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Impact of considering need for work and risk on performance of construction contractors: An agent-based approach

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ABSTRACT

Competitive bidding is the main mechanism of allocating projects in the construction market. In the traditional single criterion bidding method, the markup decision has a significant impact on a contractor's business success. Contractors usually take into consideration several factors in the process of determining their markup. This study has reviewed the literature and identified a range of contractors' behaviors when making their markup decision within a competitive bidding environment. An additive markup function consisting of three components, namely competition, risk, and need for work, was developed in order to replicate markup behaviors of contractors. Then, agent-based modeling has been employed for simulating the bidding process within a market formed of a set of heterogeneous contractors with different risk attitudes and defined markup behaviors. This model was used to study the impact of considering need for work and risk allowance in markup determination on financial performance of contractors in various market scenarios. Results suggest that the optimal policy is moderation in both dimensions of risk attitude and need for work.

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1. Introduction

Once a contracting firm has made the decision to bid on a project, it is then faced with a more challenging decision which is to select a bid price that is low enough to win the project and at the same time high enough to make a good profit. A reasonable objective for each construction company is maximizing its profit in order to ensure survival in the market. However, while profit maximization is usually the most frequently used bidding objective [7], many researchers argue that it should not be the sole criterion upon which the markup is based. A contractor's need for work might sometimes play a conflicting role with short-term profit maximization and thus is identified as a major factor when determining the optimum markup for a project [1,12,39]. For instance, if a contractor is in a bad financial situation and is in urgent need of cash flow to cover its overhead and its general and administrative expenses, winning the project becomes a priority even if it comes at the expense of a much lower profit. Thus, the need to continuously cover some fixed costs such as offices' rentals, utilities, personnel salaries, insurance payments on property and equipment, and others might sometimes drive the contractor to submit a very low bid in order to at least breakeven and stay in the business. Moreover, the attitude of a contractor towards risk is another primary factor in determining the optimum markup for a project. Contractors have varying perceptions about market conditions and projects' uncertainties according to their inner state, bidding preferences and risk tolerance [33]. In fact, a construction project can be considered as a lottery with different profit outcomes and with a level of uncertainty resulting from the expected variance in the final cost of the project. The value of this lottery and its desirability differs from one contractor to another depending on their risk attitudes. Thus, it is important to consider the behavior of a contractor towards risk when making decisions under uncertainty such as the optimum markup decision, and in complex and risky environments such as the construction field. A third major component that defines the markup choice by contractors and that is outside their control is the intensity of competition in the market determined by the number of potential opponents bidding on the same project and their observed competitiveness degree. Contractors need to adjust their profit margins from one project to the other depending on the change in the number or identity of competitors [9]. Some other less important factors affecting the optimal markup decision were also identified in the literature such as type of project and inherent complexity, client character and record of payment, reliability of subcontractors, and the degree of uncertainty in cost estimates.

Several researchers listed and ranked the different factors a contractor takes into consideration when deciding whether to bid on a certain project or not and determining which markup to use. Moreover, many analytical and simulation models were presented in the literature that provided insight into the complexities and dynamics of the bidding

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process in the construction industry. These models reflected the multi-attribute nature of the bid/markup decision and devised approaches to help contractors in making bidding decisions carefully. However, findings from such models remain mere theoretical recommendations since top management in contracting firms keep relying on their subjective assessment, their experience and their intuition in determining their optimum markup [1,11,16].

The main contribution of multi-attribute bidding models is that they reflected the invalidity of the homogeneous bidding behavior assumption adopted in previously developed bidding models and paved the way for a new set of studies emphasizing heterogeneity in bidding preferences among contractors operating in the same environment and between groups of bidders operating in different markets. For instance, Oo et al. [32,33] designed bidding experiments to imitate the decision to bid and optimal markup selection in two construction markets, Hong Kong and Singapore, and showed that the two nations exhibited different behaviors in response to four bidding factors, namely number of bidders, market conditions, project type and size. Kim and Reinschmidt [25,26] addressed the heterogeneity in the risk behavior of contractors and used an evolutionary simulation approach to investigate its effect on the markup decision, the contractor's success, and the market structure within a competitive environment. Ho and Hsu [23] also considered heterogeneity among contractors in their competitive advantage over each other and followed a game theoretic approach to explore the effect of several bid compensation strategies on encouraging bidders to put more effort into project planning and tender preparation.

