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Recommended Citation

A. Elsayegh et al., "An Agent-Based Model to Study Competitive Construction Bidding and the Winner's Curse," *Procedia Computer Science*, vol. 168, pp. 147-153, Elsevier B.V., May 2020.
The definitive version is available at https://doi.org/10.1016/j.procs.2020.02.278

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ScienceDirect

Procedia Computer Science 168 (2020) 147–153

Procedia Computer Science

www.elsevier.com/locate/procedia

Complex Adaptive Systems Conference with Theme:
Leveraging AI and Machine Learning for Societal Challenges, CAS 2019

An Agent-based Model to Study Competitive Construction Bidding and the Winner's Curse

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Abstract

Reverse auction theory is the basis for competitive construction bidding process. The lowest bid method is utilized for selecting contractors in public projects. The winning contractor having the lowest bid value could be cursed when the submitted bid value results in negative profits. This is caused by many factors such as the contractor's estimation accuracy and markup. This is addressed in this paper by providing a model simulating the construction competitive bidding and the occurrence of the winner's curse. To this end, the authors show the extent to which the winner's curse affects the status of contracting companies. The objectives are to understand the characteristics of the competitive bidding phase in construction and to study the behavior of contractors subject to competitive bidding and the occurrence of the winner's curse. As such, the authors implemented a two-step methodology that incorporates (1) developing a general simulation model involving a population of contractors and projects using agent-based modeling for the competitive bidding process and (2) analyzing the results of the simulation model. This model should provide a better understanding to the construction profession as in contractors, project owners and Departments of Transportation of how decisions are made in this bidding environment.

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Peer-review under responsibility of the scientific committee of the Complex Adaptive Systems Conference with Theme: Leveraging AI and Machine Learning for Societal Challenges

Keywords: Construction bidding; Contracting; Winner's curse; Agent-based modeling; Simulation.

1. Introduction

Winning projects bids is the blood that gives life to contractors in the construction industry. Contractors bid on projects to ensure that more cash flow keeps coming towards their companies. Most public projects are bid by choosing the lowest bidder which is

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10.1016/j.procs.2020.02.278

commonly known as Reverse Auction theory. As the construction industry grows, the competition between contractors increases and becomes more complex [1]. Bidding for a project is a major decision that contractors make after receiving relevant information about such project [2]. The major challenge in competitive bidding is that the contractor needs to bid low enough to win the contract but still high enough to generate positive profits [3]. Contractors try to be as accurate as possible in their estimates and include a minimum acceptable markup to maximize their chances of winning a bid. The estimation accuracy is subjective and depends on multiple factors such as the estimation staff, their experience and previous knowledge of similar projects [4]. Determining the markup is a strategic decision made by the upper management in each company which depends upon many factors such as size of the company, size of the project and how desperate they are willing to win. Desperate or unexperienced contractors could end up submitting low bids to secure winning a certain project. This could also be another strategy implemented by claims-conscious contractors that plan to compensate their low bids through future change orders by filing claims during construction which will only harm the project objectives [5]. This is one of the major drawbacks of the lowest bid method. Such bids might end up too low resulting in negative profits as the submitted bid value is less than the actual true cost of this project which is known as the winner's curse. As contractors bid for projects, they become more experienced and gain a better understanding of how their next bid should be.

In this paper, the authors attempt to simulate the competitive construction bidding market while incorporating different actions performed by the contractors trying to win more projects and learning from past experiences. Agent-based Modelling has been suggested to be suitable for the construction bidding process as it defines both elements of the project and the contractor and incorporates the different interactions between the two agents [6]. This model should provide a better understanding to the construction profession as in contractors, project owners and Departments of Transportation of how decisions are made in this bidding environment.

2. Goal and Objectives

The main goal of this paper is to provide a generic and simple simulation of the construction competitive bidding showing the extent to which the winner's curse affects the status of contracting companies. The objectives of this study are to 1) understand the characteristics of the competitive bidding phase in construction, and 2) study the behavior of contractors subject to competitive bidding and the occurrence of the winner's curse.

