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Construction Bidding and the Winner'S Curse

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By

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In the construction industry, the winner's curse occurs when the winning contractor has underestimated the project's true cost. Using a game and auction theory approach, this study aims to analyze - and potentially reduce - industry exposure to the effects of the winner's curse in construction bidding. A simulation model for single and multi-stage bidding processes was developed and analyzed an actual dataset of California Department of Transportation projects. The majority of general contractors and sub-contractors suffer from the winner's curse in both single and multi-stage bidding environments. The multi-stage bidding environment incurs more losses than the single-stage bidding environment. Through learning from past experiences though, the multi-stage bidding environment provides contractors with better opportunity to avoid the winner's curse. Finally, it was shown that the symmetric risk neutral Nash equilibrium optimal bid function provides the contractors with a tool to avoid the winner's curse and gain strategic positive profits.

DEDICATION

I would like to dedicate this research to *my father, mother, family and friends* for their continuous love, care, and support, to *my future wife* for her fully support and care during all my study period, to *Dr. Sherif Mourad* Dean of Engineering Faculty at Cairo University for his support and belief in my abilities, to *Dr. Adel Akl* Professor of Structural Design at Cairo University, to *Dr. Kamal Abdelrahman* and *Dr. Al-Sir Hamza* for their fatherly support and advices. For all of you, I would like to thank you and hope to be always up to your expectations.

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CHAPTER I

INTRODUCTION

1.1 Research topic

Construction has a long history since the beginning of human civilization. A great example is the Egyptian pyramids which had been constructed in 2600 before Christ. Nowadays, construction works are an integral part of everyone's daily life. The homes we live in, the stores we buy from, the offices we work at, the hospitals that house patients, the roads we travel upon, the schools and universities we study at, and many other facilities are products of the construction industry. The construction industry is not only important for its final product, but also provides a numerous job opportunities. Therefore, understanding the basic processes within the construction industry is essential for contractors to remain competitive, and also for a nation's economy to operate effectively and efficiently.

According to Kululanga (2001), the construction industry incorporated simple and straightforward processes in the early years. However, the modern construction industry is becoming complex. The construction industry's growth has developed a competitive environment for contractors. Consequently, contractors need to create well-developed plans that incorporate different perspectives in order to stay ahead of competitors. One of the difficult tasks in the construction industry is the contractor selection process. Auctions have long been used as a method for allocating contracts (Seydel, 2003).

Moreover, in the public sector, auctions are a legal requirement. Therefore, it is argued that one of the main factors that have a great effect on the success of construction projects is the firms' bidding strategies.

According to Park and Chapin (1992), contractors submit their proposals to show their desires to carry out a construction project for an agreed price. Generally, in the construction bidding process, submitted bids are evaluated technically, and then the technically approved bids are evaluated financially or based on the submitted price. For the financial evaluation of the submitted bids, there are many methods such as the low-bid method, the second lowest bid method, the average bid method, and the below average bid method (Ioannou and Awwad 2010). Also, according to Ioannou and Awwad (2010), the low bid method is the most common method for construction contracts in the US. In the low bid method, which is applied in this research, the contract is awarded to the contractor who has the lowest price among the technically approved submitted bids. Accordingly, the winning contractor is expected to construct the project based on the agreed price, schedule and to provide, at least, the required level of quality.

Finally, construction projects face a high level of uncertainty relative to events that may occur during the project's life cycle. For instance, contractors must contend with inevitable and unforeseen increase of input cost, labor issues, and construction conditions that must be accounted for when developing a bid for a long term project. Therefore, at time of submitting bids, contractors cannot know with certainty the actual project construction cost. As such, the construction industry relies on estimates of the project cost based on the contractors' current information, past experience, and utilizing some sources such as RS means. The RS means provides a construction cost estimation database based on historical data, that is used by professional estimators for calculating project cost, based on its type and region, prior to beginning of construction.

1.2 Problem statement

In the light of the above, contractors face two sources of incomplete information at time of submitting their bids:

1. Actual project construction cost.
2. Their competitors' estimates of the project construction cost.

Thus, in construction bidding, contractors, who underestimated project cost and bid less than the actual project construction cost, face the problem of adverse selection. Adverse selection results in what is known as the "winner's curse". As such, the winning contractor will most likely lose money or, at least, earn below normal profits and being cursed by winning. Contractors may resort to many mechanisms to avoid the winner's curse problem such as change orders. Such mechanism is considered ineffective due to its disadvantage of resulting in adversarial relationship between the sub-contractors, general contractors and owners, as well as its potential legal costs.

Being the case, contractors must carefully consider all factors while preparing their bids such as project location, number of competitors, or time. Significant project factors are its size, type and scope. Considering those factors and utilizing effective bidding tools is essential for contractors to avoid falling prey to the winner's curse.

1.3 Research objective

Using a game theory approach, this research analyzes construction industry exposure to the effects of the winner's curse in construction bidding. To this end, this research identifies the degree of the winner's curse in two common construction bidding environments; namely, single-stage bidding and multi-stage bidding. The objective is to compare the aforementioned two construction bidding environments, and determine how learning from past bidding decisions and experiences can affect the winning contractor's degree of suffering from the winner's curse. Furthermore, this research would provide an effective tool for contractors to mitigate the winner's curse. Generally, these objectives are presented as follows:

1. Defining the relationship between the construction bidding and auction theory.
2. Presenting the symmetric risk neutral Nash equilibrium (SRNNE) which can be used as an optimal bid function in construction bidding.
3. Developing simulation models for the single and multi-stage construction bidding processes.
4. Analyzing the results of the simulation model and determining the effect of the winner's curse in the construction bidding.

1.4 Research organization

This research is organized as follows:

1) Chapter II, titled "LITERATURE REVIEW", would briefly discuss the importance of construction industry for the economy growth; present some of the findings of many researchers who have studied the construction bidding, cover construction bidding methods, construction bidding models, brief background of basics of game theory, common value

auctions, the winner's curse, and present the basics of SRNNE optimal bid function.

2) Chapter III, titled "RESEARCH METHODOLOGY", would describe the underlying logic of this research, in addition to the procedures utilized to accomplish the research objectives. The said methodology is to design the single-stage and multi-stage construction bidding environments, and simulate the two construction bidding environments providing a summary of the dataset used in the simulation process.

3) Chapter IV, titled "RESULTS AND ANALYSIS", would present and analyze the results of the developed simulation model.

4) Chapter V, titled "CONCLUSIONS AND RECOMMENDATIONS", would outline the main purpose of this research, its objectives, summarize the research outcomes, and provide recommendations of the researcher for further research under the topic of construction bidding.

CHAPTER II

LITERATURE REVIEW

2.1 The role of construction industry in economy

The word "economy" is derived from the Greek word which means "the one who manages a household" (Mankiw 2006). Robbins (1945) defined economy, in a way which reflects much of modern economics, as "the science which studies human behavior as a relationship between ends and scarce means which have alternative uses". In today's world, construction is a major industry, which plays a main role in the economic growth of any nation, for its sizeable proportion in the Gross Domestic Product (GDP) and the Gross National Product (GNP) of most countries around the world

In US, according to Cheeks (2003), the construction industry is considered the biggest production sector. It contributes about US $1.2 trillion to the US economy and provides 7.5 million full and part time jobs. Furthermore, the US construction industry's annual revenue is nearly US $1.75 trillion. In addition, the construction industry represents nearly 20% of the Gross Domestic Product (GDP) and 13% of the Gross National Product (GNP) in US (Cheeks 2003).

Moreover, Tse and Ganesan (1997) mentioned that the outputs of the construction industry represent a main proportion in the GDP of both developed and underdeveloped countries. According to Lowe (2003), the value added by the construction sector represents from 7% to 10% in the developed economies and from 3% to 6% in the underdeveloped economies as shown in figure 2.1.

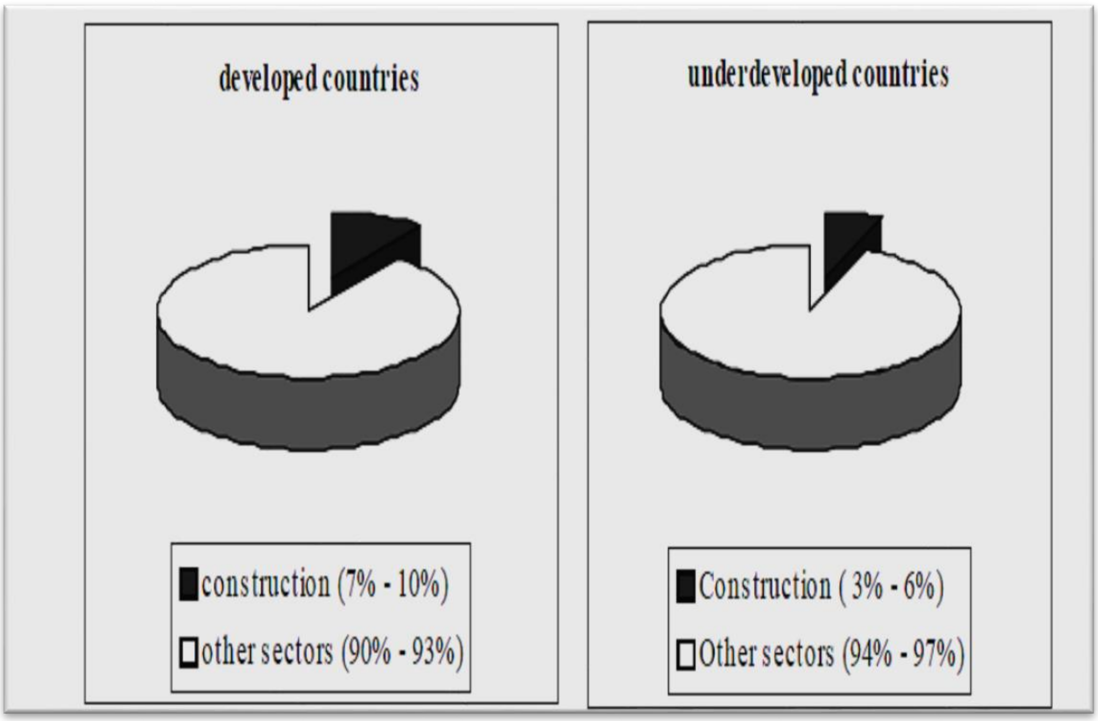

Figure 2.1 The contribution of the construction industry into the GDP (Lowe 2003).

Many statistics, related to the construction industry, confirm the fact that the construction sector is playing a main role in economic growth through its products which add to productivity and quality of life. In addition, as long as this sector is labor intensive, large sections of the nations' work force is active, when the construction sector is working at full capacity. Therefore, it is anticipated to consider the construction industry as a backbone of the nation's economy and an indicator of the effectiveness and efficiency of its economy.

2.2 Construction bidding

Competitive bidding is the way through which many services are priced (Seydel 2003). In the construction industry, auctions have long been used as a method for allocating of contracts. Especially in the public sector, it has been considered as a legal requirement to use competitive bidding for contractor selection.

Furthermore, as quoted by Friedman (1956), there are two kinds of competitive bidding. One is the "closed bidding" and the other kind of bidding is "open bidding". In the closed bidding, two or more bidders submit independent bids and usually, only one bid is allowed for each bidder. After bids are received, they are evaluated by the owner with the assistance of a design engineer. Then, the owner accepts one of the bids based on both price and qualifications, and according to the rules of the bidding process. On the other hand, in open bidding, two or more bidders continue to bid openly for a project until no body is willing to increase the bid. The last bid is considered the winning bid. Usually, the construction bidding is taking the way of the first kind of competitive bidding (closed bidding).

Despite that competitive bidding has been accepted for allocating construction contracts, Parks and McBride (1987) argued that the use of competitive bidding for engineering services reduces the quality of engineering work and results in an adversarial relationship between the engineer and the client, which is in contrast with the nature of the engineer's job as the client's representative.

Parks and McBride (1987) highlighted the advantages and disadvantages of using competitive bidding for engineering services. They stated the advantages as follows:

1. “Open competition without preference fulfills its normal role of stimulating efficiency, economy, and effectiveness, as well as the needed quality and general performance of the parties involved. Engineers necessarily limit their profit to an amount that allows them to remain competitive.
2. Assuming that all involved parties operate with integrity, open competition builds public confidence by demonstrating that the taxpayer “Client” is getting the best price for the work.
3. Open competition requires the client to prepare an adequate, clear, and comprehensive performance statement of work.
4. Firms selected on the basis of their bid use their best personnel so they can get the job done quicker and improve their profit margin.
5. The planning that goes into the preparation of the bid shortens the actual job and reduces the number of changes, thus lowering the total costs
6. Price is considered secondarily. Therefore, the low bidder will presumably only be selected if he has the best combination of technical and price proposals, insuring that quality is maintained”

Further, Parks and McBride (1987) highlighted the main disadvantages of the use of competitive bidding for engineering services as follows:

1. “It eliminates mutual work scope development; therefore the engineer by virtue of his training is uniquely qualified to recommend and explain project refinement and technical approach, is precluded from doing so…

2. Attendance at bidders' conference and preparation of bids and technical proposals by all potential consultants on a job wastes money.
3. Even with detailed work scopes: (1) assumptions must be made causing wide variations in the services bid and, as a result, widely ranging bids; (2) errors and omissions are common, resulting in the engineer imposing change orders with potentially higher profit. More importantly, this philosophy leads to an adversarial relationship between engineer and client….etc.
4. To prepare a detailed work scope, the client must do a considerable amount of the engineering work himself.
5. Fee- bidding requires good engineering firms to submit bids that do not allow an adequate profit in order to secure work"

Therefore, Parks and McBride (1987) recommended that the engineering services should not be awarded through competitive bidding. In addition, the authors provided guidelines for the situations in which the competitive bidding is the only method to be used for awarding of engineering services.

On the other hand, the success of using competitive bidding for selecting contractors is due to many factors, such as the slowdown in the global economic growth, globalization of the construction market, and development in technology. Those factors are producing the main sources of the competitive environment between contractors in the construction industry. Therefore, contractors are faced by the challenge of finding a way to take the business away from competitors for many reasons such as sustaining their growth rate in this competitive environment. As noted by Gates (1967), there are many reasons for a contractor to desire winning the project contract, such as:

1. Increasing earned profit (the most common reason).
2. Minimizing losses, as contractor must keep his firm intact even during recession periods.
3. Minimizing the profits of the competitors in order to maintain a long-term good competitive position within the construction industry market.

Due to all the aforementioned reasons, before submitting a bid, every contractor is making many critical decisions corresponding to each bidding situation. As noted by Bagies and Fortune (2006), whether to bid or not for a construction project is one of the most critical decisions. Even in the case of the availability of good numbers of bids for the contractor and a high chance of winning, the bid/no bid decision is still critical. Not bidding for a project may result in losing of the contractor for a good chance to make a substantial profit, and improve the contractor position in the industry. On the other hand, bidding for inappropriate projects may result in incurring large monetary losses, and losing the opportunity of utilizing the resources in more profitable projects. Therefore, it is of great importance for contractors to initially evaluate a project, considering all external and internal factors that affect the bid/no bid decision, before bidding for a construction project.

Furthermore, Bagies and Fortune (2006) mentioned that in the stage before committing to a construction project, the contractor's decision is affected by: (i) the first decision is bid/no bid decision, in which the contractor considers many factors which would help in determining the benefit expected from a project and correctly evaluating it,

(ii) the second decision is the mark-up decision, which is related to the bidding strategy. As quoted by King and Mercer (1985), the bidding strategy is an important part of the overall business planning of any construction company. Many researches have been conducted in the area of the bidding strategy and would be reviewed later in this chapter.

In addition, Bagies and Fortune (2006) reviewed last researches and highlighted the essential factors which affect the contractor's bid/ no bid decision. The authors concluded that the factors depend on the following ten groups: project characteristics, business benefits, the client characteristics, the contract, project finance, company characteristics/situation, firms' previous experience, bidding situation, economic situation, and competition.

Regarding the mark-up decision, many researchers discussed the factors affecting the bid mark-up decision. Ahmad and Minkarah (1988) identified 31 factors affecting the bid mark-up decision made by the US contractors. In addition, Shash and Abdul-Hadi (1992) further identified 37 factors affecting the mark-up decision of the contractors operating in Saudi Arabia. Then, Shash (1993) identified 55 factors which should be considered by contractors working in UK. Furthermore, Dulaimi and Shan (2002) reviewed the aforementioned researches, in addition to many other researches related to the mark-up decision, and identified 40 common factors affecting the contractor's bid mark-up decision. The factors have been divided to five groups, as shown in table 2.1. It is noticeable that there is strong link between the factors affecting both bid/no bid and mark-up decisions.

Table 2.1 Factors affecting the bid mark-up decision (Dulaimi and Shan 2002).

Category	Factors	Category	Factors
Project Characteristics	• Size of contract • Duration of project • Project cash flow • Location • Type of owner • Degree of difficulty • Degree of safety	Economic Environment	• Overall economy • Risk involved in investment • Anticipated rate of return • Availability of labor/ equipment • Government division requirement • Tax liability
Project Documentation	• Type of contract • Type of procurement • Completeness of document • Owner's requirement • Use of nominated sub-contractors • Value of liquidated damages • Risk of fluctuation in material price • Insurance premium	Company's Characteristics	• Availability of required cash • Uncertainty in cost estimate • Need for work • Past profit • Current work load • General overhead • Portion subcontracted to others • Experience in similar project • Need for public exposure • Availability of qualified staff • Establishing long relationship with client
Bidding Situation	• Tendering method • Tendering duration • Pre-qualification requirement • Bidding document price • Availability of other projects • Number of competitors • Identity of competitors • Requirement of broad capacity		

2.2.1 Construction bidding methods

In general, the bids, submitted by the contractors, are first evaluated technically. Then, after being accepted from technical perspective, they are evaluated corresponding to their price. There are many methods used for evaluation of bids corresponding to their price. The researcher addresses here the basic features of the most common methods used, highlighting the advantages and disadvantages of each.

2.2.1.1 The low-bid method

The low-bid method is the most used method for financial evaluation of submitted bids in the construction bidding in United States. In this method, the construction contract is awarded to the contractor submitting the lowest bid. From a contractor's perspective, each contractor concerns about the minimum of bid prices submitted by the other competitors (Ioannou and Awwad 2010). A contractor can increase profits by bidding a penny less than the lowest bid, considering that the bid price is above the construction cost (Seydel 2003). It is also important to mention that both Friedman and Gates bidding models, discussed later in this chapter, are basically following the low-bid method.

On the one hand, one of the main advantages of the low-bid method is its simplicity in calculations. It just requires the bids to be arranged in increasing order and the lowest bid is the winner. In addition, it encourages the contractors to develop cost saving techniques through technological and managerial innovations, and consequently, the owner receives the specified quality at the lowest cost (Ioannou and Awwad 2010).

On the other hand, the main disadvantage of the low-bid method is that awarding the contract to the lowest bidder may result in a contract with a contractor who submits either "accidentally" or "deliberately" unrealistic low bid price. This is usually the case when the construction industry is in recession. Such a contractor cannot perform the required work according to the specified quality and within the submitted price, and ends making a reasonable profit (Ioannou and Awwad 2010). As a result, the quantity of claims and disputes increases during construction, leading to delays, increased costs and bad quality (Grogan 1992). For example, Florida DOT (2000) reported that the low-bid contracts had, on average, 12.4% cost overrun and 30.7% time overrun, while the other contracts had only 3.6% cost overrun and 7.1% time overrun.

Therefore, as stated by Ioannou and Awwad (2010), some countries tried to take a direction away from the low-bid method and developed another bidding methods based on the average of all submitted bids. The average and below average bidding methods are considered from the new adopted bidding methods.

2.2.1.2 The average and below average-bid methods

Based on the general concept of average-bid method, the contract is awarded to the contractor whose bid satisfies a specific relationship with the average of all submitted bids. According to Ioannou and Leu (1993), there are many average-bid methods, differing in the way of calculating the average, or the way of determining the winner bid. For example, in the average-bid method, the winner is the contractor whose bid is the closest to the average of all submitted bids, while in the below average-bid method, the winner is the contractor whose bid the closest, but less than the average. For example, the average-bid method is used in Taiwan, while the below average-bid method is used in Italy (Ioannou and Leu 1993).

Furthermore, Ioannou and Leu (1993) developed a bidding model for the average-bid method. Ioannou and Awwad (2010) further developed a bidding model for the below average-bid method. Both of the models were investigated analytically through Monte Carlo simulation. The authors also explored the merits of both bidding methods, compared to the low-bid method, and concluded with the advantages and disadvantages of both.

For the average-bid method, according to Ioannou and Leu (1993), the main advantage is that it protects the owner from entering into a contract with a bidder whose bid is unrealistically low, and avoiding the consequences of schedule delays and increased costs. In addition, it also protects the contractor from submitting a bid which contains a gross mistake. On the other hand, the main drawback of the average-bid method is that it does not guarantee that the cost savings through technological and managerial innovations are passed to the owner, unless such innovations are available to all bidders.

For the below average-bid method, it shares the same advantages and drawbacks of the average-bid method. In addition, based on the profit margins, both the average and below average-bid methods are preferred by contractors for providing higher profits than those provided by low-bid method, which is preferred by owners. Furthermore, the below average-bid method has the same drawback as the low-bid method, in case of small number of bidders, which is that the contract may be awarded to a contractor whose bid is unrealistically low (Ioannou and Awwad 2010).

Generally, there are many other methods which can be used in evaluating the submitted bids regarding the price. For example, some construction contracts are awarded to the contractor who submits the second lowest bid. In each bidding situation, the contractor should exercise the most appropriate bidding strategy which suits the used bid evaluation method.

2.2.2 Construction bidding models

In the construction bidding, selecting an appropriate bidding strategy is the ambition of most contractors. Over the last 50 years, many models have been developed for the application in the construction bidding. According to Wanous et al. (2000), the majority of these bidding models have focused only on the mark-up decision. Generally, the main objective of these models is to provide contractors with criteria to maximize the expected profit.

Initially, Friedman (1956), in his paper "A competitive bidding strategy", developed a model considering the strategy of how to win a bid. The concern of that study was to maximize the expected profit from a tender in which each contractor simultaneously submits one closed bid. The bidder should select the mark-up on construction cost which will maximize the expected profit from executing a construction project.

Furthermore, Gates (1967) applied Friedman's concept for a single bid, and provided a general profit maximization model for general application for tendering. As quoted by Bagies and Fortune (2006), there are many similarities between Friedman and Gates models. For example, both models are following the low-bid method. The main difference between the two models was in how to estimate the probability of winning in the case of more than one competitor. Posteriorly, as stated by Wanous et al. (2000), many bidding models have been developed since the publication of Friedman's model, and the bidding theory has gained more focus and popularity in academic research.

Benjamin and Meador (1979) focused on the differences between the proposed bidding models by Friedman and Gates. As the authors mentioned, the objective of both Friedman and Gates bidding models is to find the optimal bid amount which maximize the expected monetary value of the job. The expected value of the job is equal to the product of the profit that would be earned by submitting the bid and the probability of winning the job. In general, Friedman and Gates models differ in their ways for calculating the probability of winning.

On the one hand, Friedman estimates the probability of winning for a bid as the product of the probabilities that the bid is less than the bids of the other bidders. This is shown as follows:

$$P[(b_o < b_1)\Pi \dots \Pi(b_o < b_n)] = P(b_o < b_1)\,P(b_o < b_2) \dots P(b_o < b_n) = \Pi_{i=1}^{n} P(b_o < b_i) \quad (2.1)$$

On the other hand, Gates estimates the probability of winning against (n) bidders as follows:

$$P[(b_o < b_1)\Pi \dots \Pi(b_o < b_n)] = [\sum_{i=1}^{n} \frac{1-P(b_o<b_i)}{P(b_o<b_i)} + 1]^{-1} \quad (2.2)$$

Where b_o= the bid of the contractor by using the model, and b_i, i=1, 2… n, = the bids of the other bidders (Benjamin and Meador 1979).

Thereafter, Benjamin and Meador (1979) presented the simulation which was developed at the University of Missouri-Columbia. The purpose of that simulation was to answer the following questions:

- "Do the probabilities of winning at optimality found by the Friedman and Gates models differ significantly?

- Do the optimal markups found by the Friedman and Gates models differ significantly?
- Do the relative frequencies of winning bids differ significantly from the probabilities of winning found at optimality?
- Does the use of one bidding model consistently "better" results than the use of the other model? As quoted by Benjamin and Meador (1979), "better" is measured corresponding to the total long term profit.
- Does the use of one of the bidding models result in a significantly different volume of work than obtained by the use of the other model?"

The simulation model was related to a contractor's 3-yr bidding history. This contractor faced 704 competing bids from 189 different bidders in 131 bidding situations. The concept was to generate bids for each job, and then compare the optimal bid against the actual lowest bid to determine if the job was won or lost through the model's optimal bid.

Furthermore, Benjamin and Meador (1979) concluded, based on the results of the simulation model, the following:

- Friedman's model always gives a smaller optimal mark-up than the mark-up given by Gates's model.
- The probability of winning at the optimal mark-up given by Friedman's model is less that that by Gates's model.
- The quantity of jobs won by using Friedman's model is more than those won by using Gates's model (due to less mark-up).

- The use of Friedman's model will not always result in more total profits over the long run than Gates's model.
- On average, the use of Friedman's model takes about twice the volume of work to get the same profit gained by the use of Gates's model.
- The use of Gates's model is giving a closer correspondence between the relative frequency of the successful bids and the probability of winning than Friedman's model.

It is important to highlight that the aforementioned remarks do not give advantage to either Friedman or Gates models over the other. The success of one of the models should be based on the criterion used to measure the success (Benjamin and Meador 1979).

However, despite the many publications related to construction bidding, the bidding models are largely lacking in utilization among contractors due to ignoring many human behaviors (Ahmad and Minkarah 1988). Many researchers argued that in reality, the bidding decisions are based on experience, intuition and influenced by the emotional responses towards the pressures of each bidding situation (Fayek 1998). Runeson and Skitmore (1999) argued that some basic assumptions, which were applied in the bidding models, are not realistic and their predicted results are not always correct. According to Seydel (2003), lack of confidence in the profit maximization models is the main reason of the bidders' reluctance to use them. More recently, many researchers have tended to develop new techniques to aid contractors in rendering their bidding decisions utilizing fuzzy neutral networks (Polat et al. 2014). These techniques should help contractors in estimating the optimal bid mark-up for a bidding situation.

A question which arises here is what are the reasons of the failure of these bidding models? As aforementioned, some basic assumptions of these bidding models are not realistic, especially the assumption of rationality. Usually, people's behaviors and thoughts are not strictly rational as assumed to be (Zhu 2008). Moreover, Runeson and Skitmore (1999) pointed out that the profit maximization is not always the goal of construction firms. Thus, it is obvious the need for a more efficient bidding model to be used in construction bidding, which matches the realistic situation of the construction bidding process in its assumptions and overcomes the limitations of the previous published bidding models. Therefore, this research utilizes a game theory approach to provide contractors with effective tool to mitigate the aforementioned limitations of the bidding models from the engineering literature. To this end, the following sections provide background information of game theory and auction theory from economic literature due to lack of utilization of game theory in engineering literature, and presents the symmetric risk neutral Nash equilibrium (SRNNE) which can be used as an optimal bid function in construction bidding.

2.3 Game theory

Recently, social and behavioral sciences have developed mathematical tools to describe human behaviors. Game theory is one of the most important developed mathematical tools. Game theory is defined as "the study of mathematical models of conflict and cooperation between intelligent rational decision-makers" (Myerson 1991). Generally, it is considered as a substantial contribution to social and behavioral sciences through providing a tool to develop a framework for decision making in the presence of conflict of interest.

Historically, Game theory became an important mathematical tool for examining different aspect of human behaviors since the publication of "Theory of Games and Economic Behavior" in 1944 by John von Neumann and Oskar Morgenstern. The basic terminology of game theory concept has been provided through this book. Since 1944, game theory has been applied to different aspects of humans' life. In the 1950s and 1960s, game theory was applied in battle field decisions and political problems. In 1970s, game theory revolutionized the field of economic studies. Moreover, it has been applied to sociology, psychology, and biology. Game theory and its practitioners received a long awaited recognition after the awarding of the Nobel prize in economic sciences to Nash, John Harsanyi, and Reinhard Selten in 1994 (Turocy and Stengel 2001).

In the construction industry, researchers have applied various game theoretical models to explain and predict outcomes of different aspects in construction industry. Ho (2001) utilized game theory to analyze BOT project procurement process in the presence of asymmetric information and its effect on project financing and government policy. Furthermore, Drew and Skitmore (2006) analyzed bidding schemes in the construction industry by means of auction theory, a sub-discipline of game theory. Moreover, Ho and Liu (2004) analyzed the dynamics between contractors and owners in construction claims through a game theoretical model. In addition, game theory has been also applied to examine strategies for subcontractor selection (Unsal and Taylor 2011), and to analyze the effect of bid compensation on the bidding process (Ho 2005). Thus, game theory became an important tool to analyze issues in the construction industry.

In general, game theoretical models can be classified according to information completeness, and the way in which games are played. Based on the way of playing the game, there are two types: (i) Static games, in which players make decisions and take actions simultaneously, without knowing the decisions chosen by other players, (ii) Dynamic games, in which players make decisions and take actions sequentially, with the observation of other players' actions (Ho and Hsu 2014). Generally, construction bidding model can be considered following the static game concept, as bidders do not know bids of their rivals at the time of submitting their bids.