This paper focuses on three of the most influential bidding factors identified in the literature namely, the market competition, the contractor's risk behavior and his need for work. None of the prior studies discussed the interaction among the aforementioned markup defining components and the relative dominance of one on the other within a market of heterogeneous contractors exhibiting different bidding behavior and strategies. How does considering a contractor's need for work in his markup decision affect his longterm performance in the market? To what extent should a markup be adjusted to account for need for work without compromising profitability? How is this process affected by the risk behavior of a contractor and how do these two components interact? To answer the latter questions, this study presents an agent-based simulation model of the construction bidding process where contractors are modeled as autonomous agents competing on projects over time which allows observing the long-term effect of a contractor's risk attitude, his need for work and the market competition intensity on his optimal markup, his financial growth and survival, and his bid success rate. Hence, the three main objectives of this paper can be summarized as follows: (1) observing the impact of a contractor's risk attitude on his markup decision taking into account his need for work and the market competition, (2) assessing if and to which extent considering need for work in the markup decision affects the financial growth of a contractor and his market share, and (3) identifying emergent market patterns in a diverse competitive environment exhibiting different degrees of risk tolerance and different levels of need for work considerations.

2. Previous works

Following the very first statistical construction bidding models that focused on the sole criterion of profit maximization [8,19,21] in determining the optimal markup for a contractor, several multi-attribute models were presented in the literature that emphasized the importance of considering multiple factors when making bidding decisions. Indeed, the first addition to the aforementioned profit maximization models was the introduction of the risk notion based on utility theory and concepts. A group of studies emerged in this regard and focused on the impact of the risk behavior of a contractor on his bidding decisions [13,24,43]. Then, the literature on this topic went in two directions: a set of empirical studies that focused on defining the most influential factors in a contractor's optimal markup decision, and another set of articles that attempted at modeling the multi-attribute nature of the optimal markup decision using different approaches.

2.1. Multi-attribute nature of markup decision

Ahmad and Minkarah [1] presented the results of a survey administered to US contractors to determine the main factors considered in their bid/no bid and markup decisions. This study identified the contractor's need for work, type of job, degree of hazard, economic conditions, competition, degree of uncertainty in cost estimate, and reliability of subcontractors among others as important factors in determining the project markup value. Also, Shash [39] presented the findings of a questionnaire that collected feedback from 85 top UK contracting firms about the most prominent factors that affect their bidding decisions and their weights. Degree of difficulty, risk involved, current workload and need for work were identified as the most influential ones among several other listed factors. Chua and Li [12] conducted interviews with competitive bidding experts and top contractors in the Singapore construction industry through which they identified the potential level of competition, the inherent project risk, the contract type, the company's bidding position and its need for the job as essential considerations in bidding decisions. In turn, Dulaimi and Shan [16] identified forty factors that medium and large size contractors in Singapore perceive to be important when considering their bid markup decision. These factors were classified into project characteristics, company's attributes, bidding situation, economic environment, and project documentation. Furthermore, Ye et al. [45] presented a study that defined key factors contractors in China consider when preparing tender prices for public projects. These factors were ranked and classified under different categories including construction cost, contractor heterogeneity, payment terms, potential competitors, client requirements, market conditions, and third-party stakeholders.

All of the aforementioned empirical studies identifying factors that contractors take into consideration when faced with bidding decisions highlighted that the firm's internal conditions (including need for work, risk behavior, current workload, financial capacity, firm size and others) are equally and sometimes more important than project attributes and market characteristics. In a study conducted by Ahmad and Minkarah [1], need for work was identified as the most influential factor in making a contractor “desperate to get the work”. Also, in his survey about UK contractors, Shash [39] reiterated the observation that 90% of the respondents identified need for work as the main incentive that would make them take any measures to win the job. In fact, more than 70% of contractors pass through situations where they are in urgent need for the job and have to bid accordingly [12]. Hence, the focus of this paper will be on studying to which extent the need for work component affects the bid markup decision and the survival of a contractor in a risky and competitive market.

