5th International/11th Construction Specialty Conference
5e International/11e Conférence spécialisée sur la construction

Vancouver, British Columbia
June 8 to June 10, 2015 / *8 juin au 10 juin 2015*

MULTI-STAGE BIDDING FOR CONSTRUCTION CONTRACTS: A GAME THEORY APPROACH

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Abstract: In the construction industry, auctions have long been used as a method for allocating contracts. Not addressed in the literature (engineering or economics) is the fact that most, if not all, large jobs are awarded to a general contractor who in turn sub-contracts most, if not all, actual engineering services. Optimal bidding strategies in this setting require the general contractor to not only account for the optimal bidding strategies of rivals, but sub-contractors as well. Because the true cost of construction is not known until after the completion of the contract, adverse selection occurs when the winner of the contract is the one that most has under estimated the true cost. Due to the multi-stage bidding environment, adverse selection may be compounded. Therefore, not accounting for the potential for adverse selection by bidders may result in requested change orders by the general and sub-contractors or lower quality services. Either state ultimately results in an adversarial relationship between the sub-contractor and general contractor, and the client as well. This paper uses game theory to determine to what extent the multi-stage aspects of large construction contract bidding may contribute to inefficient allocation of contracts. This should better help in creating an efficient and effective contracting environment that result in less conflicts, claims and disputes for all the associated stakeholders.

1 INTRODUCTION

Construction has 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 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 maintain a competitive position within the market, and also for nations' economy to operate effectively and efficiently.

According to Kuluanga (2001), the construction industry incorporated simple and straightforward processes in the early years. However, the construction industry is getting more complex and sophisticated in today's world. Nowadays, one of the complicated areas in the construction industry is the contract allocation process. Competitive bidding has long been used as a method for allocating contracts in the construction industry (Seydel 2003). In the public sector, competitive bidding has been considered as a legal requirement. Furthermore, it is argued that one of the main factors that have a great effect on the success of construction projects is the firms' bidding decisions.

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. 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 paper, the contract is awarded the contractor who is technically approved, and has the lowest price among the 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.

The main difference between construction projects and other types of projects is the high level of uncertainty of events that may occur during the project's life cycle. For instance, contractors must contend with inevitable and unforeseen input price increases, 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 their current information, past experience, and utilizing methods such as RS means. The RS method is 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. Thus, in construction bidding, contractors, who underestimated project cost and bid less than the realized project construction cost, face the problem of adverse selection. Adverse selection results in what is known as the "winner's curse".

2 GOALS AND OBJECTIVES

The goal of this paper is to identify the degree of the winner's curse in two common construction bidding settings. The authors aim to compare the construction bidding environments of "single-stage bidding vs. multi-stage bidding". Furthermore, this research would provide an effective tool for contractors to mitigate the winner's curse.

3 BACKGROUND INFORMATION

3.1 Construction Bidding and Common Value Auctions

Historically, auctions have been used over thousands of years to sell numerous types of goods and services. In our today's world, auctions are of great practical importance because the value of goods being exchanged in auctions, in both public and private sectors, is relatively high (Kagel and Levin 2002). From the perspective of game theory, auctions are considered one of 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.

Generally, the same logic of auctions applies to construction bidding. Basically, contractors have two sources of incomplete information at time of submitting their bids; (i) actual project construction cost, and (ii) their competitors' estimates of the project construction cost. In auction theory, auctions are classified into two types; (i) private value auctions, and (ii) common value auctions. In private value auction, the bidders know their own value of the item being auctioned with certainty, but they do not know other bidders' values. On the other hand, in common value auction, the item being auctioned has the same value to everyone, but none of the bidders know this value with certainty. Each bidder generates different estimate about the true value, which is generally being observed after the auction is over (Kagel and Levin 2002).

According to Dyer and Kagel (1996), construction bidding is considered as a common value auction. This is due to the unknown true cost of construction projects which cannot be realized with certainty until completion of the project. Furthermore, the auction theory also refers to bidding for construction contracts as a reverse auction, where bidder usually wins the project, based on the low bid method, when they have the lowest estimate of the project cost.

3.2 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. Thereafter, many researchers have claimed the same problem of the winner's curse, such as in book publication rights (Dessauer 1981), in corporate takeover battles (Roll 1986), and in real-estate auctions (Ashenfelter and Genesore 1992).

