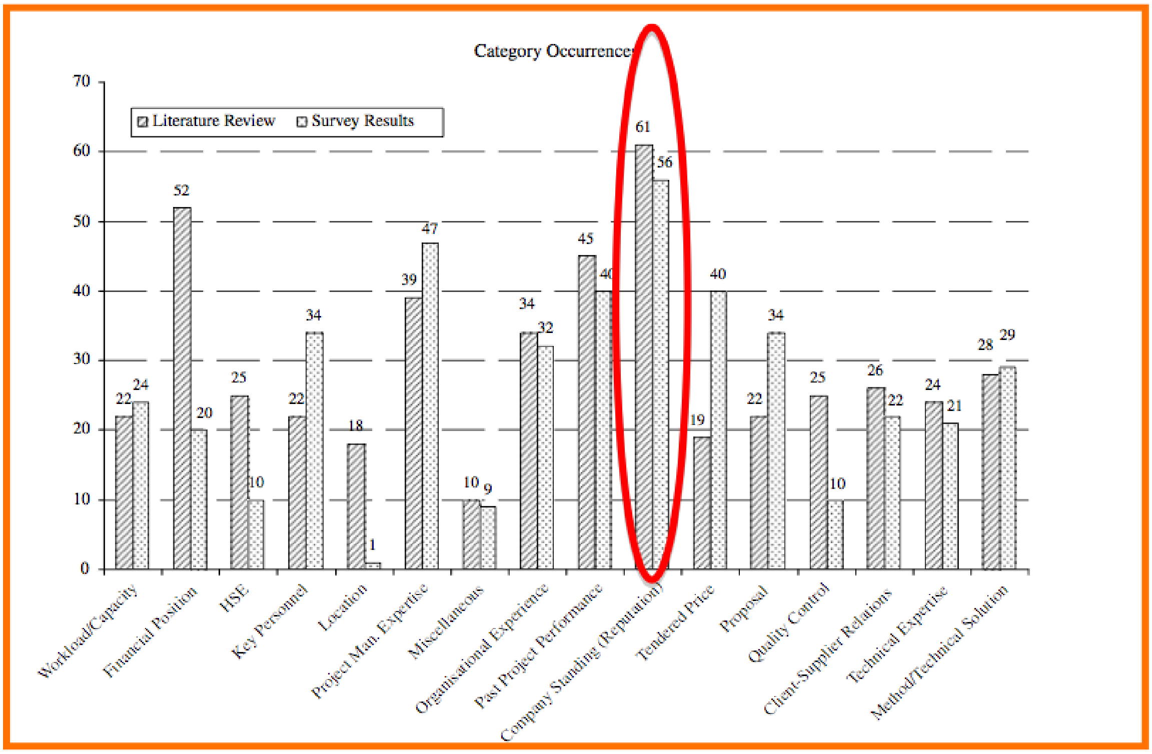

Figure 1- 2- Different Categories for tender evaluation and their occurrences in literature and surveys (Watt, Kayis, & Willey, 2009)

In a later research done by Watt and his colleagues, they looked at the relative importance of each of the most noticed criteria from their previous research to find the most important criteria of tender evaluation. It is worth stating that these relative importance criteria were based on the opinions of the contractors. They stated that: “Results indicate Past Project Performance, Technical Expertise and Cost are the most important criteria in an actual choice of contractor with Organizational Experience, Workload, and Reputation being the least important” (Watt, Kayis, & Willey, 2010). Once again, these critera can all be achieved and evaluated by doing succesful projects for the client.

Throughout their research, Watt and his colleageus stated that the quality of product was the most important criteria of contractor selection. Notably, this criterion was consistent in all industries (Watt, Kayis, & Willey, 2010). This is consistent with the assumption that a contractor only gets the project to perform well and maintain the satisfaction of the client. Obviously, the client's satisfaction depends on the quality of the work.

The bar-chart shown in Figure 1-3 shows the relative importance of evaluation criteria.

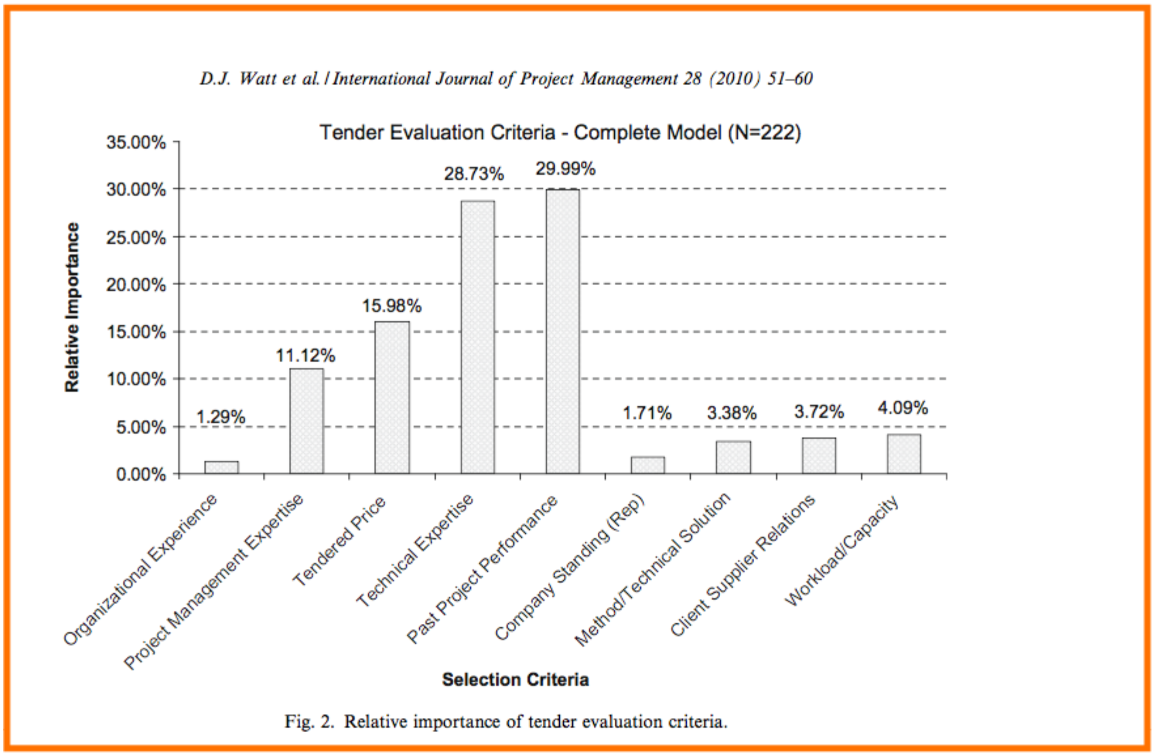

Figure 1-3- Relative importance of evaluation criteria in tenders (Watt, Kayis, & Willey, 2010)

As mentioned throughout the entire chapter 1, in addition to the tender price and the monetary evaluation, doing successful projects for a specific client will increase the chances of winning future auctions held by that client quite dramatically. Therefore, this research focuses on helping contractors come up with a reasonable bid/no-bid decision and a suitable bidding price based on building reputation and doing successful projects for owners. The reputation of a firm depends on both the number of projects done or successfully awarded and the firm's performance in those projects. A project with a good quality and high performance will positively affect a firm's reputation. On the other hand, if the project is awarded but is executed with low quality, the firm's reputation will be affected negatively.

In this research we have assumed that the qualities of the projects are high and therefore any project awarded to the firm will result in an increase in the reputation. Thus from here on the term “reputation” will be exchanged with “eminence” and should be interpreted as the number of projects awarded.

1.6 Problem Statement

The goal of this research is to maximize the expected profit of a contractor. In order to do so, an index that represents the expected profit of a contractor is maximized by finding the most profitable set of projects to bid on. In addition to the projects selected for bidding a relative markup is proposed as well. This markup is proposed in a way that considers the effect doing a project for a specific client at current time has on the likelihood of winning a bid from that client in the future.

A graphical illustration of this problem is provided in Figure 1- 4. As it can be seen, at each time several projects are provided by different clients/owners. The goal is to select the best set of projects for bidding to maximize profit. Once the projects are selected for bidding, at each time, the auctions happen and based on the outcomes and new data about projects an update occurs. Therefore this is a dynamic problem which is solved using rolling horizon.

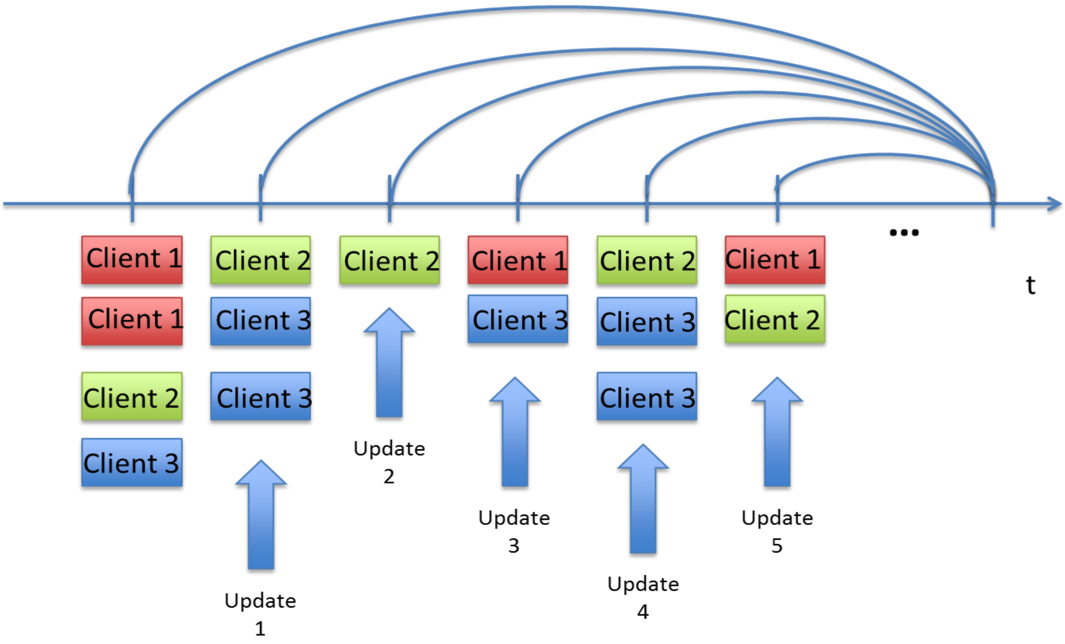

Figure 1- 4 Graphical represantation of probelm

1.7 Motivation and contributions

Projects are the main source of income for a contracting firm. In an environment that is so project-orientated and challenging, blindly selecting projects for bidding will in no way guarantee success. In such an environment, the contractors should wisely select projects for bidding in a way that maximizes their chances of winning and their profits. During this research, the following contributions are made:

- Proposing a new mathematical model that considers both monetary and, non-monetary criteria, namely, previous works and number of projects awarded. (eminence)
- Considering the effect that winning a project has on the chance of winning future projects in the project selection decision-making (Portfolio selection).
- Combining the bid/no-bid, markup size, and project selection decision-making.
- Using a Genetic Algorithm (GA) as a meta-heuristic to solve the nonlinear complex binary model.

1.8 Structure of the thesis

This thesis is organized as follows. In chapter 1, an introduction to the project selection and bidding decision-making was provided. Chapter 2 will address related previous works done in the field of project selection and making a bid/no bid decision. In chapter 3, we will define how the model is structured. In chapter 4, the mathematical model is presented. In chapter 5, a method (GA) for solving the optimization problem is suggested and implemented. In chapter 6, the results of the model, which are two characteristics of considering the effect that past project performance has on the project selection and bidding markup, are explained and sensitivity analysis is done on the various parameters of the model. Finally, in chapter 7, the conclusions of this research are presented and suggestions are made for future research.

Chapter 2: Literature review

According to Ahmad, the regular practice in making bid/no-bid decisions is based on intuition and gut feelings, which themselves are based on experiences, and guesses (Ahmad, 1990). Ahmad's statement has also been supported by a finding Egemen and his Colleague had when they analyzed the questionnaires that were filled out by 80 small and medium-sized contracting firms from the Northern Cyprus and Turkey regions. Their finding was that 92.5% of the responding contractors have never used a statistical or mathematical model as a tool to help them in making bid/no bid and markup size decisions. Further, almost all of them (97.5%) used intuition as their primary tool in decision-making process (Egemen & Mohamed, 2007).

Making the bid/no-bid decision along with making the markup decision just based on intuition will decrease the chances of the company's success. Hence, many researchers have developed methods to assist the contractors to make the bid/no-bid decision and the markup size for preparing the bid to help the company succeed in the long run.

Some of the major researches done in the bid evaluation criteria were presented in chapter 1. In this chapter we will cover the bidding decisions which the contractor has to make.

In the following, first, we will go through previous works that have considered monetary criteria and, later, we will mention those works that have considered non-monetary criteria, as well as monetary criteria.

2.1. Models based on monetary criteria

As mentioned before, contractors tend to bid on projects for which their chance of winning is high. The chances of winning projects are related to the evaluation criteria an owner/client has while evaluating tenders. One of the major criteria that the previous literature has paid attention to is the bidding price. The bidding prices are evaluated depending on the type of auction. For instance in the sealed bid lowest price auction, the project is awarded to the bidder with the lowest price. So, the chance of winning the bid is equal to the probability of having the lowest bidding price.

By having the mean markup and the variance of the markups for each tenderer from historical data, the total bidding price of them can be simulated. It has mostly been treated as a random variable from a specific distribution. According to previous works, these specific distributions have been: Normal; Lognormal; Weibull; or just positively Skewed (Skitmore, 2002).

When there are just two companies competing over the project, the chance of outbidding the competitor can be calculated by knowing his or her distribution of the Markup (Bid-price/Cost ratio). In order to have an estimate of thsituation case where there are multiple competitors, two well-known models were derived: Friedman's model (Friedman, 1956); and Gates' model (Gates, 1967). Each has a set of assumption and its own supporters. Since these models were first developed within the years 1956 and 1967, there has always been a controversy between the supporters of each. Friedman's model is more pessimistic in contrast to the Gates model, which is more optimistic.

Crowley has discussed the long-lasting controversy between the Friedman and Gates models for the probability of winning. He has used Carr's model (Carr, 1982) as a basis of his evaluation and has concluded that the Gates model produces bids more similar to Carr's model than to Friedman's model, since Gates' model considers the variability of cost estimate and does not assume the project cost to be deterministic. At the end, Crowley has stated that although Friedman's model is theoretically correct, the bidding problem is incorrectly specified due to the assumption that the cost estimates are the same among different bidders. On the other hand, Gates' model is practically correct although it is lacking enough proof. Therefore, he has mentioned it might be best to use Carr's model (Crowley, 2000).

Crowley has gone through the story of the controversies between the two and in that review he has stated some of the results from other researchers.

Carr in 1982 introduced a model that considered costs not to be a fixed amount in contrast to what Friedman's model assumed when calculating the bid-to-cost ratio. He used his model as a reference and after comparing his model to the models presented by Friedman and Gates, he came up with a conclusion that Gates model seems to be more accurate and similar to his model(Carr, 1982).

Griffis stated that the difference between the two models is a result of the assumption of independence. The Gates model does not need that assumption while Friedman's model does. In addition, he states that the use of both approaches is acceptable for bidding (Griffis, 1992).

Skitmore and his colleagues have argued that using the Gates method for determining probabilities of winning bids in a closed bid competitive auction "is valid if, and only if, bids can be described using the proportional hazards family of statistical distributions." They have argued that assuming a Weibull distribution for the bids is essential when applying Gates' method for calculating probabilities of winning (Skitmore, Pettitt, & McVinish, 2007).

In a research done by Hosni and his colleague, they have automated the three steps of coming up with an optimum markup estimation. The three steps are: a) building a database of other competitors bidding behaviors (markups) and updating it, b) predicting the competitors' bidding behaviors c) selecting an optimum bidding markup. They have used Friedman's model to combine the different competitors' probabilities of winning (Hosny & Elhakeem, 2012).

In this research we will introduce both the Gates' and Friedman's models to predict the chances of winning the auction based on the bidding prices (markup).

2.2 Research considering monetary and non-monetary criteria

At this point, we will look at research that considers the non-monetary criteria. These are mainly research that can be categorized in the bid/no-bid decision-making field.

Oo and his colleagues have compared different environmental scenarios and measured the effects of those scenarios and situations on a bid/no bid decision. Their study has been done in Hong Kong and Singapore. They have collected data from different medium-size and large-size contractors. The situations that they have considered are:

(1) different market conditions. At one extreme it is recession that leads to a high desire to have work, and the other extreme is when there is a low need for work due to an already sufficient amount of workload. They have measured the probability of a bid/no-bid decision under the influence of changes to market conditions;

(2) different number of bidders and their influence on the bid/no-bid decision (Oo, Drew, & Lo, 2008).