2.2. Multi-attribute bidding models

Inspired by the former studies which highlighted key attributes that form the basis of the bid markup decision, some researchers went further to develop multi-attribute bidding models that can assist contractors in determining their optimal markup. For example, Seydel and Olson [38] presented a quantitative method based on the analytical hierarchy process that can be used by contractors to determine their optimal markup for a particular project given their bidding preferences at that time. This model took into consideration three factors in the markup decision which are profit maximization, risk exposure minimization and workforce continuity. On the other hand, DeNeufville and King [14] focused on two influential factors in a contractor's bidding behavior which are risk and need for work, and developed profit markup utility functions for different possible combinations of these two factors based on an empirical investigation of the bidding decisions of 30 selected contractors in Boston. Moreover, Hegazy and Moselhi [22] developed an optimum markup estimation model based on artificial neural networks technique which determines the best optimum markup for a certain project based on analogy with previous similar projects. The bidding factors considered in their model were based on the ones identified in the survey conducted by Ahmad and Minkarah [1]. As for Dozzi et al. [15], they also used some of the bidding criteria identified in Ahmad and Minkarah [1] including market conditions, competition, current workload and other factors based on which they developed a utility theory model that can assist contractors in their markup selection. Fayek [18] used fuzzy set theory to model the margin-size decision based on 93 bidding factors compiled from previous research [1,39]. Christodoulou [11] also combined neurofuzzy systems and multidimensional risk analysis algorithms to develop a bidding model that assists contractors in their optimal markup decision. Then, Liu and Ling [30] used fuzzy neural network technique to model the markup estimation process by contractors. The model was based on data collected through a survey of 29 large size contractors about the importance of several attributes when determining the bid markup component. The study revealed that payment record of client, competitiveness of other bidders, availability of work, project complexity and the presence of owner's special requirement were respectively the top ranked attributes in the bid markup decision. Furthermore, Wang et al. [42] presented a simulation-based cost model that takes into account cost uncertainties and a multi-criteria evaluation model that uses fuzzy integrals to reflect the bidding preferences of the contractor in question. The model recommends an optimal bid price to be tendered by the contractor based on several bidding factors classified under environmental, project and company conditions as determined by previous studies.

These models do have insightful implications for the management side of a construction firm and do reveal important information about bidding practices and patterns in different construction markets; however, they are rarely used by construction professionals in actual decision-making processes. Traditionally, contractors have not been relying on any of the empirical or analytical bidding models presented in the literature in estimating their bid markup values on tendered projects but they rather depend on their gut feeling, judgment and previous experience [1,12,16,18,29]. Hence, the purpose behind this study is not to offer one additional bidding model that serves the same objective as the previous literature but rather to create a virtual experimental setting that mimics the construction bidding dynamics to a large extent in order to observe and understand how the different identified bidding attributes interact together and influence each other. Specifically, this paper uses the benefits of agent-based modeling and simulation to observe how do three of the most influential bidding attributes (contractor's risk attitude, need for work, and market competition) make up the bid markup decision, affect the contractor's survival and financial growth on the long-term, and shape the market patterns.

3. Methodology & description of experiments

3.1. Simulation model

Agent-based modeling (ABM) is relatively a new development that has found extensive use in areas such as economics, transportation, sociology, biology, marketing, sales, and others [37]. ABM is a powerful tool for modeling and analyzing complex environments where complexity emerges from a large number of unknown and known variables and autonomous interacting decision makers. In such problems, game theory and mathematical models, considered as prescriptive approaches in decision science, cannot help alone and need to be integrated with agent-based modeling. For further reading on integration of game theory and mathematical modeling with agent-based modeling, Unsal and Taylor [41] and Awwad et al. [3] are suggested. Also, a comprehensive review of game theory applications in construction management can be found in Asgari et al. [2].