The winner's curse can be described in many ways. In construction industry, the winner's curse can be defined as the situation when the bidder, with the most optimistic information and project cost estimate, wins the project contract based on a submitted bid less than the true project construction cost. Such a bidder, who fails to take the winner's curse problem into account, ends up with negative or below normal profits.

According to Dyer and Kagel (1996), in construction bidding, US general contractors usually utilize one of the following three mechanisms to avoid the winner's curse:

- One mechanism is that 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 contractors can benefit from this to escape from the winner's curse by withdrawal of their submitted low bids.
- Second mechanism is depending on the relationship between general contractors and sub-contractors. General contractors can bid too high with the assistance of their sub-contractors to cover that. Usually, sub-contractors assist their general contractors in that in order to get the job, and for the usual long term work relationship between general contractors and sub-contractors.
- Third mechanism to avoid the winner's curse is through change orders. Change orders refer to situations in which clients or owners adjust the original scope of construction of the project after signing the contract. Usually, the price of a change order is established through negotiations between associated stakeholders. Through tough negotiations, general contractor, who 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 which is considered ineffective due to its many disadvantages such as the resulted adversarial between the sub-contractor and general contractor, and the client as well, and its potential legal costs. Therefore, in order to avoid the winner's curse problem, and due to the relatively ineffectiveness of the aforementioned mechanisms, contractors must carefully consider all factors while preparing their bids such as market factors as location of the project, number of competitors, and time, and project factors as its size, type and scope. Being the case, the following section provides the contractors with guidelines in order to obtain the optimal strategic bid to submit and avoid the winner's curse.

3.3 The Symmetric Risk Neutral Nash Equilibrium (SRNNE) Bid Function

From past research in auction theory, Wilson (1977) developed the first Nash equilibrium solution for first price sealed-bid common value auctions. Thereafter, Dyer et al. (1989) presented the symmetric risk neutral Nash equilibrium bid function (SRNNE) for a sealed-bid first price common value auctions. Furthermore, Dyer et al. (1989) utilized this optimal bid function to analyze a series of laboratory sealed-bid common value auctions, in which bidders were competing for the right to supply an item of unknown cost such as construction contracts. Dyer et al. (1989) focused primarily on analyzing and comparing the behavior of experienced executives in the construction industry with inexperienced students.

According to Dyer et al. (1989), it was found that both inexperienced students and experienced executives were almost similar in suffering from the winner's curse. Furthermore, it was concluded that the use of SRNNE optimal bid function guarantee that bidders would not suffer the winner's curse problem, subject to winning the project contract.

As aforementioned, the actual cost of construction project C, is unknown at the time of submitting bids. Therefore, each contractor (i) has a different estimate of the project cost. Generally, the winner of the construction project contract expect to earn a profit which is equal to the difference between his bid and the actual cost of the project, as shown in the following equation 1:

[1] Profit = Winner's bid – Actual Cost

When the winner's profit is negative or below normal profits, then the winning bidder is considered a prey to the winner's curse. In deriving the SRNNE optimal bid function, the actual cost of project C, is assumed to be randomly 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 $[C-\epsilon, C+\epsilon]$. Moreover, it is also assumed that the uniform distributions of the actual cost C, the private signal c_i, ϵ, and the number of bidders N, are a common knowledge to all participating bidders.

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

[2] $b(c_i) = c_i + \epsilon - Y$

Where $Y = [2\epsilon/N+1] \exp [- (N/2\epsilon) (X_2 - \epsilon - c_i)]$, and N is the number of bidders. The variable ϵ represents the range of private signal around the true cost, and depends on the accuracy of bidder's estimate. It is important to notice that the Y term diminishes rapidly as c_i moves below $(X_2-\epsilon)$. Also, the SRNNE implies that signals are just marked-up by a value equal to ϵ, which represents a strategic profit, just to avoid the winner's curse problem of negative profits.

The main objective of SRNNE optimal bid function is to determine the optimal amount a bidder shall submit without being subjected to the winner's curse problem, in case of winning the contract. It is logical that if the bidder bids based on estimating the project cost close to $(X_1+\epsilon)$, he may 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 $(X_1+\epsilon)$, he will lose money eventually, in expectations, based on the winner's curse concept.