In another research study, Egemen and his colleagues introduced a framework to make strategically correct decisions in the two distinct but sequential bidding decisions, the bid/no bid decision and the related markup. They have concluded that any model regarding the bidding and mark-up size should "definitely differentiate" among different sizes of contractors. Further, they stated that the correlation between markup prices in different sizes of contractors was more than the correlation regarding the bidding decision process (Egemen & Mohamed, 2007).

Egemen and his colleague have also proposed a practical knowledge-based system software called SCBD to help the contractors identify a 'strategically correct' bid/no bid and markup size decisions. They have developed a user-friendly software that assists the contractors reach those decisions. The accuracy of their model which was based on the similarity to real data from contractors bidding behaviors in bid/no bid decisions was 86% percent and in the markup size decision was 1.75%. They have considered different factors in their decision-making process, factors thar are related to the firm itself (size, etc.), to the market, and to the project (Egemen & Mohamed, 2008).

Cagno and his colleagues have described a simulation approach based on the Analytic Hierarchy Process to assess probabilities of winning from a contractor’s point of view in a competitive bidding process where the bids are evaluated based not only on price. The criteria that he and his colleagues have taken into account were basically criteria that are important in plant design construction and some important elements that are addressed within the contract such as: delivery time; technology assistance; technology transfer; safety; price; dependability; process technology; terms of payment; financial package; liquidated damages clause; conformity to tender documents; contractors co-operation; and utilization of local vendors (Cagno, Caron, & Perego, 2001).

Lin and his colleague have identified 21 important factors for determining markups from a contractor's point of view. They indicated that among those factors those that were related to the clients (owners) characteristics, for example, payment record and size & type of client, were the most important. They adopted a fuzzy logic approach which helps the contractors make the bid/no-bid decision faster and thus allows the contractors to have more time for preparing completer RFPs. (Lin & Chen, 2004).

Ahmad and his colleague have analyzed a survey which was conducted among 400 of the top general contractors in the US. Based on the results, they have concluded that type of job and need of work are the top factors in making the bid/no-bid decision. Moreover, the top factors for making the markup decision have been identified to be: degree of hazard and degree of difficulty. They have observed that Potential client/owner relationship, quality of architectural/engineering design, and reliability of subcontractors have considerable influence on the pair of bid decisions (Ahmad & Minkarah, 1998).

Lee and his colleague have concentrated on determining the bid markup for micro tunneling projects which are associated with uncertainties. They have developed a decision support system based on survey results which assists the contractors in selecting an appropriate markup (Lee & Chang, 2004).

More detailed information about bidding especially in the construction industry can be found in (Park, 1979) and (Barrie & Paulson, 1991).

2.3 Conclusions

As mentioned in chapter 1 and 2, although there are mathematical models that help the contractors in project bid/no-bid and markup decision-making, most of them only consider monetary criteria. The other models that consider non-monetary criteria as well, are mainly multi criteria decision-making models, and do not provide a mathematical formulation as their basis for decision-making. Moreover, to the best of the author's knowledge there is no model that does portfolio management and project selection for a contractor and considers projects that are available later. Most of the research which is done from the contractor's side and point of view focuses on just one project.

In this thesis we will consider a pool of available projects and assist the contractor to select the most profitable portfolio of projects. We will consider the effect that doing a project for a specific owner has on the chances of winning a prospective future project provided by the same owner.

Chapter 3: Elements of the project selection model

Since the importance of doing previous works (and improving the eminence) for designated owners has been shown in the previous chapters, a mathematical model that can assist the contractors in selecting projects and a bidding markup for those project is very valuable.

The model we are proposing has two major elements:

1- The bidding price.
2- The contractor's index of eminence and previous works done for the project provider.

3.1 Bidding Price

This element has been the focus of many previous investigations by many researchers. Researchers have come up with different models that give the contractors an estimate of what they could expect to have as a profit. The expected profit for each project can be defined as the profit that is expected from the project if the project is going to be selected to be done. It can be easily represented by equation (3-1):

$$E(P_i) = Prob_i \times Prof_i \quad (3\text{-}1)$$

Where:

- $E(P_i)$: is the expected profit for project "i".
- $Prob_i$: is the probability that project "i" would be awarded to the contractor.
- $Prof_i$: is the profit associated with project "i" if the project is done.

By having the expected profit of each project, the overall expected profit for a contractor based on the projects in which he will choose to participate would be as follows (equation (3-2)):

$$\sum_i EXPPROF(P_i) = \sum_i Prob_i \times Prof_i \qquad (3\text{-}2)$$

But for all projects that are available the correct formula will be:

$$\sum_i EXPPROF(P_i) = \sum_i Prob_i \times Prof_i \times y_i \qquad (3\text{-}3)$$

Where y_i is a binary variable which indicates whether or not the project will be selected for bidding.

The profit of the project can be calculated as the difference between the bidding price and the cost of that project. Since the bidding price is equal to the cost of the project plus a percentage markup, the profit of the project can be calculated using equation (3-4):

$$Prof = b - c = (1 + m) \times c - c = m \times c \qquad (3\text{-}4)$$

Where:

- b: is the bidding price of the project.
- c: is the cost of the project
- m: is the markup for that project

By knowing the profit, the only non-clear part of the expected profit equation is the probabilities of winning the auction. This is equal to the probability of having the lowest bidding price.

In order to win an auction based on price, a contractor has to have the lowest bidding price. By assuming that the cost estimates of any unique project done by different contractors are the same, the lowest bidding price will be equivalent to the lowest markup by a contractor.

Having the assumption that all contractors have the same estimates of a project's cost is not that much far from reality if it is assumed that all contractors have a good amount of knowledge about the project and have enough experience in those kinds of projects. In other words, the contractors are the same size.

In order to find the lowest bidding markup percent among all contractors, all of the bidding markups from different contractors need to be known, but they are not. A contractor has to assume a markup distribution for the other participants. The contractor can generate that distribution based on the past bidding behavior of other contractors. If the mean and the variance of the markups of other competitors are known, the contractor can draw a distribution for other competitors' markup.

If no historical data about the bidding markup of a competitor is available, it is rational to assume that he will be bidding the same as an average bidder in that industry. Hence the mean will be equal to the mean of the industry and the variance will be derived from the industry.

When the distributions for other competitors are known, the probability of winning a bid will be equal to the probability of the bidding markup presented by the contractor being less than the minimum bidding markup of the other contractors. In Figure 3- 1, a normal distribution is illustrated for the markups. The colored area under the curve that is smaller than "a" represents the probability of losing in the auction when the markup percent is equal to "a". All of the points on the horizontal axis that are smaller than "a" represent bidding markups that are smaller than "a". Therefore, the probability of winning from a single competitor is equal to the area that is not colored (the white area under the curve). This is equal to one minus the probability of losing. An example is illustrated below.

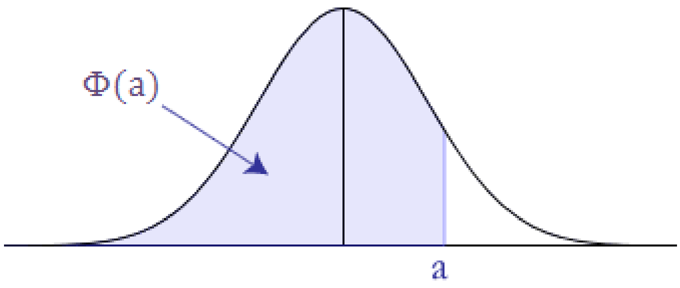

Figure 3- 1 The distribution of markups following a normal distribution

Assume that a contractor is using a markup of 8% and from previous history he knows that his or her only competitor's mean markup has been 9% with the coefficient of variance (C.O.V.) of 4%. By assuming that the distribution of the markup for the competitor is normal, the contractor's chance of winning is equal to:

1-0.309 = 0.691 = 69.1%

Where, 0.309 is the colored area that can be calculated from MS Excel using the =NORM.DIST(8,9,2,1) formula.

The main question about the probabilities of winning arises when there is more than one competitor in an auction. In this case, what is the probability of winning the auction and having the lowest bid among all competitors?

There are two main models that are used for calculating the probability of winning among all competitors who are competing to win the auction:

1- Friedman's model
2- Gates' model

3.1.1 Friedmans model

Friedman's model is the first model that addressed the issue of probabilities of winning a multi-competitor auction (Friedman, 1956). Friedman had one main assumption which was: the probability of winning each competitor is independent from the probability of wining another competitor because he had assumed that the uncertainties in the marginal bids by contractors are independent. Hence, based on the characteristics of probabilities, the overall probability of winning all competitors can be calculated by equation 3-5:

$$P_{win} = \prod_i P_i \tag{3-5}$$

Where:

- P_i: is the probability of winning against competitor i,, equivalent to having a markup less than the markup of the competitor.
- i: is the index on the set of n competitors bidding in for the project.

In the case that the competitors' previous bidding behaviors are not known, and the chance of winning a project compared to the industries mean is equal to P_{ave} the Friedman's formula can be written as equation 3-6:

$$P_{win} = P_{ave} \times P_{ave} \times ... \times P_{ave} = (P_{ave})^n \tag{3-6}$$

As the number of competitors rise, the probability of winning decreases. For example, if the chance of an auction from an average bidder in the industry is 50% the chance of 5 average bidders will be only (0.5)^5 = 0.03. This is a very low probability..

3.1.2 Gates model

Gates' empirical model was developed after Friedman's model. He developed his model based on the concept that the competitors' probability distributions are not mutually independent as opposed to Friedman's model. The formulation of it is given in equation 3-7:

$$P_{win} = \frac{1}{\left[\frac{1-P_1}{P_1}\right]+\cdots+\left[\frac{1-P_n}{P_n}\right]+1} = \frac{1}{1+\sum_i\left[\frac{1-P_i}{P_i}\right]} \quad (3\text{-}7)$$

Where:

- P_i: is the probability of winning from competitor i. Winning from competitor i is equivalent to having a markup less than the markup of the competitor.
- i: is the index on the set of n competitors bidding in for the project.

In the case that the distribution of the competitors is unknown, the formulation will be modified as shown in equation 3-8:

$$P_{win} = \frac{1}{n\times\left[\frac{1-P_{ave}}{P_{ave}}\right]+1} \quad (3\text{-}8)$$

Where:

- P_{ave} is the probability of winning from an average competitor in the industry.
- n: is the number of competitors.

Obviously, in this model as the number of competitors grows the probability of wining from all competitors decreases. For instance, if the probability of winning a typical bidder is 0.5 then the probability of winning 5 typical (unknown) bidders will be:

$$P_{win} = \frac{1}{n\times\left[\frac{1-P_1}{P_1}\right]+1} = \frac{1}{5\times\left[\frac{1-0.5}{0.5}\right]+1} = 0.2$$

This is as opposed to the 0.03 resulting from the Friedman's model. As mentioned before, the Gates' model is generally more optimistic than the Friedman's model.

As it was mentioned throughout chapter 1, among all elements that are used by owners to evaluate the contractors participating in an auction, the bidding price and the previous projects done by the contractor for the owner (eminence) are of the highest importance. Considering eminence in the decision making process leads to many desirable outcomes. It helps differentiate between the firms' sizes (large, medium, small) that according to research done are important in the project selection decision-making. This could be done by setting a higher degree of eminence for larger firms. It also helps consider the effect of having preferential bidders, which as explained in the previous chapters, is somehow desirable by assigning more eminence to preferred bidders.

Inserting reputation into the model was done by the use of weighting indexes. This can be simply done by giving a higher weight to those projects for which the contractor's relationship with the owner is more eminent. Hence, the chance of winning the project is higher.

The questions that arise at this point are: How should different weights be assigned to different levels of eminence? How much should the eminence have an effect on choosing to bid on a project or not? What is the cap that should be put on or used? What should represent the weight of the price factor?

We have dealt with these different weights in this research by the use of relative weights. If the weight of eminence and previous works is high (being eminent is very important) this will imply that the weight of the bidding price is low and vice versa. These questions are answered in chapter 4 where the model is presented and in chapter 6 where sensitivity analysis is done on different parameters.

Chapter 4: Project selection model, based on eminence and bidding price

4.1 Objective Function formulation

The objective of this research is maximizing an index which will maximize the profit of the contractor by helping him or her strategically choose the best set of projects on which to bid. As mentioned in the previous chapters, considering non-monetary factors in the process of decision making is important. And among all of the non-monetary criteria previous works and eminence are very important. Thus, the index which is presented for valuing different projects considers this non-monetary criterion. It also considers the bidding price and its relative markup as the main monetary criteria. Each of these monetary and non-monetary criteria is factored in by using probability theory.

For the monetary part, the probability of winning from each of the other participants in the auction based on the markup is used. Calculations regarding the probability of winning based on price (markup) were provided in chapter 3. Then the overall probability of winning based on price from all competitors is computed using Friedman's method.

For the non-monetary part, a shape and probability of winning based on r is proposed in the following subsection.

4.1.1 The Eminence probability

At each point in time, depending on the relationship a contractor has with the one who is in charge of the auction (owner), the probability of winning against other contractors who are competing can be estimated. The relationship between a contractor and the owner (degree of eminence) is based on the successful previous works. Once the probability of winning from other competitors based on eminence alone is known, the overall probability of winning can be calculated by using either Friedman's or Gates' methods.

The probability of winning against each competitor can be simulated as the probability of winning an auction just based on eminence from every other bidder with an average profile (i.e., the chance of winning from an average industry bidder based on eminence). Thus we need a probability function based only on eminence that for every contractor at each time provides the probability of winning against other contractors. This is equivalent to the probability of having done more or equal number of projects than the competitor. If the shape of the Cumulative Distribution Function (CDF) is known, the probability of winning based on eminence which is equal to having done more projects for the owner can be derived. This probability depends on the number of projects done and the initial eminence with the owner. The initial eminence is based on the number of previous projects which were awarded at earlier times, times before the model is being executed. We assume that the probability (CDF) due to eminence can be presented using a piecewise linear function. Figure 4- 1 illustrates a portion of the an example CDF. The horizontal axis in Figure 4- 1 is the expected number of projects awarded (decided to bid on), and the vertical axis is the probability of winning the bid based on just eminence. The entire CDF starts from the probability of Zero and increases. However in Figure 4- 1 only a portion of the CDF is shown. The portion that is important in this optimization model.

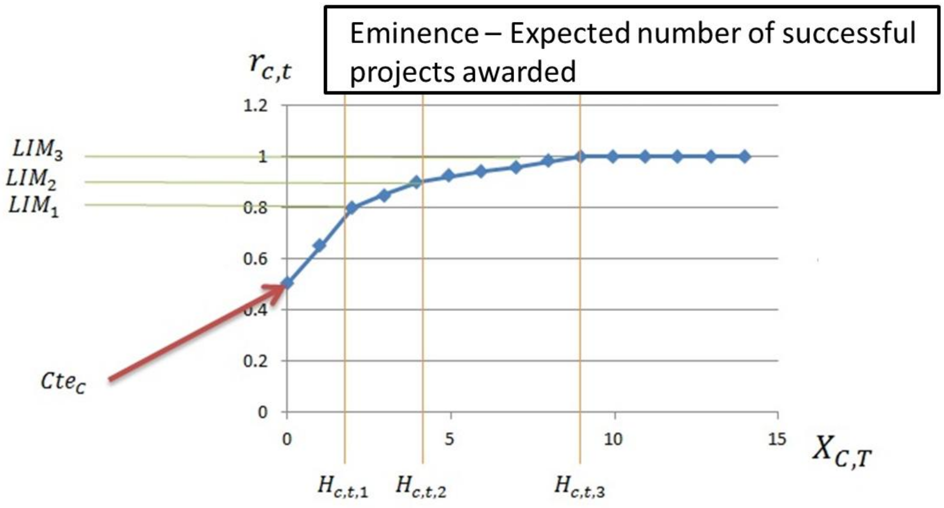

Figure 4- 1- The growth in the probability of winning due to eminence

As observed in Figure 4- 1, the probability of winning from an average competitor increases as the number of successful projects in the past increases.

The rate of increase in the probability is high for the first few projects won if the initial probability of wining is low (Less than Lim1). As the probability of winning increases, the change of the probability due to doing each successful project decreases. The increase continues until the probability reaches “1” which means that if the auctions are solely based on reputation, the project will be awarded to the contractor.

The eminence function can be written as equation 4-1:

$$X_{C,T} = \sum_{k=1}^{K} \sum_{n=1}^{N} \sum_{t=1}^{T-1} P_{k,C,t,n} \times y_{k,C,t,n} \tag{4-1}$$

Where:

- $X_{C,T}$ denotes to the expected number of projects awarded to the contractor up to time “T” by owner “C”. Since time “T” is in the future, this value is stochastic. The expected number of projects provided by owner “C” that are selected for bidding until time “T” is used as opposed to the actual number which is not available.
- $P_{k,c,t,n}$: The probability of winning the n’th project that owner “c” has provided at time “t” with the bidding price scenario of “k”. This probability is just based on the bidding price and is calculated by using either the Friedman’s model or the Gates’ model.
- $y_{k,c,t,n}$: Binary variable which indicates the selection of the n’th project owner “c” has provided at time “t” under the bidding markup which is associated with the k’th scenario. (If project selected under the bidding scenario of “k”: $y_{k,c,t,n}$=1, other wise $y_{k,c,t,n}$=0).