Moreover, there are basically two main branches of game theory concepts: (i) Cooperative game theory, in which players cooperate together to get more benefits for each and allocate the gains fairly between them, and (ii) Non-cooperative game theory, in which each player selects his strategy independently, tries to maximize his payoff, and there is no collusion between the players (Asgari and Afshar 2008). According to Nash (1950), Nash Equilibrium is considered as the solution to non-cooperative games under the assumption that all players are rational. Generally, construction bidding can be described as a non-cooperative game, as each general contractor or sub-contractor is trying to win the competition and maximize his own payoff in the presence of conflict of interest. Thus, it can be concluded that to develop better model which describes construction bidding in reality, the game theoretical model shall be non-cooperative with static moves and incomplete information.

2.4 Auction theory

Auction theory is a sub-discipline of game theory. Historically, auctions have been used to distribute goods and services for over thousands of years. The report by the old Greek historian Herodotus of Halicarnassus is considered one of the earliest reports of auctions. He wrote about men in Babylonia used to bid for women to become their wives around 500 B.C. This auction is considered the earliest auction in history. Furthermore, in 193 A.D., the Praetorian Guard put the entire Roman Empire for auction, which is considered the most astounding auction in history (Shubik 1983)

In today's world, auctions are of great practical importance because the value of goods being exchanged in auctions is relatively high in both public and private sectors. In public sector, governments usually use auctions to sell assets, purchase services, and fund their national debt. On the other hand, in private sector, auctions are used widely in many areas, such as the utility market, and selling of items through internet auctions (Kagel and Levin 2002).

Auctions are considered one the most outstanding applications of games with incomplete information, because participants in auctions have different private information which is the main factor affecting their strategic behavior. Traditionally, auctions are typically classified to major two types from the information perspective: (i) private value auctions, and (ii) common value auctions. In a private value auction, the bidders know their own value of the item being auctioned with certainty, but they do not know other bidders' values. However, in a common value auction, the item being auctioned has the same value (i.e. cost) to everyone, but none of the bidders know this value with certainty. As such, each bidder develops an independent and identically distributed estimate about the true value, and the winner is the one having the most pertinent information to such true value. Finally, only the winner will typically observe the true value (Kagel and Levin 2002).

2.4.1 Common value auctions

According to Dyer and Kagel (1996), construction bidding is considered as a common value auction. In construction bidding, the project cost is considered a variable for the different bidders. Generally, bidders develop some estimates the true cost of the project which cannot be realized until completion of the project. Each bidder has different access to the information about the factors affecting the project cost upon which his estimate of the true cost is based. Basically, project true cost is affected by many factors, such as market factors as location, competitors and time, and project factors as its size, type and scope. Being the case, in construction bidding, the bidders have two sources of incomplete information, i) true cost and ii) their rivals' estimates of the true cost.

Furthermore, in construction bidding, it is considered illegal for bidders to cooperate and exchange their bidding information. Moreover, the intensive competition environment in the construction industry prevents such collusion between bidders because, in construction bidding, each bidder is willing to increase his earned profit and decrease the profits earned by his competitors to maintain a competitive position within the construction industry market. All the aforementioned reasons lead to the consideration of the construction bidding as a common value auction.

In addition, bidding for construction contracts is referred to as a 'reverse auction'. Unlike auctions for the purchase of goods and services, construction auctions are for the sale of goods and services. In such a setting, the auctioneer determines the winner as the bidder submitting the lowest bid, based on the low bid method, rather than the highest bid to purchase an item. Therefore, in construction bidding, bidders are usually subject to adverse selection, which is prevalent in common value auctions. Unless this adverse selection problem is carefully considered while preparation of bid, the winner, who has underestimated the true cost, will most likely end up making below normal or negative profits. Generally, adverse selection results in what is known as the winner's curse.

2.4.1.1 The winner's curse

According to Kagel and Levin (2002), the story of the winner's curse was firstly introduced by Capen, Clapp, and Campbell (1971). The three petroleum engineers claimed that oil companies had suffered unexpectedly low rates of return in early outer continental shelf (OCS) oil lease auctions, in other words, oil companies fell prey to the winner's curse. Thereafter, researchers have recognized the influence of the winner's curse in auctions for publication rights (Dessauer 1981), corporate takeover battles (Roll 1986), real-estate auctions (Ashenfelter and Genesore 1992), and cattle auctions (Coatney et. al, 2012).

Particular to the construction industry, the winner's curse can be defined as the situation when the bidder, with the most optimistic (low) project cost estimate, wins the project contract based on a submitted bid less than true project cost. Such a bidder, who fails to take the winner's curse problem into account, will most likely lose money or, at least, earn below normal profits.

According to Dyer and Kagel (1996), US general construction contractors usually utilize one of three mechanisms to avoid falling as a prey to winner's curse in construction bidding. The three mechanisms are as following:

- Bid withdrawal: Most states' law allows low bidders to withdraw their bids for public projects in case of arithmetic errors, and without being subjected to penalty. The meaning of arithmetic errors is broad and not well defined, and experienced contractors can benefit that to escape from the winner's curse by withdrawal of their submitted bids.

- Low Sub-contractors' bids: General contractor can bid higher benefiting from the low submitted bids by the sub-contractors in lowering the joint submitted bid and reducing the likelihood of suffering from the winner's curse in his part of the project in case of winning the project contract.
- Change orders: Change orders refer to situations in which owners adjust the original scope of construction of the project after signing the contract. Usually, the price of a change order is established based on a negotiation process between the general contractor and the owner. Through tough negotiations, general contractor, who has underbid a project, can recover at least his losses, and in some instances, make some profit.

Generally, the aforementioned mechanisms are considered ineffective, especially the third mechanism of change orders due to its disadvantage of resulting in an adversarial relationship between the sub-contractor and general contractor, and client, as well as potential legal costs. Therefore, in order to avoid the winner's curse, and due to the relatively ineffectiveness of the aforementioned mechanisms, contractors must carefully consider all factors while preparing their bids. Being the case, the following section discusses the Symmetric Risk Neutral Nash Equilibrium (SRNNE) bid function as a potential tool for optimal strategic bidding that could avoid the winner's curse.

2.4.1.2 The symmetric risk neutral Nash equilibrium (SRNNE) bid function

As previously discussed, in the construction bidding process, the project cost is considered a variable for different contractors, because each contractor has different access to the information about the project conditions and has different estimate based on the project attributes. Generally, all the contractors know their own cost estimate, but they do know neither their opponents' cost estimates nor the true cost of the project.

From past research, Wilson (1977) developed the first Nash equilibrium solution and later, Dyer et al. (1989) presented the symmetric risk neutral Nash equilibrium bid function (SRNNE) for a first price sealed-bid common value auction, in which bidders independently submit their bids in a closed auction, and the winner is the one who has submitted the lowest bid value. Furthermore, Dyer et al. (1989) utilized this optimal bid function to analyze a series of laboratory experiments, in which the bidders competed for the right to supply an item of unknown cost such as construction contracts.

Dyer et al. (1989) focused primarily in analyzing and comparing the behavior of experienced executives in the construction industry with inexperienced students. The authors conducted four experiments, three of those experiments employed University of Houston upper-level economics majors students with no prior laboratory experience, while experiment 4 employed executives from local construction industry. Each experiment consisted of different auction periods in which the right to supply was awarded to the low bidder. The presumption was that experienced bidders would not fall prey to the winner's curse to inexperienced bidders. Interestingly, the authors found that both inexperienced students and experienced executives were almost similar in suffering from the winner's curse, as shown in figure 2.2.

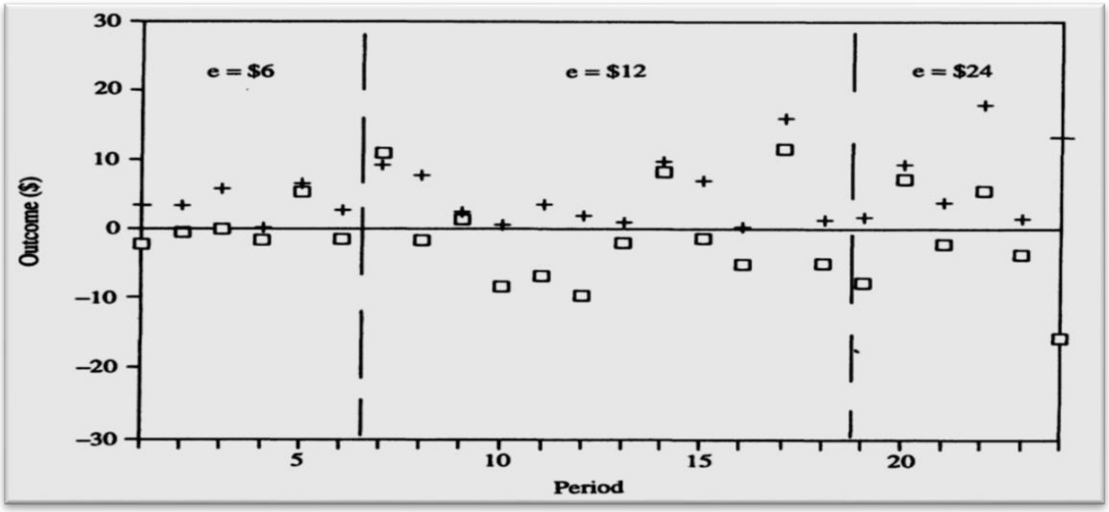

Figure 2.2 Outcomes of experiment 4.

(□ Actual profits based on experiment, + SRNNE profits) (Dyer et al. 1989).

Furthermore, the authors studied the effect of increasing numbers of bidders in their behaviors. Dyer et al. (1989) argued that in a common value auction, there are two forces when number of bidders is increased. Those two forces were referred to as a Strategic force and item valuation considerations. The strategic force leads to lower bidding with increasing in the number of bidders, because the probability of winning with higher mark-up decreases. On the other hand, item valuation considerations leads to higher bids as the adverse selection problem (winner's curse) increases with increasing in the number of bidders. Therefore, in order to avoid the winner's curse, the symmetric risk neutral Nash equilibrium bid function (SRNNE) requires that bids be constant or increasing with increasing in number of the bidders.

Based on the results of the conducted experiments, Dyer et al. (1989) found that both categories of inexperienced students and experienced executives suffered from increased losses with increasing in the number of rivals, which implies that bidders were responding in the wrong direction and affected by the strategic force, or were not responding sufficiently in the right direction. Ultimately, the authors concluded that the winner's curse is mainly depending on the market size, auction form and subject population.

The description of the SRNNE is as follows: let the actual cost of constructing project "C" is unknown at the time of submitting bids. The i^th bidder, who wins the construction project contract, will earn a profit which is equal to the difference between his bid "B" and the actual cost of the project"C", as shown in the following equation (3.1), where c_i is the contractor's initial estimated cost (i.e. bidding value):

$$Profit\ i = B_i\,(c_i)\ - C \tag{2.3}$$

In deriving the optimal bid function, the actual cost of project "C", is assumed to be drawn from a uniform distribution on $[X_1, X_2]$. Furthermore, each bidder receives a private signal "c_i" about the true cost. This private signal is assumed to be randomly drawn from a uniform distribution on $[C - \varepsilon, C + \varepsilon]$. The variable "$\varepsilon$" represents the range of private signal around the true cost, and depends on the accuracy of bidder's estimate. Moreover, it is also assumed that the uniform distributions of the actual cost "C"and the number of bidders N are a common knowledge to all participating bidders, while each bidder privately knows his private signal "c_i" and as a function of "ε".

The SRNNE bid function, as stated by Dyer et al. (1989), in the interval $[X_1 + \varepsilon < c_i < X_2 - \varepsilon]$ is as follows:

$$b(c_i) = c_i + \varepsilon - Y \tag{2.4}$$

Where $Y = \left[\frac{2\varepsilon}{N+1}\right] \exp[-\left(\frac{N}{2\varepsilon}\right)(X_2 - \varepsilon - c_i)]$. It is important to notice that the Y term diminishes rapidly as c_i moves below $(X_2 - \varepsilon)$. Also, the SRNNE implies that signals are just marked-up by a value equal to ε to avoid the winner's curse.

The main objective of SRNNE bid function is to determine the optimal amount a bidder shall submit without being subjected to the winner's curse, in case of winning the contract. It is logical that if the bidder bids only based on estimating the project cost close to $(X_1 + \varepsilon)$, he will lose money in case of winning. This fact is expected to happen most of the times but not always. Sometimes, improbable things happen which turns bad decisions to be good. However, if this bidding competition is played many times and the bidder always estimates a project cost close to $(X_1 + \varepsilon)$, he will lose money eventually, in expectations, based on the winner's curse concept. To this end, the following chapter III (RESEARCH METHODOLOGY) presents the methodology used in this research in order to address its main objectives.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Introduction

This research is basically conducted to illustrate the construction bidding and its correlation with the common value auctions from the perspective of the winner's curse. Furthermore, the researcher aims to analyze the construction bidding setting (single-stage bidding vs. multi-stage bidding) and its effect on the winning contractor's degree of suffering from the winner's curse. Moreover, the researcher aims to examine the aforementioned symmetric risk neutral Nash equilibrium (SRNNE) which can be used as an optimal bid function which aids the contractors to avoid being a prey of the winner's curse in case of winning the project contract.

In order to accomplish those objectives, an efficient methodology is required. This research is a descriptive research, as it aims to address the problem statement stated in chapter I, i.e. the construction bidding and the winner's curse. A simulation model of the two construction bidding settings (single-stage bidding and multi-stage bidding) is conducted to obtain the required data for the analysis and accomplish the research objectives. Figure 3.1 layouts the used methodology of this research.

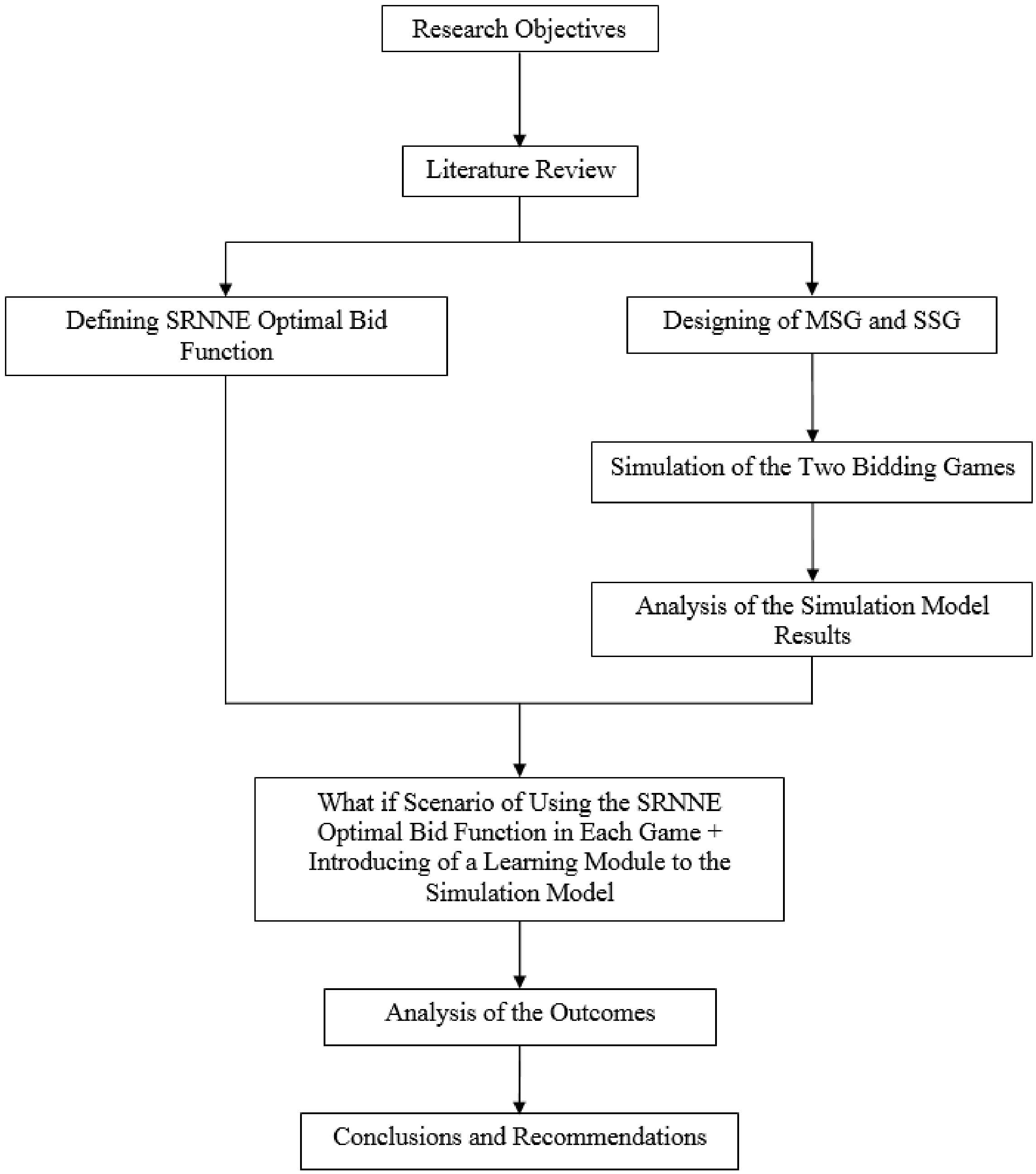

Figure 3.1 Research methodology layout (MSG = Multi-Stage Bidding Game; SSG = Single-Stage Bidding Game).

3.2 Simulation model development

In this research, the researcher applies the theoretical approach of SRNNE using some real projects dataset, illustrated in section 3.2.4, and compares the results of the SRNNE optimal bid function to those of the implemented model, which simulates the bidding procedure in reality. The main purpose of this simulation is to analyze the behavior of the sub-contractors and general contractors towards the threat of the winner's curse, and compare it to the results of the SRNNE optimal bid function. Moreover, the researcher aims to examine the effect of the nature of construction bidding environment (single-stage bidding vs multi-stage bidding) on the results from the winner's curse perspective. It is expected that multi-stage bidding environment will result in more losses to the winner of the contract than single-stage bidding environment.

Generally, the simulation model consists of single-stage bidding game (SSG) and multi-stage bidding game (MSG). The model is implemented on NetBeans IDE 7.4 platform using JAVA programming language. The model is implemented twice. First, it is assumed that the agents (general contractors and sub-contractors) choose their bids randomly within the range of the value of the error in their estimates (ε) (Model 1). This model (Model 1) is to represent the situation of lack or misuse of past bidding experience by contractors. Second, a learning module is integrated into the model 1 (Model 2), in order to analyze the effect of learning from past bidding experience in regards to the agents' bidding decisions.

For modeling purposes, in each round in both models, each contractor would be given a different private signal, which represents his estimate of the true cost of the project, and the value of the variable (ε) representing the value of the error in the contractor's estimate of the true cost. The value of the estimate's error (ε) would be divided into six equal fragments above and below the given private signal. As such, each contractor has 13 values from which he can choose for his bid in each round.

In model 2, the learning module follows the Roth Erev Reactive Reinforced Learning, (Erev and Roth 1998), in which the used decision variable and the achieved reward (positive or negative) are determined according the following plan shown in the following equations.

Propensity of contractor action: $q_j(t+1) = q_j(t)[1-\emptyset] + E_j(k) * (1-\alpha)$ (3.1)

Probability of contractor action: $pr_j(t) = q_j(t)/\sum q_j(t)$ (3.2)

Where, $q_j(t)$ is the propensity of action j in time t, pr is the probability distribution of action j, Ø is the forgetting parameter, and α is the experimenting parameter. Both Ø and α allows the contractor to explore more actions in subsequent rounds based on the earned rewards. Thus, following Roth-Erev reactive reinforcement learning, the learning model (Model 2) can change the propensity of the decision variables, and correspondingly their selection probabilities based on the earned reward (E_{ik}).

Where, E is the reward for the i^{th} available action, given the action is taken in the k^{th} round. In case j=k, E will be either +1 or -1 based on if the project contract is won or not, respectively, and -2 if the contract is won with a submitted bid less than the true cost of the project. The aforementioned was a brief explanation of the simulation model and its objectives. The code of the simulation models is in Appendix B. The following is the illustration of each game, defining the elements of the game and the possible actions for the players.

3.2.1 Single-stage bidding game (SSG)

In the single-stage bidding game (SSG), as shown in figure (3.2), there are only three general contractors who are competing to win a similar project contract in each round. The contract is awarded to the general contractor who submits the lowest bid. The projects in the single-stage bidding game (SSG) are designed to be the same as those in the multi-stage bidding game (MSG) order to facilitate direct comparison between the two bidding game settings.

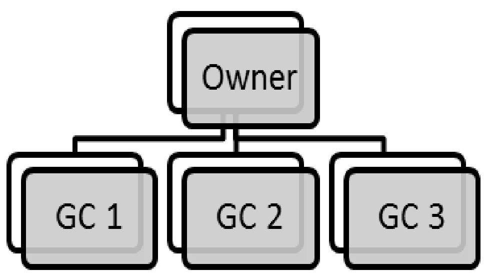

Figure 3.2 Single-stage bidding game

(GC = General Contractor).

3.2.2 Multi-stage bidding game (MSG)

In the multi-stage bidding game, as shown in figure (3.3), there are three general contractors. Each general contractor receives bids from three sub-contractors for a symmetric part of the project. In the MSG, it is assumed that the general contractor subcontracts up to 30% of the project work based on the low bid method. Thereafter, the three general contractors compete against one another to win the project by submitting their joint bids to the owner. Finally, the contract is awarded to the lowest of the three submitted joint bids by the general contractors, and consequently, his winning sub-contractor wins the project contract.

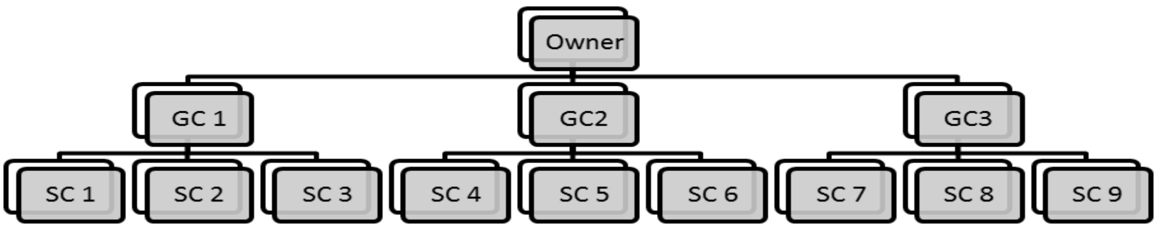

Figure 3.3 Multi-stage bidding game

(GC = General Contractor, SC = Sub-Contractor).

3.2.3 Basic assumptions and considerations

In order to reduce the variability and facilitate the comparison between the two game types (MSG and SSG), there are some basic assumptions and considerations for each game type in each round. Those assumptions serve as the rules for the simulation models, which are as follows:

- At each round in both SSG and MSG, each subcontractor and general contractor is randomly given a different private signal which represents his estimate of the true construction cost of his part in the project. All the given private signals, at each round, are within the range of the expected estimate's error (ε).
- The simulation model is designed such that, at each round in both SSG and MSG, the contractors would choose a random bid within the range of ε, which is shown

afterwards in Table 3.1, around the given private signal for model 1 or utilizing the learning module for model 2.

- In both SSG and MSG, there are six projects' categories and each category is represented by 15 different projects.
- The true cost of the project is considered unknown for contractors at the time of submitting their bids.
- In case of model with learning module (model 2), for simplicity, it is assumed that the contractors would learn how to prepare more accurate bids based on their past bid decisions within the same category, and start over in next category.

For example, for general contractors who are bidding for one of the projects in category 1 in the SSG, the true cost is assumed to be drawn from a uniform distribution with the range from $25,000 to $50,000. Furthermore, the private signals are randomly drawn within $750, which represents the value of ε, around the true cost. This implies that, at each round, the true cost of the project would be within ±$750 around the private signal. Figure 3.4 illustrates the distribution of the private signals and the true cost at a round in category 1 in SSG as an example.

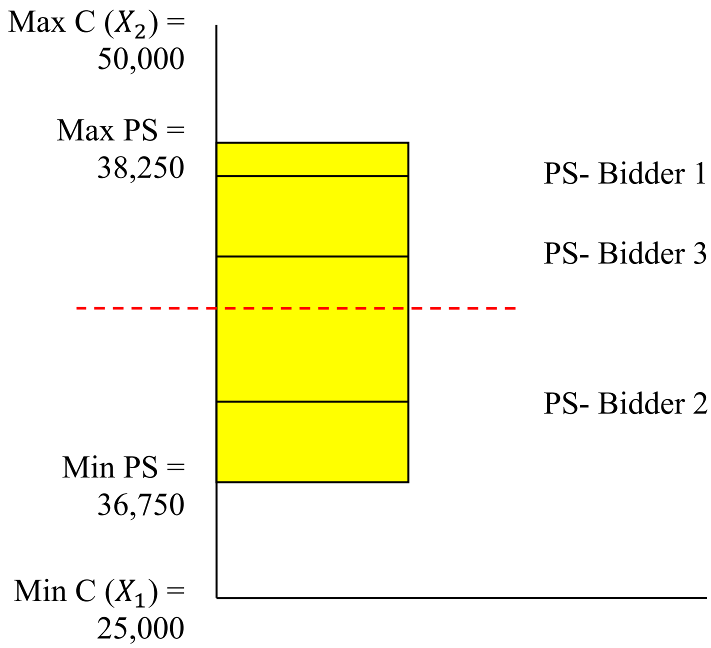

Figure 3.4 An example of the true cost and private signals distribution (C = True Cost; PS = Private Signal).

3.2.4 Simulation model dataset

As previously mentioned, the simulation model is implemented using some data, which is based on real projects conducted by California Department of Transportation (California DOT), to simulate the construction bidding process in reality. The available data is the true costs for 3,500 different projects conducted by California DOT. These projects are limited to the type of projects conducted by California DOT such as highways and bridges. For modeling purposes, in both SSG and MSG, the projects are divided into six categories, based on the true cost of the project as shown in Table 3.1. It is found that the maximum number of available California DOT projects between US $5 to 10 million ($6^{th}$ Category) is 15 projects. Therefore, in order to maintain symmetry between the six projects' categories, each category is chosen to be represented by 15 projects in each game type in the simulation model. The 15 projects in each project's category are chosen through a function for random selection from the data of California DOT. The input data of true costs of the selected projects and private signals used in the simulation model for each round in both SSG and MSG are in Appendix A.

In addition, the value of ϵ is different from one category to another in order to maintain a reasonable degree of accuracy of contractors' estimates in reality. Based on a review from experienced individuals in construction industry, the value of ε is assumed to equal, on average, 2% of the project true cost in each category. The number of bidders "N" is assumed to be always equal to three in each bidding situation, either between sub-contractors or general contractors, as shown in Figures 3.2 and 3.3. In addition, X_1 and X_2 refers to the upper and lower boundaries of the true costs in each of the projects' categories. The following Table 3.1 shows the six categories, and the value of ε for each category.

Table 3.1 Projects' categories and the corresponding ε value

Category	Range	MSG		SSG
		ε for SC	ε for GC	ε for GC
1	$25,000 -- 50,000	$222	$528	$750
2	$50,000 -- 100,000	$450	$1,050	$1,500
3	$100,000 -- 500,000	$1,800	$4,200	$6,000
4	$500,000 -- 1,000,000	$4,500	$10,500	$15,000
5	$1,000,000 -- 5,000,000	$18,000	$42,000	$60,000
6	$5,000,000 -- 10,000,000	$45,000	$105,000	$150,000

Note: (MSG = Multi-Stage Bidding Game; SSG = Single-Stage Bidding Game; SC = Sub-Contractor; GC = General Contractor)

CHAPTER IV

RESULTS AND ANALYSIS

4.1 Introduction

This chapter presents the results of the implemented model and the analysis of the collected data based on the methodology shown in chapter III. The researcher assigns these results to meet the previously highlighted research objectives. Besides highlighting the research findings, the researcher clarifies them either by linking them to previous literature or by judging them under personal and practical belief. First, the researcher presents the results of implemented model in case of random function (Model 1), in which the contractors make their bid decisions randomly; then, compares them to the results of the implemented model in case of incorporating a learning module (Model 2), highlighting the effect of the learning from past bidding experience on the results. Furthermore, the winning bids of Model 1 would be compared those in case of using the SRNNE optimal bid function.

4.2 The model with the random function (Model 1)

This section presents the results of model 1, in which the contractors choose their bids randomly within the given range of choices as illustrated in chapter III. The results and its analysis is divided into different sections. First, the results of the single-stage bidding game (SSG) are presented in different six categories based on the project true cost, as previously shown in table 3.1. Then, those results are compared to the results in case of using the SRNNE optimal bid function for SSG. Second, the results of the multi-stage bidding game (MSG) are presented in the same different six categories for sub-contractors, general contractors, and both combined together. Those results are also compared to the results in case of using the SRNNE optimal bid function for MSG. Finally, an overall comparison is conducted between the results of SSG and MSG from the winner's curse perspective.