4 RESEARCH METHODOLOGY

In this paper, the authors apply the aforementioned theoretical approach of SRNNE using some real projects dataset conducted by California Department of Transportation. Furthermore, the authors compare the results to those of the implemented model, which simulates the bidding procedure in reality. The main purpose is of the simulation model is to analyze the behavior of sub-contractors and general contractors towards the threat of the winner's curse. Moreover, the authors aim 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. As aforementioned, it is expected that multi-stage bidding will result in that the winner will suffer more losses, than in single stage bidding. To this end, this research uses a three-step research methodology in which the authors (1) design the single-stage and multi-stage bidding games; (2) set up the basic assumptions and considerations required for the simulation model; and (3) collect some real projects dataset to be utilized in the simulation model.

4.1 Design of the Single-Stage and Multi-Stage Bidding Games

In the single-stage bidding game, as shown in Figure 1, 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 following the low bid method concept. The projects in SSG are designed to be the same as those in MSG.

Figure 1: Single-stage bidding game (GC=General Contractor)

On the other hand, in the multi stage bidding game, as shown in Figure 2, there are three general contractors. Each general contractor receives bids from three sub-contractors for a symmetric part of the project. In MSG, it is assumed that the general contractor subcontracts up to 30% of the project work. Based on the low bid method, the winning sub-contractor for each general contractor is the one who submits the lowest bid. Thereafter, the three general contractors are competing in between to win the project and submit their joint bids to the owner. Eventually, 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.

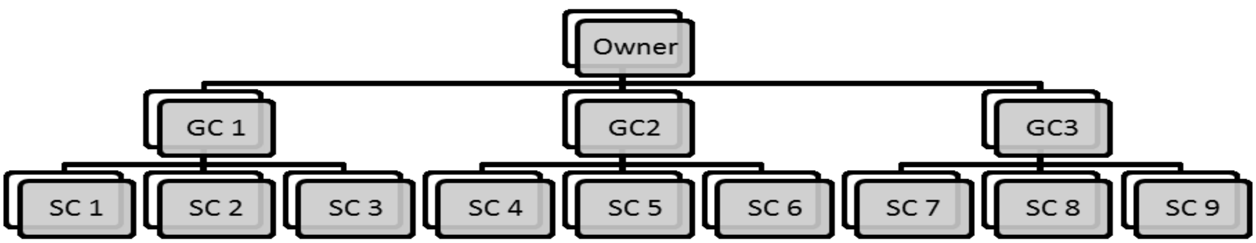


Figure 2: Mutli-stage bidding game (GC=General Contractor, SC=Sub-Contractor)

4.2 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 model, which are as follows:

- In both SSG and MSG, there are six projects' categories and each category is represented by 15 different projects.
- 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 true cost is considered unknown for contractors at the time of submitting their bids.
- The simulation model is designed such that, at each round, the contractors would choose randomly to bid within the range of ϵ, which is shown in table 1, around the given private signal.

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 randomly 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 illustrates the distribution of the private signals and the true cost at a round for in category 1 in SSG as an example.

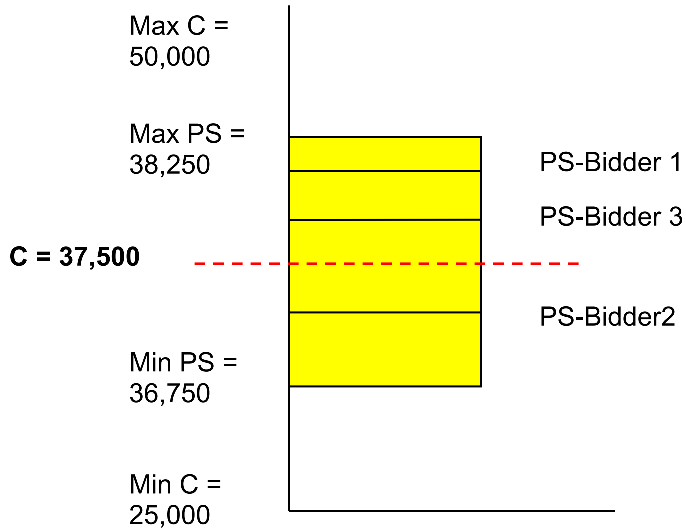


Figure 3: An example of the true cost and private signal distributions (C = True Cost, PS = Private Signal)

4.3 Simulation Model Dataset

As previously mentioned, the simulation is implemented using some dataset, which is based on real projects conducted by California Department of Transportation, to simulate the construction bidding process in reality. Either MSG or SSG is divided into six categories, based on the true cost of the project. Each category is represented by 15 projects in each game type in the simulation model. Furthermore, the value of ϵ is different from one category to another in order to be reasonable relative to the true cost of the project and simulate, as possible, the accuracy of contractors' estimates in reality, e.g. 2%. The following Table 1 shows the six categories, and the value of ϵ for each category.