Recently, ABM has been used in some construction management applications as well such as infrastructure management [35], dispute resolution [17], subcontractor selection [41], sustainable design and management of the built environment [4,5,10,34], and competitive bidding [3,25,26]. ABM proves to be very helpful when it comes to modeling a collection of independent decision-making entities as agents that sense and stochastically respond to emerging conditions in their local environments. Each agent assesses its individual situation, analyzes it in relation to the other agents, and then makes decisions based on a set of developed rules [20]. Hence, ABM is a promising tool to mimic the complex bidding process where contractors are considered as agents having different bidding behavior and strategies, and competing over projects with varying characteristics for the purpose of achieving growing profits and survival. In this paper, the construction bidding environment is simulated using an agent-based approach where two classes of objects are defined, namely Projects and Contractors, for the purpose of studying the interaction between different markup components and their long-term influence on contractors' performance. Projects are generated sequentially over a simulation period of ten years and are assigned a set of characteristics such as the project budget chosen uniformly over the range [80, 120] M $, the project duration also selected uniformly between 20 and 30 weeks, the project complexity (low or high), and its actual cost based on the inherent uncertainty. On the other hand, a set of contractors is created in the market along with their attributes including their attitude towards risk, expertise, cost estimation skills, bidding competitiveness, financial status, work backlog and need for work, in addition to their decision making rules with respect to bidding on projects and markup choice. Fig. 1 shows a schematic representation of the bidding process simulation and reflects the interaction among the different agents over time within one competitive environment. Several contractor agents are created in the market with different attributes that influence their decision to bid or not on a certain project and their subsequent selection of the optimal markup. For instance, a variable called "working capital" is assigned to every contractor and may increase or decrease depending on the accumulated profits or losses from won projects. This variable is used to assess the financial situation of each contractor in the market and thus affects directly his need for work, as indicated through the unidirectional link between the two variables in Fig. 1. Besides, a contractor's resources and expertise define the scope and amount of work that can be performed at one point in time. Hence, if a contracting firm has all its resources assigned to projects' tasks, then it will not be in need for work. A third major attribute defined under the contractor agent is its risk attitude which is typically the byproduct of the firm's culture and leadership. The firm's risk attitude determines the way it perceives the inherent risk and complexity in a project and hence affects the corresponding risk contingency embedded in the firm's bid price. The aforementioned internal attributes of each contractor influence his markup choice in addition to other external factors such as the market competition and the project complexity, as shown in the Contractor X box in Fig. 1. Looking at the big picture, the developed simulation imitates the construction market environment which consists of a group of heterogeneous contractors competing over a set of projects with different characteristics generated throughout the simulation time. Each project has a certain complexity level (low or high) which affects the contingency component of the markup used by bidders on this project as well as the project actual cost. The Contractor agent also includes among its attributes a markup decision function that serves to determine the optimal markup when bidding on a new project as will be illustrated further in Section 3.2. This markup percentage is a summation of three components: (1) market competition influenced by the number and competitiveness of opponents, (2) the contractor's need for work affected by his financial situation and the amount of work at hand, and (3) the risk allowance which is a result of internal and external characteristics, i.e., the contractor's risk tolerance and the project inherent uncertainty. It is worth noting that the agent–environment boundary represents the limit of the agent's absolute control, not of its knowledge.

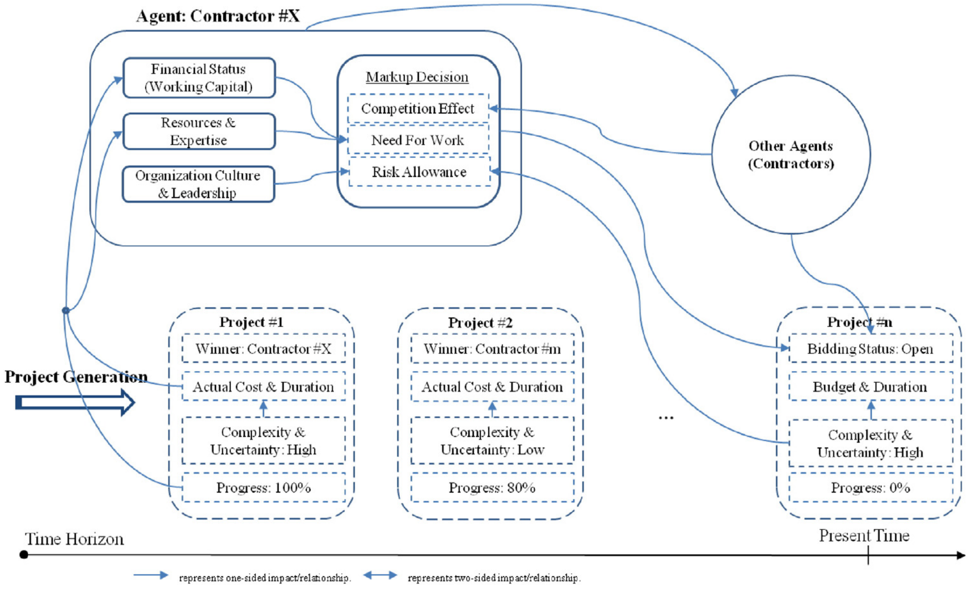

Fig. 1. An abstraction of a contractor in the bidding environment and the network structure of the market.

Readers can refer to the virtual bidding laboratory developed in [3] for further details about the abstraction and definition phases of the simulation model used in this study.

3.2. Markup function

Using the agent-based approach to simulate the construction bidding mechanism focuses on the heterogeneity feature among competitors in their internal attributes such as their behavior towards risk, financial capacity, need for work, management expertise and others, as well as their different perceptions of and reactions to external conditions like market competition, availability of projects, and project risk level among others. A set of parameters, variables and functions for the two defined agents, Contractors and Projects, are defined as illustrated in the previous section. Besides, behavioral rules of agents are also defined in a simple and reasonable manner [31].