4.2.1 Single-stage bidding game (SSG)

In the single-stage bidding game, in which only three general contractors are competing against each other for the whole project in each round. It was found that, in 75 out of the 90 projects in all the six categories of projects as shown in figure 4.1 to 4.6, the winning general contractor suffered from the winner curse, by winning the project contract with a submitted bid less than the actual true cost of the project, which represents approximately 83% of all the projects being bid for in all the six projects' categories.

Based on past literature, this result is consistent with the four laboratory experiments conducted by Dyer et al. (1989), in which both inexperienced students and experienced executives suffered the winner's curse in three of the four experiments, and the profits just exceeded zero in the other experiment. Table C.1 in appendix C shows the results of the SSG of the implemented model 1.

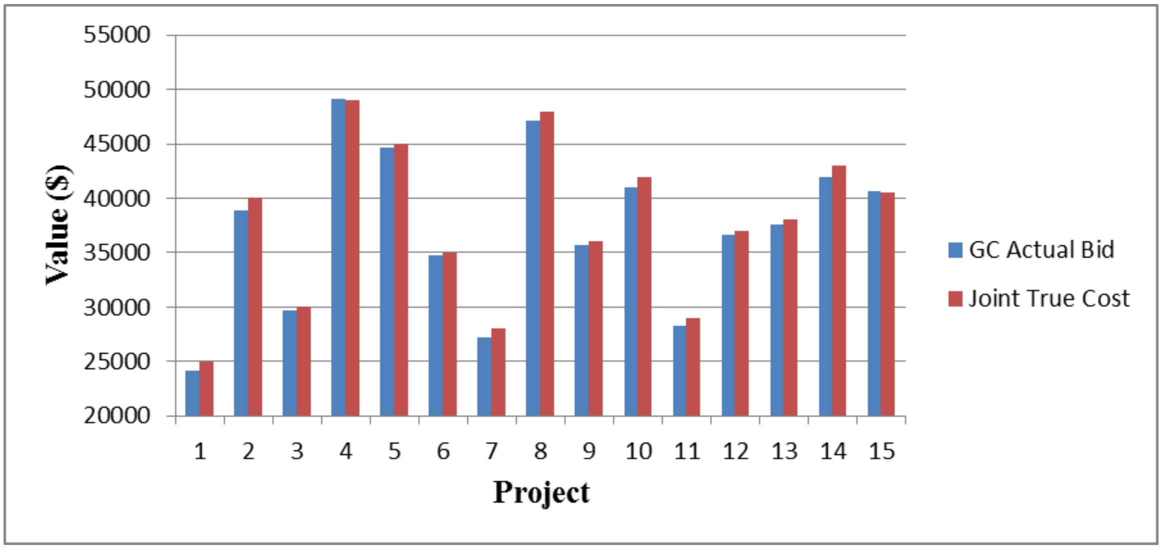

Figure 4.1 Category 1: GC actual bid vs. joint project true cost

(GC = General Contractor)

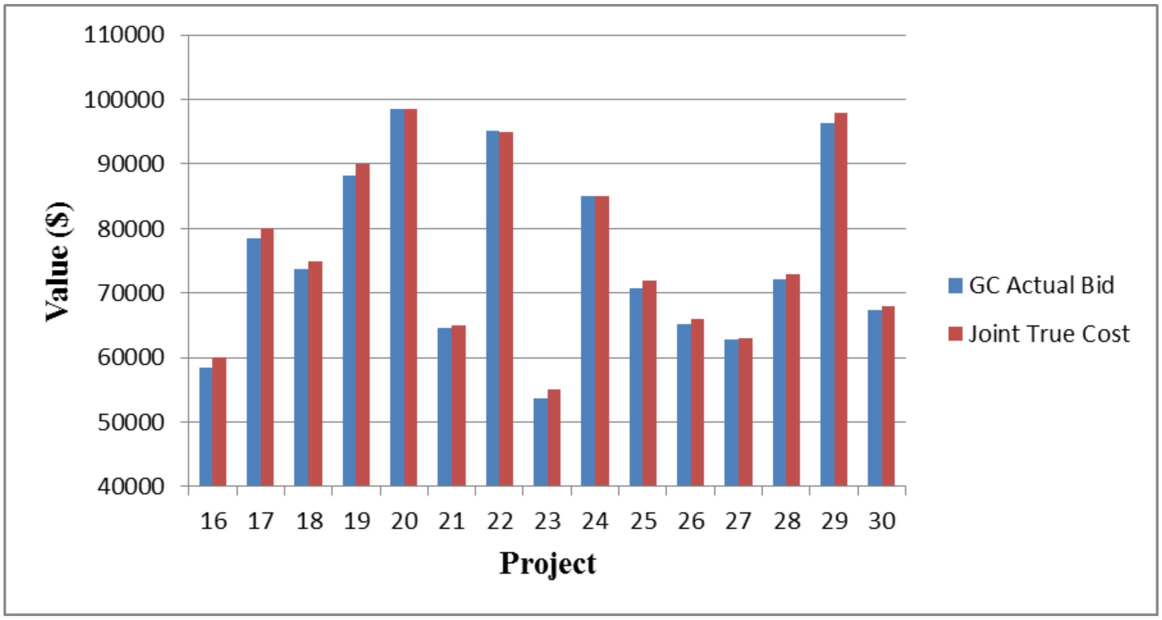

Figure 4.2 Category 2: GC actual bid vs. joint project true cost

(GC = General Contractor)

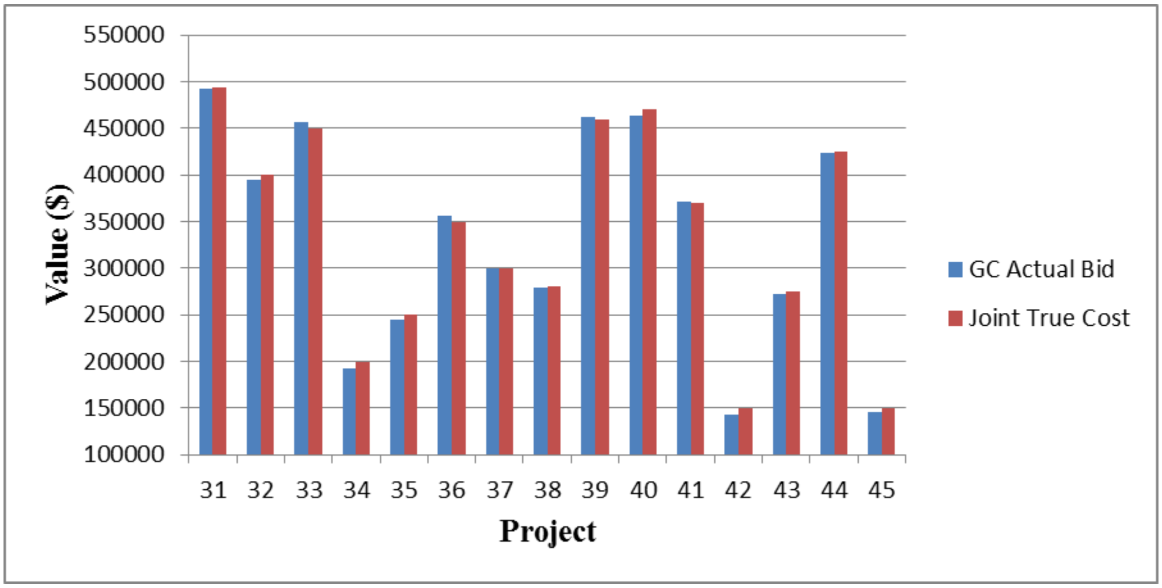

Figure 4.3 Category 3: GC actual bid vs. joint project true cost

(GC = General Contractor)

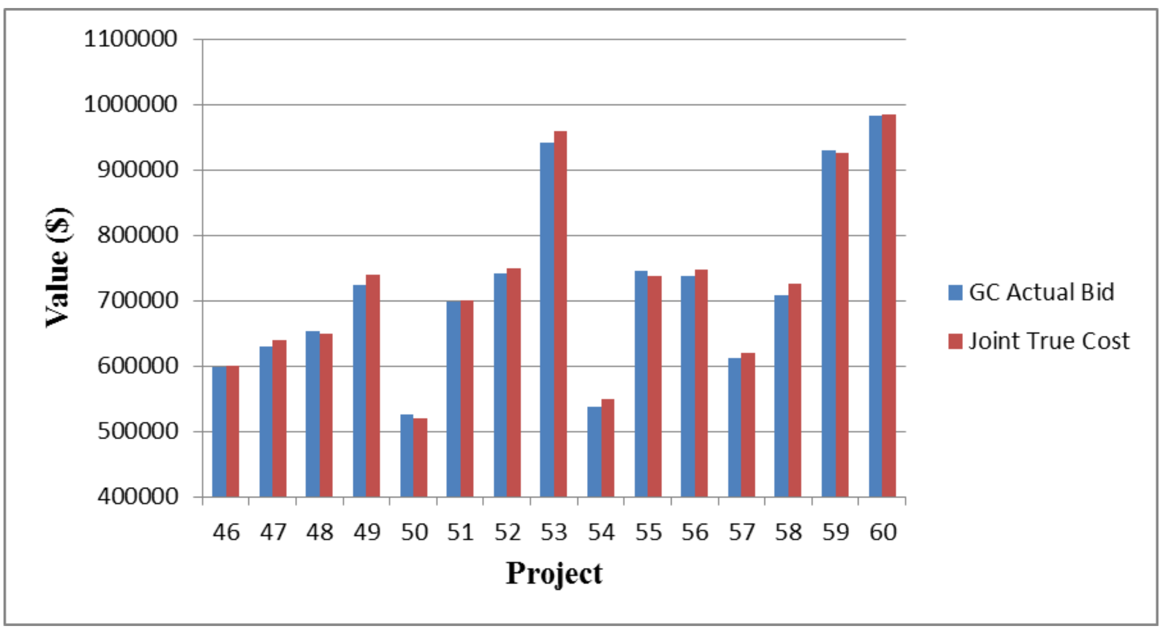

Figure 4.4 Category 4: GC actual bid vs. joint project true cost

(GC = General Contractor)

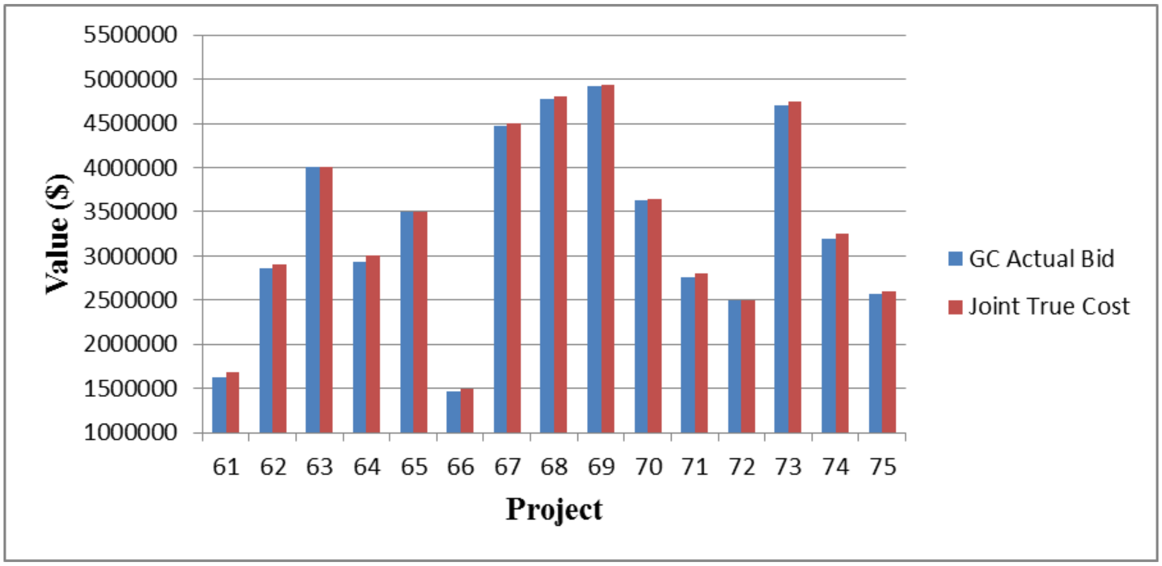

Figure 4.5 Category 5: GC actual bid vs. joint project true cost

(GC = General Contractor)

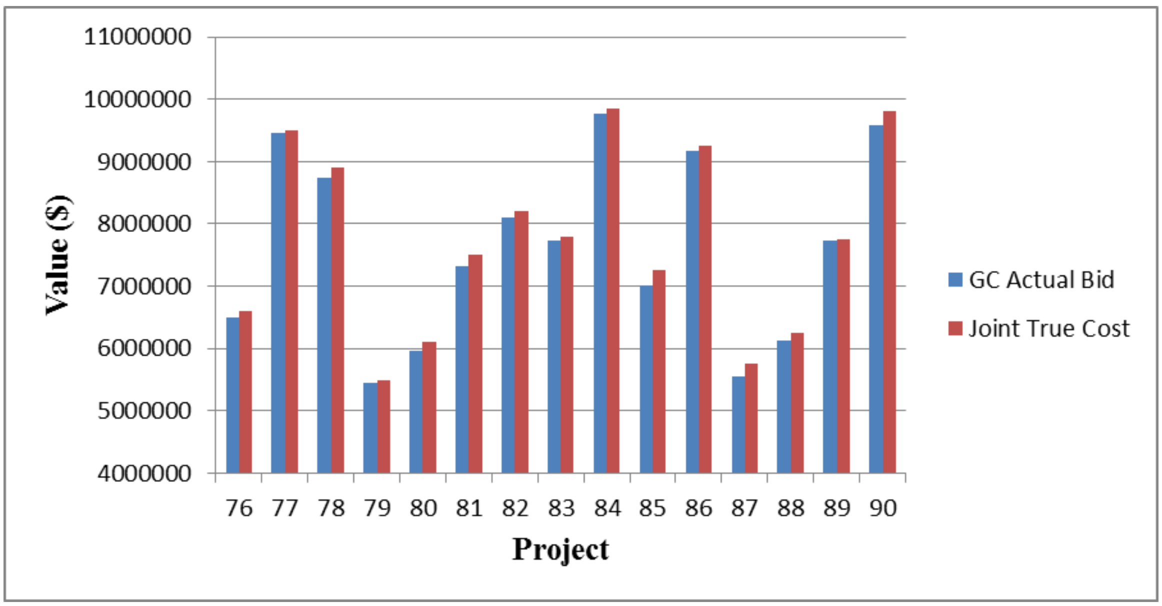

Figure 4.6 Category 6: GC actual bid vs. joint project true cost

(GC = General Contractor)

4.2.1.1 Case of using SRNNE optimal bid function for SSG

As aforementioned in chapter II, the SRNNE optimal bid function provides the contractors with a tool to avoid falling prey to the winner's curse. Based on the conducted analysis, it was found that using the SRNNE optimal bid function gives positive profits in 100% of the projects. In other words, all the optimal bids are greater than the projects' true cost.

In addition, as previously highlighted, the SRNNE does not guarantee that the contractor will win the project contract, but it guarantees that the contractor will not suffer, on average, from the winner's curse in case of winning the project contract. In other words, it guarantees that the winning contractor will earn, on average, positive profits based on a submitted bid which is greater than the true cost of the project, which makes it desirable for the use by the contractors is preparing their optimal bids.

Furthermore, the optimal bids give only a strategic profit just to be above the project true cost. Based on the implemented model 1's results, the average of the overall earned profits is 1.31% relative the project true cost. The results of the optimal bids for the SSG of model 1 are shown in table C.1 in appendix C. The following figures 4.7 to 4.12 show the comparison between the earned optimal profits and the actual losses or profits for each of the six categories. It is important to notice that the X-axis (zero in Y-axis) in the following figures represents the project true cost in each round, because in case of submitting a bid equal to the project true cost, the winning contractor will end up making zero profits or losses.

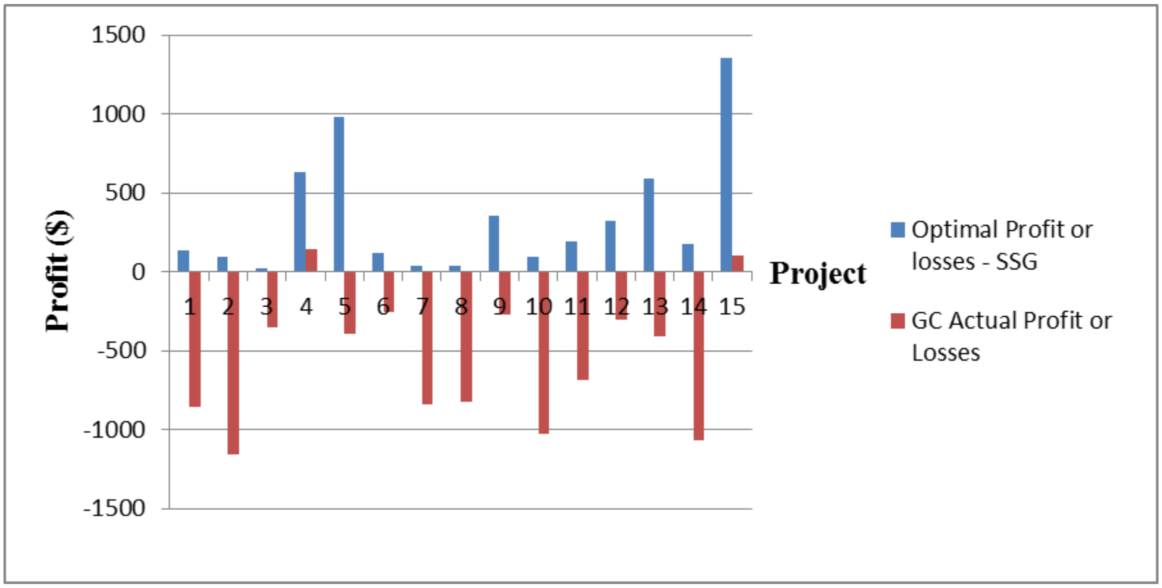

Figure 4.7 Category 1: the SSG optimal vs. actual profits or losses

(SSG = Single-Stage Bidding Game; GC = General Contractor)

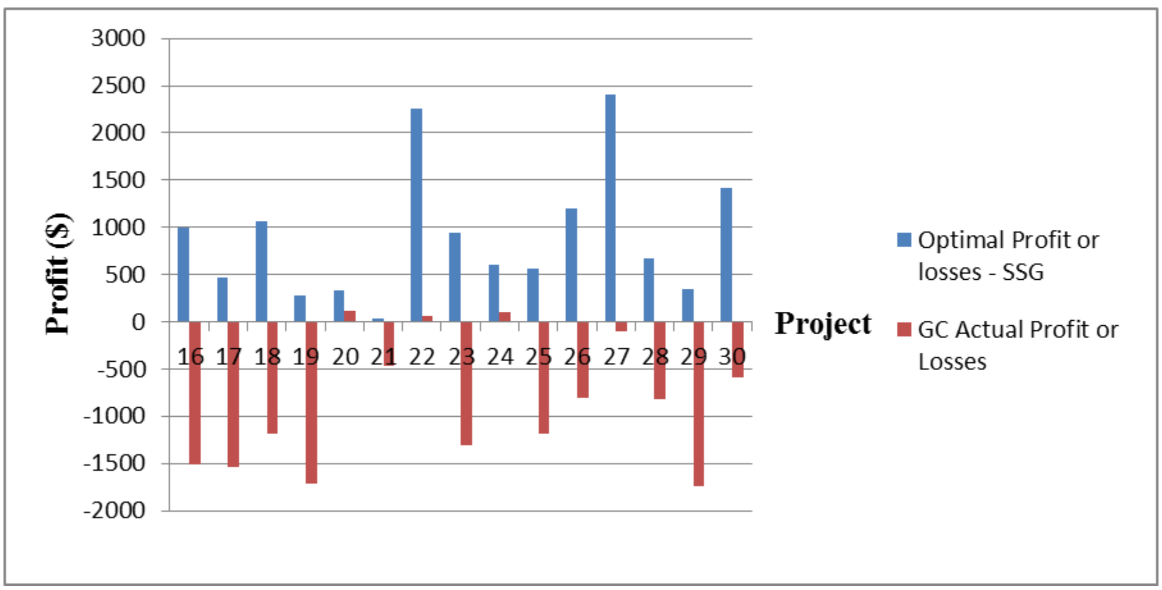

Figure 4.8 Category 2: the SSG optimal vs. actual profits or losses

(SSG = Single-Stage Bidding Game; GC = General Contractor)

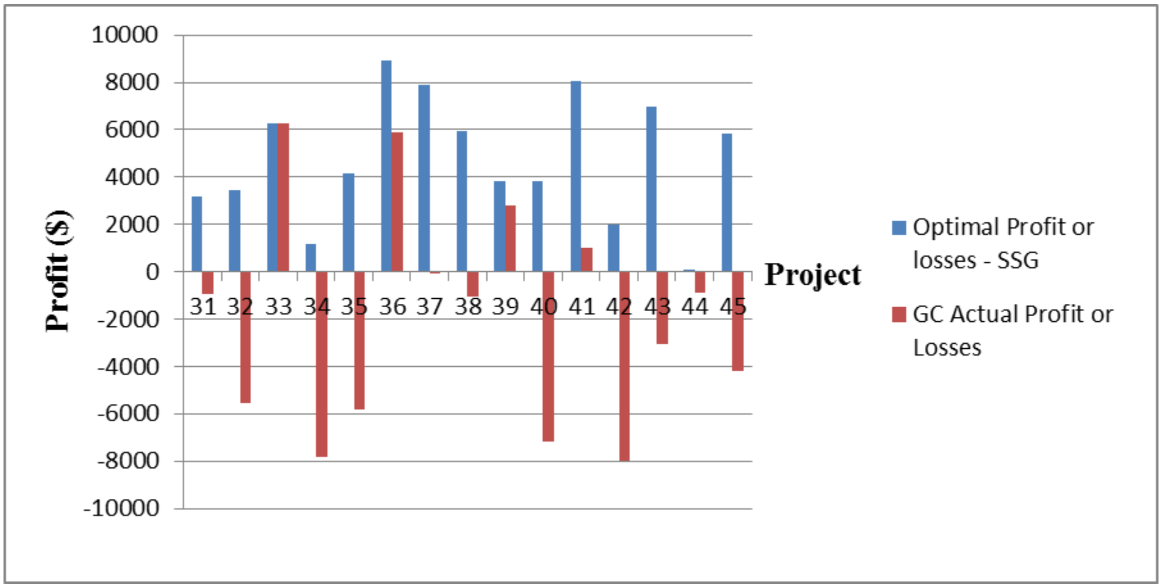

Figure 4.9 Category 3: the SSG optimal vs. actual profits or losses

(SSG = Single-Stage Bidding Game; GC = General Contractor)

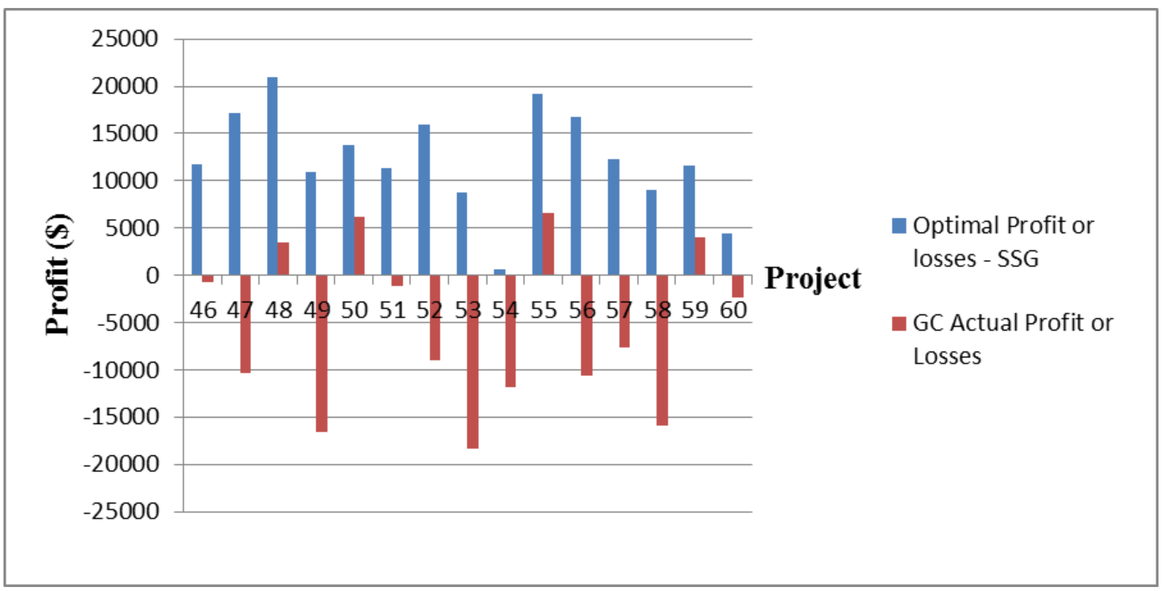

Figure 4.10 Category 4: the SSG optimal vs. actual profits or losses

(SSG = Single-Stage Bidding Game; GC = General Contractor)

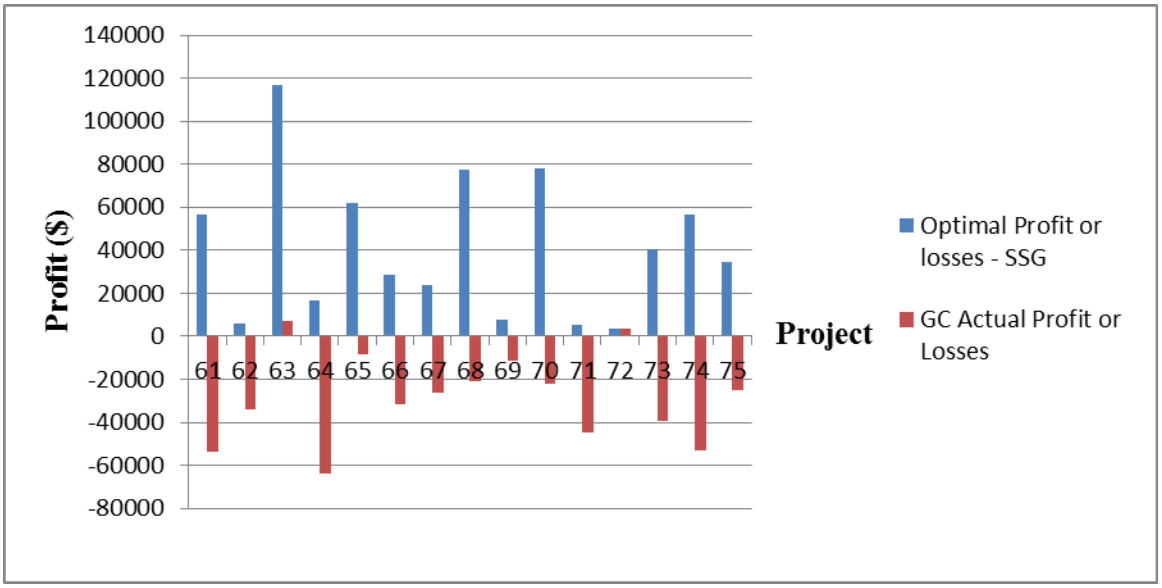

Figure 4.11 Category 5: the SSG optimal vs. actual profits or losses

(SSG = Single-Stage Bidding Game; GC = General Contractor)

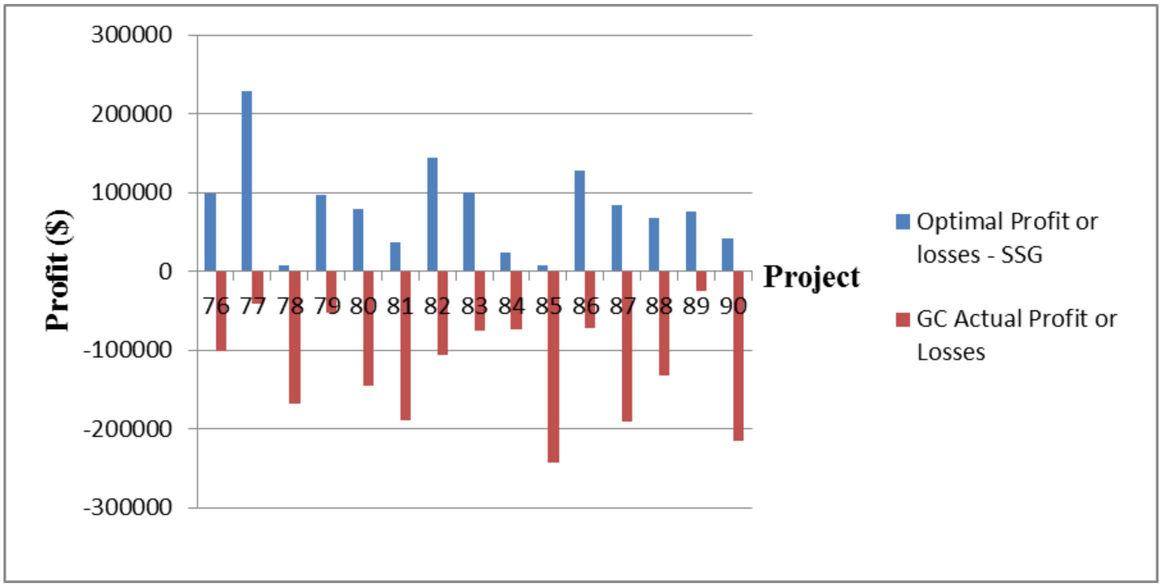

Figure 4.12 Category 6: the SSG optimal vs. actual profits or losses

(SSG = Single-Stage Bidding Game; GC = General Contractor)

4.2.2 Multi-stage bidding game (MSG)

This section shows the results of the MSG of the implemented model 1. As aforementioned in chapter III, in the MSG, there are three different sub-contractors who are competing against each other for each of the three general contractors. Being the case, the results of the winning sub-contractors relative to their part of the project are presented, then, the results of the winning general contractors at each round just for their part of the project. Thereafter, the results of the overall joint winning bids are presented and compared to those in case of using the SRNNE optimal bid function.