Once the number of previous won bids is calculated, by using the initial eminence at time 1 the probability of winning based on eminence can be calculated as follows:

$for\ \forall c,t$:

$if\ CTE_c \leq Lim_1$:

$$if\ 0 \leq X_{c,t} \leq H_{c,t,1} \ \ \Rightarrow \ \ r_{c,t} = CTE_c + Z_1 \times X_{c,t}$$

$$if\ H_{c,t,1} \leq X_{c,t} \leq H_{c,t,2} \ \ \Rightarrow \ \ r_{c,t} = LIM_1 + Z_2 \times (X_{c,t} - H_{c,t,1})$$

$$if\ H_{c,t,2} \leq X_{c,t} \leq H_{c,t,3} \ \ \Rightarrow \ \ r_{c,t} = LIM_2 + Z_3 \times (X_{c,t} - H_{c,t,2} - H_{c,t,2})$$

$$if\ H_{c,t,3} \leq X_{c,t} \ \ \Rightarrow \ \ r_{c,t} = 1$$

$else\ if\ Lim_1 \leq CTE_c \leq Lim_2$:

$$if\ 0 \leq X_{c,t} \leq H_{c,t,2} \ \ \Rightarrow \ \ r_{c,t} = CTE_c + Z_2 \times X_{c,t}$$

$$if\ H_{c,t,2} \leq X_{c,t} \leq H_{c,t,3} \ \ \Rightarrow \ \ r_{c,t} = LIM_2 + Z_3 \times (X_{c,t} - H_{c,t,2})$$

$$if\ H_{c,t,3} \leq X_{c,t} \ \ \Rightarrow \ \ r_{c,t} = 1$$

$else\ if\ Lim_2 \leq CTE_c \leq Lim_3$:

$$if\ 0 \leq X_{c,t} \leq H_{c,t,3} \ \ \Rightarrow \ \ r_{c,t} = CTE_c + Z_3 \times X_{c,t}$$

$$if\ H_{c,t,3} \leq X_{c,t} \ \ \Rightarrow \ \ r_{c,t} = 1 \qquad (4\text{-}2)$$

Where:

- $H_{c,t,i}$'s are the limits to the number of projects done in each part of the piecewise linear function (The breakpoints for the slope in the eminence probability).
- $r_{c,t}$: The probability of winning from another competitor in an auction that owner "c" is presenting at time "t", just based on eminence.

- Z_i: The slope of the probability function.
- LIM_i: The limit on the probability for eminence before/after a change in slope happens.
- CTE_c: The initial eminence probability with owner "c" at time "t=1".

The $H_{c,t,i}$'s can be calculated as follows:

$\forall\, c, t$:

$$H_{c,t,1} = \frac{LIM_1 - CTE_c}{Z_1} \tag{4-3}$$

$$H_{c,t,2} = \min\left(\frac{LIM_2 - LIM_1}{Z_2}, \frac{LIM_2 - CTE_c}{Z_2}\right) \tag{4-4}$$

$$H_{c,t,3} = \min\left(\frac{LIM_3 - LIM_2}{Z_3}, \frac{LIM_3 - CTE_c}{Z_3}\right) \tag{4-5}$$

The overall probability of winning in an auction from all other competitors which is solely based on eminence can be combined and calculated using either the Friedman's method or Gates' by using equations 4-6 and 4-7:

$$r_{c,t,n} = {r_{c,t}}^{CMT_{c,t,n}} \tag{4-6}$$

or

$$r_{c,t,n} = \frac{1}{CMT_{c,t,n} \times \left(\frac{1 - r_{c,t}}{r_{c,t}}\right) + 1} \tag{4-7}$$

Where:

- $r_{c,t}$: The probability of winning from one average bidder who bids on a project that owner "c" provides at time "t" solely based on eminence (calculated using the probability piecewise linear function).

- $CMT_{c,t,n}$: The number of competitors who are competing for the "n"'th project that owner "c" is providing at time "t".

4.1.2 Objective function

The overall objective function which considers both monetary and non-monetary criteria is as follows (equation 4-8):

$$max \sum_k \sum_c \sum_t \sum_n EV_{c,t,n} \times Cost_{c,t,n} \times M_{k,c,t,n} \times (PI_c \times P_{k,c,t,n} + RI_c \times r_{c,t,n}) \times y_{k,c,t,n} \tag{4-8}$$

Where the uppercase words and alphabets represent parameters and constants and the lowercases represent variables. The variables are defined as follows:

- $y_{k,c,t,n}$: Binary variable which indicates the selection of the n'th project owner "c" has provided at time "t" under the bidding markup which is associated with the k'th scenario. (If project selected under the bidding scenario of "k": $y_{k,c,t,n}$=1, otherwise $y_{k,c,t,n}$=0).
- $r_{c,t,n}$: A real auxiliary variable that represents the probability of winning the n'th project at time "t" from owner "c" solely based on eminence.

The parameters in the objective function are:

- $M_{k,c,t,n}$: The markup % associated with the k'th scenario of bidding for the n'th project that owner "c" provides at time "t".
- $Cost_{c,t,n}$: The cost estimate of doing the n'th project owner "c" provides at time "t".
- PI_c: The relative importance of the price factor in evaluating bids for owner "c". It is an input to the model which ranges between 0 and 1. Setting this parameter equal to 1 means that for client, "c", price is the only important criterion for evaluating bids. And the term "$Cost_{c,t,n} \times$

$M_{k,c,t,n} \times (PI_c \times P_{k,c,t,n} + RI_c \times r_{c,t,n}) \times y_{k,c,t,n}$" will be equal to the expected profit just based on price. The probability of winning due to price in this expected profit is calculated by either Friedman's or Gates' model.

- RI_c: The relative importance of the eminence factor in evaluating bids for owner "c". This parameter is equal to 1 minus the importance of price. So, if the importance of price is high, the relative importance of eminence is low (the formulation is provided in equation 4-9).

$$RI_c = 1 - PI_c \qquad \forall c \tag{4-9}$$

- $EV_{c,t,n}$: A weighting factor which represents the likelihood of the "n'th" project which owner "c" provides at time "t" actually being provided in tender. This weighting factor is an input from the contracting firm which uses this model. The amount of this varies between 0 and 1 (1 representing 100 percent likelihood). By definition, this should be equal to one for projects which are definitely available at time 1. Since, this parameter is an input to the model, if a contractor is optimistic or risk prone, he will tend to give higher likelihoods than one who is pessimistic or risk averse.
- $P_{k,c,t,n}$: The probability of winning the n'th project that owner "c" has provided at time "t" with the bidding price scenario of "k". This probability is just based on the bidding price and is calculated by using either the Friedman's model or the Gates' model.

4.2 Resource Constraints

Every optimization model has a set of constraints and limitations that build up the domain of the optimization problem (the feasible region). The following describes the different kinds of constraints used in this model.

4.2.1 Project Manager Constraint

This set of constraints is needed because of the limited number of Project Managers (PM) each contractor has. Each contractor has a certain and known number of PMs to carry out all projects. The number of Project Managers may vary by time. Each project has a certain amount of resource requirements at each time. The PM requirement of each project may also vary by time. For the purpose of satisfaction of the PM constraint, the total number of PMs working at different projects at each time should be less than the total quantity of the resources available to the contractor's company.

Since the problem that we are trying to address is a planning problem, the knowledge of exactly what is going to happen is not available, i.e., this problem is only for the purpose of helping the contractor make a decision on whether to bid or not to bid. Therefore when the decision is made, there is no assurance that the contractor will win the auction. The contractor has to use a level of contingency when solving the problem. For example, if the contractor has R amount of a resource, when planning it is suggested to use (1+c)*R amount of resource as the limitation, in which c is the percentage of contingency the contractor is using.

By having this in mind, the formulation of the PM resource constraint is shown in equation 4-10 for each time period and the projects that are on-going during that time period:

$$\sum_{k} PM_{c,t,n} \times y_{k,c,t,n} \leq PMR_{tv} \qquad for\ \forall\ tv\ \in\ \{1, \dots, TV\}$$

(4-10)

Where:

- PMR_{tv}: the total number of project managers the firm has at time "tv" including the contingency explained earlier.
- $y_{k,c,t,n}$: Binary variable which indicates the selection of the n'th project owner "c" has provided at time "t" under the bidding markup which is

associated with the k'th scenario. (If project selected under the bidding scenario of "k": $y_{k,c,t,n}$=1, otherwise $y_{k,c,t,n}$=0).

- $PM_{c,t,n}$: the number of project managers which the n'th project that owner "c" provides at time "t" requires per each time period it is ongoing.
- TV: is the total time horizons that should be considered. The calculation of it is provided bellow.

TV at its utmost is calculated by equation 4-11:

$$TV = \max(t) + \max(L_{c,t,n}) \tag{4-11}$$

Where:

- $L_{c,t,n}$: the duration of the n'th project that owner "c" provides at time "t"
- $\max(t) = T$**:** The last time we are considering for projects to be available

When the projects are completed, the resources they are consuming will be available again. The formula provided above for each project stands for the period that project is on-going. A set of auxiliary variables is used to recognize the time periods for projects that are chosen for bidding under any bidding price and scenario to be used in the constraint. These auxiliary variables are calculated by using the formula presented below:

$$\sum_k y_{k,c,t,n} = f_{c,t,n} \qquad \forall\, c,t,n \tag{4-12}$$

$$\beta_{c,t,n,h} = f_{c,t,n} \qquad \forall\, c,t,n \;\;,\;\; \forall\, h \in \{t, \dots, t + L_{c,t,n}\} \tag{4-13}$$

Where:

- h: is the time period in which the project is on-going (has started and is still has not reached its estimated final duration).

- $L_{c,t,n}$: The duration of the project that starts at time “t” and is the n’th project which is offered by owner “c” at time “t”.
- $\beta_{c,t,n,h}$: The auxiliary variable that indicates whether the project which is specified with the index c,t,n is ongoing at time “h” or not. This is a binary variable which it is equal to 1 when the project is ongoing and 0 otherwise.
- $f_{c,t,n}$: An auxiliary binary variable which states whether project c,t,n is selected for bidding under any bidding scenario or not. If selected the value for this variable is 1, otherwise it will be 0.

Now that for each time it is known whether a project is still ongoing or not if selected for bidding, the PM constraint can be illustrated as equation 4-14:

$$\sum_c \sum_t \sum_n PMTV_{c,t,n,TV} \times \beta_{c,t,n,TV} \leq PMR_{TV} \qquad \forall\, TV \qquad (4\text{-}14)$$

Where:

- $PMTV_{c,t,n,h}$: Is the amount of PM resources needed at time “TV” for the n’th project that owner “c” provides at time “t”.
- TV: is the total time that is being considered. It is equal to the final time any project is provided added by the duration of the longest project.
- PMR_{TV}: The total number of project managers the company has at each time, “TV”, by taking into account the required level of contingency.

In the case that the resources needed at each time period is uniformly distributed, the $PMTV_{c,t,n,h}$ can be calculated using equation 4-15:

$$PMTV_{c,t,n,h} = PM_{c,t,n} \qquad \forall\, c,t,n \qquad ,\forall\, h \in \{t, \ldots, t + L_{c,t,n}\} \qquad (4\text{-}15)$$

Where $PM_{c,t,n}$ is the uniform number of project managers that the n’th project owner “c” at time “t” will use if awarded.

4.3 One scenario happening constraint

In the models presented by Friedman and Gates, each bidder has a distribution. Hence depending on the bidding markup, the probability of winning the other auctioneers can be calculated. The number of bidding scenarios considered for each project depends on the amount of accuracy desired. If it is set to 3, we would be considering only three markups. If it is set to 100 we would be considering 100 different markups. Under any type of scenario categorization, only one scenario will happen for each project. Hence:

$$\sum_k y_{k,c,t,n} \leq 1 \tag{4-16}$$

4.4 The model type

From the structure of the model, it can be seen that all constraints are linear. However, the objective function is a nonlinear objective function. Therefore in general the problem is a Non-Linear Program with Integer (Binary) variables (NLIP).

Based on the theorem provided below, if the objective function is concave, finding the optimal solution would be easy using a hill climbing method or a commercial optimization solver.

Theorem: Consider a NLP and assume it is a maximization problem. Suppose the feasible region S for the NLP is a convex set. If the objective function is concave on S, then any local maximum for the NLP is an optimal solution to this NLP (Winston, 2003).

All constraints are linear and thus the feasible region is convex. The only part that remains to be checked is the objective function. Since the problem that is to be solved is a maximization problem, it is very much desirable if the objective function is concave.

In the following subsection the convexity/concavity check is explained.

4.4.1 Convexity/Concavity check

A function, f, is concave on a convex set S whenever for any $x \in S, x' \in S$ and $0 \leq c \leq 1$ (Winston, 2003):

$$f[cx' + (1-c)x'] \leq cf(x') + (1-c)f(x') \tag{4-17}$$

The Convexity/Concavity of a function can also be checked by calculating the Hessian matrix. If the Hessian matrix is positive semi-definite (PSD), the function is Convex. The Hessian Matrix was calculated and it was observed that it does not follow any special structure and it is not PSD. Therefore the objective function is not convex (concave). Because of this, when Xpress-mosel software was used it gave errors about the convexity check not being passed. And, when the convexity check was set off manually, the optimal solution provided by Xpress was a local optimal and that was far inferior to the global optimal, even for a small-sized example. It was concluded that in order to solve this problem, a different procedure should be developed.

4.5 The mathematical model summary

The entire optimization model with all of its constraints at a glance is as follows:

$$maximize\ \sum_k \sum_c \sum_t \sum_n EV_{c,t,n} \times Cost_{c,t,n} \times M_{k,c,t,n} \times (PI_c \times P_{k,c,t,n} + RI_c \times r_{c,t,n}) \times y_{k,c,t,n} \tag{4-8}$$

subject to:

$$\sum_c \sum_t \sum_n PMTV_{c,t,n,TV} \times \beta_{c,t,n,TV} \leq PMR_{TV} \qquad \forall\, TV \tag{4-14}$$

$$\sum_k y_{k,c,t,n} \leq 1 \tag{4-16}$$

$$H_{c,t,1} = \frac{LIM_1 - CTE_c}{Z_1} \tag{4-3}$$

$$H_{c,t,2} = \min\left(\frac{LIM_2 - LIM_1}{Z_2}, \frac{LIM_2 - CTE_c}{Z_2}\right) \tag{4-4}$$

$$H_{c,t,3} = \min\left(\frac{LIM_3 - LIM_2}{Z_3}, \frac{LIM_3 - CTE_c}{Z_3}\right) \tag{4-5}$$

$$r_{c,t,n} = {r_{c,t}}^{CMT_{c,t,n}} \tag{4-6}$$

$$\sum_k y_{k,c,t,n} = f_{c,t,n} \qquad \forall\, c,t,n \tag{4-12}$$

$$\beta_{c,t,n,h} = f_{c,t,n} \qquad \forall\, c,t,n \;\;,\;\; \forall\, h \in \{t,\dots,t+L_{c,t,n}\} \tag{4-13}$$

$$TV = \max(t) + \max(L_{c,t,n}) \tag{4-11}$$

$$X_{C,T} = \sum_{k=1}^{K} \sum_{n=1}^{N} \sum_{t=1}^{T-1} P_{k,C,t,n} \times y_{k,C,t,n} \tag{4-1}$$

$$RI_c = 1 - PI_c \qquad \forall c \tag{4-9}$$

Chapter 5: Solution Method

5.1 Introduction to Heuristic approaches:

There are several situations in which using traditional approaches cannot solve a desired optimization problem. Some of these situations are: complexity of the objective function; discrete feasible region; lack of computational resources (not enough time, low memory, etc.). In these and many other cases where traditional methods are not well performing, heuristics are used to try to reach a feasible and near optimal or hopefully optimal solution.

Using heuristics is highly preferable to exhaustive enumeration in cases where the feasibility domain is large because they take much less effort and time to reach an almost optimal solution. A heuristic can be as a simple random search.

Meta-Heuristics are a higher level of optimization algorithms where the algorithm can be applied to almost any optimization problem. There are many famous Meta-Heuristics that are widely used. Some of them are as follows:

- Simulated annealing
- Tabu Search
- Ant colony
- Evolutionary Algorithms

These are all guided random search techniques. Some of the heuristics are single-solution based local solution methods, such as: simulated annealing and tabu search, and some are population-based, such as Genetic Algorithms and Ant Colony.

The idea behind evolutionary algorithms is derived from what happens in the real world. Usually, all Meta Heuristics require two functions: one that is in charge of evaluating solutions, and another one, which is in charge of generating new valid solutions, based on previous solutions.