Every time a project is generated in the market, the present contractors will evaluate their interest and capability to bid on this project through a function called Shallbid(). This function checks if the contractor's specialty and size can accommodate the project type and complexity, and if the contractor's bonding capacity and current amount of work allows for taking one more project with the respective budget. The second critical decision that a contracting firm has to make after deciding to bid on a project is the optimal markup to use in its bid price. Thus, another main function developed for the agent Contractor is the markup decision function which describes how a contractor chooses his markup value based on present external and internal circumstances. A contractor's markup for a project is defined as the sum of contingencies and profit and is expressed as a percentage applied to the project's estimated cost including all direct and overhead costs [30]. A slight increase in the markup value could lower the contractor's chance in winning the project and consequently affect his profitability and survival in the market. Since the main purpose of this study is to understand the interaction between different markup components and their influence on the contractors' performance, it was assumed that contractors can estimate a project cost with the same level of accuracy. This is to remove any variability in bid prices and winning chances among bidders resulting from cost estimation inaccuracies. It is also assumed that all contractors have the same level of management capability and therefore uncertainties in the actual cost at which a project is completed result mainly from different levels of project complexities. Note that the actual cost is set to follow a triangular distribution with a mean equal to the project's market budget.

This paper assumes that a typical contractor considers three criteria when trying to determine the markup for a certain project which are the market competition, the inherent risk, and the need for work. The latter components were identified in the literature among the most influential factors in a contractor's markup decision. DeNeufville and King [14] conducted an empirical study which showed that each of the two components, risk and need for work, causes independently and additively a rough increase of 3% in the bid price of a contracting firm. Based on the former study and to maintain simplicity in behavioral rules, an additive markup function was developed in this study consisting of three components described in the following subsections:

3.2.1. Competition component

Contractors consider the market competition as their prime concern when pricing their work [40]. Bidders should adjust their markups to reflect the quality and quantity of competition displayed by their opponents [9]. Competitiveness of opponents is measured in this model using the bid competitiveness ratio (BCR) expression introduced in the study by Oo et al. [33] which determines the gap between an opponent's bid and the lowest bid submitted for a project divided by the lowest bid.

$$BCR_{ip} = \frac{B_{ip} - B_{lp}}{B_{lp}} \tag{1}$$

where BCR_{ip} is the bid competitiveness ratio for opponent i on project p, B_{ip} is the bid price submitted by opponent i for project p, and B_{lp} is the lowest submitted bid for project p.

This ratio reflects how close an opponent's bid was to the lowest bid for a previous project and thus the smaller this ratio is, the more competitive the opponent is. During each bidding cycle, a contractor determines the average bid competitiveness ratios for his potential opponents over the last ten projects tendered in the market using the following code excerpt from the developed model:

```
//This piece of code shows how the BCRip of each contractor i is computed
and archived after determining the winning bid for every past project p//
for (Contractor c: get_Main().allContractors).
    {
```

```
    c.bidCompetitivenessRatio = (c.bidPrice/winningPrice) − 1;
    c.bidCompetitivenessDataset.add(this.projectID,c.bid
CompetitivenessRatio);
    }
//This piece of code shows how the average BCR_ip over the last ten projects, named bidCompetitivenessTen, is computed for each potential opponent i on the current project p//
for (Contractor c: Opponents).
    {
    sum = 0;
    for(int n = 0; n < c.bidCompetitivenessDataset.size(); n++)
    {sum + = c.bidCompetitivenessDataset.getY(n);}
    c.bidCompetitivenessTen = sum/c.bid
CompetitivenessDataset.size();
    }
```

Then, once the average bid competitiveness ratios of potential opponents are determined, the contractor will be able to compare and rank himself among his competitors and hence evaluate the percentage of opponents who have been more competitive than him in the recent past projects. The lower this percentage is, the higher markup a contractor can afford to use in his bid price for the current project and thus the higher the competition component will be in the developed additive markup function.