4.2.2.1 The winning sub-contractors' bids

In the MSG, the results indicated that the majority of winning sub-contractors suffered from the winner's curse in their part of the project by winning the project contract with a submitted bid which is less than the true cost for their part of the project. Based on the results from model 1, it was found that the winning sub-contractors suffered the winner's curse in 83 out the 90 projects being bid for, representing approximately 92% of the projects. This percentage is relatively high and refers to one of the mechanisms which are used by US general contractors to mitigate the winner's curse, as highlighted in chapter II. According to Dyer and Kagel (1996), general contractors could bid higher benefiting from the low submitted bids in part of their sub-contractors to win the project contract. Therefore, with such high percentage, it is anticipated to create more room for general contractors to avoid the winner's curse.

The results of the winning sub-contractors' bids are shown in table C.2 in appendix C. Moreover, the following figures 4.13 to 4.18 show the comparison between the winning sub-contractors' actual bids and the true cost of their part of the project.

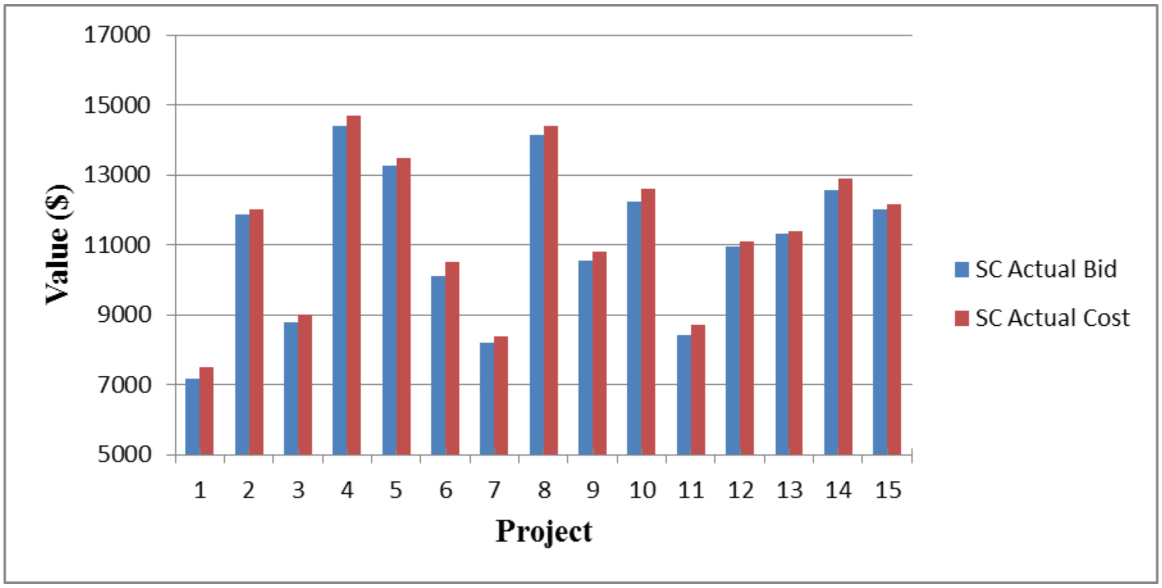

Figure 4.13 Category 1: the winning SC actual bid vs. SC actual project cost for his part of the project

(SC = Sub-Contractor)

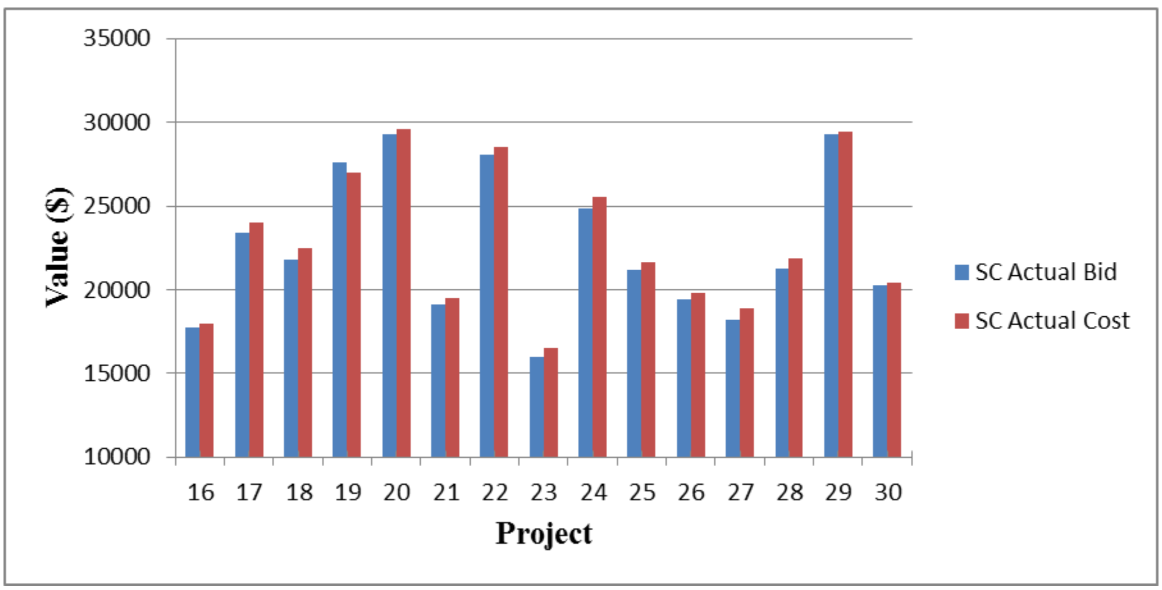

Figure 4.14 Category 2: the winning SC actual bid vs. SC actual project cost for his part of the project

(SC = Sub-Contractor)

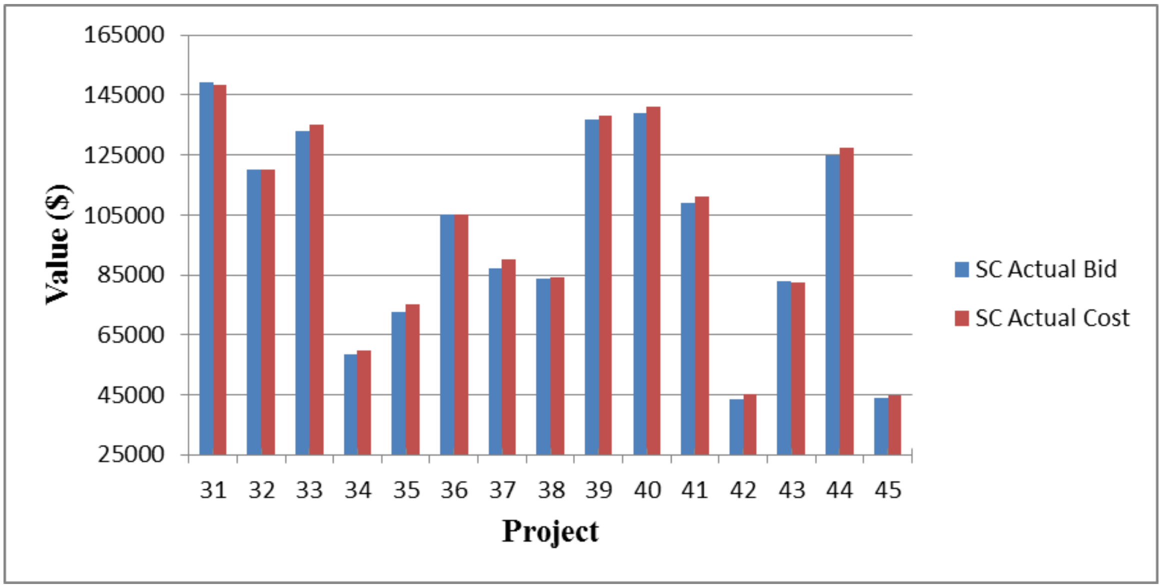

Figure 4.15 Category 3: the winning SC actual bid vs. SC actual project cost for his part of the project

(SC = Sub-Contractor)

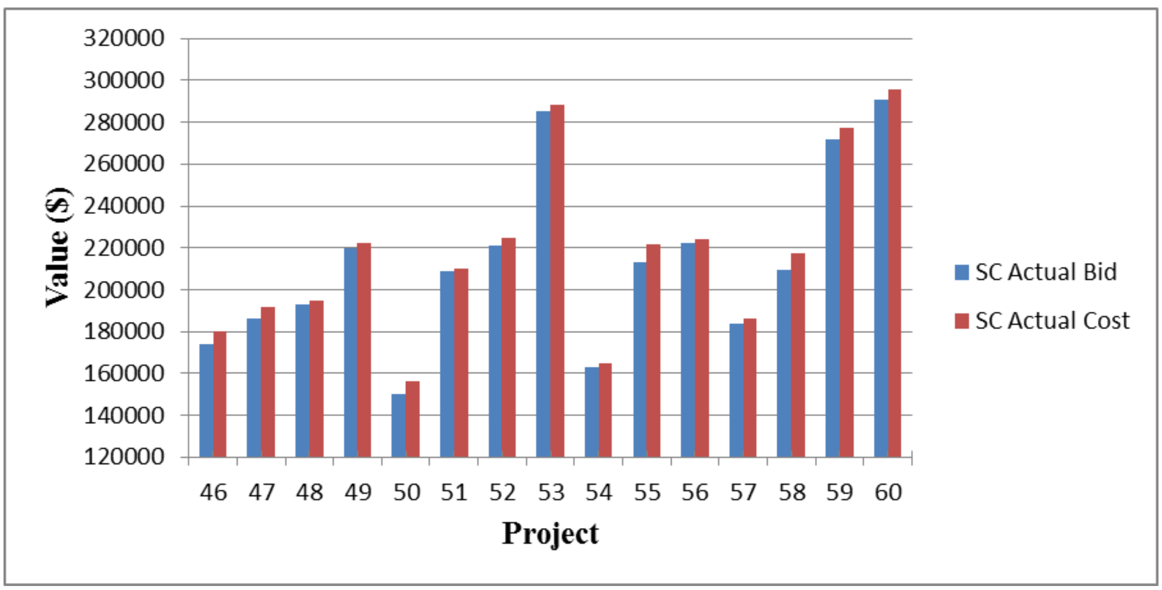

Figure 4.16 Category 4: the winning SC actual bid vs. SC actual project cost for his part of the project

(SC = Sub-Contractor)

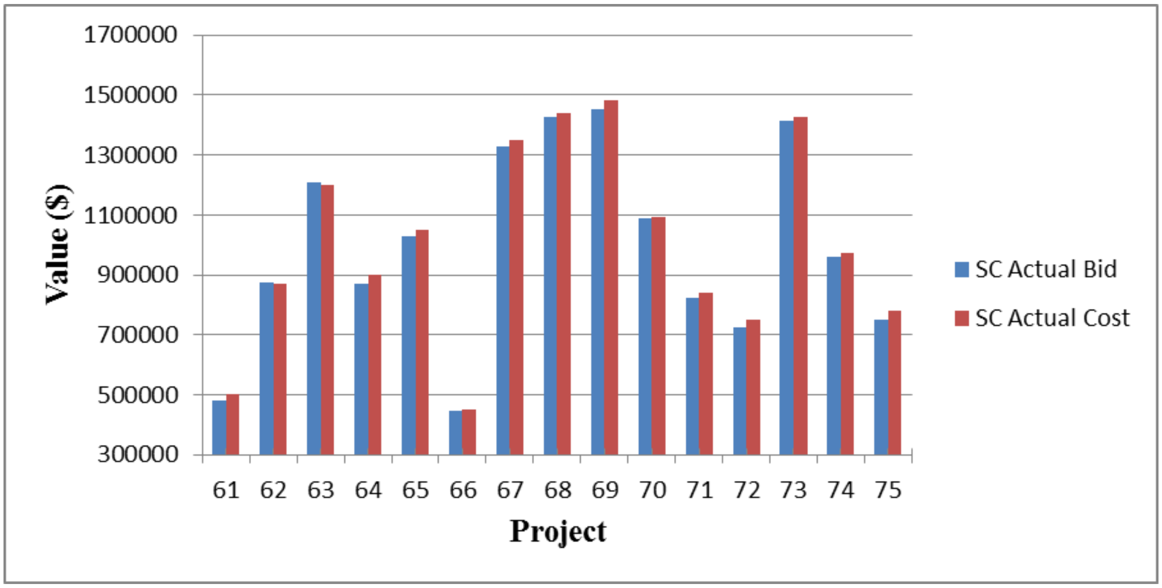

Figure 4.17 Category 5: the winning SC actual bid vs. SC actual project cost for his part of the project

(SC = Sub-Contractor)

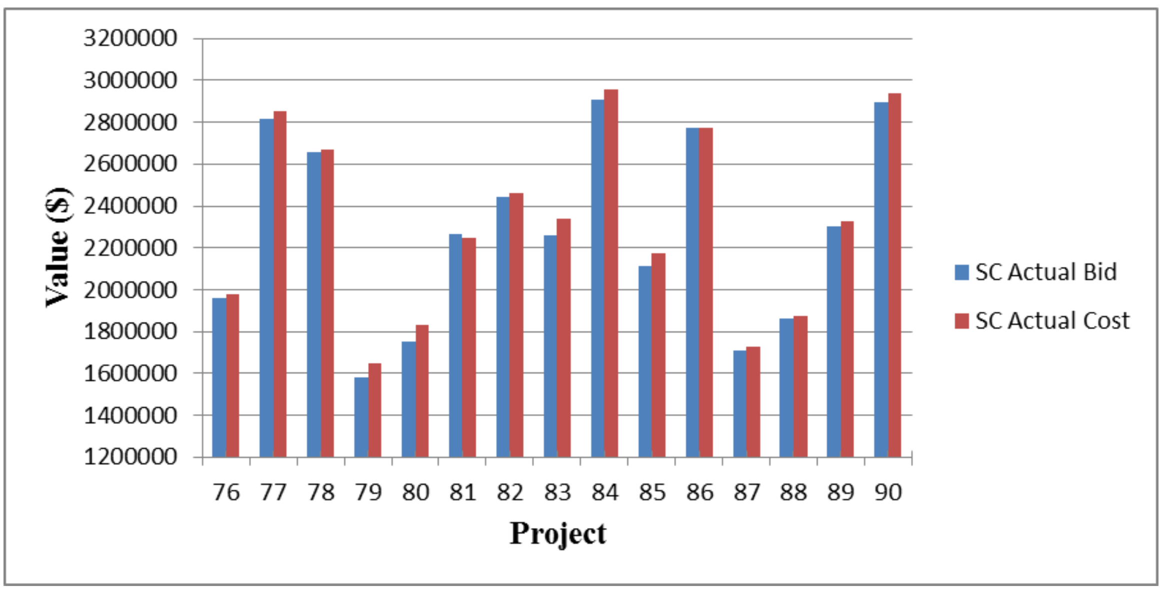

Figure 4.18 Category 6: the winning SC actual bid vs. SC actual project cost for his part of the project

(SC = Sub-Contractor)

4.2.2.2 The winning general contractors' bids

In the MSG, the results indicated that the majority of the winning general contractors also suffered from the winner's curse in their part of the project, by winning the project contract with a bid less than the true cost for their part of the project. Based on the results from model 1, it was found that the winning general contractors suffered the winner's curse in 77 out of the 90 projects being bid for, representing approximately 86% of the projects. The results of the winning general contractors' bids are shown in table C.3 in appendix C. the following figures 4.19 to 4.24 show the comparison between the winning general contractors' actual bids and the true cost of their part of the project.

Furthermore, the results indicated that in the MSG, all the projects, except one project, in which the winning general contractors earned some profits (i.e. 13 projects) in their part of the project, their corresponding winning sub-contractors suffered from the winner's curse. Therefore, it is important to highlight that based on the previously discussed characteristics of the construction bidding and non-cooperative game theory, each of the winning sub-contractors or general contractors is considered liable to his submitted bid for his part of the project. In other words, the party who suffers some losses in his part of the project is considered liable to them, while the other will earn profits based on his submitted bid for his part of the project.

Furthermore, the results indicated that the winning general contractors are able to avoid the winner's curse more often than the winning sub-contractors. This refers to the aforementioned mechanism, stated by Dyer and Kagel (1996), in which the general contractors benefit from the low submitted bids by the sub-contractors to win the project contract and mitigate the likelihood of suffering from the winner's curse.

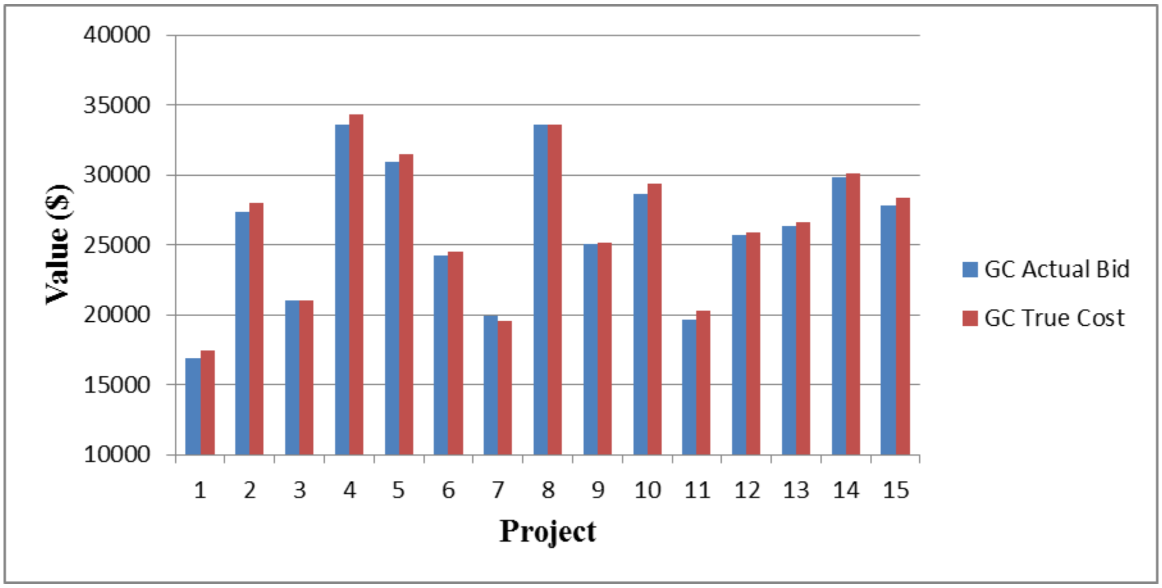

Figure 4.19 Category 1: the winning GC actual bid vs. GC actual project cost for his part of the project

(GC = General Contractor)

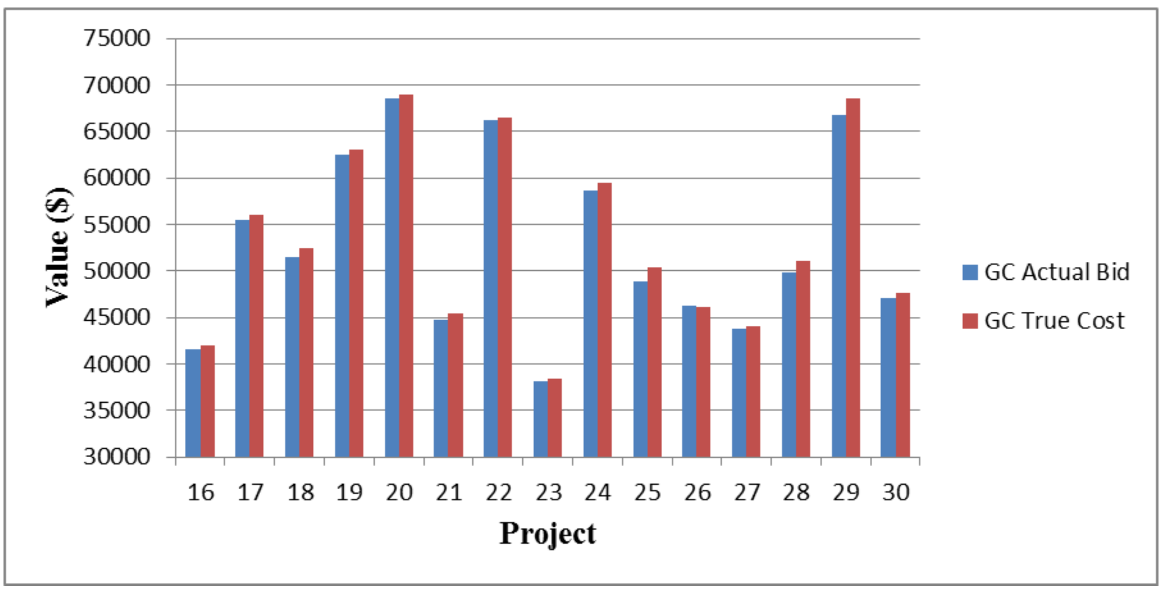

Figure 4.20 Category 2: the winning GC actual bid vs. GC actual project cost for his part of the project

(GC = General Contractor)

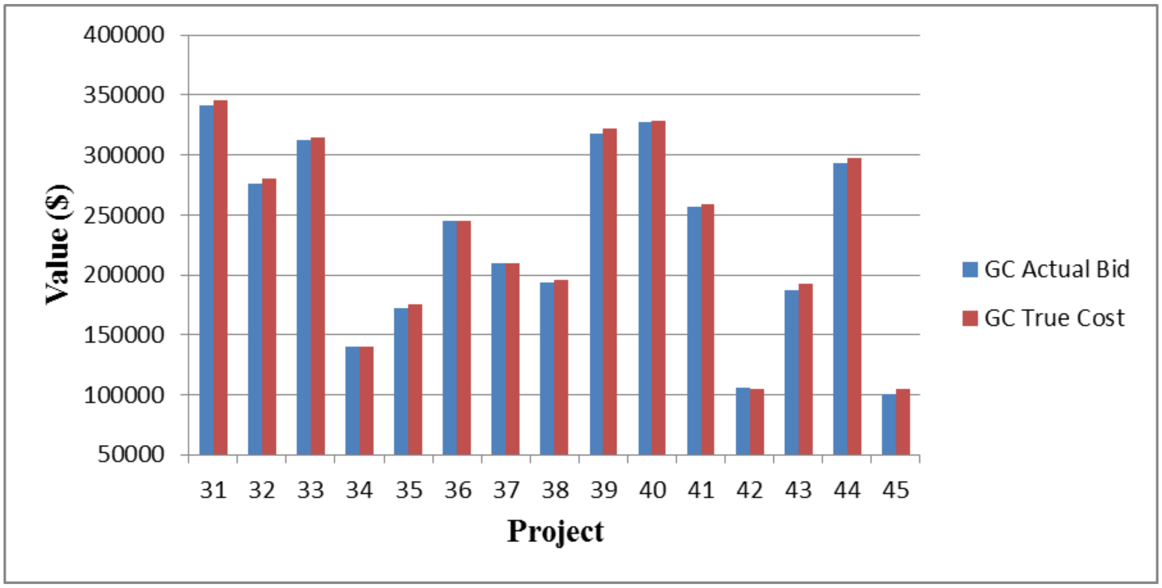

Figure 4.21 Category 3: the winning GC actual bid vs. GC actual project cost for his part of the project

(GC = General Contractor)

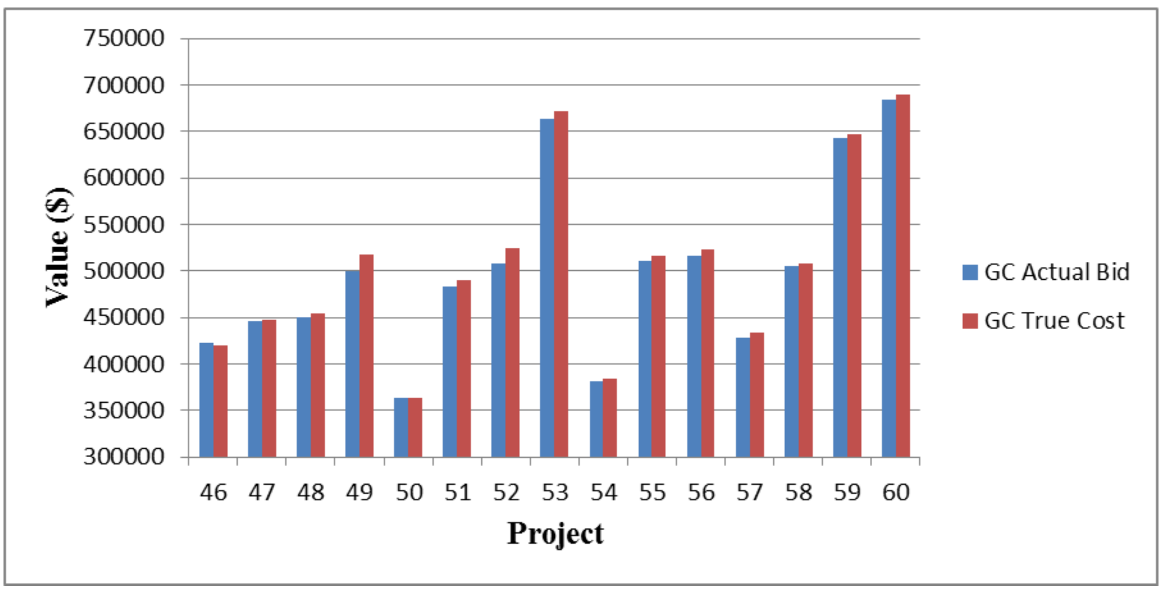

Figure 4.22 Category 4: the winning GC actual bid vs. GC actual project cost for his part of the project

(GC = General Contractor)

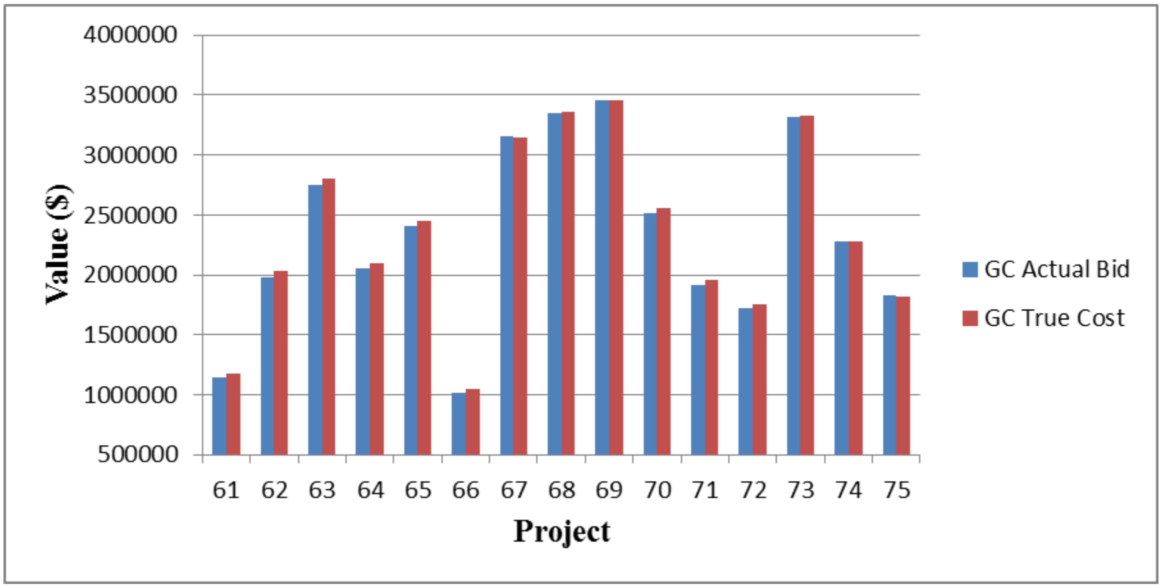

Figure 4.23 Category 5: the winning GC actual bid vs. GC actual project cost for his part of the project

(GC = General Contractor)

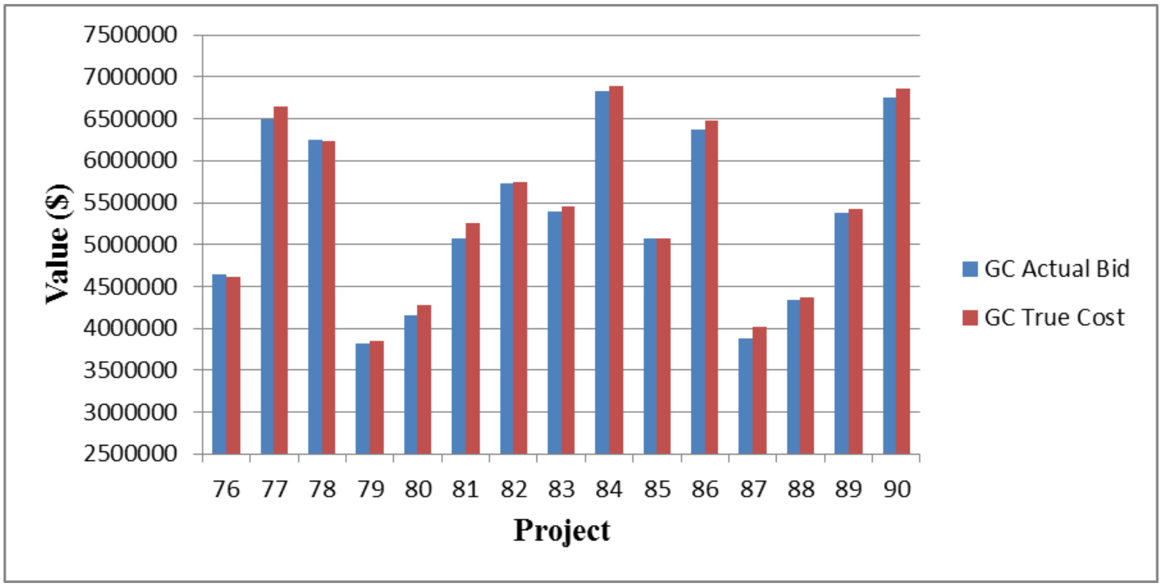

Figure 4.24 Category 6: the winning GC actual bid vs. GC actual project cost for his part of the project

(GC = General Contractor)

4.2.2.3 Case of using SRNNE optimal bid function vs. the joint actual bid for MSG

In Order to win a project contract in the MSG, a general contractor must submit a joint bid less than the joint bids submitted by his competitors. In preparing the joint bid, a general contractor considers the bid of his winning sub-contractor plus the bid for his part of the project. Based on the results of the MSG of model 1, it was found that in 85 out of the 90 projects, the overall winning joint bid is less than the joint true cost of the project, which represents approximately 94% of the projects. Despite that in some projects either the winning sub-contractor or/and general contractor made positive profits, this result is due to the high losses in the submitted bid in part of one of them.