Table 1: Projects' Categories and the Corresponding ϵ Value

		MSG		SSG
Category	Range	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)

To this end, the simulation model of the single-stage bidding game, and multi-stage bidding game was implemented on NetBeans IDE 7.4 platform using JAVA programming language.

5 RESULTS AND ANALYSIS

5.1 Results of the SSG and MSG

In the single-stage bidding game, based on the results of the conducted simulation model, it was found that, in 75 projects out of the 90 projects in all the six categories of projects, the winning general contractor suffered from the winner's curse, by winning the project contract with a submitted bid less than the actual true cost of the project, which represents 83.3% of all the projects being bid for.

Based on past literature, this result was expected according to the four experiments conducted by Dyer et al. (1989), in which the authors found that both inexperienced students and experienced executives suffered the winner's curse by earning negative profits in three of the four experiments, and profits were not statistically different from zero in the other experiment. Figure 4 shows the winning general contractor's actual bid and compares it to the actual true cost of the project for the 15 projects in category 1, as an example.

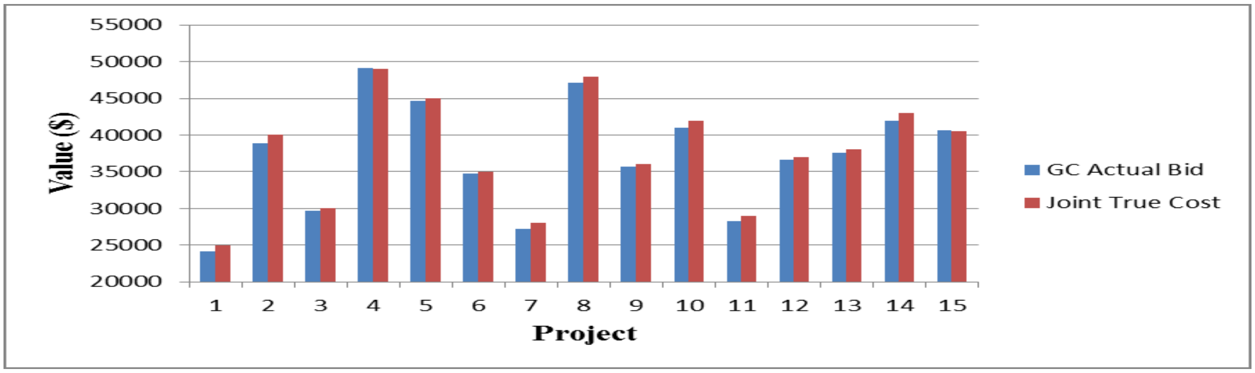


Figure 4: Category 1: GC actual bid vs. joint project true cost (GC = General Contractor)

Furthermore, in the multi-stage bidding game, the results indicated the winning sub-contractors, in their part of the project, suffered in 83 projects, out of the 90 projects being bid for, from the winner's curse, which represents around 92% of the projects. On the other hand, the winning general contractors, also in their part of the project, suffered in 77 projects, out of the 90 projects being bid for, from the winner's curse, which represents around 86% of the projects.

Moreover, the results indicated that in the MSG, all the projects, except one project, in which the winning general contractors earned some profits (13 projects) in the part of the project, their corresponding winning sub-contractors suffered from the winner's curse and vice versa. Therefore, it is important to highlight that based on the characteristics of the construction competitive bidding and non-cooperative game theory, in the MSG, 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 considered liable to them, while the other will earn the profits based on his submitted bid for his part of the project.

Furthermore, it is noticeable that the winning general contractors have avoided the winner's curse more than the winning sub-contractors. This refers to one of the mechanisms stated by Dyer and Kagel (1996), in which the general contractors benefit from the low submitted bids by the sub-contractors to earn more profits and at the same time, submit low joint bids which guarantee them the winning of the project contract.

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

Figure 5 shows the joint actual bids of the winning general contractor and his winning sub-contractor, and the joint true costs of the 15 projects in category 1 as an example.