3.2.2. Risk component

The risk attitude of a contracting firm is part of its organizational culture and it may vary depending on the internal conditions of the firm and the external conditions of the market within which it operates. The construction industry encompasses a lot of hazards and uncertainties, and thus, contractors have to consider all project complexities when deciding to bid on a project and determining the bid price to tender. However, contractors try to limit inflating their bid prices to keep their competitive edge and rely on other ways to mitigate risk including subcontracting large portions of their work, enhancing their cost estimation and management skills, tailoring contract conditions such that risks are shared with clients, and relying on claims after winning the project [27]. Also, some identified risks at the bid pricing stage such as possible inaccuracies in quantities or price estimates and anticipated operational difficulties during project execution are typically accounted for in the unit price estimates of the project pay items. But even after applying all former risk mitigation strategies, there remains some residual risk that cannot be predicted or quantified and thus, has to be evaluated and accounted for as a risk allowance in the bid price by the company's decision makers. This type of risk is usually apportioned in a bid price as part of the markup applied to the project cost and is dependent on a combination of external factors such as market conditions and internal factors such as the firm's circumstances. The range identified in the literature for residual risk allowance percentage in bids is in the order of [0–3] % which was adopted in the presented model [14,27,40]. The risk tolerance of a contracting firm affects the way it perceives the inherent risk in a project and the impact it can have on the firm's bid price. This study considers three levels of contractors' risk aversion (mild, moderate and extreme) and two degrees of project risk (low and high) which will be the two main factors defining the risk contingency component in the markup function as such:

```
if (riskAversion == mild)
    {
    if (project.riskLevel == low)
    riskcontingency = 0.00;
    if (project.riskLevel == high)
    riskcontingency = 0.01;
    }
else if (riskAversion == moderate)
    {
    if (project.riskLevel == low)
    riskcontingency = 0.01;
    if (project.riskLevel == high)
    riskcontingency = 0.02;
    }
else (riskAversion == extreme)
    {
    if (project.riskLevel == low)
    riskcontingency = 0.02;
    if (project.riskLevel == high)
    riskcontingency = 0.03;
    }
```

3.2.3. Need for work component

A contracting firm needs to maintain a certain work backlog in order to cover its general and administrative costs and to be able to retain skilled personnel. In the presented model, we defined the parameter, Work-in-Progress Limit, which indicates the average annual workload a contractor can have during a year given its size and capabilities. Consequently, the need for work ratio is determined through comparing the current work volume of a contractor against its Work-In-Progress Limit. The need for work ratio (NWR) for a contractor *i* is determined through the following expression:

$$NWR_i = 1 - \left(\frac{Current\ Work\ Volume}{Work - in - Progress\ Limit}\right). \qquad (2)$$

The closer this ratio is to 1, the higher the need for work and the lower the markup is expected to be; and the closer this ratio is to 0, the lower is the contractor's need for work and the higher markup it can afford. Through surveying contractors in the market, DeNeufville and King [14] showed that a low need for work could cause a rough decrease of 3% in the bid price of a contracting firm. The need for work component in this study is selected within the range [0–4] % and its specific value is chosen based on two variables namely the financial status of the contractor and the need for work ratio defined in Eq. (2). It is important to note here that this component, in contrast with the two previously discussed components, is a negative value indicating a decrease in the markup in order to enhance the winning chance of a contractor and thus accommodate his need for work. The financial situation of a contractor is assessed through the positive or negative change to its initial working capital. Accordingly, there are six possible scenarios considered when determining the need for work component of the markup value: a poor financial situation with a low, moderate or high need for work ratio, and a good financial situation with low, moderate or high need for work. The ideal situation is to have a contractor who is in a good financial status and with enough work at hand and thus can afford a zero decrease in its markup. And the worst combination would be a contractor who is in a bad financial shape and who has minimal or zero work at hand. In this case, a contracting firm would be willing to apply a decrease up to 4% to its markup in order to enhance its chance in winning the project and covering its overhead costs. The main focus of this paper is to investigate the long-term impact of considering need for work within a risky and competitive environment, and to observe to what extent the need for work should be considered.

To sum up, the main assumptions of the paper are the following:

- All contractors have the same size, initial working capital (which is zero), and general and administrative (G&A) costs.
- All contractors can estimate a project cost with the same level of accuracy.
- All contractors have the same level of management capability and expertise.

- The actual cost is set to follow a triangular distribution with a mean equal to the project's market budget.
- All contractors consider three criteria when trying to determine the markup for a project: the market competition, the inherent risk, and the need for work.
- All contractors have access to their competitors' bidding history.

3.2.4. Example application

In this section, a numerical application is conducted to illustrate the markup determination by a Contractor agent in the simulated bidding model. We consider the case of Contractor C1 who is informed about a newly adverstised project in the market for which he decides to submit a bid after evaluating his bidding capacity using the Shallbid() function. C1 expects to be competing on this project with three other contractors in the market C2, C3, and C4 for which he computes the average bid competitiveness ratio (BCR) based on the last ten tendered projects in the market as shown in Table 1. Based on the former computations, C1 ranked second among his three opponents in recent prior projects and thus he has been more competitive than 2/3 of his opponents.