At the following subsections a brief description of some of the Meta-heuristics are provided.

5.1.1 Simulated Annealing

The root of Simulated Annealing is in Metallurgy. It is based on the idea that heating the material and using controlled cooling reduces its defects. The method has two important factors: the temperature (T) and the energy level (E) of each state. The process usually starts at a very high level (infinity) and the temperature decreases as the process proceeds until it reaches zero. At each temperature, the energy level of each state and its neighbors are calculated. When minimizing the solution is under consideration, the probability of moving from a state with a higher level of energy to a lower level of energy based on the temperature is calculated and is positive, hence, meaning that the solution is moving downhill.

In order to prevent the method from getting stuck in a local optimal, the probability of moving from a state with a lower state of energy to a neighbor with a higher energy level (moving uphill) is positive. But, the probability decreases as the difference between the two states' increases.

As the temperature (T) decreases, the method approaches more greedy methods. When the temperature is equal to 0, the method will be a greedy method (a hill climbing method). Therefore, in higher temperatures, the method moves uphill but, as the temperature decreases, the potential of moving uphill decreases.

5.1.2 Tabu Search

Tabu search is a local solution algorithm that claims it is more enhanced than the other local solution searches. Similar to other local search algorithms this method looks for better solutions in its neighborhood. The main improvement of this method is its database. Every solution in this method is called a Tabu (Taboo), and it is saved in the Tabu list, which is the database. Different solutions from different iterations are saved in this database. Every solution in the Tabu list can no longer be a solution for another iteration.

There are some other ways to improve the search for optimality by using the Tabu list. One way is to put some illegal solutions in the database (tabu list). Hence, these illegal solutions will not be considered anymore while looking for optimality.

5.1.3 Ant Colony

The inspiration for this method was the ant's behavior while searching for food. This method was initially used for finding the shortest path. When ants move in a path they leave indicators, which are called pheromones, on the path they have moved. These pheromones evaporate after a while (hence, the solutions hopefully do not fall in a local optimum point). When an ant senses the pheromones that are still available, it moves on that path.

At the initial state where no pheromones are available, the ants move in completely random paths. In the second state where there are pheromones available in some paths, the probability of some other ants moving on those paths and placing some new pheromones increases. These new pheromones will ensure that the paths still have pheromones, and replace the evaporating ones. At the end of the process, the path with the shortest length will be the remaining path with pheromones.

5.2 Evolutionary Algorithms

Evolutionary Algorithms (EA) are in the generic population based optimization algorithm branch. EA's are highly inspired by biological concepts. They use biological evolution techniques such as: mutation; crossover; elitism, to build a better solution. The selection is based on a fitness function, and higher probabilities of being selected for building the next solution are given to those with a higher fitness value. The most famous EA algorithm is Genetic Algorithm (GA).

5.2.1 Introduction to Genetic Algorithms

The main terminologies of GA are:

- Chromosome: The data structure that represents the solution of an optimization problem
- Gene: The smallest element of the Chromosome that is representative of a parameter of that solution (chromosome)
- Fitness function: The function that weighs different chromosomes in terms of their value
- Fitness Value: The value of the chromosome in the fitness function

There are many benefits in using a GA, some are listed below:

- They can handle a large number of variables
- They are good for problems with discrete search spaces
- They support multi-objective optimization
- They can be applied to many different problems in many different fields and disciplines.
- They can be used with other methods as a part of a hybrid algorithm.

The procedure of the GA is illustrated in Figure 5- 1:

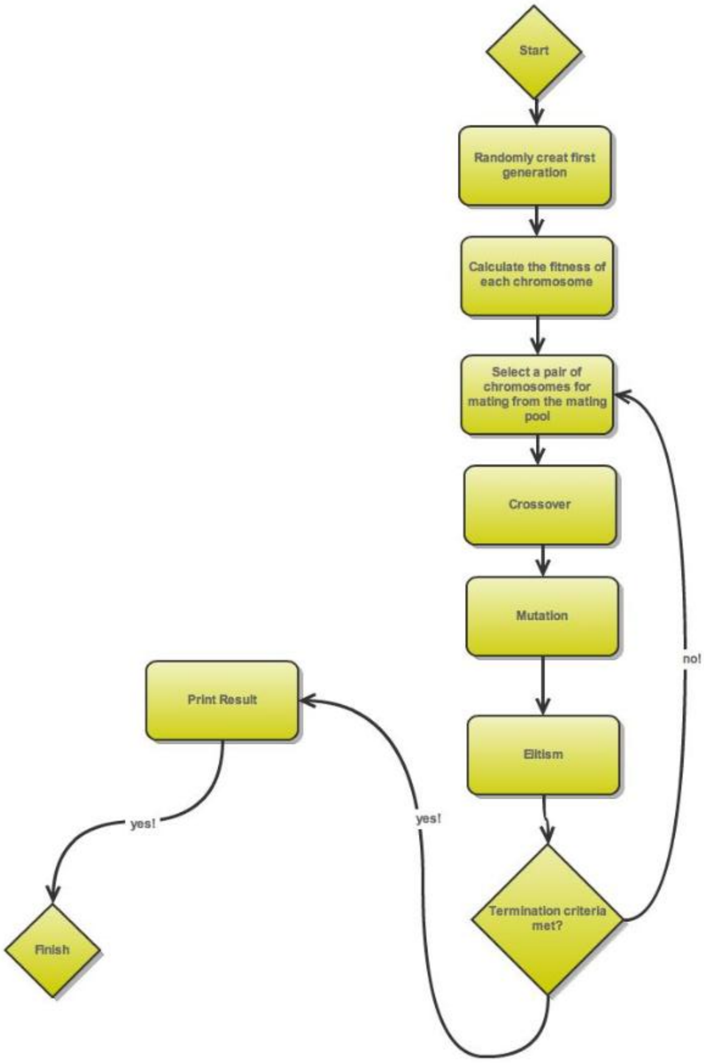

Figure 5- 1- The flowchart of a typical GA

The process of Genetic Algorithm is:

1- Encoding the Chromosomes
2- Initialization
3- Selection
4- Reproduction
5- Termination

Each of the processes for GA is described below:

Encoding:

Encoding is the genetic representation of the possible solution. This state, while being the first process in GA is one of the most important and most challenging stages in developing a GA, if not the most. In order to be able to use a genetic algorithm heuristic, one has to be able to represent each solution as a chromosome. Binary variables can be easily represented using chromosomes.

While encoding the chromosomes, it is very important to pay attention to the benefits wisely encoding a chromosome might have. Some of the benefits are: ease in decoding and reading the solutions and the ability to prevent illegal solutions.

Since the variables of this research are binary, the way that the encoding has been done is:

- Each gene represents a binary variable; 1 representing the variable being chosen; 0 representing the variable not being considered or selected.
- Each gene is representing a scenario for bidding (k) on a certain project (c,t,n) : y(k,c,t,n)
- The chromosomes structure is illustrated in Figure 5- 2. This is a part of a chromosome with t=2, k=2, n=2, and c>=2. As it can be seen, each color (two blocks aside each other) represents the bidding scenarios for each project. At a high level, the different “n”’s for each “c” and “t” are placed aside each other. At a higher level, the different times, “t”’s of each owner, “c”, are placed aside

each other. And finally, at the highest-level owners, “c”, are placed aside each other. As it can be seen from the figure, by having a chromosome, the solution can be easily decoded.

c=1								c=2			
t=1				t=2				t=1			
n=1		n=2		n=1		n=2		n=1		n=2	
k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2
0	1	0	0	1	0	0	0	0	1	0	0

Figure 5- 2- The structure of a binary Chromosome for the project selection model

Initialization:

During this process an initial population is generated. Usually this is done completely randomly. In cases where the variables are binary variables, to each gene of a chromosome either a 0 or a 1 will be assigned, randomly. Depending on the desired population size, chromosomes are initialized. These chromosomes are placed in the mating pool and are used for reproduction.

In the structure of the GA proposed in this research, initially, all of the genes for a chromosome are set to 0. Then, between all of the different bidding scenarios (“k”’s) for each project one is randomly selected and either a 0 or 1 is assigned to it. This means that just one bidding scenario will happen at the most. By using this mechanism as opposed to just randomly assigning 0’s and 1’s to the genes in a chromosome many illegal combinations are prevented. Therefore, the GA will perform better.

Because random numbers generated by the computer are not really random and many of the random calling functions always generate a unique number because they all start with the same random seed, if we just run the GA one time we will not necessarily get a desirable result which is close enough to the optimum. Therefore, we run the GA more than one time with each one starting with a different random seed (which is inputted by the computers clock). As a result of having different random seeds, different initial populations are generated and therefore the chance of falling into a local optimal will be reduced due to the different initial populations. After building the initial population, based on the fitness function, the fitness value of each chromosome is calculated.

Selection:

During this process a portion of the chromosomes available (population) are selected for reproduction and are placed in the mating pool. This selection is based on the fitness value of the chromosomes. Usually, the chromosome with a higher fitness value is more likely to be chosen for reproduction.

There are two famous methods used for selection:

1- The roulette wheel method: Based on this method, each chromosome proportional to its fitness function will have a circular sector of the roulette wheel. In order to assign a sector of the roulette wheel to each chromosome they all should be normalized. Therefore, if each individuals fitness value is represented by φ, its section will be equal to$2 \times \pi \times \varphi / \sum \varphi$ (Holland, 1975). After assigning theses angles to the chromosomes, they are sorted in a descending order. Then a random number between 0 and 1 is generated, the first chromosome which its number is more than that order is picked.

2- The tournament method: based on the binary tournament method, each time two chromosomes are randomly chosen and the one with a bigger fitness value is selected for the mating pool. This procedure is done repetitively until the desired population for the mating pool is met.

Reproduction of GA:

The reproduction of new chromosomes is done by many ways. Some of them are:

- Crossover
- Mutation
- Migration
- Elitism
- Regrouping
- Colonized-extinction

The two main methods for reproduction are known as Crossover and Mutation. The characteristics of each method along with a brief description are provided below.

Crossover:

The major method which is used for producing new chromosomes is Crossover. The idea behind Crossover is that two (or more) parent chromosomes (parent) pair together and build two (or more) new (child) chromosomes. The two parent chromosomes are picked based on different methods. One popular way is to select them randomly. When the two parents are selected from the reproduction (mating) pool, they make new chromosomes by either one of the methods as follows:

a) One point crossover: A point from the chromosomes are selected and from there the parent chromosomes are cut into two pieces, then the second half of the parent chromosomes swap their places together leading to the production of new chromosomes. The process is illustrated in Figure 5- 3.

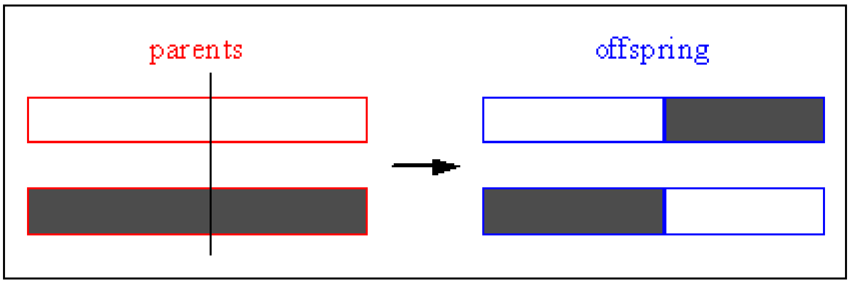

Figure 5- 3- One point crossover (Source: GEATbx)

b) Multiple point crossover: The methodology in this method is similar to the one point crossover. The difference is that instead of just having one crossover point, this method has more crossover points. (Figure 5- 4)

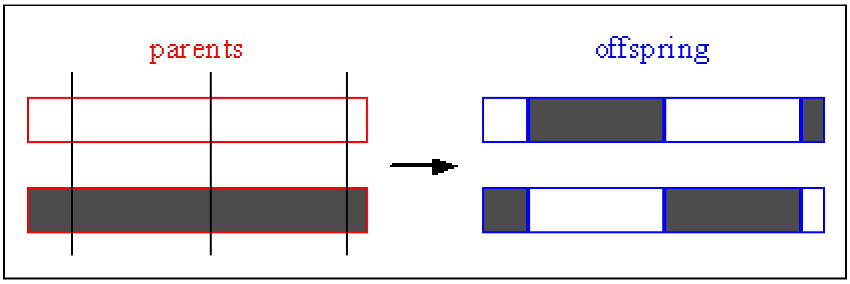

Figure 5- 4- Multiple point crossover (Source GEATbx)

The point at which the swapping in either method happens (the crossover point) is selected in different ways. A common way is selecting it in a random way. The crossover helps the problem converge to a more local optimal solution.

Throughout this research, we have used the one point crossover method. The crossover points are selected wisely in a manner that no illegal reproduced chromosomes are created. The crossover points are set to be randomly selected from the points that each project is ended (i.e., either the beginning of a gene which represents bidding scenario one or the ending point of a gene which represents the last bidding scenario). The crossover points are illustrated in Figure 5- 5.

c=1								c=2			
t=1				t=2				t=1			
n=1		n=2		n=1		n=2		n=1		n=2	
k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2
0	1	0	0	1	0	0	0	0	1	0	0

Figure 5- 5- Possible crossover points in the chromosome

In Figure 5- 5, the vertical lines (red lines) underneath the chromosome show the possible crossover points. From the possibilities a crossover point is selected randomly for the procedure of crossover. The illegality that is prevented by this method is resulting from having different bidding price scenarios for one project happening all at the same time.

Mutation:

Another famous reproduction operator is mutation. Mutation is usually done after crossover and on the offspring's of the crossover. It is done to prevent the solutions from falling into a local optimal point by stopping them from becoming too similar to each other. Mutation randomly changes one of the genes in the new offspring. The process is simple. At the beginning some genes (bits) are selected from the offspring and then they are randomly changed. When the genes are binary variables, it simply changes the genes which are selected for mutation from 0 to 1 and vice versa.(Figure 5- 6)

1	0	0	0	0	1	0	0	0	1	0

1	0	0	0	0	1	0	0	1	1	0

Figure 5- 6- a &b – Mutation (the red gene which is selected for mutation has flipped its value

The probability of mutation is a user defined parameter. It is usually set to a small number. If the mutation probability is set to 100% then, the GA would be just a random search technique. Mutation is done to allow diversity.

In our GA to prevent illegal solutions the mutation is modified. Whenever a gene is selected for mutation there are two possibilities:

1- The gene's value is 1: When this happens, the gene's value is simply switched to 0.
2- The gene's value is 0: There are two different sub-cases which might happen under this case:
    a. *The project was selected before:* This means that there is another gene that its value is one for that project (i.e. a gene representing a different bidding scenarios for that projects value is 1). When this is the case, the GA turns that genes which it value was already set to 1 into 0. And, flips the gene's value which was selected for mutation into 1.
    b. *The project was not selected before:* Under this scenario, the gene's value is simply flipped to 1.

As it has been mentioned before, the illegality is due to different bidding scenarios happening at one time. Figure 5- 7 illustrates the procedure of mutation used in our GA.

c=1		c=2
t=1	t=2	t=1

n=1		n=2		n=1		n=2		n=1		n=2	
k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2
0	1	0	0	1	0	0	0	0	1	0	0

0	1	0	0	1	0	0	0	0	0	0	0

case 1

c=1								c=2			
t=1				t=2				t=1			
n=1		n=2		n=1		n=2		n=1		n=2	
k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2
0	1	0	0	1	0	0	0	0	1	0	0

1	0	0	0	1	0	0	0	0	1	0	0

case 2-a

c=1								c=2			
t=1				t=2				t=1			
n=1		n=2		n=1		n=2		n=1		n=2	
k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2	k=1	k=2

0	1	0	0	1	0	0	0	0	1	0	0

0	1	0	0	1	0	1	0	0	1	0	0

case 2-b

Figure 5- 7- Different cases for mutation (the yellow gene is selected for mutation)

Elitism:

Elitism means that at least the best chromosome with the highest fitness value is copied into the new population so the best solution found can remain until the end. It is believed that elitism speeds up the convergence to an optimal solution. However on the downside, there are some criticisms that state that elitism prematurely limits the search to the local optimal solution.

Termination:

The final step in the GA is setting the termination criteria. The criteria are set such that when met the search for the optimal solution ends. If there were no termination criteria, theoretically, at the end the global optimal solution would have been found because eventually all solutions would have been generated. But since there are limitations in time and the cost and resources of running a program to a great extent of time, these criteria are set. There are different termination criteria which can be set individually or can be combined. Some of them are provided below:

- Setting a maximum number of iterations
- Setting a maximum time for running the algorithm

- The average fitness of the population does not improve a lot any more (or does not improve at all)

The stopping criterion used in this research is the combination of maximum number of iteration and the improvement in the average fitness.