3. Background

Several researchers have previously successfully used agent-based modeling to simulate bidding. For example, Gordillo and Giret [7] investigated the the performance of agent-based scheduling approaches for manufacturing systems. The authors created a mechanism to measure the performance of agent-based scheduling approaches under key critical situations such as: dynamic environment, rescheduling, and priority change. Sadigh et al. [8] developed a multi-agent system for the selection of winning enterprises in virtual enterprise, wich is a collaboration between business partners in value chain. It can be used to forecast the outcomes of auctions, so that customers can plan ahead and take necessary action. Rahimi et al. [9] investigated consensus-based auction bidding methods in clustered supply–demand networks, where each supplier acts as an agent in a multi-agent system. Koenig et al. [10] also studied the use of agent-based modeling in cooperative auctions and presented an overview of the recent progress in this field.

Agent-Based modeling has also been used extensively in construction engineering and management applications, such as energy modeling of commercial buildings by simulating occupants as agents [11], collaboration within interorganizational networks of construction project teams [12], labor productivity and efficiency [13] [14], disaster management [15] [16] [17], among many other applications. Agent-based modeling has been used extensively to simulate bidding for construction projects, in order to model profitability, bidding strategies, risk attitude, the interaction between stakeholders, learning over time, and detection of market behavior [18] [19] [20]. This research follows the same research trend by implementing agent-based modeling to investigate bidding in construction projects.

4. Methodology

This paper presents a simulation model of the competitive construction bidding while addressing two main interacting agents which are projects and contractors. As such, the authors implemented a two-step methodology that incorporates (1) developing a general simulation model involving a population of contractors and projects using agent-based modeling for the competitive bidding process and (2) analyzing the results of the simulation model. All the literature review suggested using agent-based modeling for this kind of complex system as the main process here is interaction between different agents. After careful consideration, the authors chose the AnyLogic Software to be the platform for developing this model for its powerful visualization of interactions between agents. The main actions included in the model for simulating the construction bidding process are shown in figure 1.

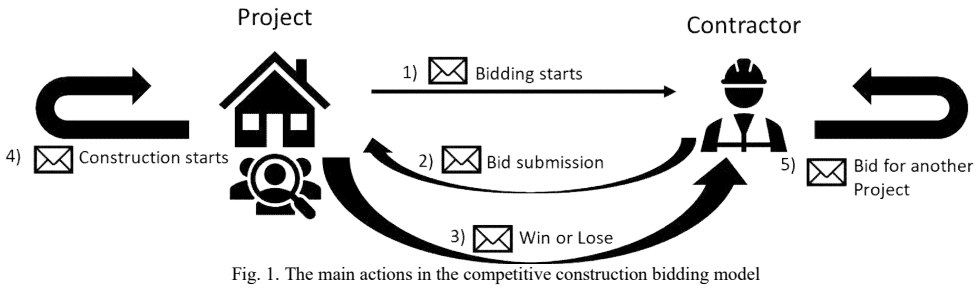


Fig. 1. The main actions in the competitive construction bidding model

The project and contractor agents are initialized with a certain population for each. The model is using synthetic data for the project and contractor parameters which are drawn from uniform distributions such as project cost and contractor's capital. This is a generic model and all the included parameters are easily adjusted to suit different bidding environments (e.g. number of contractors and projects, project cost distribution, contractor's capital distribution, contractor's estimation accuracy).

After a project is generated, it informs all contractors that it is calling for bids. The interested contractors start preparing their bids and submit their bids back to the project agent. Reverse auction theory is implemented here as the project loops the submitted bids to find the lowest price which then corresponds to a successful bidder. The project informs all bidders of its decision whether they won or lost. The successful bidder is then linked with this project to start construction till project is completed. The contractor's profit is then calculated on project closure as the difference between the submitted bid and actual cost of the project. The profit is a crucial parameter that adds to the capital of contracting companies. On the contrary, overheads decrease the capital every time step which is monthly in this model. Contractors can also go bankrupt if the contractor's capital goes below zero.

In figure 2, the states of both project and contractor start interacting by sending messages and reacting upon such messages. The project agent sends messages to all contractors which is a signal with project cost. The contractors decide whether to bid on this project based on its capacity to handle a project of such size.