Assuming that C1 typically chooses his markup within a range of [5–9] %, the algorithm takes competition into effect through choosing a specific value from this range based on the competitiveness of C1 relative to his opponents. In other words, if C1 has a lower BCR (i.e., is more competitive) than 80% of his opponents, he can afford to use the highest value in his range, 9%, as his markup competition component. On the other hand, if C1 has a BCR lower than only 20% of his opponents, he has to go down to the lowest end of his range, 5%. Following the same logic, the markup values between the two range boundaries are chosen in accordance with 20% increments of BCR values. As such, having a current BCR that is lower than 2/3 of his opponents, C1 chooses 8% as the competition component of his markup value. This value is now adjusted by C1 to account for his need for work and the project risk. Assuming that C1 is an extremely risk averse contractor and the current project he is bidding on incorporates lot of hazards and uncertainties, the risk contingency that will be applied by the developed algorithm is 3% which is the upper bound of the risk component. Finally, the need for work component depends on C1's need for work ratio (NWR) and his financial capacity. C1 is currently working on 4 projects and his Work-in-Progress Limit is 5, hence, his NWR is equal to 0.2. This means that C1 has a minimal need for work and thus can afford a high markup. Assuming a good financial capacity for C1 and given the need for work range of [−4, 0] %, a 0% decrease is chosen by the model as the need for work component. In summary, contractor C1 will use a markup of 11% ($=8+3-0$) on this project after taking into account all internal and external conditions.

3.3. Description of the experiments

This subsection explains the details of three sets of simulation experiments conducted in this study. A set of contractors are defined in the market and are set to have the same value for initial working capital, Work-in-Progress Limit, and cost estimation and project management skills. Each contractor can simultaneously work on four projects at most. Given the number of contractors in the market and their work limit, the market is considered very competitive in all sets of experiments since most contractors participate in all biddings. Each experiment set has been run for 100 times in order to ensure the consistency of the results. Table 2 presents a summary of the experiments sets and their purposes.

Table 1
Bid prices of opponents on last ten tendered projects.

Project	C1 bid price (M $)	C2 bid price (M $)	C3 bid price (M $)	C4 bid price (M $)	BCR for C1	BCR for C2	BCR for C3	BCR for C4
P1	85	92	78	–	0.089	0.179	0	–
P2	95	105	102	110	0	0.105	0.074	0.158
P3	112	107	–	120	0.047	0	–	0.121
P4	75	80	82	90	0	0.066	0.093	0.2
P5	83	80	90	86	0.037	0	0.125	0.075
P6	120	110	125	113	0.091	0	0.136	0.027
P7	–	88	83	90	–	0.060	0	0.084
P8	105	110	123	120	0	0.048	0.171	0.143
P9	90	78	83	85	0.154	0	0.064	0.089
P10	115	95	110	105	0.211	0	0.158	0.105
Average bid competitiveness ratio:					0.069	0.046	0.091	0.111

The purpose of the first set of experiments is to examine what level of risk attitude results in the contractor's best financial performance on the long run. Results will be compared with findings in the literature in order to check and verify capability of the simulation model. There are nine contractors competing with each other in the market including three slightly risk averse contractors, three moderately risk averse contractors, and three extremely risk averse contractors.

Table 3 shows the risk attitude assigned to each of the nine contractors. In the first set of experiments, projects are generated in the market one at a time unit under three different scenarios. Under scenario 1, all projects have a low level of complexity and uncertainty. Under scenario 2, the market comprises a mix of projects with low and high level of complexity and uncertainty. In this case, every time a project is generated, its complexity is chosen randomly with a probability of 50% being low and 50% being high. As for scenario 3, all projects have a high level of complexity and uncertainty. These three scenarios are considered only in the first set of experiments in order to analyze the impact of project risk on the results.

The second set of simulation experiments investigates the importance of the component "Need for Work". It aims at assessing whether considering "Need for Work" impacts the business success of contractors on the longterm or not. In this experiment set, two types of contractors were considered with ten contractors in total. As shown in Table 3, there are five contractors who do not consider "Need for Work" and five other contractors who consider it and accordingly discount their markup up to 2%. Financial performance of the two sets of contractors is observed and compared in order to evaluate the impact of considering "Need for Work" in markup selection on the contractor's performance. As for the third set of experiments, they aimed at determining to what degree a markup discount should be considered in order to account for need for work without compromising the business success of the contractor. Five types of contractors were considered in this experiment with ten contractors in total. These five sets differ by the discount level they apply to their markup in order to take into consideration the "Need for Work" component.

Table 2
Summary of the experiment sets 1, 2, and 3.