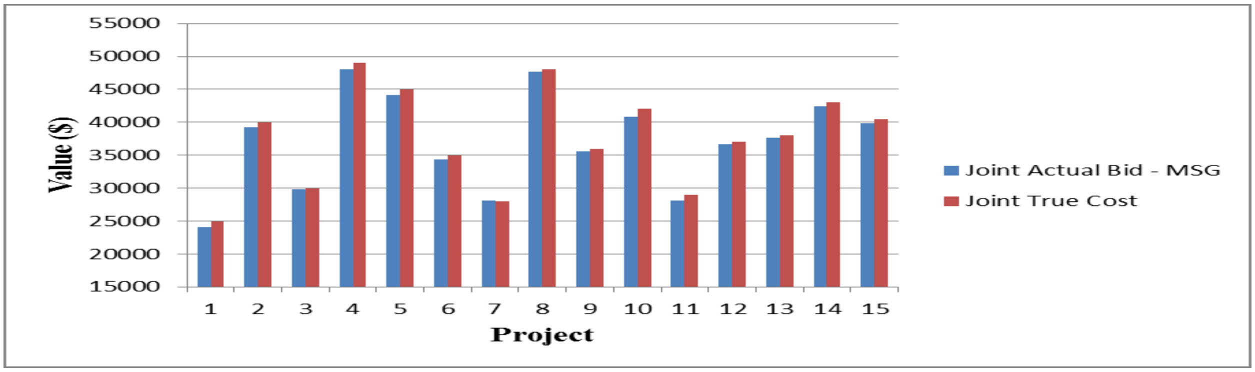
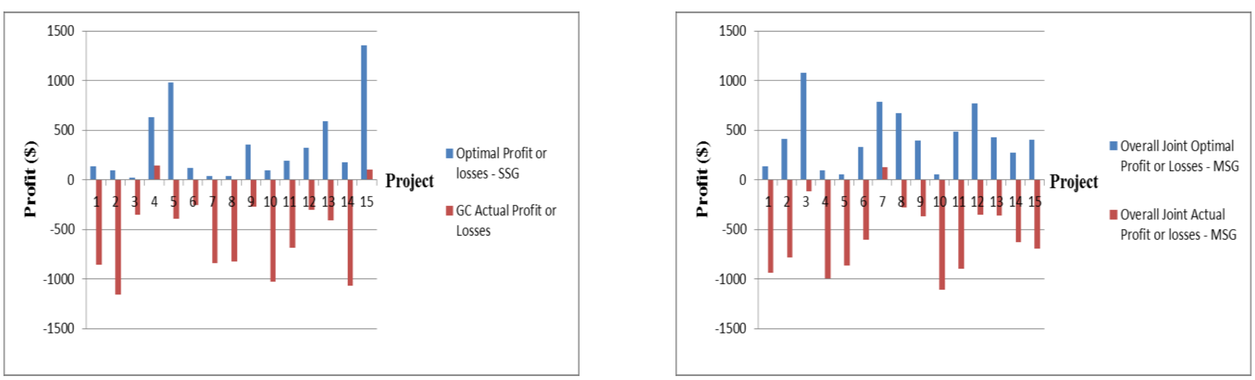


Figure 5: Category 1: the winning joint actual bid vs joint project true cost (MSG = Multi-Stage Bidding Game)

5.2 Case of Using SRNNE Optimal Bid Function in Bid Preparation for Both SSG and MSG

The SRNNE optimal bid function provides the contractors with a tool to avoid falling as a prey to the winner's curse. Moreover, the SRNNE is derived to be used for symmetric bidders within the same stage. Thus, it is assumed that the SRNNE would be used separately at each stage of bidding for the MSG. Based on the results of both SSG and MSG; it was found that using the SRNNE optimal bid function gives positive profits in 100% of the projects. In other words, all optimal bids are more than the true cost of the projects. It is important to highlight that using SRNNE optimal bid function does not guarantee that the contractor will win the project contract. But, it guarantees that the contractor will not suffer from the winner's curse in case of winning the project contract.

Furthermore, the optimal bids give only a strategic profit only to be above the project true cost. Based on the implemented model's results, the average of the overall earned profits is 1.31% and 1.27% relative the joint project true cost for SSG and MSG, respectively. Figure 6 shows the comparison between the joint actual winning bids' profits or losses and the earned joint optimal profits for the 15 projects in category 1 for both SSG and MSG. It is important to highlight that the X-axis (zero in Y-axis), in Figure 6, represents the joint true cost of the project.