The Flowchart of the GA used in this research illustrated in Figure 5- 8:

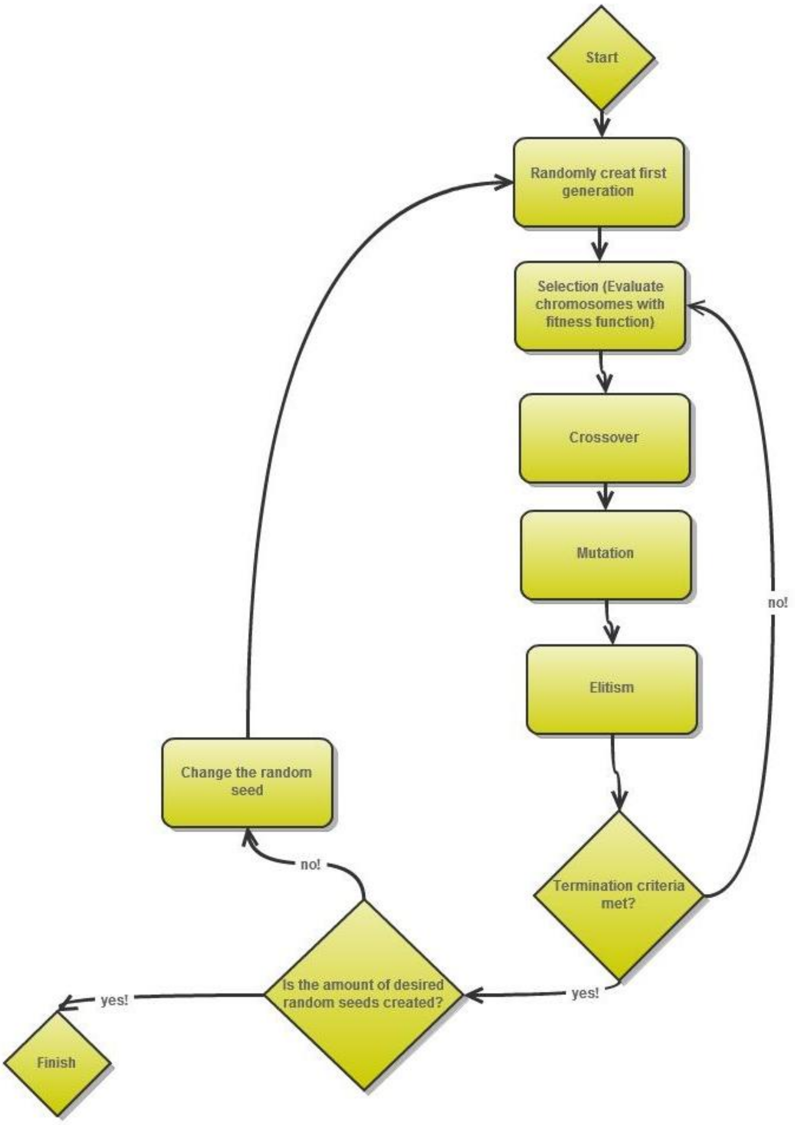

Figure 5- 8- The flowchart of the GA used for solving this model

The algorithm for this GA is as follows:

1- Set run = 0
2- Set run = run +1
3- Randomly create the first generation.
4- Set iteration = 0
5- Set iteration = iteration +1
6- Evaluate the chromosomes (check fitness values).
7- Select the chromosomes with the biggest fitness value and assign a higher probability for being selected as a parent for crossover.
8- Do crossover. The parents are selected from the pool of chromosomes and the Roulette wheel method is used.
9- Do mutation on the chromosomes.
10- Select the chromosome with the highest fitness value and keep it in the pool (Elitism).
11- If stopping criteria met, i.e. either enough iterations are done or the average fitness value of the population is not growing enough, go to step 12, else go to step 5.
12- If enough runs are made, go to step 14, else go to step 13.
13- Generate a new random seed and go to step 2.
14- Print solutions.

5.2.2 Validating the GA with a small sample

For the purpose of checking the coding of the GA and seeing how well it converges to the optimal solution, a small sample problem was solved by using enumeration and then it was solved by the GA. The GA was able to find the optimal value for this small sample.

The sample consisted of 9 different projects which are provided by 3 different owners at 5 different times. A summary table of the samples input is provided in Table 5- 1 and Table 5- 2 (in this sample all EV's are set as 1):

Table 5- 1- Example problem used for validating the GA

					Friedmans			

Project	c,t,n	L	Cost	# of bidders	P(k=10%)	P(K=8%)	Pm	k=1	k=2
1	1,1,1	7	151000	6	0.182	0.23	2	0.1	0.8
2	2,1,1	4	229000	3	0.308	0.374	3	0.1	0.8
3	3,1,1	5	159000	6	0.182	0.23	4	0.1	0.8
4	1,2,1	6	66000	2	0.401	0.473	4	0.1	0.8
5	1,2,2	5	316000	7	0.16	0.204	3	0.1	0.8
6	3,3,1	7	292000	5	0.211	0.264	2	0.1	0.8
7	2,3,1	3	145000	7	0.16	0.204	4	0.1	0.8
8	2,5,1	3	26000	8	0.143	0.183	3	0.1	0.8
9	3,5,1	5	175000	7	0.16	0.204	4	0.1	0.8

Table 5- 2- The RHS's of the project management constraint

Tv	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
PMR	7	13	13	15	15	12	12	8	8

The optimal answer to this small optimization problem was equal to: 13606.41, which was resulted by choosing the following set of projects and bidding scenarios to bid on:

Y 0 0 1 1 = 1 Index=6

Y 0 1 0 0 = 1 Index=20

Y 1 2 0 0 = 1 Index=41

Y 0 2 2 0 = 1 Index=48

Y 0 2 4 0 = 1 Index=56

The index numbers indicated in the front of the solutions are representing the gene number which represented that solution in the chromosome. Those which are equal to one, represent the bidding markups and their respective projects which are selected for bidding. By having these index numbers and being aware of the encoding of the chromosomes, the respective bidding scenario and the project could be calculated and vice versa. For example, for the project:

Y 1 2 0 0 = 1

That is actually representing:

k=2

c=3

t=1

n=1

The index is calculated using equation 5-1:

$$index = c \times T \times N \times K + t \times N \times K + n \times K + k \qquad (5\text{-}1)$$

Where:

- T: the maximum of t which indicates the furthest time the user using this model is considering for projects to bid on.
- K: the maximum bidding scenarios for the projects
- N: the maximum projects offered at any time by any owner
- C: the total number of owners which provide all the projects

Solving equation 5-1 for k=2; c=3; t=1; n=1 will lead to:

$index = (c - 1) \times T \times N \times K + (t - 1) \times N \times K + (n - 1) \times K + (k - 1) = 2 \times 5 \times 2 \times 2 + 0 \times 2 \times 2 + 0 \times 2 + 2 - 1 = 41$

It should be noted that this model outputs are only as good and reliable as the data available. This model is not capable of predicting future events. If there is no information about a very profitable project in the future the model is not capable of saving resources to be able to do that project in the future. However if the data is complete and available, the model is capable of making such sacrifices.

Also, due to the structure of this model, when the importance of eminence is high, the projects which are from a certain owner are more valuable. This model's behavior makes it rely on projects which are provided by a few owners. This increases risk. If one of those specific owners suddenly changes its evaluation criteria and gives more weight to bidding price when evaluating bids, the reputation and degree of eminence that we have built becomes less valuable. Another instance that has a negative consequence is when the owner suddenly goes out of business. In that case all of the reputation and eminence we have built for that owner has very small value, if any. This risk should be considered in future works.

5.2.3 The Tuning of the GA

Genetic Algorithm has three main parameters which have to be set at the start of the GA:

1- Crossover Probability (P_c): This parameter indicates how often Crossover takes place for generating the offsprings. If the probability is set to 100% this means that all offsprings are generated by the crossover of their parents. If it is set to 0%, all of the offsprings are the exact same as their parents (with the assumption that mutation is not occurring).

2- Mutation Probability (P_m): This parameter provides data on how often mutation takes place. If it is 100%, the whole chromosome is changed and if it is 0% no mutation takes place.

3- Population size: This parameter informs that how many chromosomes are in a generation. If the number is low, only a small search space is being covered, but if it is high the GA slows down. So, this parameter has a big effect in the speed.

A good combination of P_c and P_m will result into a good search that will not fall into local optimums. This combination is different for every GA. Hence, tuning the GA is very important. For the purpose of this research, since time was not a critical factor in the planning phase problems, the population size was set to 1000 (which is a large enough size) and the tuning was done to find the best combination for the mutation and crossover probabilities. A small-size problem was solved under different probabilities and the fitness values were drawn. It is noteworthy to state that the stopping criteria in this GA was the minimum number of iterations between, 1000 and the number of iterations needed after which the average fitness value is not improved by 0.005. 10 different runs was done each time by starting with different random seeds to generate different starting points.

In Figure 5- 9 and Table 5- 3, the best fitness value from the runs for each combination of P_c and P_m is presented. Further, the average of the 10 different runs (each starting with a different random seed) is plotted against different combinations of P_c and P_m in Figure 5- 10 through Figure 5- 12 and Table 5- 4 contains the data for the average fitness value from the 10 runs.

Table 5- 3- The maximum fitness values resulted from different runs for each set of crossover and mutation pairs

Mutation \ Crossover	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9
0	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.03	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.06	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.09	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.12	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.15	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.18	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.21	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.24	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.27	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.3	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.33	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.36	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.39	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.42	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41
0.45	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41	13606.41

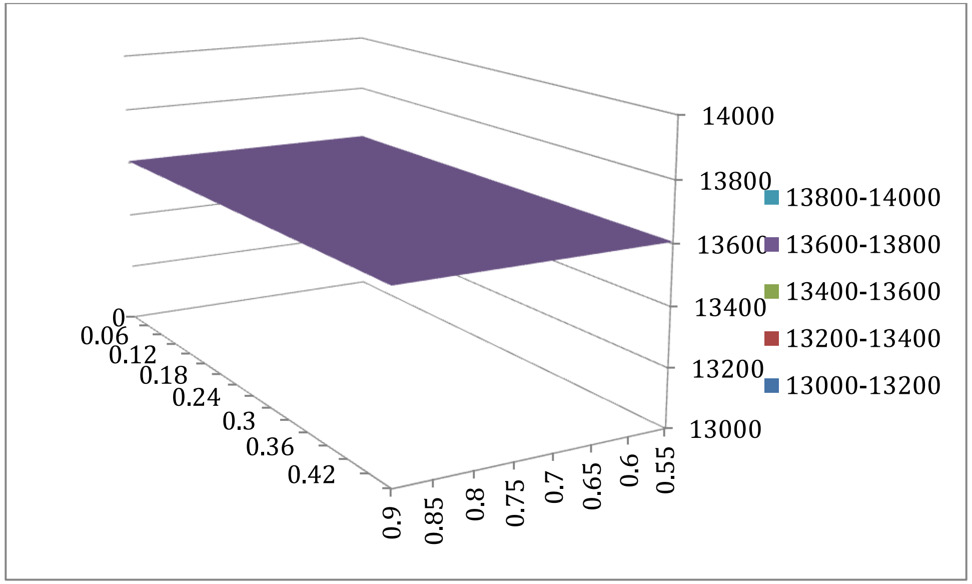

Figure 5- 9- Fitness value Vs. pairs of mutation and crossover probabilities

Table 5- 4- Average fitness values of different pairs of crossover and mutation probability for ten runs

	Mutation								
Crossover		0.00	0.03	0.06	0.09	0.12	0.15	0.18	0.21
	0.55	13391.47	13391.47	13391.47	13391.47	13425.30	13425.30	13425.30	13425.30
	0.60	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30

0.65	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30
0.70	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30
0.75	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30
0.80	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30
0.85	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30
0.90	13464.53	13509.82	13542.08	13414.88	13453.51	13535.44	13496.12	13498.16

Table 5- 5 - Average fitness values of different pairs of crossover and mutation probability for ten runs (Continued)

Crossover \ Mutation	0.24	0.27	0.30	0.33	0.36	0.39	0.42	0.45
0.55	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30
0.60	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30
0.65	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30
0.70	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30
0.75	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30
0.80	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30
0.85	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30	13425.30
0.90	13554.49	13444.36	13556.48	13491.33	13583.86	13549.93	13508.40	13593.41

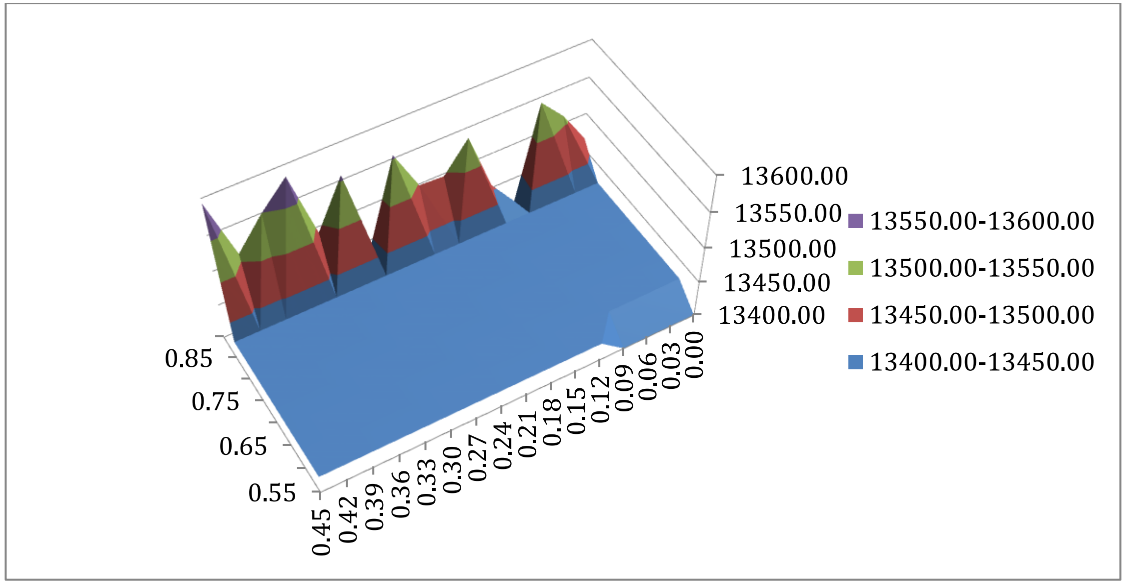

Figure 5- 10- The average fitness values resulted from ten runs for different pairs of mutation and crossover – view a

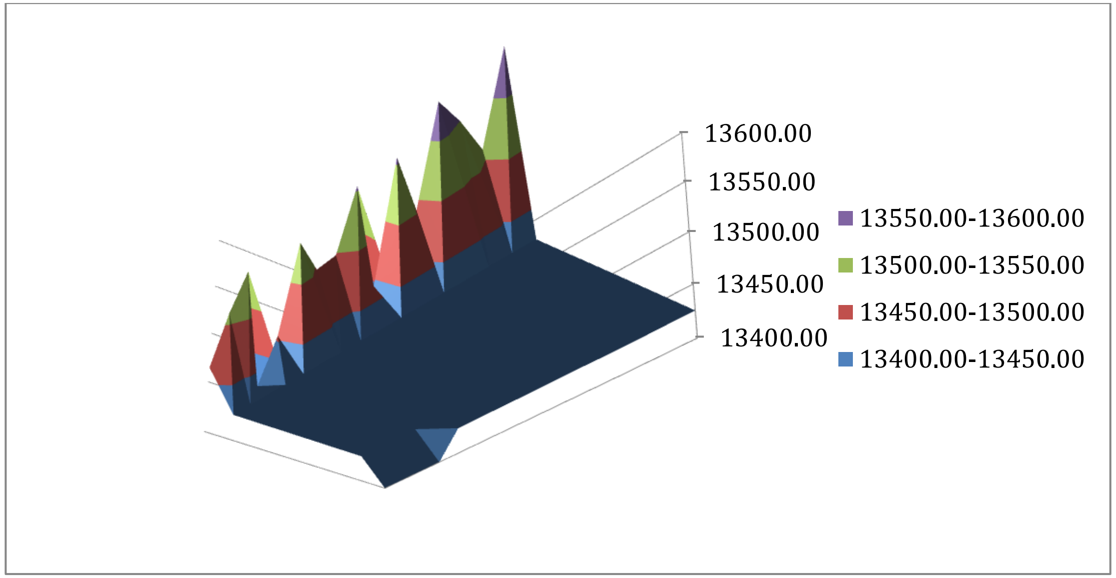

Figure 5- 11- The average fitness values resulted from ten runs for different pairs of mutation and crossover – view b

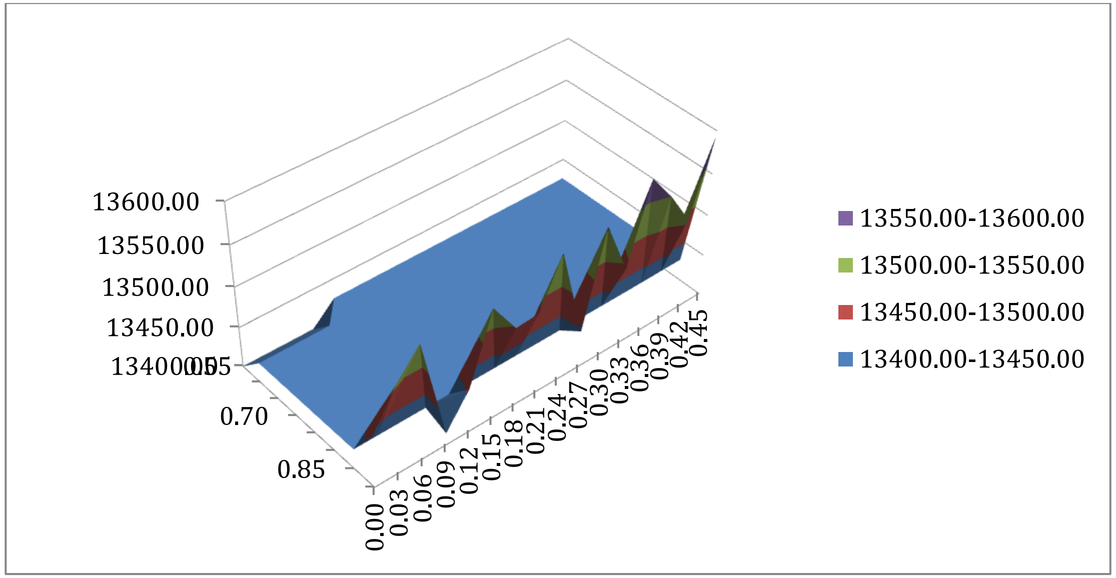

Figure 5- 12- The average fitness values resulted from ten runs for different pairs of mutation and crossover – view c

As it can be seen, all of the different combinations have led to the optimal solution, although on average, those for which the mutation and the crossover probabilities both have higher values have resulted in a better average fitness values resulting from 10 different runs. Hence, based on the averages, the combination of Mutation Probability of 0.45 and Crossover Probability of 0.9 was used for solving other problems.