Furthermore, the SRNNE is derived to be used for symmetric bidders within the same stage of bidding. Thus, in this research, it is assumed that the SRNNE is used separately at each stage of bidding for the MSG. Based on the results, it was found that using the SRNNE optimal bid function by both the winning sub-contractors and general contractors, both in their parts of the project, will result in an optimal joint bid which is greater than the joint true cost of the project, which guarantees positive profits for both of the winning parties, and aids the winning parties to avoid the winner's curse. Based on the implemented model 1's results, the average of the overall earned profits is 1.27% relative to the joint project true cost.

The results of the joint actual bids of the MSG and joint optimal bids for each of the projects in the six projects' categories are shown in table C.4 in appendix C. the following figures 4.25 to 4.30 show the comparison between the earned joint optimal profits and the joint actual profits or losses for the MSG for each of the six projects' categories. It is important to highlight that the X-axis (zero in Y-axis) in the following figures represents the joint true cost of the project in each round.

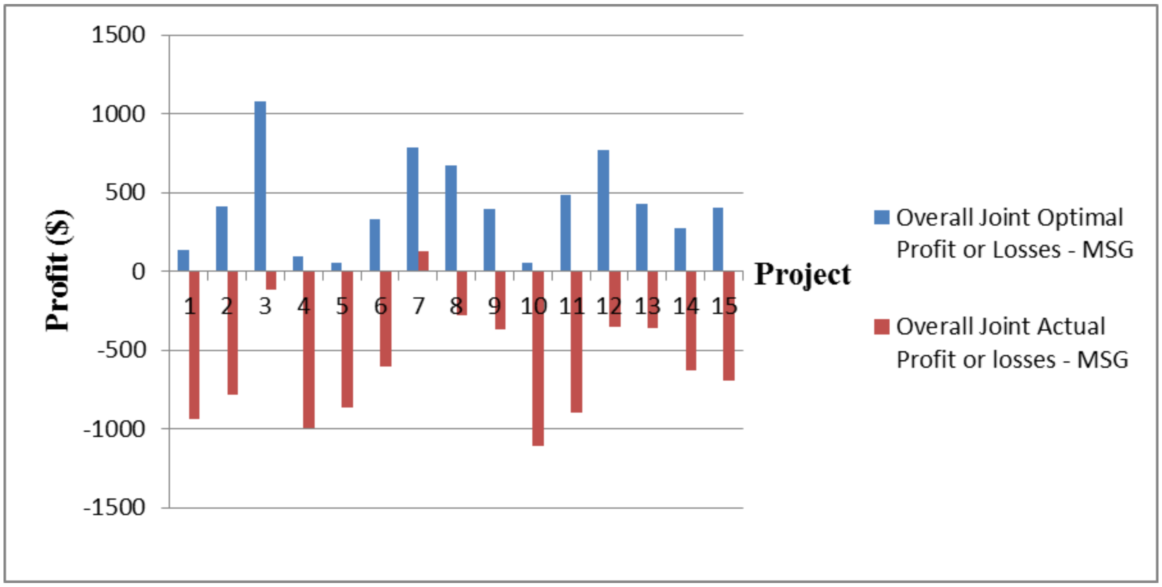

Figure 4.25 Category 1: the MSG joint optimal vs. joint actual profits or losses (MSG = Multi-Stage Bidding Game)

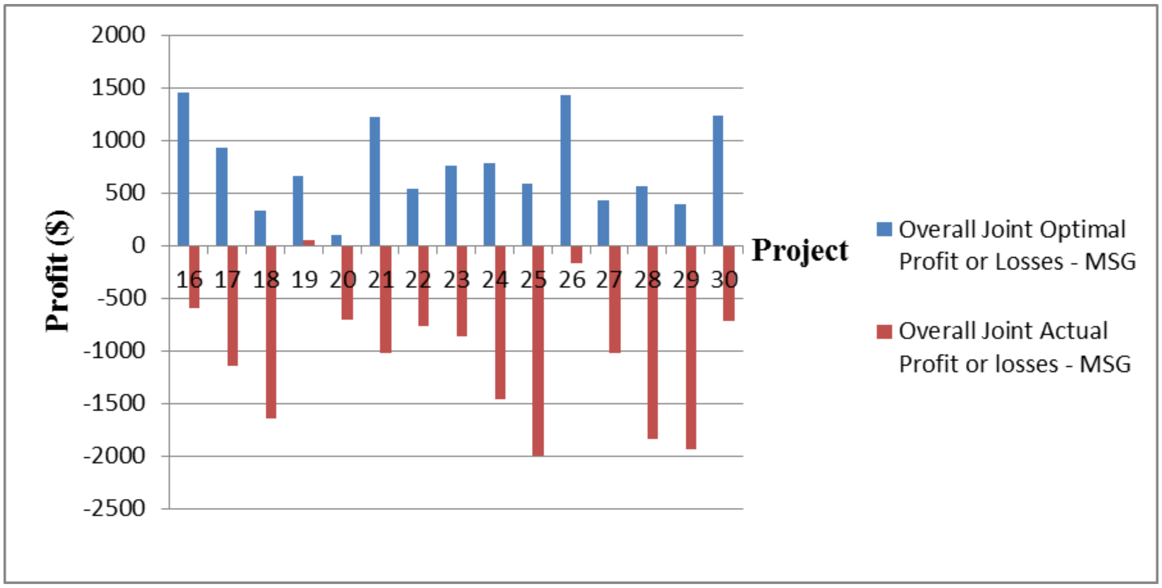

Figure 4.26 Category 2: the MSG joint optimal vs. joint actual profits or losses

(MSG = Multi-Stage Bidding Game)

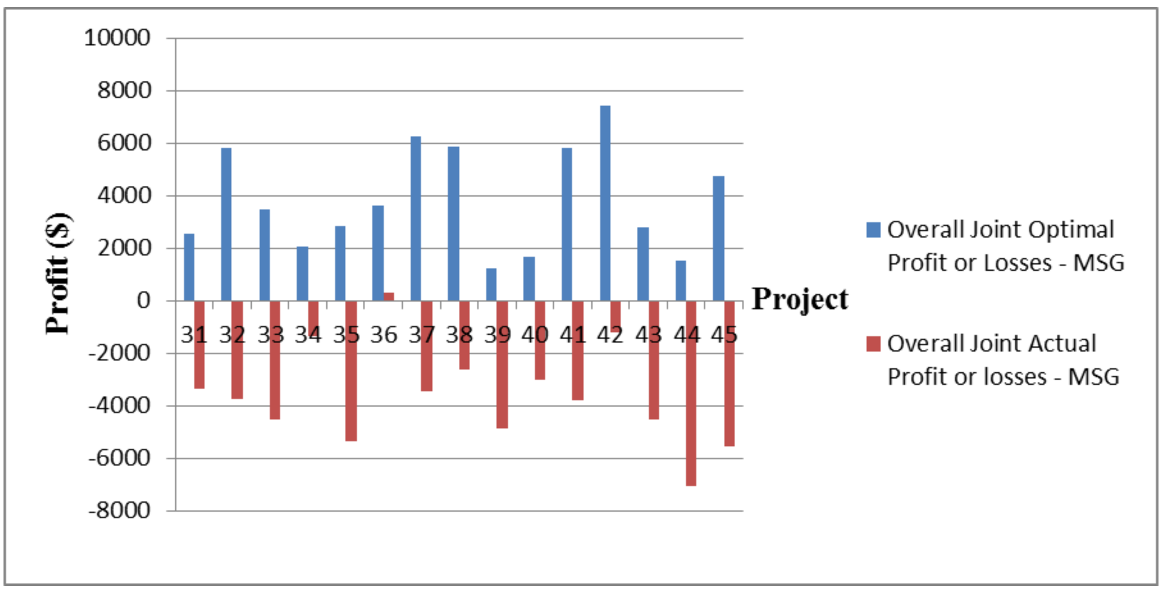

Figure 4.27 Category 3: the MSG joint optimal vs. joint actual profits or losses

(MSG = Multi-Stage Bidding Game)

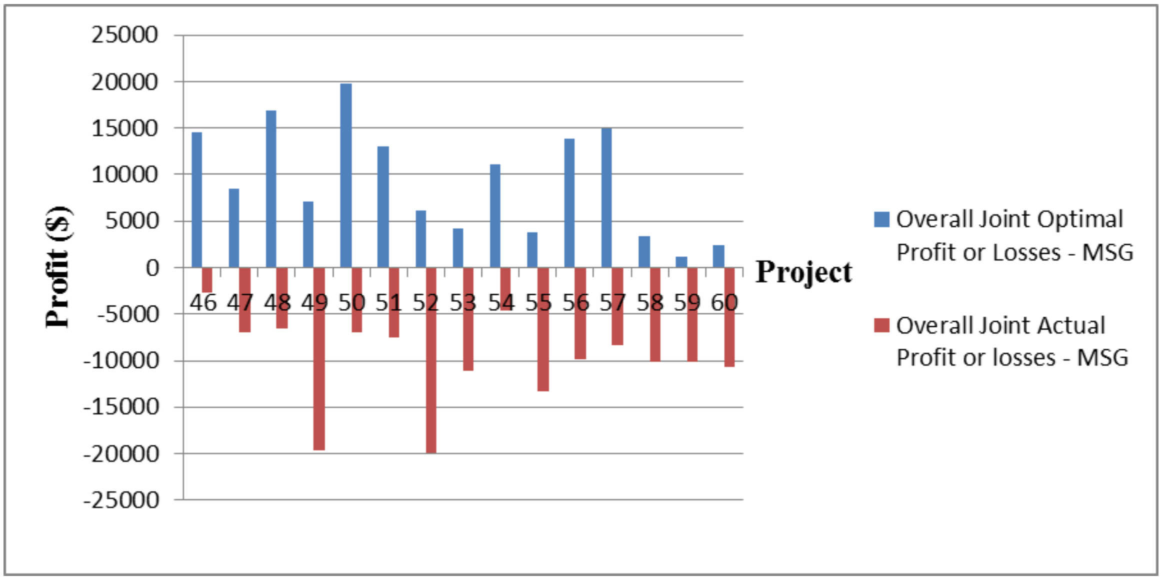

Figure 4.28 Category 4: the MSG joint optimal vs. joint actual profits or losses

(MSG = Multi-Stage Bidding Game)

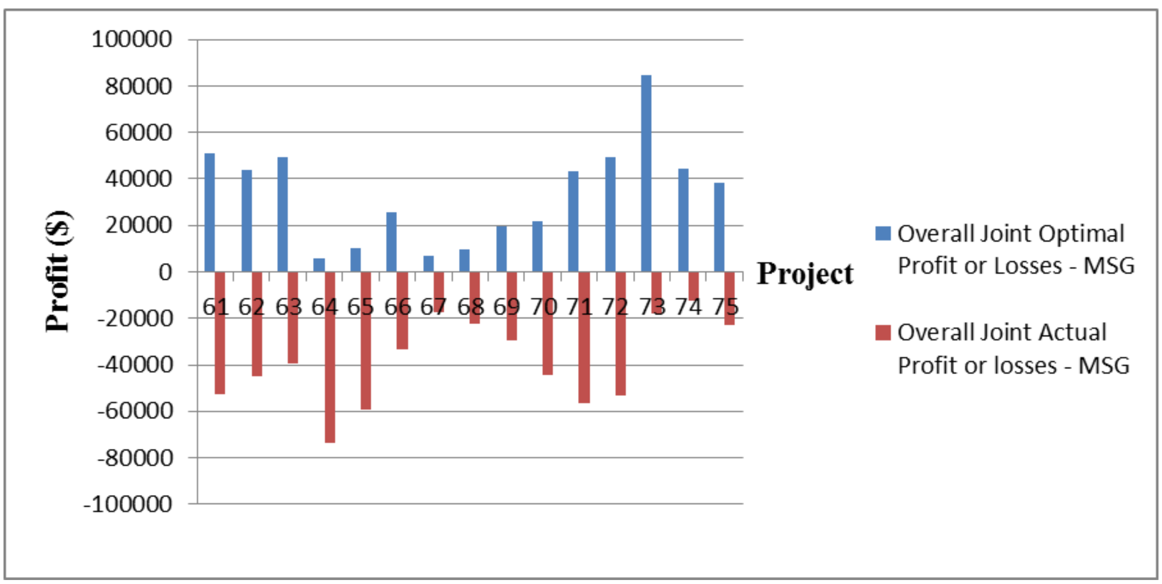

Figure 4.29 Category 5: the MSG joint optimal vs. joint actual profits or losses

(MSG = Multi-Stage Bidding Game)

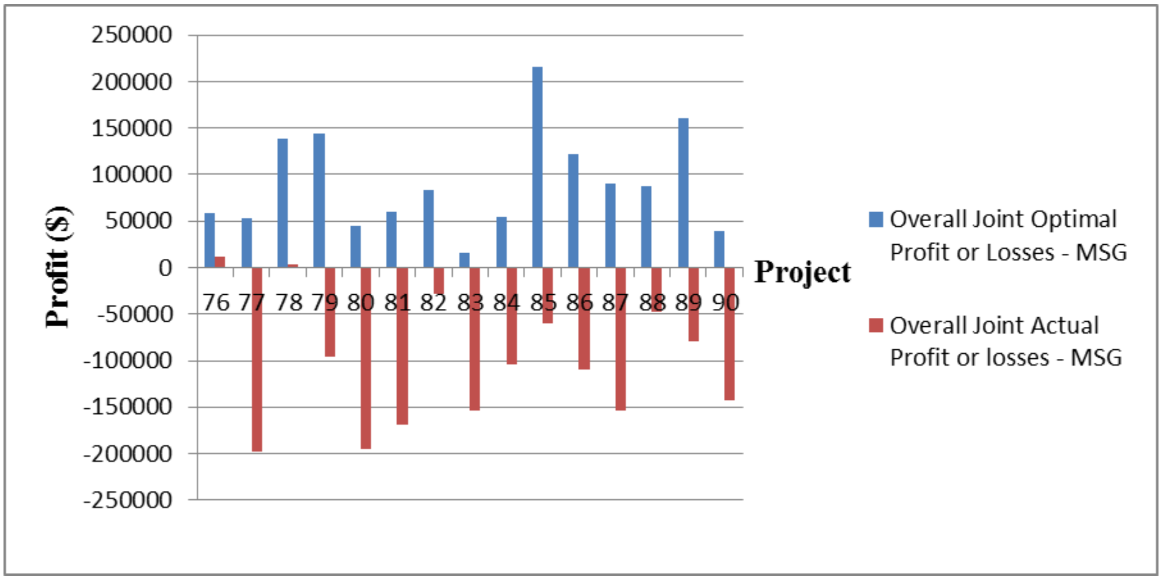

Figure 4.30 Category 6: the MSG joint optimal vs. joint actual profits or losses (MSG = Multi-Stage Bidding Game)

4.2.3 The comparison between single-stage bidding game and multi-stage bidding game of model 1

Based on the results of the implemented model 1, it was found that the SSG is giving less losses as compared to the overall losses of the MSG. This result was observed in 56 projects of the total 90 projects, which represents approximately 62% of all projects, as shown in table 4.1.

In fact, this result was expected because in the MSG, the winner's curse is expected to happen twice, one in part of the winning sub-contractors and the other in part of the winning general contractors. Not addressed in the literature is the fact that most, if not all, large jobs are awarded to a general contractor who in turn-subcontracts most, if not all, actual engineering services. Therefore, due to the multi-stage bidding environment, adverse selection and the winner's curse problem is compounded in most of the projects in the MSG. Being the case, the projects, which incorporates multi-bidding environment, is expected, due to suffering more losses than those of single-stage bidding environment, to face more conflicts, claims, and disputes for all the associated stakeholders.

From the general contractor perspective, the results indicated that the winning general contractors suffered, on average, approximately the same percentage of losses relative to the true cost of their part of the project as shown in Table 4.1. Therefore, the general contractors have no preference to either MSG or SSG from the winner's curse perspective. They might prefer the SSG over the MSG due to the aforementioned increased amount of conflicts, claims, and disputes associated with the MSG. on the other hand, they might prefer the MSG over the SSG based on the size of the project.

The following figures 4.31 to 4.36 show the comparison between the overall actual profit or losses of the MSG and those of the SSG for each project in each of the six projects' categories. Moreover, the X-axis (zero in Y-axis) in the following figures represents the joint true cost of the project in each round.

Table 4.1 Comparison between MSG and SSG from the winner's curse perspective

Case	% of the projects which gives positive profits	% of the projects which gives less losses than the other case	Average % of losses relative to the overall project true cost	Average % of GC losses relative to the GC part of the project
SSG	16.66%	62.22%	1.20%	1.19%
MSG	5.56%	37.78%	1.38%	1.21%

Note: (SSG = Single-Stage Bidding Game; MSG = Multi-Stage Bidding Game; GC = General Contractor)

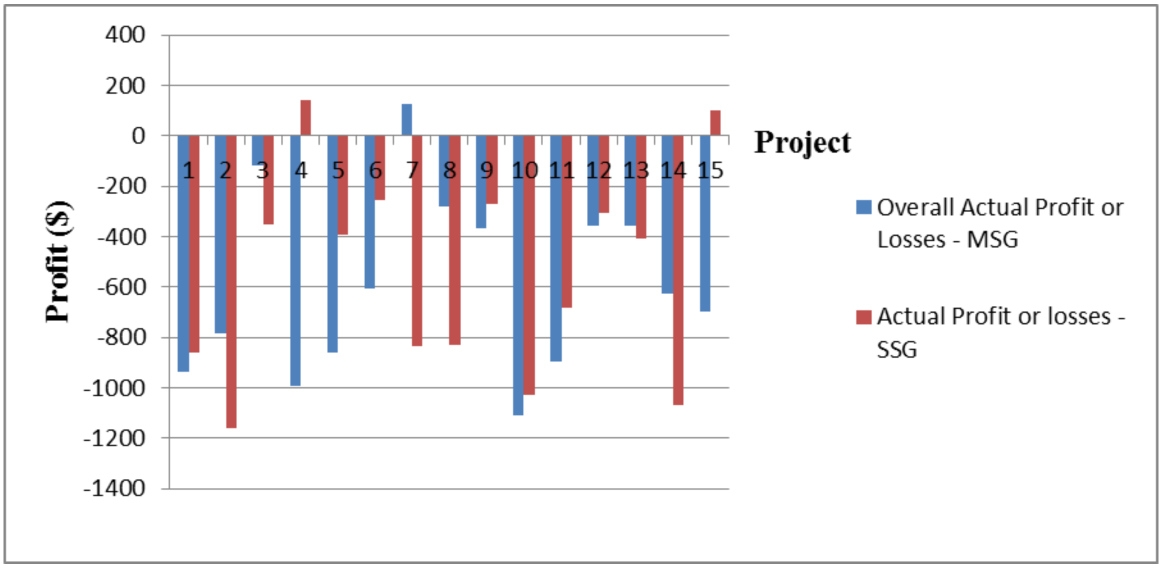

Figure 4.31 Category 1: overall MSG vs SSG actual profit or losses – model 1

(SSG = Single-Stage Bidding Game ;MSG = Multi-Stage Bidding Game)

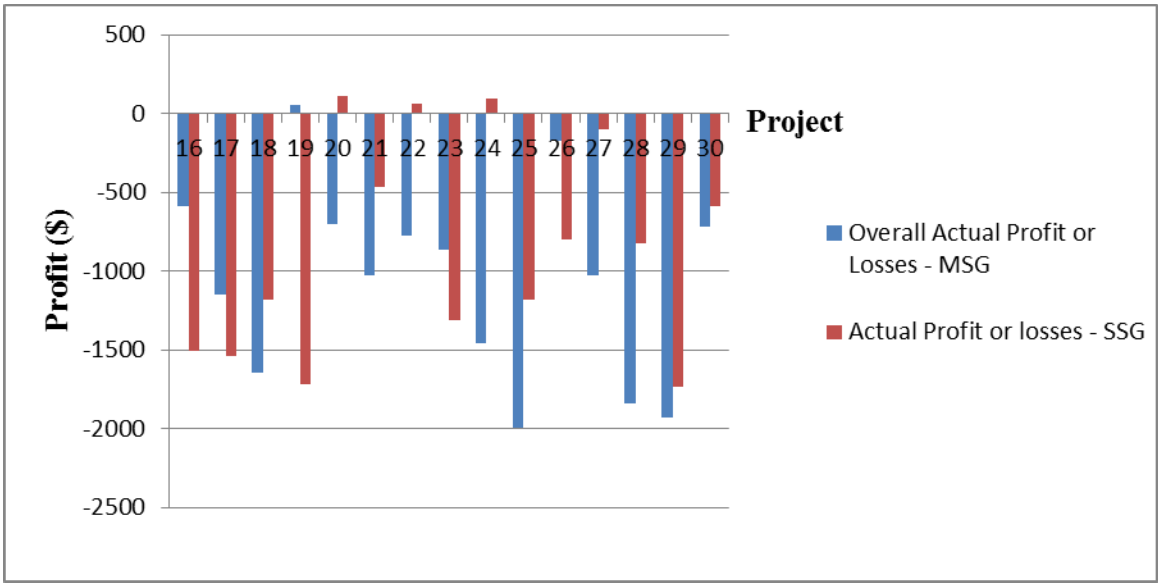

Figure 4.32 Category 2: overall MSG vs SSG actual profit or losses – model 1

(SSG = Single-Stage Bidding Game ;MSG = Multi-Stage Bidding Game)

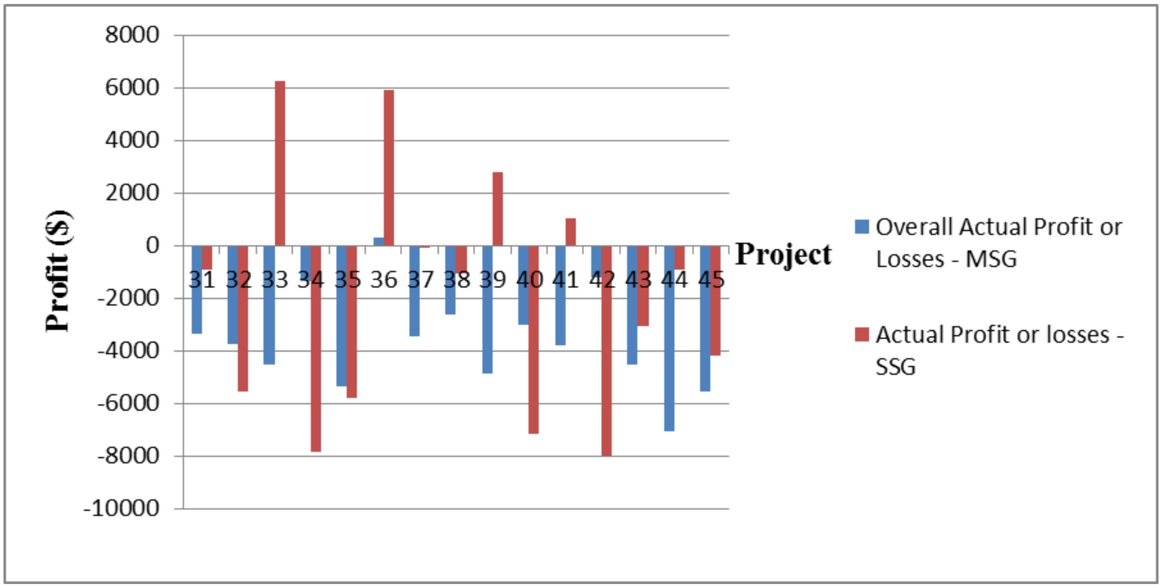

Figure 4.33 Category 3: overall MSG vs SSG actual profit or losses – model 1

(SSG = Single-Stage Bidding Game ;MSG = Multi-Stage Bidding Game)

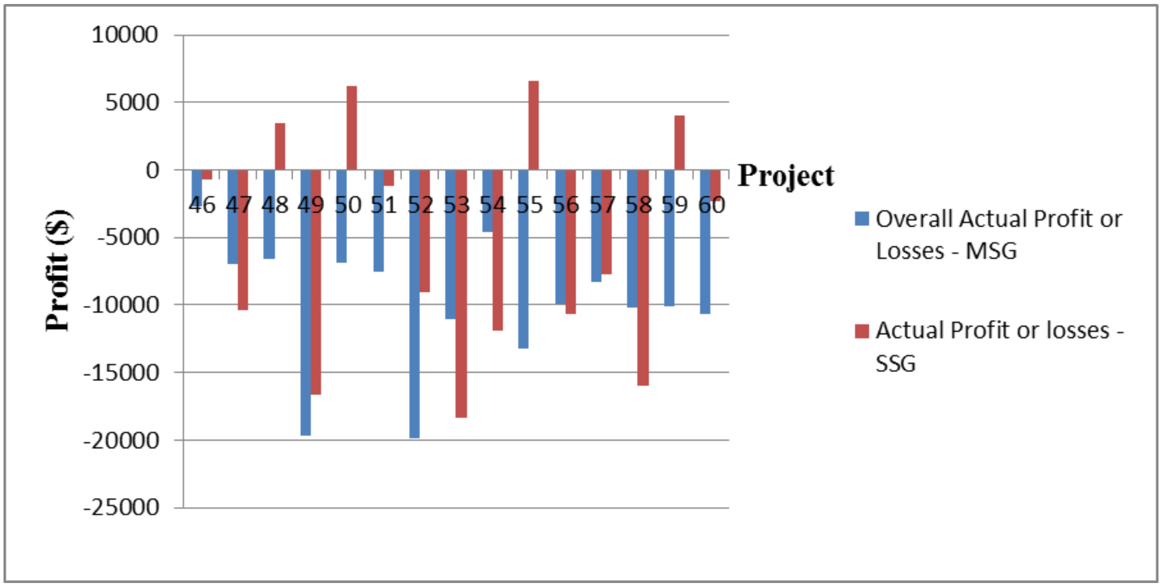

Figure 4.34 Category 4: overall MSG vs SSG actual profit or losses – model 1

(SSG = Single-Stage Bidding Game ;MSG = Multi-Stage Bidding Game)

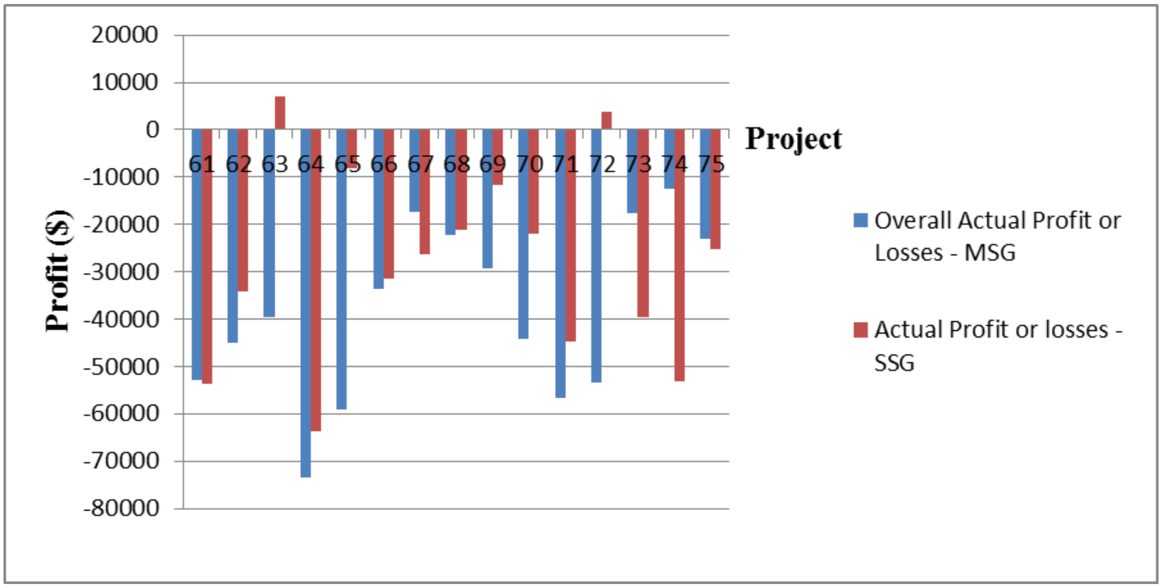

Figure 4.35 Category 5: overall MSG vs SSG actual profit or losses – model 1

(SSG = Single-Stage Bidding Game ;MSG = Multi-Stage Bidding Game)

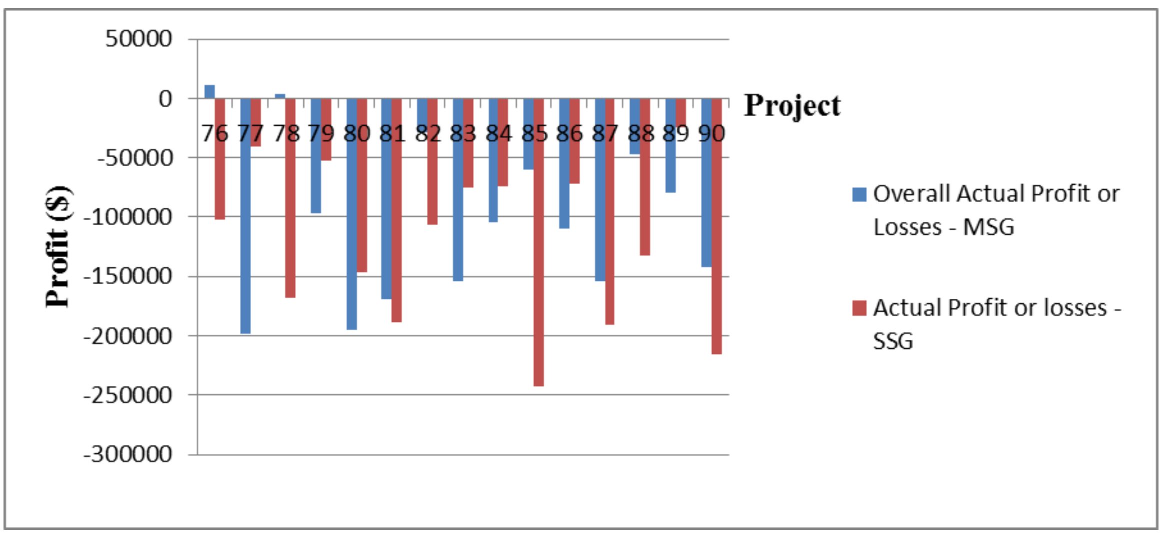

Figure 4.36 Category 6: overall MSG vs SSG actual profit or losses – model 1

(SSG = Single-Stage Bidding Game ;MSG = Multi-Stage Bidding Game)

4.3 The model with the learning module (Model 2)

The learning module was introduced to the random function model (Model 1) in order to examine the effect of learning from past experience and bid decisions on the results of the SSG and MSG. In general, based on the researcher's point of view, the learning model (Model 2) is more representative of the construction bidding in reality. Because contractors gain more bidding experience with time, they learn how to prepare bids to mitigate the likelihood of the winner's curse and increase the probability of their long term survivability. Therefore, learning and benefiting from information gained from every bidding competition are important factors of real construction bidding. Being the case, model 2 was implemented to compare its results to those of model 1 and analyze the effect of learning on contractors' bid decisions.