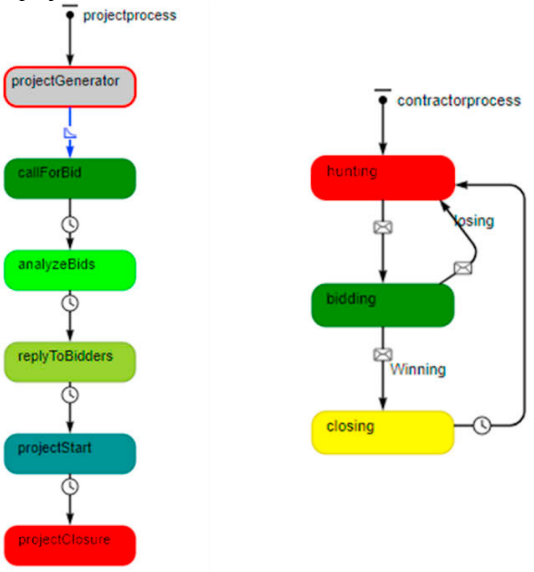


Fig. 2. (a) Project State chart; (b) Contractor State chart.

The contractor starts preparing a bid for this project based on the signal it received about the project cost. The bid value is then dependent upon the contractor's estimation accuracy and markup. One of the limitations of this study is that the contractor can only prepare one bid at a time. The project agent stores the submitted bids with relevant information such as the interested contractor ID, submitted bid value and status of this bid (i.e. successful or unsuccessful). The project then loops the submitted bid values to determine the lowest price which ends up being the winning bidder.

The project informs all bidders about its decision whether they won or lost the bid. In case of losing, the contractor goes back to hunting state which is looking for other possible projects to bid on. Losing means that the submitted bid is out of competition. To have better chances in future bids, the contractor works on enhancing its estimation accuracy by learning from past experiences and mistakes in estimation. The contractor also decreases its markup in another attempt to maximize its future winning chances.

In case of winning the bid, the contractor then moves to the closing state to be linked with the project start till its closure. There are two scenarios that can happen when a contractor wins a bid, the first is that the contractor's bid value was higher than the actual project cost which results in positive profits. The other unwanted scenario is that the bid value was lower than the actual project cost which results in negative profits, which is also known as the winner's curse. At that point, the contractor wants to make sure this situation will not happen again in future bids, so the contractor enhances its estimation accuracy and increases its markup.

5. Simulation and Results

The simulation of this model starts with a user-friendly interface that is easy to understand and follow as shown in figure 3. It describes the whole process of the simulation run of competitive construction bidding and the occurrence of the winner's curse. The simulation time step is assumed to be monthly. Contractors are presented as circles while projects are presented as squares. The agents change their colors frequently representing the status of such agent at a certain time of the simulation run as previously shown in figure 2.