(a) (b)

Figure 6: Category 1: the joint optimal vs. joint actual profits or losses {(a) SSG = Single-Stage Bidding Game; (b) MSG = Multi-Stage Bidding Game}

5.3 The Comparison between Single-Stage Bidding Game and Multi-Stage Bidding Game

Based on the results of the implemented simulation model, it was found that the SSG is giving less losses as compared to the overall losses of the MSG. This result was observed to occur in 56 of the total 90 projects, representing approximately 62 percent of all projects, as shown in table 2.

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 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 2. 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. Figure 7 shows the comparison between the overall actual profit or losses of the MSG and those of the SSG for each project in category 1 as an example. Moreover, the X-axis (zero in Y-axis) in the figure 7 represents the joint true cost of the projects in category 1.

Table 2: Comparison between MSG and SSG from The Winner's Curse Perspective

Case	% of the projects which give positive profits	% of the projects which give 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: (MSG = Multi-stage Bidding Game; SSG = Single-Stage Bidding Game; SC = Sub-Contractor; GC = General Contractor)

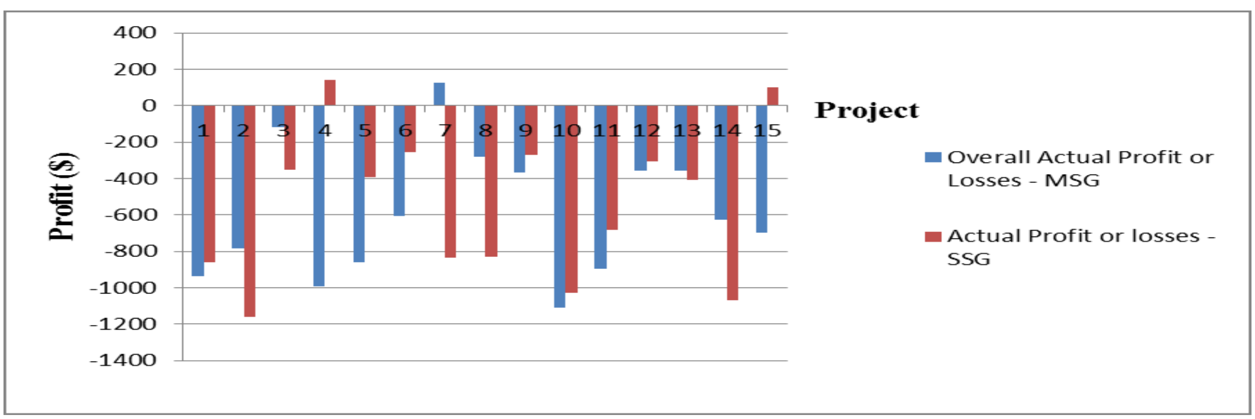


Figure 7: Category 1: overall MSG vs SSG actual profit or losses (SSG = Single-Stage Bidding Game; MSG = Multi-Stage Bidding Game)

6 CONCULSION

The winner's curse is a major concern associated with construction bidding. The results and analysis conducted in this study demonstrate that in construction bidding, the majority of the winning sub-contractors as well as general contractors suffer from the winner's curse in both single-stage and multi-stage bidding environments. However, the winner's curse is more severe in the multi-stage bidding environment. A question which arises here is why contractors suffer from the winner's curse in reality? Actually, this might happen for variety of reasons as follows:

- Inaccurate estimates of project cost.
- New contractors intend to enter the construction market.
- Minimizing losses in case of recession of construction industry.
- Strong competition within the construction market
- Opportunity costs which can affect the behavior of contractors towards the winner's curse.
- The intention to win the project, then remedy the losses through change orders, claims, and other mechanisms.

Therefore, it is obvious the need for a tool which aids contractors in preparing more accurate bids to initially avoid the winner's curse. It has been also demonstrated that the SRNNE optimal bidding methodology, in both bidding environments, provides the contractors with a tool to avoid the winner's curse problem and gain strategic positive profits.

Furthermore, the aforementioned SRNNE optimal bid function considers only a strategic amount of profit to avoid the winner's curse. For further research, the authors recommend the extension of the SRNNE optimal bid function to include more factors associated with bid preparation such as mark-up, overhead costs, contingency costs.

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