From the simulations of the learning model (Model 2) it is demonstrated that the MSG results in less overall losses than the SSG, which is opposite to what happened in model 1. As shown in table 4.2, in model 2, the MSG resulted in less overall losses or more positive profits in 68 out of the 90 projects, representing approximately 75.56% of all the projects being bid for in the six projects' categories. By comparing this result to that of model 1, which was only, 37.78%, it is obvious that the learning from gained bidding experience aids contractors in the MSG to mitigate the winner's curse more than in the SSG.

The aforementioned result is reasonable of model 2 is considered reasonable as in the MSG, there is more chance for learning in the same round (same project contract competition) than in the SSG. In the MSG, it is expected that learning is going to happen twice, one on side of the sub-contractors and the other on side of the general contractors. Therefore, as shown in Table 4.2, the MSG started to give better results than the SSG, from the perspective of suffering from the winner's curse problem, when the learning behavior was introduced to the model. The following figures 4.37 to 4.42 show the comparison between the overall actual profit or losses of the MSG and those of the SSG of model 2 for each project in each of the six projects' categories. Moreover, the X-axis (zero in Y-axis) in the following figures represents the joint true cost of the project in each round. The results of SSG and MSG of model 2 are shown in tables D.1 and D.2 in appendix D.

Table 4.2 Comparison between SSG and MSG of both models from the winner's curse perspective

From	Model 1 with Random Function		Model 2 with Learning Module	
	SSG	MSG	SSG	MSG
% of the projects which give less losses (SSG vs. MSG)	62.22%	37.78%	24.44%	75.56%

Note: (SSG = Single-Stage Bidding Game; MSG = Multi-Stage Bidding Game)

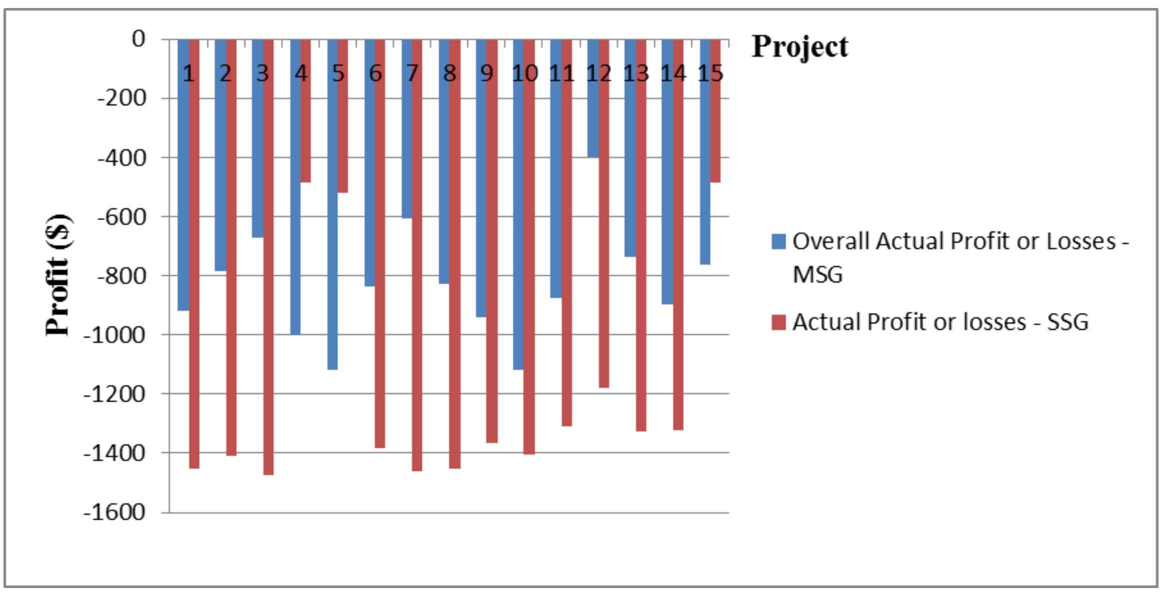

Figure 4.37 Category 1: overall MSG vs SSG actual profit or losses – model 2

(SSG = Single-Stage Bidding Game ;MSG = Multi-Stage Bidding Game)

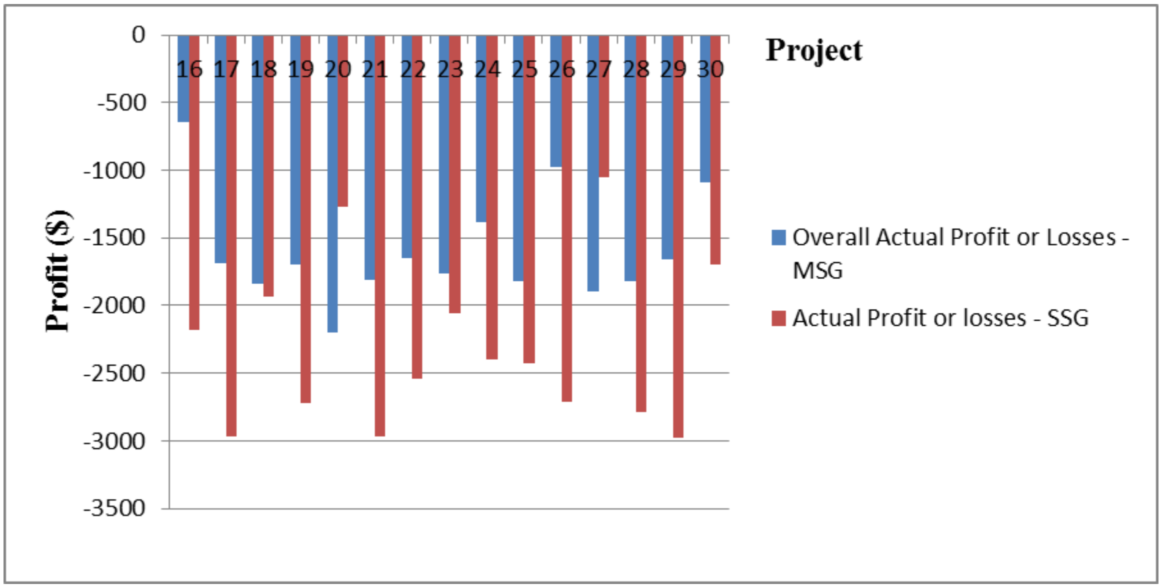

Figure 4.38 Category 2: overall MSG vs SSG actual profit or losses – model 2

(SSG = Single-Stage Bidding Game ;MSG = Multi-Stage Bidding Game)

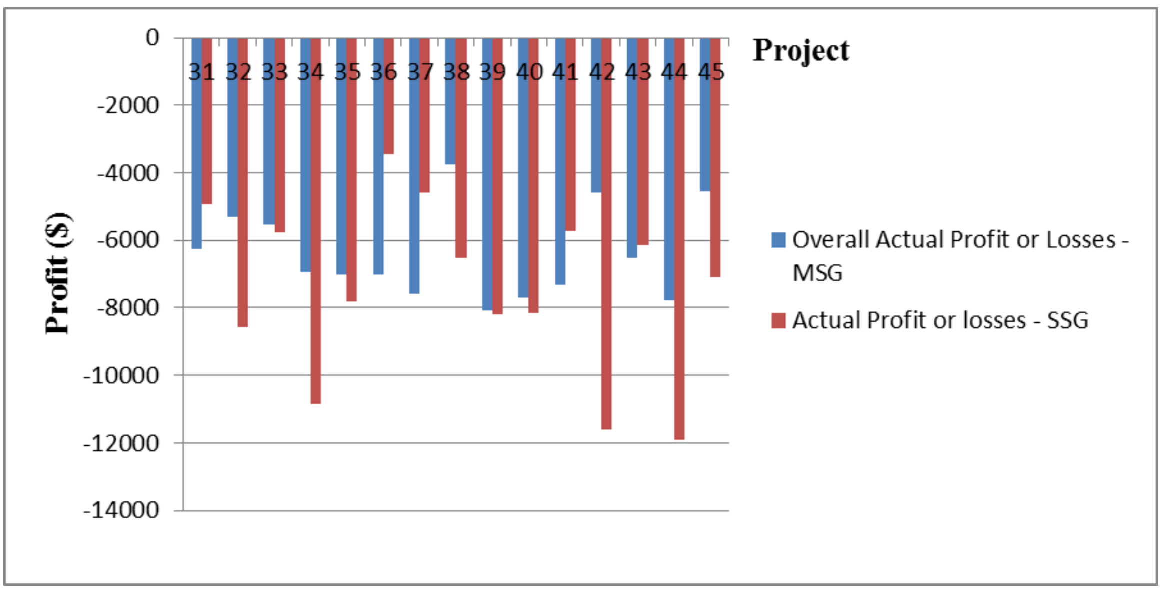

Figure 4.39 Category 3: overall MSG vs SSG actual profit or losses – model 2

(SSG = Single-Stage Bidding Game ;MSG = Multi-Stage Bidding Game)

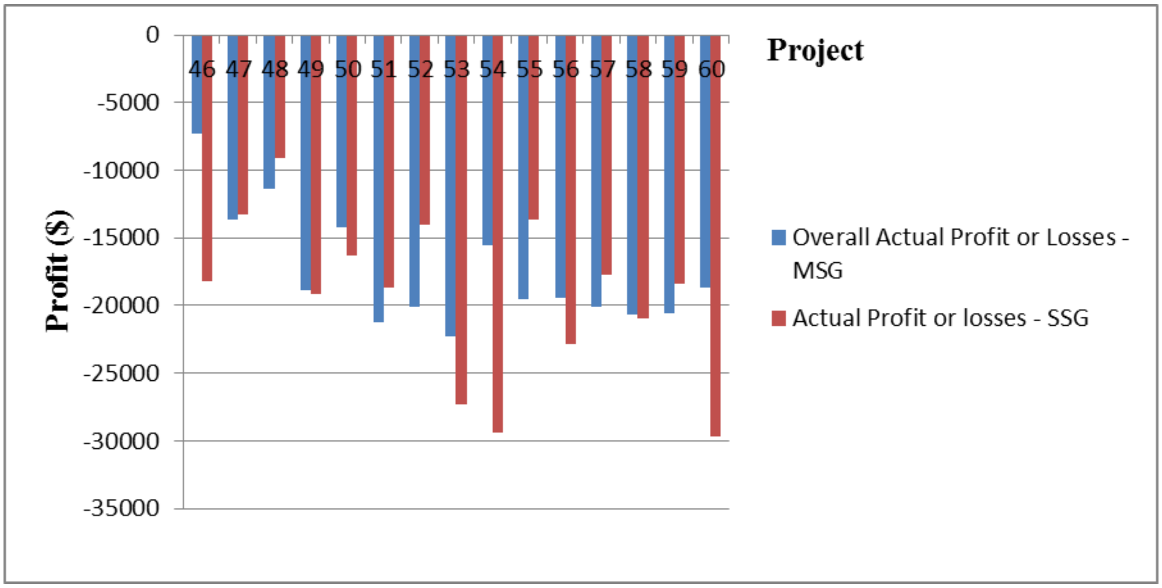

Figure 4.40 Category 4: overall MSG vs SSG actual profit or losses – model 2

(SSG = Single-Stage Bidding Game ;MSG = Multi-Stage Bidding Game)

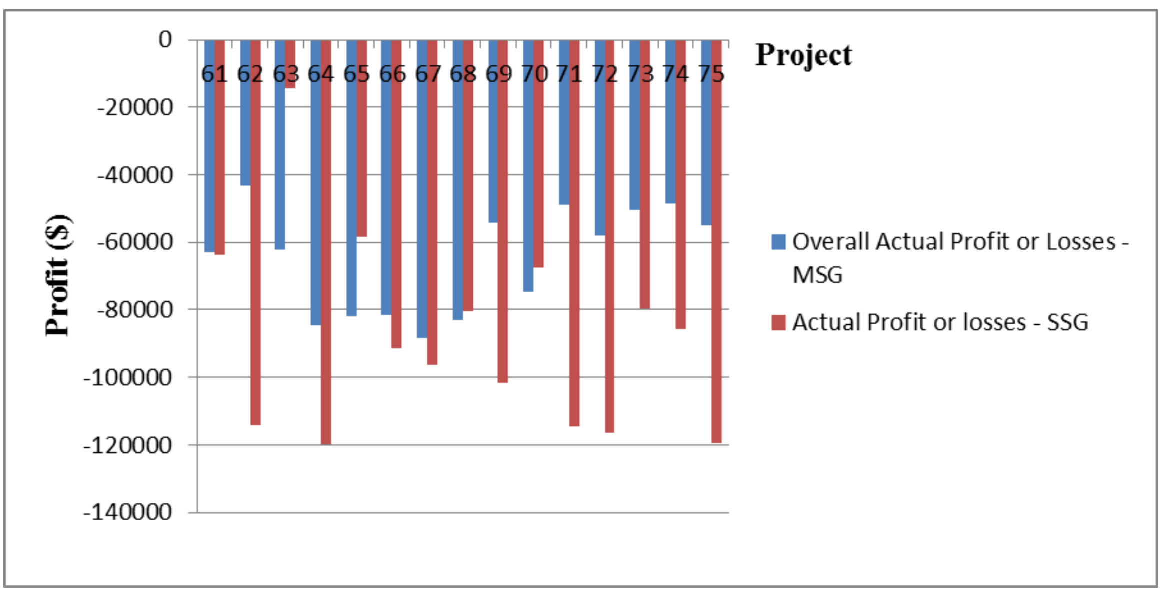

Figure 4.41 Category 5: overall MSG vs SSG actual profit or losses – model 2

(SSG = Single-Stage Bidding Game ;MSG = Multi-Stage Bidding Game)

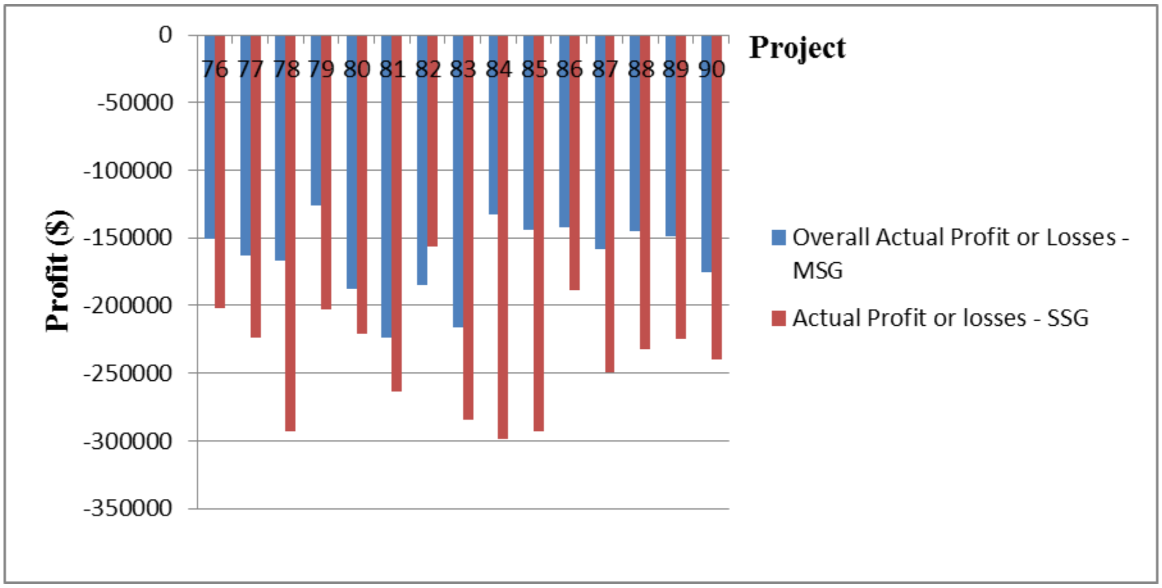

Figure 4.42 Category 6: overall MSG vs SSG actual profit or losses – model 2

(SSG = Single-Stage Bidding Game ;MSG = Multi-Stage Bidding Game)

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The winner's curse is a major concern associated with construction bidding. In fact, contractors suffer from the winner's curse for variety of reasons including: inaccurate estimates of project cost; new contractors entering the construction market; minimizing losses in case of recession of construction industry; strong competition within the construction market; differential opportunity costs which can affect the behavior of contractors; and the intention to win the project and then remedy the losses through change orders, claims, and other mechanisms.

The goal of this research is to identify the degree of the winner's curse in two common construction bidding settings. To this end, a comparison has been made between the construction bidding environments of "single-stage bidding vs. multi stage bidding" from the perspective of the winner's curse. In addition, an estimate has been made of how the construction bidding environment can affect the winning contractor's degree of suffering from the winner's curse. Furthermore, this research analyzed the effect of the learning on the results of the construction bidding.

Furthermore, this research applied the symmetric risk neutral Nash equilibrium (SRNNE), which can be used as an optimal bid function for construction bidding. Actual data related to projects conducted by California Department of Transportation has been used in this research. A simulation model was developed to mimic the construction bidding procedure in reality. Actually, the model was implemented twice. First, it is assumed that the agents (general contractors and sub-contractors) chose their bids randomly (Model 1) in order to represent the situation of lack or misuse of past bidding experience by contractors. Second, a learning module was integrated into model 1 (Model 2), in order to analyze the effect of learning on contractors' bid decisions.

The results of both models and the analysis conducted in this research demonstrated that in construction bidding, the majority of the winning sub-contractors as well as general contractors suffer from the winner's curse problem in both single-stage and multi-stage bidding environments. However, in model 1, the results indicated that the winner's curse is more severe in the multi-stage bidding environment.

Moreover, when learning is introduced, it was shown that the multi-stage bidding environment results in less instances of the winner's curse than the single-stage bidding environment from the perspective of the winner's curse. This result may be due to the fact that in multi-stage bidding environment, there is more opportunity for learning than in the single-stage bidding environment.

Being the case, it is obvious the need for a tool which aids contractors in preparing more accurate bids to initially avoid the winner's curse. Through this research, it has been shown that the symmetric risk neutral Nash equilibrium (SRNNE) optimal bid function, in both bidding environments in both models, provides contractors with a tool to avoid the winner's curse problem and gain strategic positive profits.

It is anticipated that this research would provide contractors with guidelines to mitigate the effect of the winner's curse during the construction bidding including: (i) the use of SRNNE optimal bid function, (ii) effective and efficient learning from gained bidding experience, and (iii) benefiting from rule of thumbs, as stated by Dyer et al. (1989), in the real construction field. It is anticipated that following these guidelines would have positive effect on the associated contracting parties, projects, and the overall construction industry.

5.2 Recommendations for Further Research

There are several opportunities for further research related to the work conducted in this research. First, the aforementioned SRNNE optimal bid function considers only a strategic amount of profit to avoid the winner's curse. Therefore, the researcher recommends extension of the SRNNE optimal bid function to include more factors associated with bid preparation such as mark-up, overhead costs, and contingency costs. In addition, future theoretical work should consider making the general and the sub-contractors' bids, in the application of the SRNNE optimal bid function, interrelated rather than independent as assumed in this research.

Second, this research utilized some data of projects conducted by California department of transportation (California DOT). Those projects are limited to the type of projects conducted by California DOT such as highways and bridges. Therefore, the researcher recommends implementing the simulation model using data for other type of construction projects and examining the effect of that on the results and findings of this research.

Third, based on the assumptions of the learning model (model 2); the contractors continue learning from one project to another within the 15 projects in the same category, and then start over from the beginning at the next category. Thus, for further research, it is recommended that the effect of learning on the results be studied by modeling more projects within the same category and examining if learning can lead to bids which fully avoid the winner's curse.

Fourth, in this research, the non-cooperative game theory concept was applied to analyze the construction bidding and its relation with the winner's curse. For further research, it is believed that cooperative game theory can be applied to analyze construction bidding for integrated project delivery systems. Cooperative game theory is one of the two types of game theory which studies the interactions among coalitions of players. From a game theory perspective, a coalition is simply a subset of the set of players which coordinate strategies and agree on how to divide the total earned payoff. On the other hand, Integrated Project Delivery (IPD) is an approach which combines people, systems, industry structures, and practices in a process which effectively utilizes the talents and abilities of all associated parties to meet the desired project results and maximize efficiency (AIA 2007). Such application of cooperative game theory in construction bidding exercising the IPD principles would help all associated parties to simultaneously achieve their objectives.

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APPENDIX A

SIMULATION MODELS INPUT DATA

A.1 Single-stage bidding game (SSG)

Table A.1 SSG general contractors' private signals and the total true cost of the project

Round	Private Signals			True Cost = MSG Joint True Cost
	GC1	GC2	GC3	
1	24389	24907	24296	25000
2	40578	39341	39425	40000
3	29275	30638	29523	30000
4	49265	49393	49627	49000
5	45261	45231	45697	45000
6	35360	34369	34988	35000
7	28561	27288	28586	28000
8	48400	47297	47306	48000
9	35385	35902	35603	36000
10	41346	41446	42425	42000
11	29505	29171	28440	29000
12	37035	37403	36571	37000
13	37424	37841	37597	38000
14	42429	43127	43390	43000
15	41103	40879	40765	40500
16	61238	59319	59494	60000
17	79993	78963	78531	80000
18	74565	75701	75251	75000
19	91272	88782	89185	90000
20	99377	98726	99613	98500
21	65062	63533	65368	65000
22	95809	93957	96463	95000
23	55177	54439	56417	55000
24	84097	86175	86490	85000
25	71069	72278	71543	72000
26	64688	65599	66162	65900
27	63900	63447	64253	63000
28	71713	72175	74287	73000
29	97015	96922	98930	98000
30	67805	67913	68400	68000

Table A.1 (Cont'd)

Round	Private Signals			True Cost = MSG Joint True Cost
	GC1	GC2	GC3	
31	496552	495070	497315	494000
32	401060	397445	404660	400000
33	455432	451953	450255	450000
34	195166	205255	205803	200000
35	255534	248177	252420	250000
36	352540	355427	352901	350000
37	303627	301423	301907	300000
38	279460	279950	280350	280000
39	465034	457808	460947	460000
40	467848	472177	469770	470000
41	372030	370292	372503	370000
42	149938	146509	144875	150500
43	275954	274846	276865	275000
44	423885	419098	426801	425000
45	149807	155478	148924	150000
46	596801	608422	614155	600000
47	648991	642148	641748	640000
48	655944	663885	657764	650000
49	739244	735894	750038	740000
50	528509	518724	522725	520000
51	714525	696362	711178	700000
52	764997	750988	760600	750000
53	954143	947720	962435	960000
54	545117	535592	540099	550000
55	739391	742130	742478	738000
56	749813	757863	740163	748000
57	617392	620757	617299	620000
58	719065	731111	735670	725000
59	921566	939062	922574	925000
60	995181	989217	977295	985000

Table A.1 (Cont'd)

Round	Private Signals			True Cost = MSG Joint True Cost
	GC1	GC2	GC3	
61	1695303	1676429	1720534	1680000
62	2845695	2889199	2857739	2900000
63	4051573	4057063	4045517	4000000
64	2970699	2940100	2956366	3000000
65	3501734	3512659	3515482	3500000
66	1468457	1485809	1499570	1500000
67	4531477	4523700	4463632	4500000
68	4779747	4857865	4818960	4800000
69	4941874	4898398	4943573	4940000
70	3665054	3668063	3642656	3650000
71	2827783	2745364	2796113	2800000
72	2443722	2528471	2555685	2500000
73	4769935	4730487	4784078	4750000
74	3224115	3246747	3250317	3250000
75	2572925	2540403	2574783	2600000
76	6548200	6717571	6604342	6600000
77	9529777	9584101	9426079	9500000
78	8757217	9008476	8985372	8900000
79	5484159	5447258	5607370	5500000
80	6028842	6181506	6163488	6100000
81	7618169	7385982	7456457	7500000
82	8345014	8303779	8193706	8200000
83	7750112	7665217	7838264	7800000
84	9751012	9912413	9980122	9850000
85	7106941	7358281	7123460	7250000
86	9211508	9227723	9269367	9250000
87	5820184	5684709	5650989	5750000
88	6167673	6314125	6315443	6250000
89	7675185	7838039	7833473	7750000
90	9785867	9816165	9709792	9800000

Note: (SSG = Single-Stage Bidding Game; MSG = Multi-Stage Bidding Game; GC = General Contractor; All values are in US Dollars)

A.2 Multi-stage bidding game (MSG)

A.2.1 Input data for sub-contractors

Table A.2 MSG private signals for subcontractors 1,2,3, and 4, and true cost of their part of the project

ROUND	PRIVATE SIGNALS				SC TRUE COST
	SC1	SC2	SC3	SC4	
1	7501	7479	7707	7324	7500
2	11862	12053	12068	12100	12000
3	8839	9097	9133	8837	9000
4	14810	14913	14912	14869	14700
5	13426	13679	13321	13631	13500
6	10670	10473	10301	10604	10500
7	8531	8426	8412	8359	8400
8	14608	14301	14371	14512	14400
9	11005	10680	10933	10961	10800
10	12388	12483	12602	12393	12600
11	8838	8599	8765	8635	8700
12	11089	11044	10907	11252	11100
13	11614	11555	11234	11466	11400
14	13104	12890	12860	13080	12900
15	12312	12027	12228	12167	12150
16	17815	17804	18252	17968	18000
17	23990	23671	24226	23948	24000
18	22254	22274	22261	22664	22500
19	26585	26973	27110	27188	27000
20	29561	29231	29747	29601	29550
21	19242	19325	19369	19425	19500
22	28822	28542	28696	28876	28500
23	16063	16234	16262	16331	16500
24	25310	25178	25661	25348	25500
25	21503	21902	21317	21705	21600
26	19786	19678	19669	20045	19770
27	19272	19130	18997	18784	18900
28	21817	21849	21890	21529	21900
29	29344	29592	29432	29569	29400