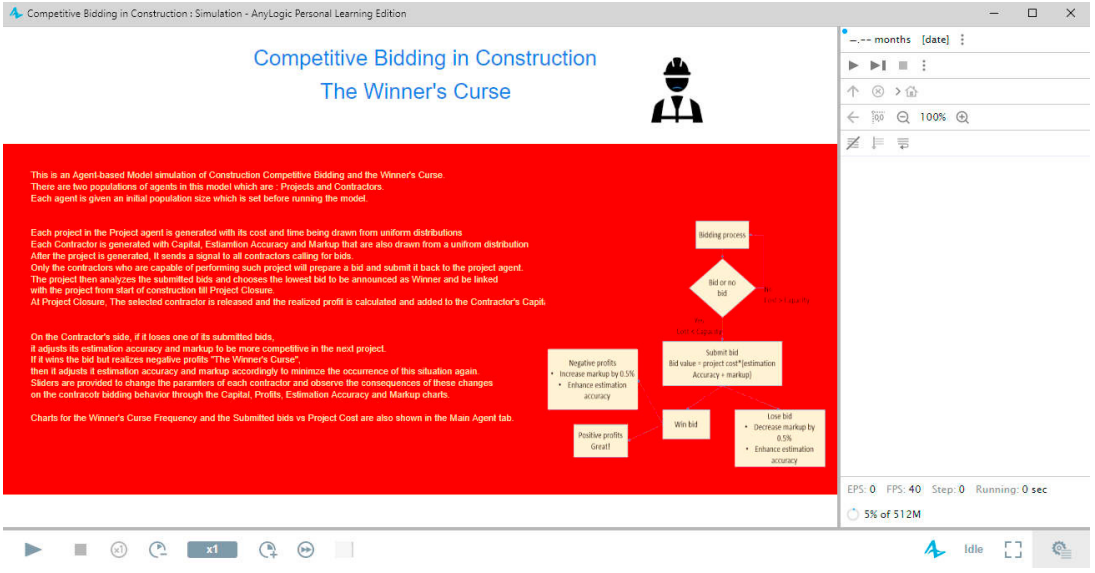


Fig. 3. Simulation user-friendly interface

The authors started the simulation with a small population of 2 contractors and 20 projects to validate that the model is working properly as shown in figure 4. The circles represent the contractors while the squares represent the projects and the color of each agent represent the state they are currently in. For example, the two contractors are in green color which means that they are in the bidding state for the project in lime color which means that the project is analyzing these submitted bids.

Fig. 4. Simulation user-friendly interface

Two graphs are produced as shown in figure 5 which are Project Cost vs Bid Value graph and the frequency of winner's curse graph. The winner's curse occurred two times when the submitted bids were less than the actual costs of the projects. As such, the model seems to be working as expected. Furthermore, the contractors are adjusting their estimation accuracy and markup as a reaction for bidding on projects in case of losing or the occurrence of the winner's curse.

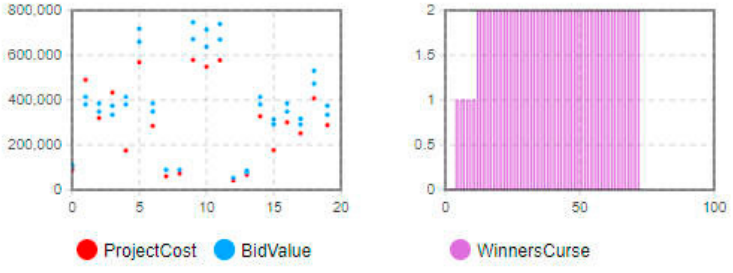


Fig. 5. (a) Project Cost vs Bid Value; (b) Frequency of the Winner's Curse.

Figure 6 shows the simulation from the contractor's side. It shows multiple graphs defining the contractor's main parameters over time such as capital, estimation accuracy, markup and profit. After winning a bid, profit is calculated as the difference between submitted bid value and actual project cost. The profit is not added to the contractor's capital until the project is completed and the final actual cost is computed. Sliders are also provided to change these parameters and display how these changes would affect the behavior and status of contractors.