Chapter 6: Results

In this chapter, some sensitivity analysis is done on the results of the model and it is compared to the previous models that only consider the effect of bidding price in winning projects. In the first section of this chapter, sensitivity analysis and validation is provided. At the end of this chapter, the differences between this model and the previous project selection models are brought to attention and a comparison is provided.

6.1 Sensitivity Analysis and Validation

6.1.1 Building a Base Model

Getting access to real data for this thesis was very hard because companies usually don't share their financial data and bidding data are usually confidential. Thus real data was not used in this thesis and was left out of the scope.

In order to be able to perform sensitivity analysis, a base model should be generated. In this base model, there are only two owners who are providing projects. Owner number 1 is providing 5 projects and owner number 2 is providing only one project. The details of this example are available in Table 6- 1. A graphical presentation of the projects is provided in Figure 6- 1. In this base example, price and eminence and previous works were equally important (PI=RI=0.5). And for both owners, the initial eminence probability was set at 0.4 .The rate of growth of the Probability of eminence was 0.3 up until the probability was 0.7, 0.05 until the probability was 0.9 and, 0.02 until the probability was 1. The resource availability at different times is always 6 project managers. For the purpose of simplicity it is also assumed that all projects are available 100% (EV=1).

Table 6- 1 Base example for sensitivity analysis

C	t(month)	n	l(month)	pm(man)	cost($)	EV	# of competitors
1	1	1	4	2	100000	1	4

1	2	1	5	2	70000	1	4
1	5	1	2	3	110000	1	4
1	7	1	2	2	200000	1	4
1	8	1	4	4	85000	1	4
2	2	1	5	3	230000	1	4

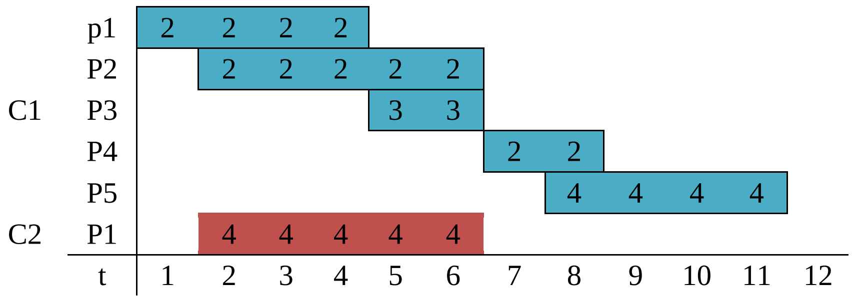

Figure 6- 1 Base case for Sensitivity Analysis graphical representation

The different Markups which are used in this model are based on a research done by Groeger and based on the fact that the typical profit in the general contracting industry is 8% (Get A Quote). The average markup size for large bidders is 21.46% (Groeger, 2009). It is also assumed that the Standard deviation of the markup is 2%. Since the Profit is 8%, we decided to select the project markup cases such that a range of profit from around 1% to around 10% was covered. The increments of profits considered were 1 percent. Thus, in this base example we have 10 different bidding scenarios. Scenario number 1 indicates a markup of 14% and scenario number ten indicates a markup of 23%.

The eminence probability function in this example is illustrated in Figure 6- 2.

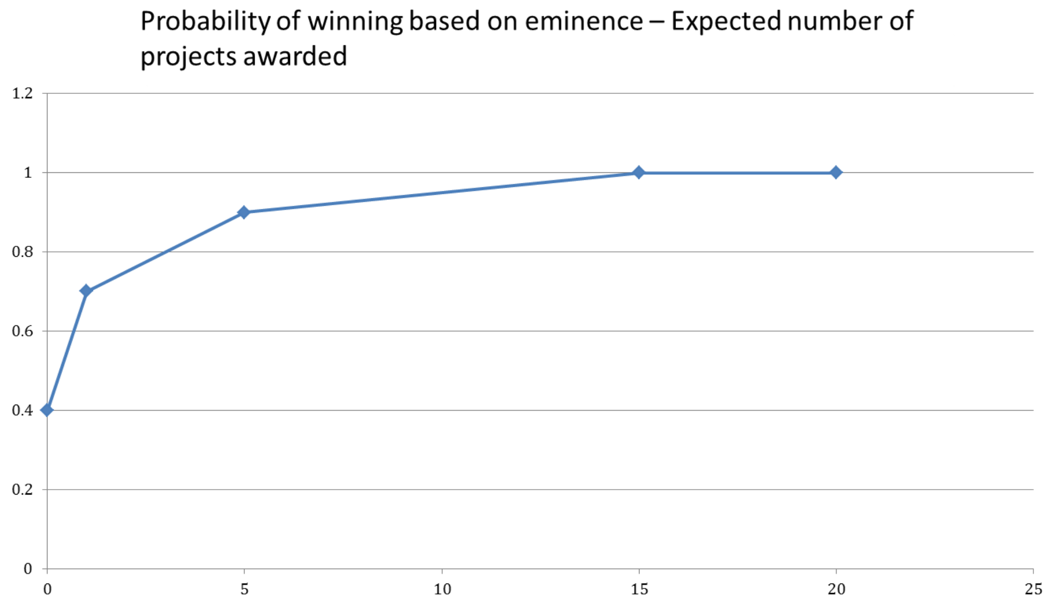

Figure 6- 2 Eminence Probability Growth of examples 1 and 2

Based on Figure 6- 2, the initial eminence is 0.4 with both owners, C1 and C2. Z1= 0.3, Z2= 0.05, and Z1= 0.02. And Lim1= 0.7, Lim2= 0.9, and Lim3= 1. It was assumed that for each project there are a total of 5 competitors (4 excluding the bidder using the model).

Friedman's model was used for combining different probabilities of winning from different competitors. This base case was solved using the proposed Genetic Algorithm. The largest feasible objective value gained from many runs was 60,136.9.

However, the big variance between the feasible solutions from different runs lead to this thought that the solutions provided by this GA is not necessarily global optimal. They are good feasible solutions. The results from this example to some extent show the priority in selecting projects but when it comes to selecting the proper markups for the projects the trend cannot be derived clearly. In order to enhance the visibility and priority in selecting bids, another example was derived which is a subset of the main base problem. The difference between the sub-problem and the main base problem is in only project provided by owner (client) number 2. In this sub-problem all the projects are only provided by owner 1. This reduction in the problem size reduced the variables (Genes) in the GA by half and as a result the solutions from almost all of the ten runs were the same. This negligible variance leads to this thought that the solution is hopefully optimum. The graphical representation of example 2 is provided below (Figure 6- 2).

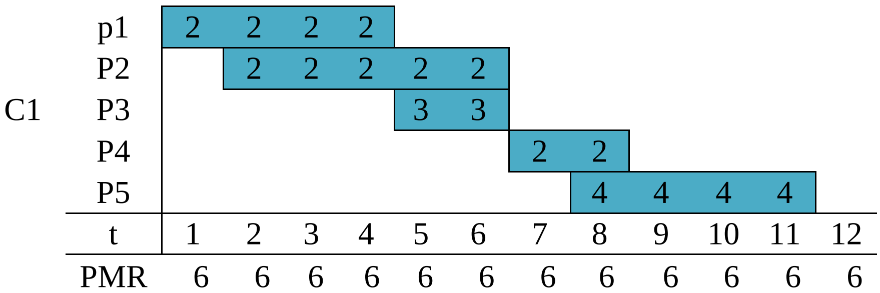

Figure 6- 3 Subproblem (example 2) for Sensitivity Analysis

In the next subsections, the results of sensitivity analysis on different parameters are provided.

Example 1 is used to observe the changes in project selection and example 2 is used for observing the changes in the markup percent.

6.1.2 Sensitivity on Eminence and Bidding Price importance

For both examples provided in the previous subsection, the eminence relative importance is varied between 0 and 1. The increments are 0.1. The results for example one and two are captured in Table 6- 2 through Table 6- 5. Table 6- 2 and Table 6- 3 present the selected projects, the proposed bidding markups, and the value of the objective function for the feasible solution which is presented. Table 6- 4 and Table 6- 5 present the Probability of eminence at the time the project is available for every project which is considered for bidding.

Table 6- 2 Project selected and Markups example 1 – Sensitivity Analysis on RI/PI

	PI=	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
	RI=	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
C1	Proj1	17	17	17	17	17	16	18	16	16	16	14
	Proj2					14	17	15	14	17	15	18
	Proj3					18	17	18	15	16	15	17
	Proj4	14	16	16	16	16	17	15	17	17	18	23
	Proj5	15	18	17	16	17	18	19	18	18	23	23
C2	Proj1	17	18	16	17							
	Value of Obj Func:	93973.9	87307.1	80818.4	72616.7	64114.1	60136.9	50603.7	46925.3	42009.5	36606.6	34538.5

Table 6- 3 Projects selected and Markups example 2 – Sensitivity Analysis on RI/PI

	PI=	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	RI=	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
c1	Proj1	14	15	16	16	16	16	17	17	17	17	17
	Proj2	16	16	16	17	17	17	17	17	17	17	17
	Proj3	17	17	17	17	17	17	17	17	17	17	17
	Proj4	23	18	18	17	17	17	17	17	17	17	17
	Proj5	23	23	18	18	17	17	17	17	17	17	17
	Obj func	35372.3	37243.5	42326.6	48178.6	54231.1	60335.4	66483.4	72662.4	78841.4	85020.5	91199.5

	Value:											

Table 6- 4 Eminence Probability example 1 – Sensitivity Analysis on RI/PI

	PI	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
	RI	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
C1	1	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000
	2					0.6848	0.6962	0.6529	0.6962	0.6962	0.6962	0.6999
	3					0.7475	0.7468	0.7420	0.7494	0.7468	0.7492	0.7421
	4	0.6848	0.6848	0.6848	0.6848	0.7896	0.7943	0.7842	0.7992	0.7962	0.7991	0.7896
	5	0.7475	0.7468	0.7468	0.7468	0.8390	0.8418	0.8340	0.8467	0.8437	0.8413	0.7897
C2	1	0.4000	0.4000	0.4000	0.4000							

Table 6- 5 Eminence Probability example 2 – Sensitivity Analysis on RI/PI

	RI=	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
	PI=	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
C1	1	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000
	2	0.6999	0.6993	0.6962	0.6962	0.6962	0.6962	0.6848	0.6848	0.6848	0.6848	0.6848
	3	0.7494	0.7492	0.7487	0.7468	0.7468	0.7468	0.7449	0.7449	0.7449	0.7449	0.7449
	4	0.7968	0.7967	0.7962	0.7943	0.7943	0.7943	0.7924	0.7924	0.7924	0.7924	0.7924
	5	0.7969	0.8389	0.8384	0.8418	0.8418	0.8418	0.8399	0.8399	0.8399	0.8399	0.8399

Based on Table 6- 2, whenever the importance of eminence is increased, all the projects which owner 1 is providing are preferred as opposed to selecting the projects which have the most profit (their price is more). This was expected, because by doing more projects for an owner the eminence probability increases over time. The increase in the eminence probability is desirable. On the other hand, if the importance of bidding price is high in evaluating bids, improving the eminence of the firm and doing previous works is no longer desirable. Therefore, those projects which have the most profit (cost more) are selected.

Based on Table 6- 3 and Table 6- 5, as the importance of eminence increases, the initial markups proposed are smaller. These small markups increase the probability of winning and therefore the probability of winning based on eminence on later projects are increased. For example when eminence is the most important factor (RI=1 & PI=0), the initial markup is small to increase the chances of winning the future projects which are mainly based on eminence. When we reach to projects 4 and 5, since these are the last projects that are being considered, there is no need to build eminence for future projects. Thus, the markups increase. On the other hand, when the price is the most important factor, the optimum combination of $Profit \times Probability\ of\ winning\ based\ on\ price$ are the same for all projects.

6.1.3 Sensitivity on the Growth Slope of the Eminence

In this section, the slope of the steepest slope of the eminence function (Z1) is changed and the different results are provided. Table 6- 6 and Table 6- 7 provide the results, i.e. the selected projects, the proposed bidding markups, and the value of the objective function for the feasible solution for examples 1 and 2. Table 6- 8 and Table 6- 9 present the probability of winning from an average bidder based on eminence.

Table 6- 6 Projects selected and Markups example 1 – Sensitivity Analysis on Z1

	Z1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
C1	Proj1	17	17	16	17	17	17	16	17
	Proj2		17	17	14	17	14	14	14
	Proj3		17	17	18	18	17	15	18
	Proj4	17	18	17	17	17	16	18	17
	Proj5	18	15	18	15	19	16	17	18
C2	Proj1	17							
	Obj Func Value=	51887.8	56561.2	60136.9	58936.5	59992.2	60355.5	60278.9	61209.8

Table 6- 7 Projects selected and Markups example 2 – Sensitivity Analysis on Z1

	Z1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
C1	Proj1	17	17	16	17	17	17	17	17
	Proj2	17	17	17	17	17	17	17	17
	Proj3	17	17	17	17	17	17	17	17
	Proj4	17	17	17	17	17	17	17	17
	Proj5	17	17	17	17	17	17	17	17
	Obj Func Value=	53211.6	58132.4	60335.4	61357.4	61951.7	62357.3	62651.7	62875.1

Table 6- 8 Eminence probabilities example 1 – Sensitivity Analysis on Z1

	Z1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
C1	Proj1	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000
	Proj2		0.5899	0.6962	0.7100	0.7175	0.7225	0.7279	0.7287
	Proj3		0.7199	0.7468	0.7600	0.7649	0.7725	0.7779	0.7787
	Proj4	0.4949	0.7674	0.7943	0.8021	0.8071	0.8199	0.8278	0.8209
	Proj5	0.5899	0.8096	0.8418	0.8496	0.8546	0.8693	0.8699	0.8683
C2	Proj1	0.4000							

Table 6- 9 Eminence Probabilities example 2- Sensitivity Analysis on Z1

	Z1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
C1	Proj1	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000
	Proj2	0.4949	0.5899	0.6962	0.7100	0.7175	0.7225	0.7260	0.7287
	Proj3	0.5899	0.7199	0.7468	0.7574	0.7649	0.7699	0.7735	0.7762
	Proj4	0.6848	0.7674	0.7943	0.8049	0.8124	0.8174	0.8210	0.8237
	Proj5	0.7399	0.8149	0.8418	0.8524	0.8599	0.8649	0.8685	0.8711

Based on Table 6- 6 and Table 6- 8, it can be observed that when the growth in eminence due to doing previous works is not high, the model decides to do the most profitable set of projects except for focusing on improving the eminence. On the other hand, as the slope increases, the model prefers to select projects from the same owner to increase the chances of winning dramatically by improving the eminence probability noticeably.

Based on Table 6- 8 and Table 6- 9, it can be concluded that the markups are not very sensitive to the change in slope. The only point that a change in markup strategy was observed was in the base example number 2. Where the initial markup is 16% and the rest of the markups are all 17%. This could be due to the fact that by using a markup of 16% the eminence probability will be almost equal to 0.7 which is the second threshold. After that threshold (eminence probability = 0.7) the probability will grow in a smaller rate (0.05).