Table A.2 (Cont'd)

ROUND	PRIVATE SIGNALS				SC TRUE COST
	SC1	SC2	SC3	SC4	
30	20410	20010	20356	20159	20400
31	149824	148761	149192	148207	148200
32	121464	120865	120077	121684	120000
33	133702	134764	135725	135663	135000
34	60103	59595	60868	60391	60000
35	74166	73367	74462	73435	75000
36	105576	105103	103806	106628	105000
37	88248	90204	88777	89615	90000
38	83126	83752	84316	85371	84000
39	138664	138123	136425	137834	138000
40	140561	140823	139705	140583	141000
41	111072	110162	111798	110019	111000
42	44595	43830	44698	46047	45150
43	84070	82773	82239	83083	82500
44	126007	126298	126302	127400	127500
45	44179	45920	44027	45922	45000
46	176411	180872	181312	182288	180000
47	190720	190679	195658	190400	192000
48	198671	195144	195766	193497	195000
49	217822	223992	221317	224969	222000
50	155715	153982	158782	160420	156000
51	207586	206708	211157	213708	210000
52	228795	225523	224485	220714	225000
53	287592	284064	291779	291704	288000
54	164030	168560	160625	165373	165000
55	225851	216994	225710	224913	221400
56	222111	224732	225420	222395	224400
57	190418	184207	187492	181892	186000
58	221805	220873	221481	218972	217500
59	281480	280141	274976	281403	277500
60	296494	296245	297104	299313	295500

Table A.2 (Cont'd)

ROUND	PRIVATE SIGNALS				SC TRUE COST
	SC1	SC2	SC3	SC4	
61	488166	513836	490935	510725	504000
62	872898	880657	880065	875592	870000
63	1207149	1214363	1203230	1191368	1200000
64	908313	905276	914499	900806	900000
65	1040728	1046338	1045532	1055133	1050000
66	463598	449318	452117	454152	450000
67	1333761	1335915	1345569	1344146	1350000
68	1454194	1450474	1428210	1428253	1440000
69	1488463	1493852	1485195	1491077	1482000
70	1080751	1087534	1094723	1111392	1095000
71	851304	851592	840285	850774	840000
72	741642	739059	737866	766169	750000
73	1422682	1412316	1429540	1420556	1425000
74	957551	966443	969891	957018	975000
75	788974	784258	766095	781258	780000
76	2021944	1972413	1989230	1939464	1980000
77	2890346	2869413	2880602	2893834	2850000
78	2696397	2700011	2656482	2646452	2670000
79	1655793	1618754	1657154	1628529	1650000
80	1791647	1789341	1856575	1852962	1830000
81	2276915	2211195	2215020	2265762	2250000
82	2434174	2455688	2419139	2499555	2460000
83	2307966	2312041	2348840	2365588	2340000
84	2922212	2984835	2980672	2990559	2955000
85	2152263	2138155	2192534	2199930	2175000
86	2749945	2742146	2776291	2816925	2775000
87	1718380	1702075	1737623	1700128	1725000
88	1831840	1890370	1906896	1903468	1875000
89	2323018	2337818	2310100	2348751	2325000
90	2912035	2919742	2961895	2895704	2940000

Note: (MSG = Multi-Stage Bidding Game; SC = Sub-Contractor; All values are in US Dollars)

Table A.3 MSG private signals for subcontractors5, 6, 7, 8, and 9, and true cost of their part of the project

ROUND	PRIVATE SIGNALS					SC TRUE COST
	SC5	SC6	SC7	SC8	SC9	
1	7399	7430	7315	7659	7577	7500
2	12072	11938	12112	12088	11879	12000
3	9138	9052	9198	8918	8991	9000
4	14922	14803	14850	14601	14535	14700
5	13459	13384	13551	13575	13622	13500
6	10428	10295	10677	10664	10585	10500
7	8561	8493	8185	8582	8431	8400
8	14501	14555	14359	14230	14539	14400
9	10809	10747	10587	10942	10630	10800
10	12421	12806	12815	12644	12758	12600
11	8729	8896	8821	8578	8640	8700
12	11172	11075	10907	11190	10952	11100
13	11480	11372	11414	11611	11273	11400
14	12751	12731	12871	12836	12982	12900
15	12132	11951	12052	12009	12256	12150
16	17991	17622	17849	18089	17819	18000
17	23596	24121	24346	23826	23896	24000
18	22445	22105	22556	22478	22182	22500
19	27157	27253	26680	26607	26944	27000
20	29205	29414	29644	29199	29219	29550
21	19475	19309	19371	19771	19384	19500
22	28261	28065	28196	28155	28921	28500
23	16335	16415	16706	16805	16506	16500
24	25638	25081	25890	25402	25653	25500
25	21543	21398	21464	21816	21474	21600
26	19341	19330	19695	19738	20119	19770
27	18606	19039	18857	18546	18466	18900
28	21892	21518	21755	21644	21584	21900
29	29818	29342	29508	29704	29494	29400
30	20626	20829	20185	20398	20701	20400

Table A.3 (Cont'd)

ROUND	PRIVATE SIGNALS					SC TRUE COST
	SC5	SC6	SC7	SC8	SC9	
31	149667	148200	149740	148126	147659	148200
32	121431	119939	119382	120143	121703	120000
33	136777	136085	133632	133751	135558	135000
34	59891	60700	60812	59440	60400	60000
35	73984	75006	75585	75187	75425	75000
36	105831	104050	105946	105412	106730	105000
37	90573	89588	88222	91594	90940	90000
38	84940	82717	83659	84074	84560	84000
39	138534	137812	137093	139284	137550	138000
40	142574	140729	141762	139791	141213	141000
41	109763	111297	110200	111244	110508	111000
42	44330	46873	45766	43577	46560	45150
43	81430	84270	81113	82065	83090	82500
44	126187	129059	128444	127218	127639	127500
45	45975	45525	44883	46642	43211	45000
46	181615	184164	183804	176382	179638	180000
47	188030	188468	194512	188939	191521	192000
48	197882	197190	197269	194456	197637	195000
49	221128	225085	224084	220136	222865	222000
50	155175	154754	152875	155236	158852	156000
51	206637	209737	208387	208106	210955	210000
52	222530	223942	223599	223620	227270	225000
53	292055	286480	291431	287671	291115	288000
54	161937	162850	168535	164717	161827	165000
55	219701	224048	219861	220192	224536	221400
56	222167	225672	227868	220867	224285	224400
57	182061	184536	186773	189650	187090	186000
58	221649	219080	216267	213053	217883	217500
59	273193	277937	274710	273090	275527	277500
60	298170	299602	299362	296703	299929	295500

Table A.3 (Cont'd)

ROUND	PRIVATE SIGNALS					SC TRUE COST
	SC5	SC6	SC7	SC8	SC9	
61	503605	511583	497519	501272	511363	504000
62	861405	872488	868567	870309	870438	870000
63	1194153	1211187	1208366	1214952	1184787	1200000
64	884073	892022	882843	903920	906194	900000
65	1036054	1060842	1060669	1038873	1037565	1050000
66	465673	450893	441363	451857	434945	450000
67	1353725	1341017	1361263	1338989	1336455	1350000
68	1437419	1443677	1452930	1422332	1440545	1440000
69	1468197	1493019	1477795	1481841	1494340	1482000
70	1086460	1105804	1094628	1091010	1108024	1095000
71	838374	854411	836321	857621	833937	840000
72	750321	733894	763998	734749	764168	750000
73	1426286	1420908	1411422	1420773	1419293	1425000
74	976316	977711	959293	975009	992536	975000
75	777781	773125	763181	795787	792650	780000
76	1972147	1984092	1945313	1967621	1956624	1980000
77	2819184	2809510	2892203	2829875	2874013	2850000
78	2671274	2689840	2689664	2642901	2699310	2670000
79	1612599	1670837	1644739	1675652	1613506	1650000
80	1840581	1818973	1792526	1873329	1841727	1830000
81	2254990	2288855	2207332	2243131	2274084	2250000
82	2489051	2445738	2426451	2418985	2473584	2460000
83	2295661	2366848	2362620	2319318	2310190	2340000
84	2965204	2976155	2947337	2956429	2957159	2955000
85	2203909	2173303	2158775	2156192	2152462	2175000
86	2802050	2769310	2808478	2743194	2809724	2775000
87	1740870	1738416	1710251	1753292	1731474	1725000
88	1906900	1889441	1892541	1844239	1915439	1875000
89	2341907	2281630	2355833	2367728	2327472	2325000
90	2979390	2977966	2907930	2953726	2901162	2940000

Note: (MSG = Multi-Stage Bidding Game; SC = Sub-Contractor; All values are in US Dollars)

A.2.2 Input data for general contractors

Table A.4 MSG general contractors' private signals, true cost of their part of the project and total true cost of the project

ROUND	PRIVATE SIGNALS			GC TRUE COST	JOINT TRUE COST
	GC1	GC2	GC3		
1	17963	17230	17073	17500	25000
2	27796	27620	28493	28000	40000
3	20870	21389	21340	21000	30000
4	34431	34090	33882	34300	49000
5	30979	31077	31870	31500	45000
6	24416	24286	24236	24500	35000
7	19462	19450	19851	19600	28000
8	33654	33462	33361	33600	48000
9	24798	24895	25513	25200	36000
10	29647	28907	29703	29400	42000
11	20132	19906	20438	20300	29000
12	26221	25945	26309	25900	37000
13	26920	26307	26602	26600	38000
14	30229	29791	29876	30100	43000
15	28860	28410	28146	28350	40500
16	42641	42336	42638	42000	60000
17	55314	55831	56396	56000	80000
18	53248	51727	52176	52500	75000
19	62685	61968	63704	63000	90000
20	68480	68742	68115	68950	98500
21	44776	45691	45353	45500	65000
22	66775	65988	66322	66500	95000
23	37999	39164	39208	38500	55000
24	60391	59207	59104	59500	85000
25	50440	49539	51420	50400	72000
26	46348	46487	46773	46130	65900
27	44463	44292	43459	44100	63000
28	51001	50748	50417	51100	73000
29	68140	68055	67674	68600	98000
30	47832	47574	47552	47600	68000

Table A.4 (Cont'd)

ROUND	PRIVATE SIGNALS			GC TRUE COST	JOINT TRUE COST
	GC1	GC2	GC3		
31	344962	343943	342493	345800	494000
32	281416	278400	278003	280000	400000
33	316043	312152	313706	315000	450000
34	140751	136824	136610	140000	200000
35	174354	172867	173847	175000	250000
36	243576	243101	240882	245000	350000
37	211989	206693	207505	210000	300000
38	198038	196846	196211	196000	280000
39	318795	319844	320389	322000	460000
40	325895	325098	330891	329000	470000
41	255813	260116	259313	259000	370000
42	107308	109084	105625	105350	150500
43	193205	190362	192411	192500	275000
44	299793	294340	298499	297500	425000
45	107126	103214	108088	105000	150000
46	422274	419993	423170	420000	600000
47	452739	445047	453784	448000	640000
48	462306	452671	457435	455000	650000
49	525243	515996	509229	518000	740000
50	360036	365430	371958	364000	520000
51	490393	494299	479623	490000	700000
52	523134	518191	517535	525000	750000
53	661867	675155	681206	672000	960000
54	382112	388264	394488	385000	550000
55	509746	518674	514737	516600	738000
56	524774	522056	516739	523600	748000
57	423950	439163	433167	434000	620000
58	501034	517995	500281	507500	725000
59	650481	637978	640661	647500	925000
60	681114	683530	682614	689500	985000

`

Table A.4 (Cont'd)

ROUND	PRIVATE SIGNALS			GC TRUE COST	JOINT TRUE COST
	GC1	GC2	GC3		
61	1180140	1137383	1174886	1176000	1680000
62	2018171	2042663	2015326	2030000	2900000
63	2786224	2791360	2783049	2800000	4000000
64	2121222	2119840	2062700	2100000	3000000
65	2430252	2449925	2412359	2450000	3500000
66	1073946	1011259	1013546	1050000	1500000
67	3110693	3132819	3156487	3150000	4500000
68	3321613	3342482	3331287	3360000	4800000
69	3452549	3450490	3450845	3458000	4940000
70	2575840	2561086	2517211	2555000	3650000
71	1960738	1953042	1947092	1960000	2800000
72	1751710	1763818	1740389	1750000	2500000
73	3345787	3355602	3318190	3325000	4750000
74	2299818	2277615	2310201	2275000	3250000
75	1811971	1848624	1841871	1820000	2600000
76	4680702	4704925	4563709	4620000	6600000
77	6694932	6739791	6574483	6650000	9500000
78	6192405	6161740	6252457	6230000	8900000
79	3874754	3843390	3952486	3850000	5500000
80	4367459	4200360	4202694	4270000	6100000
81	5147319	5155451	5280698	5250000	7500000
82	5678373	5831423	5805820	5740000	8200000
83	5418051	5370305	5375416	5460000	7800000
84	6877388	6894995	6853080	6895000	9850000
85	5156625	5015136	5162864	5075000	7250000
86	6511619	6420586	6461599	6475000	9250000
87	3972457	3990706	4016420	4025000	5750000
88	4426532	4378614	4343374	4375000	6250000
89	5422919	5478270	5356594	5425000	7750000
90	6795311	6828355	6855339	6860000	9800000

Note: (MSG = Multi-Stage Bidding Game; GC = General Contractor; All values are in US Dollars)

APPENDIX B

SIMULATION MODELS CODE (MODEL 1 AND MODEL 2)

Main Class

```
package cbwc;

import java.io.BufferedReader;

import java.io.FileReader;

import java.util.Scanner;


public class CBWC {


    public static void main(String[] args) {

     int tMax = 15; //maximum game (need to verify the number before start)

        DataOut file = new DataOut();

        file.CreateFile();


        SubContractor[] SC = new SubContractor[9];

        // initial propensity and probability

        for (int i = 0; i < 9 ; i ++)

        { SC[i] = new SubContractor();

            for (int j = 0; j < 13; j ++)

            {

            SC[i].q[j] = 1;

            SC[i].prob[j] = 1/13;

            }

        }
```

```
GContractor[] GC = new GContractor[3];
//initial propensity and probability
for (int i = 0; i < 3 ; i ++)
{ GC[i] = new GContractor();
   for (int j = 0; j < 13; j ++)
   {
      GC[i].q[j] = 1;
      GC[i].prob[j] = 1/13;
   }
}

//file input data
Scanner ScanSubContractorSignal = null;
Scanner ScanSubContractorTrueCost = null;
Scanner ScanGContractorSignal = null;
Scanner ScanGContractorTrueCost = null;
//file locations
String SubContractorSignal;
String SubContractorTrueCost;
String GContractorSignal;
String GContractorTrueCost;
```

```
SubContractorSignal = "C:\\Muaz\\Data\\6\\subSignal.csv";
SubContractorTrueCost = "C:\\Muaz\\Data\\6\\subTrue.csv";
GContractorSignal = "C:\\Muaz\\Data\\6\\GSignal.csv";
GContractorTrueCost = "C:\\Muaz\\Data\\6\\GTrue.csv";

double[][] SCSIGNAL = new double[9][tMax];
double[][] GCSIGNAL = new double[3][tMax];
double[] SCTrueCost = new double[tMax];
double[] GCTrueCost = new double[tMax];
try{
   ScanSubContractorSignal = new Scanner (new BufferedReader (new
FileReader(SubContractorSignal)));
   ScanGContractorSignal = new Scanner (new BufferedReader (new
FileReader(GContractorSignal)));
   ScanSubContractorTrueCost = new Scanner (new BufferedReader (new
FileReader(SubContractorTrueCost)));
   ScanGContractorTrueCost = new Scanner (new BufferedReader (new
FileReader(GContractorTrueCost)));

   for (int x = 0; x < tMax; x ++)
   {
      for (int i = 0; i < 9 ; i ++ )
      {
```

```
            SCSIGNAL[i][x]  = ScanSubContractorSignal.nextDouble();
        } SCTrueCost[x] = ScanSubContractorTrueCost.nextDouble();
    }

    for (int x=0; x < tMax; x ++)
    {
        for (int i = 0; i < 3; i ++)
        {
            GCSIGNAL[i][x]= ScanGContractorSignal.nextDouble();
        }GCTrueCost[x] = ScanGContractorTrueCost.nextDouble();
    }
}catch (Exception e)
{System.out.println(e);}
```

```
/*===========================================================
==========
                    GAME START

==============================================================
====*/
```

```
int t = 0;
//repetitive game
do
{
    //clear all
    for (int i = 0; i< 9; i ++){SC[i].win = false;}
    for (int i = 0; i<3; i++){GC[i].win =false;}
    for (int i = 0; i < 9 ; i ++) // reading subcontractor signals
    {
        SC[i].signal = SCSIGNAL[i][t];
        SC[i].getBid(); // setting the subcontractor bid
    }

    for (int i = 0 ; i < 9 ; i ++)
    {
        System.out.println("Subcontractor #" + i + "Signal = " + SC[i].signal);
        System.out.println("Subcontractor #" + i + "Bid = " + SC[i].bid);
    }
    //choose the subcontractor for each general contractor
    int x = 0;
    for (int i=0; i < 3; i ++)
```

```
{
   double min = 999999999;
   for (int j = x; j < x +3 ; j ++ )
   {
      if (SC[j].bid < min)
      {
         GC[i].SC = j;
         min = SC[j].bid;
      }
   }x = x+3;
}

for (int i = 0; i < 3 ; i ++)
{
   GC[i].signal = GCSIGNAL[i][t];
   GC[i].getBid();// setting the general contractor bid
   GC[i].bid += SC[GC[i].SC].bid;
}

 for (int i = 0 ; i < 3 ; i ++)
{
   System.out.println("Gcontractor #" + i + "Signal = " + GC[i].signal);
   System.out.println("Gcontractor #" + i + "Bid = " + GC[i].bid);
```

```
}
//determine the winner General Contractor
double min = 999999999;
int winner= 0;
for (int i =0; i < 3; i ++)
{

  if (GC[i].bid < min)
  {
  winner = i;
  min = GC[i].bid;
  }
}

GC[winner].win = true;
SC[GC[winner].SC].win= true;

 GC[winner].trueCost = GCTrueCost[t];
SC[GC[winner].SC].trueCost = SCTrueCost[t];

 //print to the output file
file.out(SC[GC[winner].SC],GC[0],GC[1],GC[2], GC[winner],winner);
//adjust probability (learning method)
```

```
            for (int i = 0; i < 9 ; i ++)
            {
               SC[i].getProb();
            }

            //adjust probability (learning method)
            for (int j = 0; j <3; j ++)
            {
               GC[j].getProb();
            }

         t ++;
         }while (t < tMax);
file.Close(); //close file and save

   }

}
```

General Contractor Class

```
package cbwc;
import java.util.Random;

public class GContractor {
    public double signal;
   double q[] = new double[13];
   double[] prob = new double[13];

/*=============================================================
=====
                                Multi Stage

=============================================================
====*/
        //choose one depending on your game and category
           //cat1 double[] value = {528,440,352,264,176,88,0,-88,-176,-264,-352,-440,-
528};
           //cat2 double[] value = {1050,875,700,525,350,175,0,-175,-350,-525,-700,-
875,-1050};
           //cat3 double[] value = {4200,3500,2800,2100,1400,700,0,-700,-1400,-2100,-
2800,-3500,-4200};
```

```
//cat4 double[] value = {10500,8750,7000,5250,3500,1750,0,-1750,-3500,-5250,-7000,-8750,-10500};

//cat5 double[] value = {42000,35000,28000,21000,14000,7000,0,-7000,-14000,-21000,-28000,-35000,-42000};

//cat6

double[] value = {105000,87500,70000,52500,35000,17500,0,-17500,-35000,-52500,-70000,-87500,-105000};


/*=================================================================

Single Stage

=================================================================*/

//cat1 double[] value = {750,625,500,375,250,125,0,-125,-250,-375,-500,-625,-750};

//cat2 double[] value = {1500,1250,1000,750,500,250,0,-250,-500,-750,-1000,-1250,-1500};

//cat3 double[] value = {6000,5000,4000,3000,2000,1000,0,-1000,-2000,-3000,-4000,-5000,-6000};

//cat4 double[] value = {15000,12500,10000,7500,5000,2500,0,-2500,-5000,-7500,-10000,-12500,-15000};
```

```
//cat5 double[] value = {60000,50000,40000,30000,20000,10000,0,-10000,-
20000,-30000,-40000,-50000,-60000};
//cat6 double[] value = {150000,125000,100000,75000,50000,25000,0,-25000,-
50000,-75000,-100000,-125000,-150000};


double reward ;
int [] rewardIndex = new int[13];
public double profit;
public double trueCost;
public boolean win;
public double bid;
public int SC;

public int getMax()
{
/*============================================================
=====================
============================================================
======================
VERY IMPORTANT!
the getMax() function determines which value (from the 13 decision variable) to
use for the subcontractor (and general contractor, its the same process)
```

So, in principle there are two ways...

1-either through learning, in which we get the maximum probability (that's how we started the whole thing at the beginning or

2-through a random choice

And thus, this function does both, you only have to "comment" the undesired one and "uncomment" the one to be applied

NB: the learning module will work for both, but won't affect the random one at all.

===
========================

===
======================*/

```
/*
    // 1- determine the max probability
    double max = -9999;
    int index = 0;
        for (int i = 0; i < 13; i ++)
        {
            if (prob[i]> max)
                index = i;
        }
```

```
    return index;
    }
    */
//2 – get Random
    Random R = new Random();
    return R.nextInt(12);
    }

    public void getBid()
    {
    double temp = value[getMax()];
    double y = (2*temp/10) * Math.expm1(-(9/(2*temp))*(101500 -temp - signal));
        bid = signal +temp ;
    }

    public void getReward(){
        //calculate the current reward
        if (!win)
        {
            reward = -1;
        }else
        {
            reward  = 1;
```

```
        if (trueCost > bid)
            reward = reward -3;
    }
}

public void getRewardIndex()
{
    int x = getMax();
    for (int i = 0; i < 13; i ++)
    {
     if (x== i)
         rewardIndex[i]= 1;
     else rewardIndex[i] = 0;
    }
}

public void getQ(){
    double Forgetting = 0.2;
    double Exp = 0.2;
    getReward();
    getRewardIndex();
for (int i=0;i <13; i ++)
{
```

```
        if (rewardIndex[i] ==1){
            q[i] = (q[i] * (1-Forgetting)) + (reward * (1 - Exp));
        }
        else {
            q[i] = (q[i] * (1-Forgetting)) + (reward * Exp/2);
        }
    }
    }
      public void getProb(){
        getQ();
        double totalQ = 0;
        for (int i = 0; i < 13; i ++)
        {
            totalQ += q[i];
        }
        for (int i = 0; i < 13; i ++)
        {
            prob[i] = q[i]/totalQ;
        }
    }
}
```

Subcontractor Class

```
package cbwc;

import java.util.*;

import java.util.Random;

public class SubContractor {

    public double signal;

    double q[] = new double[13];

    double[] prob = new double[13];


/*================================================================
=====

                         Multi Stage


================================================================
====*/

        //cat1 double[] value = {222,185,148,111,74,37,0,-37,-74,-111,-148,-185,-
222};

        //cat2 double[] value = {450,375,300,225,150,75,0,-75,-150,-225,-300,-375,-
450};

        //cat3 double[] value = {1800,1500,1200,900,600,300,0,-300,-600,-900,-1200,-
1500,-1800};

        //cat4 double[] value = {4500,3750,3000,2250,1500,750,0,-750,-1500,-2250,-
3000,-3750,-4500};
```

```
//cat5 double[] value = {18000,15000,12000,9000,6000,3000,0,-3000,-6000,-
9000,-12000,-15000,-18000};
//cat6
double[] value = {45000,37500,30000,22500,15000,7500,0,-7500,-15000,-
22500,-30000,-37500,-45000};


/*============================================================
=====
Single Stage

============================================================
====*/
//double[] value = {0,0,0,0,0,0,0,0,0,0,0,0,0};
double reward ;
int [] rewardIndex = new int[13];
public double profit;
public double trueCost;
public boolean win;
public double bid;

public int getMax()
{
```

```
/*=========================================================
==========
==========================================================
===========VERY IMPORTANT!
the getMax() function determines which value (from the 13 decision variable) to
use for the subcontractor (and general contractor, it is the same process)

So, in principle there are two ways...
1-either through learning, in which we get the maximum probability (that's
how we started the whole thing at the beginning, or
2-through a random choice

And thus, this function does both, you only have to "comment" the undesired
One and "uncomment" the one to be applied

NB: the learning module will work for both, but won't affect the random
one at all.
==========================================================
===========
==========================================================
=========*/

/*
```

```
// 1- determine the max probability
double max = -9999;
int index = 0;
    for (int i = 0; i < 13; i ++)
    {
        if (prob[i]> max)
        {
            index = i;
            max = prob[i];
        }
    }
return index;
*/

//2 - Radom variable Choice

Random R = new Random();
return R.nextInt(12);
}

public void getBid()
```

```
{
    double temp = value[getMax()];
    bid = signal +temp ;
}

public void getReward(){
    //calculate the current reward
    if (!win)
    {
        reward = -1;
    }else
    {
        reward  = 1;
        if (trueCost > bid)
            reward = reward -3;
    }
}

public void getRewardIndex()
{
    int x = getMax();
    for (int i = 0; i < 13; i ++)
    {
```

```
     if (i == x)
         rewardIndex[i]= 1;
     else rewardIndex[i] = 0;
    }
}

public void getQ(){
    double Forgetting = 0.2;
    double Exp = 0.2;
    getReward();
    getRewardIndex();
for (int i=0;i <13; i ++)
{
    if (rewardIndex[i] ==1){
        q[i] = (q[i] * (1-Forgetting)) + (reward * (1 - Exp));
    }
    else {
        q[i] = (q[i] * (1-Forgetting)) + (reward * Exp/2);
    }
}
}
  public void getProb(){
    getQ();
```

```java
        double totalQ = 0;
        for (int i = 0; i < 13; i ++)
        {
            totalQ += q[i];
        }
        System.out.println("R= " + reward);
        for (int i = 0; i < 13; i ++)
        {
            prob[i] = q[i]/totalQ;
            System.out.println("R index"+i + "= " + rewardIndex[i]);
            System.out.println("Q"+i + "= " + q[i]);
            System.out.println("p"+i + "= " + prob[i]);
        }
    }
}
```

Data Output Class

```
package cbwc;


import java.util.Formatter;
public class DataOut {
    private Formatter Bid;


    public void CreateFile ()
    {
        try{
            Bid = new Formatter ("C:\\Muaz\\Data\\6\\bid.csv");

Bid.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s","Contracto
r 1", ",", "Contractor 2", ",", "Contractor 3",",","Subcontractor Bid",",", "JointBid
",",","Winner",",","GContractor Signal", ",","Subcontractor Signal",",","GC
Value",",","SC value",",",'\n');
        }catch ( Exception e){
            System.out.println("Error");
        }
    }
        public void out(SubContractor SC, GContractor GC1, GContractor GC2,
GContractor GC3, GContractor WinnerGC, int winner){
```

```
Bid.format("%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s%s",
GC1.SC,",",GC2.SC, ",", GC3.SC, ",", SC.bid, ",",
WinnerGC.bid,",",winner,",",WinnerGC.signal,",",SC.signal,",",WinnerGC.value[Winner
GC.getMax()],",", SC.value[SC.getMax()],",",SC.trueCost,",",'\n');
            }
              public void Close(){
               Bid.close();
            }
         }
```

APPENDIX C

RESULTS OF THE MODEL WITH RANDOM FUNCTION (MODEL 1)

Table C.1 The results of the SSG of model 1

Project	Winning GC's Private Signal	Optimal Bid Value	Winning GC Bid	Project True Cost	Actual Profit or losses	Optimal bid's profits or losses
1	24389	25139	24139	25000	-861	139
2	39341	40091	38841	40000	-1159	91
3	29275	30025	29650	30000	-350	25
4	49265	49629	49140	49000	140	629
5	45231	45981	44606	45000	-394	981
6	34369	35119	34744	35000	-256	119
7	27288	28038	27163	28000	-837	38
8	47297	48039	47172	48000	-828	39
9	35603	36353	35728	36000	-272	353
10	41346	42096	40971	42000	-1029	96
11	28440	29190	28315	29000	-685	190
12	36571	37321	36696	37000	-304	321
13	37841	38591	37591	38000	-409	591
14	42429	43179	41929	43000	-1071	179
15	41103	41853	40603	40500	103	1353
16	59494	60994	58494	60000	-1506	994
17	78963	80463	78463	80000	-1537	463
18	74565	76065	73815	75000	-1185	1065
19	88782	90282	88282	90000	-1718	282
20	99613	98830	98613	98500	113	330
21	63533	65033	64533	65000	-467	33
22	95809	97258	95059	95000	59	2258
23	54439	55939	53689	55000	-1311	939
24	84097	85597	85097	85000	97	597
25	71069	72569	70819	72000	-1181	569
26	65599	67099	65099	65900	-801	1199
27	63900	65400	62900	63000	-100	2400
28	72175	73675	72175	73000	-825	675
29	97015	98345	96265	98000	-1735	345
30	67913	69413	67413	68000	-587	1413