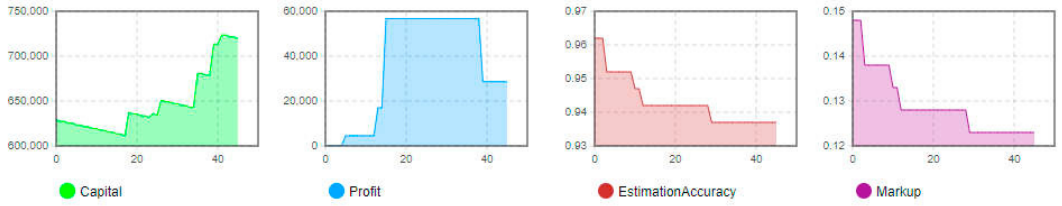
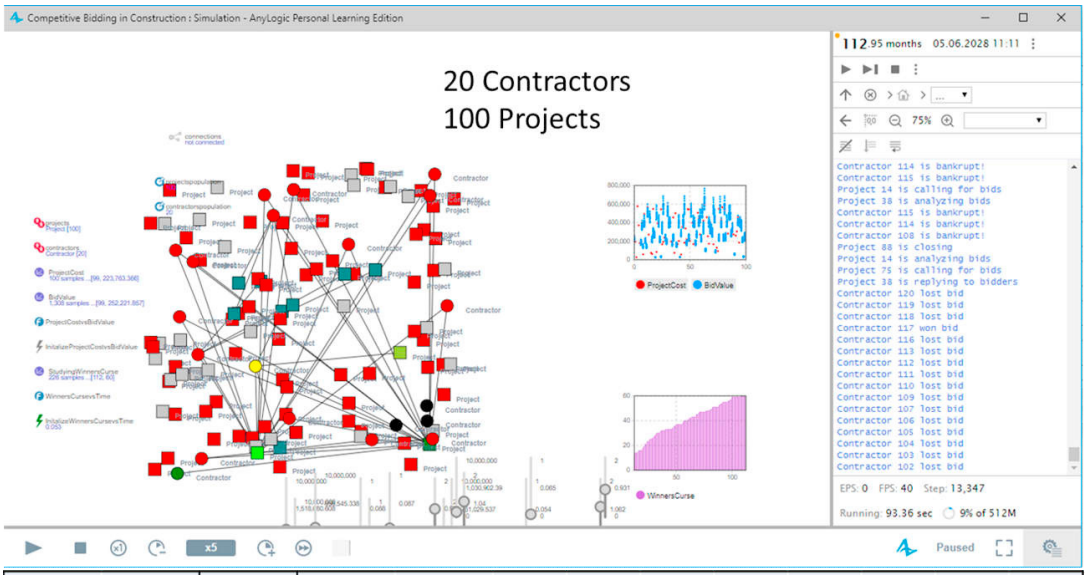


Fig. 6. (a) Capital; (b) Profit; (c) Estimation Accuracy; (d) Markup.

The model can handle large populations of contractors and projects. However, the model becomes more complex and harder to interpret but it is still behaving as expected as shown in figure 7. As the project size gets bigger, the number of interested contractors with enough capacity decreases. A big number of interested contractors means a more competitive environment and it becomes harder to win projects. If contractors cannot secure positive profits by winning projects and avoiding the winner's curse, these contractors are doomed to go bankrupt eventually (i.e. turn into black colored circles).



n	Project Cost	Bid Rank	Lowest bid	2nd lowest	3rd	4th	5th	6th	7th	8th	9th	10th
0	251715.71	Bid Value	201,710	202,337	202,886	203,426	204,200	208,485	214,663			
1	194827.35		156,117	158,003	165,355	166,691	173,832	177,225	177,450	179,394	183,698	187,122

Fig. 7. Simulation run with 20 contractors and 100 projects.

6. Conclusion and Future Work

This study presented an agent-based model of the construction bidding process showing the competition between contractors on bidding low for projects while maintaining positive acceptable profits. The winner is sometimes cursed when the submitted bid is lower than the actual cost of the project being bid on. The occurrence of the winner's curse is dependent upon the estimation accuracy and markup of contractors. The developed model works well in describing the competitive construction bidding process and the occurrence of the winner's curse. The model has some advantages as it has a user-friendly interface that explains the whole process and the model is highly adjustable in terms of the parameters of both contractor and project agents. Utilization of agent-based modeling is efficient in representing the behavior of contractors in the bidding process. The model has some limitations such as that the contractor can only apply to one bid at a time, the model is using a synthetic data, and there are only two agents addressed in this

study which are projects and contractors. The model can be enhanced by fixing the mentioned limitations and adding more agents such as owners and government to incorporate the full interaction of the construction market. Other influential parameters can also be added in each agent such as contractor's risk estimate and the project's procurement method. Using an actual dataset is beneficial to validate and calibrate the model. A game theory approach can also be implemented to see how it will affect the behavior of contractors in the construction bidding market. Finally, the developed model in this study should provide a better understanding to the construction profession as in contractors, project owners and Departments of Transportation of how decisions are made in this bidding environment.

7. Acknowledgements

The authors thank Paul Lamp (MSc Student) and Dr Nathaniel Osgood from the Department of Computer Science at University of Saskatchewan for their support and contribution towards the development of this agent-based model in AnyLogic. Paul was so helpful in providing guidance on defining specific parameters that enabled running and debugging the complex model in this study.

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