6.1.4 Sensitivity on the cost of projects

In this section, the cost of the only project provided by owner 2 is varied and the different results are provided. Table 6- 10 provides the results, i.e. the selected projects, the proposed bidding markups, and the value of the objective function for the feasible solution for example1. Table 6- 11 presents the probability of winning from an average bidder based on eminence.

Table 6- 10 Projects selected and Markups example 1- Sensitivty Analysis on Cost of P1 for C2

	Price Proj1 for C2	230000	240000	250000	260000	270000	280000	290000	300000	310000	320000	330000
C1	Proj1	16	16	16	16	16	16	16	16	16	16	16
	Proj2	17	17	17	17	17	17					
	Proj3	17	17	17	17	17	17					
	Proj4	17	17	17	17	17	17	17	17	17	17	17
	Proj5	18	18	18	18	18	18	17	16	15	15	18
C2	Proj1							17	16	16	16	16
	Obj Func Value=	60136.9	60136.9	60136.9	60136.9	60136.9	60136.9	61383.9	61381.65	62276.1	62515	63811.2

Table 6- 11 Eminence Probabilities example 1- Sensitivity Analysis on cost of P1 for C2

	Price Proj1 for C2	230000	240000	250000	260000	270000	280000	290000	300000	310000	320000	330000
C1	Proj1	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000
	Proj2	0.6962	0.6962	0.6962	0.6962	0.6962	0.6962					
	Proj3	0.7468	0.7468	0.7468	0.7468	0.7468	0.7468					
	Proj4	0.7943	0.7943	0.7943	0.7943	0.7943	0.7943	0.6962	0.6962	0.6962	0.6962	0.6962
	Proj5	0.8418	0.8418	0.8418	0.8418	0.8418	0.8418	0.7468	0.7468	0.7468	0.7468	0.7468
C2	Proj1							0.4000	0.4000	0.4000	0.4000	0.4000

Whenever costs of projects increase while the markups remain the same, the overall profit will increase. As it can be seen in Table 6- 10, this behavior is captured. Up to the cost of $280,000 although the profit of doing that project is increasing, it is not worth the loss in the eminence. After $290,000, the profit has increased so much that not selecting a project which increases eminence is justified.

6.1.5 Sensitivity on the Initial Eminence Probability

In this section, initial eminence of owner 1 is varied and the results are provided in Table 6- 12 and Table 6- 13, i.e. the selected projects, the proposed bidding markups, and the value of the objective function for the feasible solution for examples 1 and 2. Table 6- 14 and Table 6- 15 present the probability of winning from an average bidder based on eminence.

Table 6- 12 Projects selected and Markups example1- Sensitivity Analysis on CTE of C1

	CTE of C1	0.4	0.5	0.6	0.7	0.8	0.85	0.9	0.95	1
C1	1	17	17	17	17	17	17	17	17	18
	2	17	16	18	17	18	15	16	19	18
	3	18	15	18	17	19	19	17	16	15
	4	17	16	17	15	18	17	16	18	18
	5	19	16	15	17	19	16	17	16	18
C2	1									
	Obj Func Value=	59992.2	59904.7	61691.8	64187.8	71665.6	76385.8	82025.6	88586.4	91946.1

Table 6- 13 Projects selected and Markups example 2- Sensitivity Analysis on CTE of C1

	CTE of C1	0.3	0.4	0.5	0.6	0.7	0.8	0.85	0.9	0.95	1
C1	Proj1	17	16	17	17	17	17	17	17	17	18
	Proj2	17	17	17	17	17	17	17	17	17	18
	Proj3	17	17	17	17	17	17	17	17	17	18
	Proj4	17	17	17	17	17	17	17	17	18	18
	Proj5	17	17	17	17	17	17	17	17	18	18

	Obj Func Value=	58470	60335.4	61999.1	63934.4	66325	75712.1	79672.9	83470.3	90945.9	93711.5

Table 6- 14 Eminence Probabilities example 1- Sensitivity Analysis on CTE of C1

	CTE of C1	0.4	0.5	0.6	0.7	0.8	0.85	0.9	0.95	1
C1	1	0.4000	0.5000	0.6000	0.7000	0.8000	0.8500	0.9000	0.9500	1.0000
	2	0.6848	0.7141	0.7308	0.7475	0.8475	0.8975	0.9190	0.9690	1.0000
	3	0.7449	0.7635	0.7730	0.7949	0.8896	0.9189	0.9387	0.9816	1.0000
	4	0.7871	0.8134	0.8151	0.8424	0.9084	0.9315	0.9577	1.0000	1.0000
	5	0.8346	0.8628	0.8626	0.8923	0.9253	0.9505	0.9775	1.0000	1.0000
C2	1									

Table 6- 15 Eminence Probabilities example 2- Sensitivity Analysis on CTE of C1

CTE of C1	0.3	0.4	0.5	0.6	0.7	0.8	0.85	0.9	0.95	1
Proj1	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.8500	0.9000	0.9500	1.0000
Proj2	0.5848	0.6962	0.7141	0.7308	0.7475	0.8475	0.8975	0.9190	0.9690	1.0000
Proj3	0.7449	0.7468	0.7616	0.7783	0.7949	0.8949	0.9180	0.9380	0.9880	1.0000
Proj4	0.7924	0.7943	0.8091	0.8258	0.8424	0.9170	0.9370	0.9570	1.0000	1.0000
Proj5	0.8399	0.8418	0.8566	0.8732	0.8899	0.9360	0.9560	0.9760	1.0000	1.0000

Based on table 6-12, the change in the initial eminence of owner C1 will not change the projects selected. This is due to the fact that the eminence of owner C2 is kept constant and it is not competing with the projects provided by owner C1 when the initial eminence is increased. Even the earlier projects provided by owner C1 for which the contractor's eminence has not increased are more desirable.

Based on Table 6- 13, the markup percent is not very sensitive to the initial eminence whenever the initial eminence is not extremely high. The only markup which is different than 17% for the cases that the initial eminence is less than or equal to 0.9 is for when the initial eminence is 0.6. When the initial eminence is 0.6, the first project's proposed markup is 16%. This is due to the fact that when the markup is set at 16%, the eminence for the next project is almost 0.7 which is the threshold for the growth of eminence.

In the cases that the initial eminence is higher than 0.95, and when the eminence has hit its maximum value which is 1, based on Table 6- 15 and Table 6- 13 it can be seen that the markup percent is increased to 18%. This is due to the fact that when the eminence is at its maximum, there is no need to decrease the bidding markup to increase the eminence anymore.

For the cases that the eminence is 1, the driving factors in evaluating bids are the markup, and the relative importance of bidding price and eminence. So, the model no longer tries to bid lower. It is in a way similar to the case that eminence is no longer important (RI=0, PI=1). By comparing Table 6- 3 and Table 6- 13, it can be concluded that the markup has increased from the case that PI=1 in Table 6- 3. This is expected, because although eminence is not growing anymore in the cases that the eminence probability is 1, but since in Table 6- 13 the importance of bidding price is less than the example of Table 6- 3 and the eminence in Table 6- 13 is 1, there is room of bidding with a higher markup and still winning the auction.

6.1.6 Sensitivity Analysis on the number of competing parties in an auction

In this section, the number of competitors who are competing for the only project owner C2 is providing is varied in example1. In example 2, the number of competitors in all the projects provided by owner 1 is varied. Table 6- 16 and Table 6- 17 provide the results, i.e. the selected projects, the proposed bidding markups, and the value of the objective function for the feasible solution for examples 1 and 2. Table 6- 18 and Table 6- 19 present the probability of winning from an average bidder based on eminence.

Table 6- 16 Projects selected and Markups example 1- Sensitivity Analysis on number of competitors

	CMT Proj1 C2 #CMT	1	2	3	4	5
C1	1	16	16	16	16	16
	2			17	17	17
	3			17	17	17
	4	17	18	17	17	17
	5	16	17	18	18	18
C2	1	18	18			
	Obj Func Value=	65184.4	58866.5	60136.9	60136.9	60136.9

Table 6- 17 Projects selected and Markup Example 2- Sensitivity Analysis on number of competitors

	# CMT for all projects by owner C1	1	2	3	4	5
C1	Proj1	18	17	17	16	16
	Proj2	19	17	17	17	16
	Proj3	19	18	17	17	17
	Proj4	19	18	17	17	17
	Proj5	19	18	18	17	17
	Obj Func Value=	85567.7	73178.6	65438.1	60335.4	56513.2

Table 6- 18 Eminence Probabilities example 1- Sensitivity Analysis on the number of competitors

	CMT Proj1 C2	1	2	3	4	5
C1	1	0.4000	0.4000	0.4000	0.4000	0.4000
	2			0.6962	0.6962	0.6962
	3			0.7468	0.7468	0.7468
	4	0.6962	0.6962	0.7943	0.7943	0.7943
	5	0.7468	0.7415	0.8418	0.8418	0.8418
C2	1	0.4000	0.4000			

Table 6- 19 Eminence Probabilities example 2- Sensitivity Analysis on number of competitors

	# CMT for all projects by owner C1	1	2	3	4	5
C1	Proj1	0.4000	0.4000	0.4000	0.4000	0.4000
	Proj2	0.6529	0.6848	0.6848	0.6962	0.6962
	Proj3	0.7236	0.7449	0.7449	0.7468	0.7487
	Proj4	0.7551	0.7871	0.7924	0.7943	0.7962
	Proj5	0.7865	0.8292	0.8399	0.8418	0.8437

As it can be seen in Table 6- 16, as the number of competitors for the project decreases, the project becomes more desirable and hence it gets selected for bidding. Based on Table 6- 17, as the number of competitors decrease the bidding markup increases. This was expected, because as the number of competitors decrease the utilities values increase and also a change in any of the probabilities of wining from other competitors will not be very significant because their power decreases.

6.2 Major difference of this model with previous models

Based on the results from the sensitivity analysis, there are two major effects considering eminence (the number of projects awarded) will have on selecting projects. These two are:

1- The effect it has on selecting the bidding price of each project.
2- The effect it has on selecting the set of projects to bid on.

In the following subsections, these effects are explained in more detail.

6.1.1 The Bidding Price Effect

Considering eminence has an effect on the bidding price. As the importance of eminence increases, the markup selected for prior projects decreases. After the eminence probability has reached a certain level, the markup starts to increase and reaches its maximum possible when the eminence probability equals to 1. This effect is illustrated in table 6-3.

6.1.2 The Project Selection Effect

This effect demonstrates how the relative importance of eminence will lead to taking projects from the same owner in order to increase the probability of winning due to eminence. This effect can be observed in Table 6- 2.

6.3 Comparison with previous models

For the purpose of illustrating the effect the model proposed in this research has on the expected profit, a set of simple examples are generated. Then Monte Carlo simulation is used to compare the different solutions from this model with the most famous model which uses only monetary criteria.

For the purpose of simplicity in these examples it is assumed that there is no resource (PM) limitation and the contractor can bid on all projects which are all provided by the same owner. Based on what has been explained in the previous section, the contractors' behaviors using the previous models are expected to be different than those whom will use this model. These differences are due to different possible decisions. These decisions can be broken into two different levels. The first level decision is project selection and making the bid/no-bid decision. The second level decision that is made after the first level decision is selecting an appropriate markup. The markup should be selected in a way which leaves the contractor with a sufficient profit and at the same time a high enough chance of winning the auction.

Having no limitation (no resource limitations) in choosing projects to bid on, leads to bidding on all the available projects. Therefore, the first level decision is already made. The only decision to be made is therefore picking an appropriate markup.

The objective of most of the research which face uncertainty is to maximize or minimize the expectation of a consequence. The formulation of the expected profit was provided in chapter 3 and was as follows:

$$EXPPROF(P_i) = Prob_i \times Prof_i \tag{3-1}$$

Where:

- $EXPPROF(P_i)$: is the expected profit for project "i".
- $Prob_i$: is the probability that project "i" would be awarded to the contractor.
- $Prof_i$: is the profit associated with project "i" if the project is done.

The expected profit of each project is demonstrated from the probability of winning and the profit of that project. Both of these elements are dependent on markup. When a higher markup is selected, the profit increases but on the downside, the probability of winning an auction decreases.

When the markup is known, calculating the profit is straightforward. Profit is equal to the product of [1+ markup] and the cost of the project. The difficult part is finding the probability of winning based on markup and eminence/previous works.

The difficulty in calculating the probability of winning based on price, and eminence and previous works was due to the dependency of two probabilities. The first probability was the probability of winning the auction based on price. The second probability was the probability of winning based on eminence and previous works. Since these two probabilities are not necessarily independent we cannot calculate the overall probability of winning by multiplying the two probabilities by together.

Due to this difficulty, calculating an overall probability of winning based on a specific markup and a certain level of eminence is not easy. In order to assess such probability we use Monte Carlo simulation. The procedure of this simulation is illustrated in Figure 6- 4 .

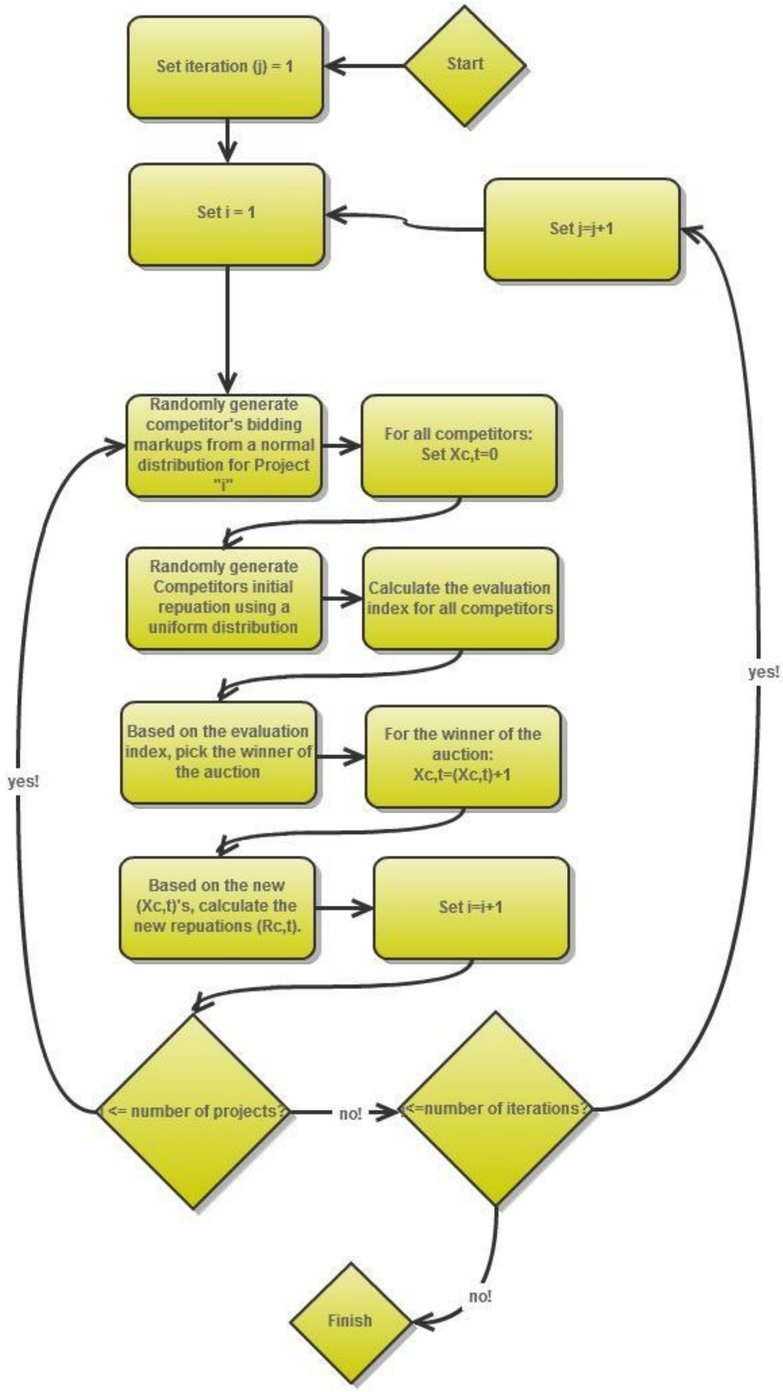

Figure 6- 4- Flowchart of the Monte Carlo Simulation

At the first stage of this simulation and for the first iteration, for each competitor we generate a random markup percent that they will use for bidding on the first project. This random number is generated by using the NORM.INV function of MS Excel. The Normal distribution used for generating random markups as mentioned before, is collected from historical bidding behaviors of the competitors. And if no historical data is available we use the mean and variance of the industry for defining the distribution. In this case similar to examples 1 and 2 earlier in this chapter a standard deviation of 2% and a mean of 21.46% is used.

At the next stage we generate random initial eminence winning probabilities for the other competitors. These are probabilities of winning in an auction in which the only evaluation criterion is eminence and previous works. These random numbers are generated by using a uniform distribution and MS Excel's "rand()" function.