Table C.1 (Cont'd)

Project	Winning GC's Private Signal	Optimal Bid Value	Winning GC Bid	Project True Cost	Actual Profit or losses	Optimal bid's profits or losses
31	495070	497150	493070	494000	-930	3150
32	397445	403445	394445	400000	-5555	3445
33	450255	456255	456255	450000	6255	6255
34	195166	201166	192166	200000	-7834	1166
35	248177	254177	244177	250000	-5823	4177
36	352901	358901	355901	350000	5901	8901
37	301907	307907	299907	300000	-93	7907
38	279950	285950	278950	280000	-1050	5950
39	457808	463808	462808	460000	2808	3808
40	467848	473844	462848	470000	-7152	3844
41	372030	378030	371030	370000	1030	8030
42	146509	152509	142509	150500	-7991	2009
43	275954	281954	271954	275000	-3046	6954
44	419098	425098	424098	425000	-902	98
45	149807	155807	145807	150000	-4193	5807
46	596801	611801	599301	600000	-699	11801
47	642148	657148	629648	640000	-10352	17148
48	655944	670944	653444	650000	3444	20944
49	735894	750894	723394	740000	-16606	10894
50	518724	533724	526224	520000	6224	13724
51	696362	711362	698862	700000	-1138	11362
52	750988	765988	740988	750000	-9012	15988
53	954143	968800	941643	960000	-18357	8800
54	535592	550592	538092	550000	-11908	592
55	742130	757130	744630	738000	6630	19130
56	749813	764813	737313	748000	-10687	16813
57	617299	632299	612299	620000	-7701	12299
58	719065	734065	709065	725000	-15935	9065
59	921566	936553	929066	925000	4066	11553
60	995181	989422	982681	985000	-2319	4422

Table C.1 (Cont'd)

Project	Winning GC's Private Signal	Optimal Bid Value	Winning GC Bid	Project True Cost	Actual Profit or losses	Optimal bid's profits or losses
61	1676429	1736429	1626429	1680000	-53571	56429
62	2845695	2905695	2865695	2900000	-34305	5695
63	4057063	4117063	4007063	4000000	7063	117063
64	2956366	3016366	2936366	3000000	-63634	16366
65	3501734	3561734	3491734	3500000	-8266	61734
66	1468457	1528457	1468457	1500000	-31543	28457
67	4463632	4523632	4473632	4500000	-26368	23632
68	4818960	4877505	4778960	4800000	-21040	77505
69	4898398	4947795	4928398	4940000	-11602	7795
70	3668063	3728063	3628063	3650000	-21937	78063
71	2745364	2805364	2755364	2800000	-44636	5364
72	2443722	2503722	2503722	2500000	3722	3722
73	4730487	4790328	4710487	4750000	-39513	40328
74	3246747	3306747	3196747	3250000	-53253	56747
75	2574783	2634783	2574783	2600000	-25217	34783
76	6548200	6698200	6498200	6600000	-101800	98200
77	9584101	9728850	9459101	9500000	-40899	228850
78	8757217	8907216	8732217	8900000	-167783	7216
79	5447258	5597258	5447258	5500000	-52742	97258
80	6028842	6178842	5953842	6100000	-146158	78842
81	7385982	7535982	7310982	7500000	-189018	35982
82	8193706	8343706	8093706	8200000	-106294	143706
83	7750112	7900112	7725112	7800000	-74888	100112
84	9751012	9873140	9776012	9850000	-73988	23140
85	7106941	7256941	7006941	7250000	-243059	6941
86	9227723	9377574	9177723	9250000	-72277	127574
87	5684709	5834709	5559709	5750000	-190291	84709
88	6167673	6317673	6117673	6250000	-132327	67673
89	7675185	7825185	7725185	7750000	-24815	75185
90	9709792	9841336	9584792	9800000	-215208	41336

Note: (SSG = Single-Stage Bidding Game; GC = General Contractor; All values are in US Dollars)

Table C.2 The results of the winning sub-contractors of MSG of model 1 (each for his part of the project)

Project	Winning SC's Private Signal	SC optimal Bid	Winning SC Bid for His Part of the Project	SC True Cost for His Part of the Project	SC Actual Profit or Losses	SC Optimal Profit or Losses
1	7315	7537	7167	7500	-333	37
2	11862	12084	11862	12000	-138	84
3	8991	9213	8806	9000	-194	213
4	14535	14736	14387	14700	-313	36
5	13321	13543	13247	13500	-253	43
6	10295	10517	10110	10500	-390	17
7	8185	8407	8185	8400	-215	7
8	14301	14519	14153	14400	-247	119
9	10747	10969	10562	10800	-238	169
10	12393	12615	12245	12600	-355	15
11	8599	8821	8414	8700	-286	121
12	11075	11297	10964	11100	-136	197
13	11372	11594	11335	11400	-65	194
14	12731	12953	12583	12900	-317	53
15	12009	12231	12009	12150	-141	81
16	17622	18072	17772	18000	-228	72
17	23596	24046	23371	24000	-629	46
18	22105	22555	21805	22500	-695	55
19	27188	27638	27563	27000	563	638
20	29219	29594	29259	29550	-291	44
21	19371	19821	19146	19500	-354	321
22	28065	28513	28065	28500	-435	13
23	16262	16712	15962	16500	-538	212
24	25081	25531	24856	25500	-644	31
25	21543	21993	21168	21600	-432	393
26	19341	19791	19416	19770	-354	21
27	18466	18916	18166	18900	-734	16
28	21644	22094	21269	21900	-631	194
29	29494	29757	29269	29400	-131	357
30	20159	20609	20234	20400	-166	209

Table C.2 (Cont'd)

Project	Winning SC's Private Signal	SC optimal Bid	Winning SC Bid for His Part of the Project	SC True Cost for His Part of the Project	SC Actual Profit or Losses	SC Optimal Profit or Losses
31	149192	148935	149192	148200	992	735
32	121431	123231	119931	120000	-69	3231
33	133751	135551	133151	135000	-1849	551
34	59440	61240	58540	60000	-1460	1240
35	73984	75784	72484	75000	-2516	784
36	106730	108530	105230	105000	230	3530
37	88248	90048	87348	90000	-2652	48
38	83659	85459	83959	84000	-41	1459
39	136425	138225	137025	138000	-975	225
40	140583	142381	139083	141000	-1917	1381
41	110508	112308	109008	111000	-1992	1308
42	44595	46395	43395	45150	-1755	1245
43	81430	83230	82930	82500	430	730
44	126187	127987	124987	127500	-2513	487
45	45525	47325	44025	45000	-975	2325
46	176382	180882	174132	180000	-5868	882
47	188468	192968	186218	192000	-5782	968
48	194456	198956	192956	195000	-2044	3956
49	222865	227365	219865	222000	-2135	5365
50	152875	157375	149875	156000	-6125	1375
51	207586	212086	209086	210000	-914	2086
52	223599	228099	221349	225000	-3651	3099
53	287592	291931	285342	288000	-2658	3931
54	164030	168530	163280	165000	-1720	3530
55	216994	221494	213244	221400	-8156	94
56	222111	226611	222111	224400	-2289	2211
57	186773	191273	183773	186000	-2227	5273
58	213053	217553	209303	217500	-8197	53
59	273193	277692	271693	277500	-5807	192
60	294494	297385	290744	295500	-4756	1885

Table C.2 (Cont'd)

Project	Winning SC's Private Signal	SC optimal Bid	Winning SC Bid for His Part of the Project	SC True Cost for His Part of the Project	SC Actual Profit or Losses	SC Optimal Profit or Losses
61	490935	508935	481935	504000	-22065	4935
62	868567	886567	874567	870000	4567	16567
63	1203230	1221230	1209230	1200000	9230	21230
64	882843	900843	870843	900000	-29157	843
65	1037565	1055565	1028565	1050000	-21435	5565
66	451857	469857	445857	450000	-4143	19857
67	1335915	1353915	1329915	1350000	-20085	3915
68	1428210	1446108	1428210	1440000	-11790	6108
69	1468197	1483348	1453197	1482000	-28803	1348
70	1094628	1112628	1088628	1095000	-6372	17628
71	836321	854321	824321	840000	-15679	14321
72	737866	755866	722866	750000	-27134	5866
73	1429540	1447426	1414540	1425000	-10460	22426
74	957018	975018	960018	975000	-14982	18
75	766095	784095	751095	780000	-28905	4095
76	1945313	1990313	1960313	1980000	-19687	10313
77	2829875	2874528	2814875	2850000	-35125	24528
78	2696397	2741393	2658897	2670000	-11103	71393
79	1618754	1663754	1581254	1650000	-68746	13754
80	1792526	1837526	1755026	1830000	-74974	7526
81	2254990	2299990	2262490	2250000	12490	49990
82	2455688	2500688	2440688	2460000	-19312	40688
83	2295661	2340661	2258161	2340000	-81839	661
84	2947337	2974909	2909837	2955000	-45163	19909
85	2152462	2197462	2114962	2175000	-60038	22462
86	2802050	2846913	2772050	2775000	-2950	71913
87	1718380	1763380	1710880	1725000	-14120	38380
88	1844239	1889239	1859239	1875000	-15761	14239
89	2337818	2382818	2300318	2325000	-24682	57818
90	2912035	2951662	2897035	2940000	-42965	11662

Note: (MSG = Multi-Stage Bidding Game; SC = Sub-Contractor; All values are in US Dollars)

Table C.3 The results of the winning general contractors of MSG of model 1 (each for his part of the project)

Project	Winning GC's Private Signal	GC optimal Bid	Winning GC Bid for His Part of the Project	GC True Cost for his part of the project	GC Actual Profit or Losses	GC Optimal Profit or Losses
1	17073	17601	16897	17500	-603	101
2	27796	28324	27356	28000	-644	324
3	21340	21868	21076	21000	76	868
4	33882	34361	33618	34300	-682	61
5	30979	31507	30891	31500	-609	7
6	24286	24814	24286	24500	-214	314
7	19851	20379	19939	19600	339	779
8	33654	34156	33566	33600	-34	556
9	24895	25423	25071	25200	-129	223
10	28907	29435	28643	29400	-757	35
11	20132	20660	19692	20300	-608	360
12	25945	26473	25681	25900	-219	573
13	26307	26835	26307	26600	-293	235
14	29791	30319	29791	30100	-309	219
15	28146	28674	27794	28350	-556	324
16	42336	43386	41636	42000	-364	1386
17	55831	56881	55481	56000	-519	881
18	51727	52777	51552	52500	-948	277
19	61968	63018	62493	63000	-507	18
20	68115	69006	68540	68950	-410	56
21	45353	46403	44828	45500	-672	903
22	65988	67030	66163	66500	-337	530
23	37999	39049	38174	38500	-326	549
24	59207	60257	58682	59500	-818	757
25	49539	50589	48839	50400	-1561	189
26	46487	47537	46312	46130	182	1407
27	43459	44509	43809	44100	-291	409
28	50417	51467	49892	51100	-1208	367
29	67674	68639	66799	68600	-1801	39
30	47574	48624	47049	47600	-551	1024

Table C.3 (Cont'd)

Project	Winning GC's Private Signal	GC optimal Bid	Winning GC Bid for His Part of the Project	GC True Cost for his part of the project	GC Actual Profit or Losses	GC Optimal Profit or Losses
31	344962	347605	341462	345800	-4338	1805
32	278400	282600	276300	280000	-3700	2600
33	313706	317906	312306	315000	-2694	2906
34	136610	140810	140110	140000	110	810
35	172867	177067	172167	175000	-2833	2067
36	240882	245082	245082	245000	82	82
37	211989	216189	209189	210000	-811	6189
38	196211	200411	193411	196000	-2589	4411
39	318795	322995	318095	322000	-3905	995
40	325098	329297	327898	329000	-1102	297
41	259313	263513	257213	259000	-1787	4513
42	107308	111508	105908	105350	558	6158
43	190362	194562	187562	192500	-4938	2062
44	294340	298540	292940	297500	-4560	1040
45	103214	107414	100414	105000	-4586	2414
46	423170	433670	423170	420000	3170	13670
47	445047	455547	446797	448000	-1203	7547
48	457435	467935	450435	455000	-4565	12935
49	509229	519729	500479	518000	-17521	1729
50	371958	382458	363208	364000	-792	18458
51	490393	500893	483393	490000	-6607	10893
52	517535	528035	508785	525000	-16215	3035
53	661867	672266	663617	672000	-8383	266
54	382112	392612	382112	385000	-2888	7612
55	509746	520246	511496	516600	-5104	3646
56	524774	535274	516024	523600	-7576	11674
57	433167	443667	427917	434000	-6083	9667
58	500281	510781	505531	507500	-1969	3281
59	637978	648475	643228	647500	-4272	975
60	681114	690030	683614	689500	-5886	530

Table C.3 (Cont'd)

Project	Winning GC's Private Signal	GC optimal Bid	Winning GC Bid for His Part of the Project	GC True Cost for his part of the project	GC Actual Profit or Losses	GC Optimal Profit or Losses
61	1180140	1222140	1145140	1176000	-30860	46140
62	2015326	2057326	1980326	2030000	-49674	27326
63	2786224	2828224	2751224	2800000	-48776	28224
64	2062700	2104700	2055700	2100000	-44300	4700
65	2412359	2454359	2412359	2450000	-37641	4359
66	1013546	1055546	1020546	1050000	-29454	5546
67	3110693	3152693	3152693	3150000	2693	2693
68	3321613	3363452	3349613	3360000	-10387	3452
69	3450490	3476430	3457490	3458000	-510	18430
70	2517211	2559211	2517211	2555000	-37789	4211
71	1947092	1989092	1919092	1960000	-40908	29092
72	1751710	1793710	1723710	1750000	-26290	43710
73	3345787	3387405	3317787	3325000	-7213	62405
74	2277615	2319615	2277615	2275000	2615	44615
75	1811971	1853971	1825971	1820000	5971	33971
76	4563709	4668709	4651209	4620000	31209	48709
77	6574483	6678944	6486983	6650000	-163017	28944
78	6192405	6297403	6244905	6230000	14905	67403
79	3874754	3979754	3822254	3850000	-27746	129754
80	4202694	4307694	4150194	4270000	-119806	37694
81	5155451	5260451	5067951	5250000	-182049	10451
82	5678373	5783373	5730873	5740000	-9127	43373
83	5370305	5475305	5387805	5460000	-72195	15305
84	6853080	6929234	6835580	6895000	-59420	34234
85	5162864	5267864	5075364	5075000	364	192864
86	6420586	6525526	6368086	6475000	-106914	50526
87	3972457	4077457	3884957	4025000	-140043	52457
88	4343374	4448374	4343374	4375000	-31626	73374
89	5422919	5527919	5370419	5425000	-54581	102919
90	6795311	6887673	6760311	6860000	-99689	27673

Note: (MSG = Multi-Stage Bidding Game; GC = General Contractor; All values are in US Dollars)

Table C.4 The joint actual and optimal bids for MSG of model 1

Project	Joint Winning Actual Bid	Joint Optimal Bid	Joint True Cost of the Project	Overall Joint Actual Profit or Losses	Overall Joint Optimal Profit or Losses
1	24064	25138	25000	-936	138
2	39218	40408	40000	-782	408
3	29882	31081	30000	-118	1081
4	48005	49096	49000	-995	96
5	44138	45050	45000	-862	50
6	34396	35331	35000	-604	331
7	28124	28786	28000	124	786
8	47719	48675	48000	-281	675
9	35633	36392	36000	-367	392
10	40888	42050	42000	-1112	50
11	28106	29481	29000	-894	481
12	36645	37770	37000	-355	770
13	37642	38429	38000	-358	429
14	42374	43272	43000	-626	272
15	39803	40905	40500	-697	405
16	59408	61458	60000	-592	1458
17	78852	80927	80000	-1148	927
18	73357	75332	75000	-1643	332
19	90056	90656	90000	56	656
20	97799	98600	98500	-701	100
21	63974	66224	65000	-1026	1224
22	94228	95544	95000	-772	544
23	54136	55761	55000	-864	761
24	83538	85788	85000	-1462	788
25	70007	72582	72000	-1993	582
26	65728	67328	65900	-172	1428
27	61975	63425	63000	-1025	425
28	71161	73561	73000	-1839	561
29	96068	98396	98000	-1932	396
30	67283	69233	68000	-717	1233

Table C.4 (Cont'd)

Project	Joint Winning Actual Bid	Joint Optimal Bid	Joint True Cost of the Project	Overall Joint Actual Profit or Losses	Overall Joint Optimal Profit or Losses
31	490654	496540	494000	-3346	2540
32	396231	405831	400000	-3769	5831
33	445457	453457	450000	-4543	3457
34	198650	202050	200000	-1350	2050
35	244651	252851	250000	-5349	2851
36	350312	353612	350000	312	3612
37	296537	306237	300000	-3463	6237
38	277370	285870	280000	-2630	5870
39	455120	461220	460000	-4880	1220
40	466981	471678	470000	-3019	1678
41	366221	375821	370000	-3779	5821
42	149303	157903	150500	-1197	7403
43	270492	277792	275000	-4508	2792
44	417927	426527	425000	-7073	1527
45	144439	154739	150000	-5561	4739
46	597302	614552	600000	-2698	14552
47	633015	648515	640000	-6985	8515
48	643391	666891	650000	-6609	16891
49	720344	747094	740000	-19656	7094
50	513083	539833	520000	-6917	19833
51	692479	712979	700000	-7521	12979
52	730134	756134	750000	-19866	6134
53	948959	964196	960000	-11041	4196
54	545392	561142	550000	-4608	11142
55	724740	741740	738000	-13260	3740
56	738135	761885	748000	-9865	13885
57	611690	634940	620000	-8310	14940
58	714834	728334	725000	-10166	3334
59	914921	926166	925000	-10079	1166
60	974358	987415	985000	-10642	2415

Table C.4 (Cont'd)

Project	Joint Winning Actual Bid	Joint Optimal Bid	Joint True Cost of the Project	Overall Joint Actual Profit or Losses	Overall Joint Optimal Profit or Losses
61	1627075	1731075	1680000	-52925	51075
62	2854893	2943893	2900000	-45107	43893
63	3960454	4049454	4000000	-39546	49454
64	2926543	3005543	3000000	-73457	5543
65	3440924	3509924	3500000	-59076	9924
66	1466403	1525403	1500000	-33597	25403
67	4482608	4506608	4500000	-17392	6608
68	4777823	4809560	4800000	-22177	9560
69	4910687	4959778	4940000	-29313	19778
70	3605839	3671839	3650000	-44161	21839
71	2743413	2843413	2800000	-56587	43413
72	2446576	2549576	2500000	-53424	49576
73	4732327	4834832	4750000	-17673	84832
74	3237633	3294633	3250000	-12367	44633
75	2577066	2638066	2600000	-22934	38066
76	6611522	6659022	6600000	11522	59022
77	9301858	9553472	9500000	-198142	53472
78	8903802	9038796	8900000	3802	138796
79	5403508	5643508	5500000	-96492	143508
80	5905220	6145220	6100000	-194780	45220
81	7330441	7560441	7500000	-169559	60441
82	8171561	8284061	8200000	-28439	84061
83	7645966	7815966	7800000	-154034	15966
84	9745417	9904143	9850000	-104583	54143
85	7190326	7465326	7250000	-59674	215326
86	9140136	9372439	9250000	-109864	122439
87	5595837	5840837	5750000	-154163	90837
88	6202613	6337613	6250000	-47387	87613
89	7670737	7910737	7750000	-79263	160737
90	9657346	9839336	9800000	-142654	39336

Note: (MSG = Multi-Stage Bidding Game; All values are in US Dollars)

APPENDIX D

RESULTS OF THE MODEL WITH LEARNING MODULE (MODEL 2)

Table D.1 The results of the SSG of model 2

Project	Winning GC Bid	Optimal Bid Value	Project True Cost	Actual Profit or losses	Optimal bid's profits or losses
1	23546	25046	25000	-1454	46
2	38591	40091	40000	-1409	91
3	28525	30025	30000	-1475	25
4	48515	49629	49000	-485	629
5	44481	45981	45000	-519	981
6	33619	35119	35000	-1381	119
7	26538	28038	28000	-1462	38
8	46547	48039	48000	-1453	39
9	34635	36135	36000	-1365	135
10	40596	42096	42000	-1404	96
11	27690	29190	29000	-1310	190
12	35821	37321	37000	-1179	321
13	36674	38174	38000	-1326	174
14	41679	43179	43000	-1321	179
15	40015	41515	40500	-485	1015
16	57819	60819	60000	-2181	819
17	77031	80031	80000	-2969	31
18	73065	76065	75000	-1935	1065
19	87282	90282	90000	-2718	282
20	97226	99286	98500	-1274	786
21	62033	65033	65000	-2967	33
22	92457	95449	95000	-2543	449
23	52939	55939	55000	-2061	939
24	82597	85597	85000	-2403	597
25	69569	72569	72000	-2431	569
26	63188	66188	65900	-2712	288
27	61947	64947	63000	-1053	1947
28	70213	73213	73000	-2787	213
29	95022	98267	98000	-2978	267
30	66305	69305	68000	-1695	1305

Table D.1 (Cont'd)

Project	Winning GC Bid	Optimal Bid Value	Project True Cost	Actual Profit or losses	Optimal bid's profits or losses
31	489070	497150	494000	-4930	3150
32	391445	403445	400000	-8555	3445
33	444255	456255	450000	-5745	6255
34	189166	201166	200000	-10834	1166
35	242177	254177	250000	-7823	4177
36	346540	358540	350000	-3460	8540
37	295423	307423	300000	-4577	7423
38	273460	285460	280000	-6540	5460
39	451808	463808	460000	-8192	3808
40	461848	473844	470000	-8152	3844
41	364292	376292	370000	-5708	6292
42	138875	150875	150500	-11625	375
43	268846	280846	275000	-6154	5846
44	413098	425098	425000	-11902	98
45	142924	154924	150000	-7076	4924
46	581801	611801	600000	-18199	11801
47	626748	656748	640000	-13252	16748
48	640944	670944	650000	-9056	20944
49	720894	750894	740000	-19106	10894
50	503724	533724	520000	-16276	13724
51	681362	711362	700000	-18638	11362
52	735988	765988	750000	-14012	15988
53	932720	962540	960000	-27280	2540
54	520592	550592	550000	-29408	592
55	724391	754391	738000	-13609	16391
56	725163	755163	748000	-22837	7163
57	602299	632299	620000	-17701	12299
58	704065	734065	725000	-20935	9065
59	906566	936553	925000	-18434	11553
60	955295	988824	985000	-29705	3824

Table D.1 (Cont'd)

Project	Winning GC Bid	Optimal Bid Value	Project True Cost	Actual Profit or losses	Optimal bid's profits or losses
61	1616429	1736429	1680000	-63571	56429
62	2785695	2905695	2900000	-114305	5695
63	3985517	4105517	4000000	-14483	105517
64	2880100	3000100	3000000	-119900	100
65	3441734	3561734	3500000	-58266	61734
66	1408457	1528457	1500000	-91543	28457
67	4403632	4523632	4500000	-96368	23632
68	4719747	4839201	4800000	-80253	39201
69	4838398	4947795	4940000	-101602	7795
70	3582656	3702656	3650000	-67344	52656
71	2685364	2805364	2800000	-114636	5364
72	2383722	2503722	2500000	-116278	3722
73	4670487	4790328	4750000	-79513	40328
74	3164115	3284115	3250000	-85885	34115
75	2480403	2600403	2600000	-119597	403
76	6398200	6698200	6600000	-201800	98200
77	9276079	9574998	9500000	-223921	74998
78	8607217	8907216	8900000	-292783	7216
79	5297258	5597258	5500000	-202742	97258
80	5878842	6178842	6100000	-221158	78842
81	7235982	7535982	7500000	-264018	35982
82	8043706	8343706	8200000	-156294	143706
83	7515217	7815217	7800000	-284783	15217
84	9551012	9873140	9850000	-298988	23140
85	6956941	7256941	7250000	-293059	6941
86	9061508	9361381	9250000	-188492	111381
87	5500989	5800989	5750000	-249011	50989
88	6017673	6317673	6250000	-232327	67673
89	7525185	7825185	7750000	-224815	75185
90	9559792	9841336	9800000	-240208	41336

Note: (SSG = Single-Stage Bidding Game; GC = General Contractor; All values are in US Dollars)

Table D.2 The joint actual and optimal bids for MSG of model 2

Project	Joint Winning Actual Bid	Joint Optimal Bid	Joint True Cost of the Project	Overall Joint Actual Profit or Losses	Overall Joint Optimal Profit or Losses
1	24082	25138	25000	-918	138
2	39215	40308	40000	-785	308
3	29329	30459	30000	-671	459
4	48000	49097	49000	-1000	97
5	43883	45050	45000	-1117	50
6	34164	35331	35000	-836	331
7	27392	28559	28000	-608	559
8	47174	48327	48000	-826	327
9	35061	36228	36000	-939	228
10	40883	42050	42000	-1117	50
11	28124	29291	29000	-876	291
12	36603	37770	37000	-397	770
13	37262	38429	38000	-738	429
14	42105	43272	43000	-895	272
15	39738	40905	40500	-762	405
16	59358	61458	60000	-642	1458
17	78310	80485	80000	-1690	485
18	73157	75332	75000	-1843	332
19	88300	90625	90000	-1700	625
20	96299	98600	98500	-2201	100
21	63193	65518	65000	-1807	518
22	93349	95738	95000	-1651	738
23	53237	55562	55000	-1763	562
24	83613	85788	85000	-1387	788
25	70182	72582	72000	-1818	582
26	64928	67328	65900	-972	1428
27	61100	63425	63000	-1900	425
28	71176	73501	73000	-1824	501
29	96343	98396	98000	-1657	396
30	66908	69233	68000	-1092	1233

Table D.2 (cont'd)

Project	Joint Winning Actual Bid	Joint Optimal Bid	Joint True Cost of the Project	Overall Joint Actual Profit or Losses	Overall Joint Optimal Profit or Losses
31	487752	494934	494000	-6248	934
32	394685	403385	400000	-5315	3385
33	444457	453457	450000	-5543	3457
34	193050	202050	200000	-6950	2050
35	243002	252302	250000	-6998	2302
36	342994	352294	350000	-7006	2294
37	292427	301727	300000	-7573	1727
38	276263	285563	280000	-3737	5563
39	451920	461220	460000	-8080	1220
40	462300	471597	470000	-7700	1597
41	362675	371975	370000	-7325	1975
42	145902	155202	150500	-4598	4702
43	268492	277792	275000	-6508	2792
44	417227	426527	425000	-7773	1527
45	145439	154739	150000	-4561	4739
46	592685	613685	600000	-7315	13685
47	626327	648077	640000	-13673	8077
48	638668	661168	650000	-11332	11168
49	721115	744365	740000	-18885	4365
50	505768	529018	520000	-14232	9018
51	678729	702729	700000	-21271	2729
52	729905	753905	750000	-20095	3905
53	937681	960780	960000	-22319	780
54	534487	557737	550000	-15513	7737
55	718490	741740	738000	-19510	3740
56	728606	752606	748000	-19394	4606
57	599907	623157	620000	-20093	3157
58	704334	728334	725000	-20666	3334
59	904421	926167	925000	-20579	1167
60	966358	987890	985000	-18642	2890

Table D.2 (Cont'd)

Project	Joint Winning Actual Bid	Joint Optimal Bid	Joint True Cost of the Project	Overall Joint Actual Profit or Losses	Overall Joint Optimal Profit or Losses
61	1616988	1700988	1680000	-63012	20988
62	2856893	2943893	2900000	-43107	43893
63	3937836	4027836	4000000	-62164	27836
64	2915543	3005543	3000000	-84457	5543
65	3418232	3511232	3500000	-81768	11232
66	1418491	1508491	1500000	-81509	8491
67	4411454	4504454	4500000	-88546	4454
68	4716823	4809560	4800000	-83177	9560
69	4885687	4959778	4940000	-54313	19778
70	3575221	3668221	3650000	-74779	18221
71	2751029	2841029	2800000	-48971	41029
72	2442138	2535138	2500000	-57862	35138
73	4699612	4789445	4750000	-50388	39445
74	3201633	3294633	3250000	-48367	44633
75	2545066	2638066	2600000	-54934	38066
76	6449022	6659022	6600000	-150978	59022
77	9336858	9553472	9500000	-163142	53472
78	8733192	8958190	8900000	-166808	58190
79	5373489	5605989	5500000	-126511	105989
80	5912720	6145220	6100000	-187280	45220
81	7276014	7508514	7500000	-223986	8514
82	8015012	8247512	8200000	-184988	47512
83	7583466	7815966	7800000	-216534	15966
84	9717100	9901235	9850000	-132900	51235
85	7105939	7338439	7250000	-144061	88439
86	9107396	9339790	9250000	-142604	89790
87	5592032	5824532	5750000	-157968	74532
88	6105113	6337613	6250000	-144887	87613
89	7601566	7834066	7750000	-148434	84066
90	9624846	9839335	9800000	-175154	39335

Note: (MSG = Multi-Stage Bidding Game; All values are in US Dollars)