In the next level we put ourselves in the shoes of the client/owner. We introduce an overall evaluation index that based on its value the winner of the auction is awarded.

The evaluation index covers both monetary criteria (markup %) and non-monetary criteria (eminence/previous works). Based on the preference of the owner a weighting index is introduced. The evaluation index is formulated as follows:

$$EI_{i,c} = (1 - MP_i) \times PI_c + R_{i,c} \times RI_c \qquad (6\text{-}1)$$

Where:

- "i" is the index which represents the i'th competitor
- MP_i is the biding Markup which competitor i uses for this project
- PI_c is a weighting factor which represents the relative importance of price (markup) in the evaluation criteria of owner/client "c"
- RI_c is the weighting factor of eminence and previous works (=1-PI_c)

- $R_{i,c}$ is the eminence which competitor “i" has with owner “c”

It should be noted that comparing different bids using the index used above is only one reasonable way. This only covers one reasonable mindset that the people in charge of evaluating bids might have.

After comparing the evaluation indexes of different competitors, the one with the highest index is selected as the winner. The winner of the auction’s eminence increases as a result of building a relationship with the owner. Therefore, while everybody else’s probability of winning based on eminence stays constant, the winner’s eminence probability increases by using the eminence probability growth function provided in chapter 4. The eminence probability function parameters used are similar to example 2 from this chapter. Obviously, it is assumed that in this example and for each iteration, for all 6 different projects, the competitors remain the same.

As a result of this change in the eminence probabilities, the next projects’ evaluation indexes for each competitor changes even if the markups are the same.

After all projects are simulated, another iteration is done with different random numbers for markup and initial eminence for the competitors. These iterations go on until the stopping criterion is met. The stopping criterion is a cap on the number of iterations which should be done to achieve a certain level of confidence. This cap can be calculated by using Chebyshev’s inequality which stands for all distributions:

$$N_C = \frac{1}{4\delta\varepsilon^2} \tag{6-2}$$

where δ is the confidence level and ε is the acceptable error. For example, the number of iterations needed for a 95% confidence ($\delta = 0.05$) and an error of 0.01 ($\varepsilon = 0.01$) is 50,000.

After the stopping criterion is met, the probability of winning based on eminence and price can be assessed. The probabilities which are based on frequency are calculated using equation 6-3.

$$P_{i,j} = \frac{N_{i,j}}{N_{c,}} \tag{6-3}$$

Where:

- $P_{i,j}$ is equal to the probability that competitor "i" wins project "j"
- $N_{i,j}$ is the number of iterations of the Monte Carlo simulation in which competitor "i" wins the bid for project "j"
- N_c is the total number of iterations required for achieving a certain level of confidence in the Monte Carlo simulation (derived from equation 6-2)

Using this probability and by having the profit of each project. The expected profit of each project can be calculated for the contractor.

The probabilities resulted from the simulation are highly depending on the markup which we are going to use. For the purpose of comparison, the two markups used for simulation are: The markup proposed by the new model introduced in this research which considers eminence and previous works in addition to monetary values, and the markup which only considers monetary values.

Once the expected profit of each project is calculated for each markup, the overall profit of those sets of projects is calculated by summing all of the expected profits of the projects.

In the first subsection, the example which is going to be used for comparison is going to be illustrated and in the next subsection the comparison is provided.

6.3.1 Example Illustration

As explained in the previous section, the goal of this comparison is to compare and show the difference between this model and the models which only consider monetary criteria in the second stage of decision making, selecting appropriate markups. Project selection is not of concern in this example. Thus, we assume that all of the 6 projects which are provided by one owner are selected for bidding. The project characteristics for the comparison example are provided in Table 6- 20.

Table 6- 20 Project characterisitics for the comparison example

	Project number	C(owner)	t(month)	N	l (months)	Pm	cost($)	EV	# of cmt
C1	P1	1	1	1	1	2	100000	1	2
	P2	1	2	1	1	2	70000	1	2
	P3	1	3	1	1	2	110000	1	2
	P4	1	4	1	1	2	200000	1	2
	P5	1	5	1	1	2	85000	1	2
	p6	1	6	1	1	2	230000	1	2

The attributes regarding the eminence probability function, the initial eminence, and different bidding scenarios are provided in Table 6- 21, Table 6- 22, and Table 6- 23. The initial index of eminence with the owner is assumed to be 0.4.

Table 6- 21 Eminence Probability Parameters, example for comparison

Z	Slope	Lim	limit
Z1	0.3	Lim1	0.7
Z2	0.05	Lim2	0.9
Z3	0.02	Lim3	1

Table 6- 22 Contractor Resources at Different Times, example for comparison

TV (month)	PMR
1	2
2	2
3	2
4	2
5	2
6	2

Table 6- 23 Bidding Scenarios, example for comparison

K (bidding scenario #)	M (markup %)	K (bidding scenario #)	M (markup %)	K (bidding scenario #)	M (markup %)
1	14.00%	10	18.50%	19	23.00%
2	14.50%	11	19.00%	20	23.50%
3	15.00%	12	19.50%	21	24.00%
4	15.50%	13	20.00%	22	24.50%
5	16.00%	14	20.50%	23	25.00%
6	16.50%	15	21.00%	24	25.50%
7	17.00%	16	21.50%	25	26.00%
8	17.50%	17	22.00%		
9	18.00%	18	22.50%		

6.3.2 Comparison Results

As discussed while doing sensitivity analysis on the relative importance of eminence and price (PI and RI), the solution is very dependent on these two parameters. Therefore, similarly to what was done in section 6.1.2, for the example provided in the previous subsection, the model is executed for different combinations of PI and RI. The solutions provided for each pair are in Table 6- 24.

Table 6- 24 Markup percent for different combinations for PI and RI, comparison example

	PI=	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	RI=	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
c1	Proj1	16	16.5	16.5	17	17	17	17	17.5	17.5	17.5	17.5
	Proj2	17	17	17	17	17.5	17.5	17.5	17.5	17.5	17.5	17.5
	Proj3	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
	Proj4	26	26	18.5	18	18	18	18	17.5	17.5	17.5	17.5
	Proj5	18	18	18	18	18	18	17.5	17.5	17.5	17.5	17.5
	Proj6	26	26	26	18.5	18.5	18	18	18	17.5	17.5	17.5
	Obj func Value:	104181.5	99760.6	98624.5	99492.1	103925.1	108489.7	113137.2	117889.3	122763.1	127667.7	132572.2

The solution provided by setting PI equal to one is the solution which previous models would have provided. So, using each pair of PI and RI, the Monte Carlo simulation is executed for 50,000 iterations to achieve a confidence level of 95% and error of 1%. Then each pair's results are compared to the result gained from PI=1 and RI=0. The results are available in Table 6- 25. In this table, the first six rows of each pair of RI and PI represent the probability of winning each of the different projects. The first column represents the results derived from setting all the markups equal to 17.5% which is equal to only considering monetary criteria. And the second column represents using the markups provided by the model. The next six rows are dedicated to the markups used for simulation. The next six rows are dedicated to the expected profit of each of the projects. The final row for each pair represents the total expected profit from the entire portfolio of projects.

Table 6- 25 Comparison results from Monte Carlo simulation

	PI=0		PI=0.1		PI=0.2		PI=0.3	
	RI=1		RI=0.9		RI=0.8		RI=0.7	
	M	M&NM	M	M&NM	M	M&NM	M	M&NM
P1	0.9535	0.95264	0.56272	0.55886	0.31284	0.31092	0.24478	0.24128
P2	0.95284	0.95236	0.655	0.65344	0.31502	0.31312	0.24478	0.24128
P3	0.95324	0.95276	0.71024	0.70976	0.31534	0.3135	0.24478	0.24128
P4	0.95346	0.95254	0.75212	0.75236	0.31544	0.31372	0.24478	0.24128
P5	0.95306	0.95376	0.78686	0.7865	0.31558	0.31372	0.24478	0.24128
P6	0.9542	0.9535	0.81712	0.81586	0.31564	0.31386	0.24478	0.24128
M1	17.50%	16.00%	17.50%	16.50%	17.50%	16.50%	17.50%	17.00%
M2	17.50%	17.00%	17.50%	17.00%	17.50%	17.00%	17.50%	17.00%
M3	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%
M4	17.50%	26.00%	17.50%	26.00%	17.50%	18.50%	17.50%	18.00%
M5	17.50%	18.00%	17.50%	18.00%	17.50%	18.00%	17.50%	18.00%
M6	17.50%	26.00%	17.50%	26.00%	17.50%	26.00%	17.50%	18.50%
EP1	16686.25	15242.24	9847.6	9221.19	5474.7	5130.18	4283.65	4101.76
EP2	11672.29	11333.08	8023.75	7775.936	3858.995	3726.128	2998.555	2871.232
EP3	18349.87	18340.63	13672.12	13662.88	6070.295	6034.875	4712.015	4644.64
EP4	33371.1	49532.08	26324.2	39122.72	11040.4	11607.64	8567.3	8686.08
EP5	14176.77	14592.53	11704.54	12033.45	4694.253	4799.916	3641.103	3691.584
EP6	38406.55	57019.3	32889.08	48788.43	12704.51	18768.83	9852.395	10266.46

EP-portfolio	132662.8	166059.9	102461.3	130604.6	43843.15	50067.57	34055.02	34261.76

	PI=0.4		PI=0.5		PI=0.6		PI=0.7	
	RI=0.6		RI=0.5		RI=0.4		RI=0.3	
	M	M&NM	M	M&NM	M	M&NM	M	M&NM
P1	0.21084	0.21948	0.1918	0.19666	0.1806	0.18402	0.17628	0.17368
P2	0.21084	0.21948	0.1918	0.19666	0.1806	0.18402	0.17628	0.17368
P3	0.21084	0.21948	0.1918	0.19666	0.1806	0.18402	0.17628	0.17368
P4	0.21084	0.21948	0.1918	0.19666	0.1806	0.18402	0.17628	0.17368
P5	0.21084	0.21948	0.1918	0.19666	0.1806	0.18402	0.17628	0.17368
P6	0.21084	0.21948	0.1918	0.19666	0.1806	0.18402	0.17628	0.17368
M1	17.50%	17.00%	17.50%	17.00%	17.50%	17.00%	17.50%	17.50%
M2	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%
M3	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%
M4	17.50%	18.00%	17.50%	18.00%	17.50%	18.00%	17.50%	17.50%
M5	17.50%	18.00%	17.50%	18.00%	17.50%	17.50%	17.50%	17.50%
M6	17.50%	18.50%	17.50%	18.00%	17.50%	18.00%	17.50%	18.00%
EP1	3689.7	3731.16	3356.5	3343.22	3160.5	3128.34	3084.9	3039.4
EP2	2582.79	2688.63	2349.55	2409.085	2212.35	2254.245	2159.43	2127.58
EP3	4058.67	4224.99	3692.15	3785.705	3476.55	3542.385	3393.39	3343.34
EP4	7379.4	7901.28	6713	7079.76	6321	6624.72	6169.8	6078.8
EP5	3136.245	3358.044	2853.025	3008.898	2686.425	2737.298	2622.165	2583.49
EP6	8486.31	9338.874	7719.95	8141.724	7269.15	7618.428	7095.27	7190.352
EP-portfolio	29333.12	31242.98	26684.18	27768.39	25125.98	25905.42	24524.96	24362.96

	PI=0.8		PI=0.9		PI=1	
	RI=0.2		RI=0.1		RI=0	
	M	M&NM	M	M&NM	M	M&NM
P1	0.16746	0.1721	0.16358	0.1646	0.15806	0.15966
P2	0.16746	0.1721	0.16358	0.1646	0.15806	0.15966
P3	0.16746	0.1721	0.16358	0.1646	0.15806	0.15966
P4	0.16746	0.1721	0.16358	0.1646	0.15806	0.15966
P5	0.16746	0.1721	0.16358	0.1646	0.15806	0.15966
P6	0.16746	0.1721	0.16358	0.1646	0.15806	0.15966
M1	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%
M2	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%
M3	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%
M4	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%
M5	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%
M6	17.50%	17.50%	17.50%	17.50%	17.50%	17.50%
EP1	2930.55	3011.75	2862.65	2880.5	2766.05	2794.05

EP2	2051.385	2108.225	2003.855	2016.35	1936.235	1955.835
EP3	3223.605	3312.925	3148.915	3168.55	3042.655	3073.455
EP4	5861.1	6023.5	5725.3	5761	5532.1	5588.1
EP5	2490.968	2559.988	2433.253	2448.425	2351.143	2374.943
EP6	6740.265	6927.025	6584.095	6625.15	6361.915	6426.315
EP-portfolio	23297.87	23943.41	22758.07	22899.98	21990.1	22212.7

Based on the different values in the expected profit of the portfolios which are resulted from selecting different markups provided by this new model and the models which only consider monetary value, the increase/decrease in the expected value can be calculated. These values are provided in Table 6- 26.

Table 6- 26 Percentage of change in the expected profit between models

	PI=0		PI=0.1		PI=0.2		PI=0.3	
	RI=1		RI=0.9		RI=0.8		RI=0.7	
	M	M&NM	M	M&NM	M	M&NM	M	M&NM
EP-portfolio	132662.8	166059.9	102461.3	130604.6	43843.15	50067.57	34055.02	34261.76
Difference	25.17%		27.47%		14.20%		0.61%	
	PI=0.4		PI=0.5		PI=0.6		PI=0.7	
	RI=0.6		RI=0.5		RI=0.4		RI=0.3	
	M	M&NM	M	M&NM	M	M&NM	M	M&NM
EP-portfolio	29333.12	31242.98	26684.18	27768.39	25125.98	25905.42	24524.96	24362.96
Difference	6.51%		4.06%		3.10%		-0.66%	
	PI=0.8		PI=0.9		PI=1			
	RI=0.2		RI=0.1		RI=0			
	M	M&NM	M	M&NM	M	M&NM		
EP-portfolio	23297.87	23943.41	22758.07	22899.98	21990.1	22212.7		
Difference	2.77%		0.62%		1.01%			

Based on this table, for this specific mindset for evaluating bids, the improvement of this model, is up to 25% when eminence is more important.

Chapter 7: Conclusions and future works

7.1 Summary and Conclusions

In an environment where the main source for profit are projects, and for almost each project there are many competitors who are bidding, wisely choosing the best set of projects is of essence. Therefore, a model that can assist contractors in choosing the best set of projects is very useful. It can increase the expected profit of the contractor up to 25%.

In this research, a mathematical model was proposed that considers both monetary and non-monetary criteria while selecting projects to bid on and the best markup percentage for preparing bidding price for those projects. By looking at the literature, it was identified that reputation and doing previous works for owners is the most important non-monetary evaluation criteria that owners use. Taking into account this criterion allows this model to consider the effect of the contractor's size (this effect is related to the initial eminence constant at time t=1, $\boldsymbol{CTE_c}$) and the effect of having preferential bidders for an auction which the importance of having a model that considers both of them is reinforced by the literature

The Fico Xpress-mosel optimization solver was not able to solve the model, so meta-heuristics were used to solve this optimization problem. After preliminary investigations a Genetic Algorithm was selected as the heuristic for solving this nonlinear binary model.

Based on our findings, considering eminence in the project selection model has two major effects:

1- *The bidding price effect:* the tenderers tend to bid with a higher markup on projects that the owners providing them give more importance to eminence compared to the bidding price while evaluating different tenderers in an auction.
2- *The project selection effect:* the tenderers bid on projects related to the preferences of the owners. If an owner gives more importance to eminence

and provides many projects later in the time stream, until a certain threshold, contractors choose to bid on their projects even if their profits are slightly less compared to other projects. This is done to build up their degree of eminence and to increase their chances of winning in later projects, which are provided by that owner. On the other hand, if an owner does not consider eminence as an important factor for evaluating tenderers, the contractors only pay attention to those sets of projects that have the maximum profits for them and they have no incentive to build up their degree of being eminent with those owners.

7.2 Future works

This research opens a door to a number of potential avenues for future investigations. Some of them are as follows:

- Modeling the problem as a multi-objective problem by minimizing risk while maximizing profit.
- Calculating the value of perfect information of the occurrence of the projects ($EV_{c,t,n}$).
- Calculating the value of perfect information of the actual winners in each tender.
- Further investigation on different meta-heuristics, namely, simulated annealing, and comparing the solutions.
- Considering different mindsets for evaluating auctioneers in the Monte Carlo simulation.
- Finding real data and comparing the results to real data.
- Building a more comprehensive model by considering other criteria used for evaluating bids in the model.
- Relaxing the assumption of having deterministic costs and allowing cost variances for each project.
- Considering the risk of relying on too few owners for projects.
- Including other resource constraints in the model. Resources such as material and machinery.

- Considering the effect of past project performance on the degree of eminence and reputation. Including cases where all projects do not meet desired performances and have a negative effect on the degree of eminence and reputation.

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