Experiment set	Purpose	Experiment conditions
1	Finding the optimal level of risk attitude for contractors	Scenario 1: the market comprises only projects with low level of complexity Scenario 2: the market comprises a mix of projects with low and high level of complexity Scenario 3: the market comprises only projects with high level of complexity
2	Finding whether considering "Need for Work" impacts business success of contractors	The market comprises a mix of projects with low and high level of complexity. All contractors are moderately risk averse
3	Finding to what degree a markup discount should be considered to account for need for work	The market comprises a mix of projects with low and high level of complexity. All contractors are moderately risk averse.

Table 3
Contractors' characteristics in the experiment sets 1, 2, and 3.

Contractor	Risk attitude in the experiment set 1	Need for work in the experiment set 2	Need for work in the experiment set 3
#1	Slightly risk averse	Ignored	Ignored
#2	Slightly risk averse	Ignored	Ignored
#3	Slightly risk averse	Ignored	Discounted up to 1%
#4	Moderately risk averse	Ignored	Discounted up to 1%
#5	Moderately risk averse	Ignored	Discounted up to 2%
#6	Moderately risk averse	Discounted up to 2%	Discounted up to 2%
#7	Extremely risk averse	Discounted up to 2%	Discounted up to 3%
#8	Extremely risk averse	Discounted up to 2%	Discounted up to 3%
#9	Extremely risk averse	Discounted up to 2%	Discounted up to 4%
#10	N.A.	Discounted up to 2%	Discounted up to 4%

Table 3 shows the varying levels of "Need for Work" consideration in the markup function of the ten defined contractors. It is worth mentioning that the second and third sets of experiments were conducted under three levels of risk attitude separately in order to ensure that results are consistent regardless of the risk behavior of contractors. Also, the market consisted of a mix of low and high risk projects (similar to the scenario 2 under the first set of experiments) in both sets.

4. Results & discussion

This section presents and discusses the results that were obtained in the three sets of experiments described in Section 3.3.

4.1. Experiment set 1

Figs. 2 to 5 as well as Table 4 and Table 5 present the results obtained for the first experiment set. In particular, Figs. 2 to 4 show the progress of the average working capital for the three levels of risk aversion versus the project ID under the three different described scenarios which exhibit varying degrees of project risk. As shown in each of these figures, moderately risk averse contractors financially outperform others in highly competitive markets in the long run. This result is consistent across all scenarios and is aligned with results from the literature [3,25,26]. Also, slightly risk averse contractors outperform extremely risk averse contractors in all scenarios. One of the methods for validating simulation models is comparing obtained results with real-world observations or findings from the literature and in this case, we can consider this experiment set as a validation tool for the simulation model.

Comparing Figs. 2, 3, and 4, it is observed that slightly risk averse contractors can do better in riskier markets. Slightly risk averse, on average, have the highest difference in working capital with moderately risk averse contractors when the market comprises low-risk projects (Scenario 1). This gap decreases when moving from low risk to high risk market; namely, from scenario 1 to scenario 2 and then scenario 3. This can be due to the fact that when facing high uncertainty in projects, the more risk averse a contractor is, the higher the allocated contingency (risk allowance) in his bid which reduces his competitiveness. This gives a winning edge to slightly risk averse contractors over moderate ones, and thus the gap between the growing working capitals for both decreases from scenario 1 to scenario 3. Another observation about Figs. 2, 3, and 4 is that, given a certain risk aversion level, the generated working capital representing an accumulation of actual project profits over time has increased from low to high risk market since all contractors are expected to allocate a higher risk allowance in their markup to hedge against high level of risk in projects.

Table 4 presents the working capital of contractors in the three scenarios. It also compares each contractor's performance with the best performance in the market in terms of working capital. It can be observed that average working capitals of contractors have increased from scenarios 1 to 3. In other words, in riskier markets, contractors increased their markups to cover higher risks and thus were able to earn higher profits. It is also observed that moderate risk averse contractors had the smallest average gap (Δ%) with the best performer in the market in all scenarios which again indicates that moderation in risk attitude is the optimal strategy regardless of the project risk level. Note that contractors #5 and #6 exhibited the best financial performance in all three scenarios ($\Delta = 0\%$). Another important observation that was emphasized earlier is that slightly risk averse contractors performed significantly better under scenario 3 where the average Δ% dropped from −41% in scenario 2 to −24% in scenario 3.

Table presents the market share of the nine contractors under the three different scenarios. The market share of each contractor *i* is defined as such:

$$\textit{Market share}_{\,i} = \frac{\text{\#of won projects by i}}{\text{\#of tendered projects in the market}} * 100. \qquad (3)$$

This table supports again the conclusion that moderately risk averse contractors, on average, have a better performance under all market scenarios through having the highest share of projects among the three types of contractors.

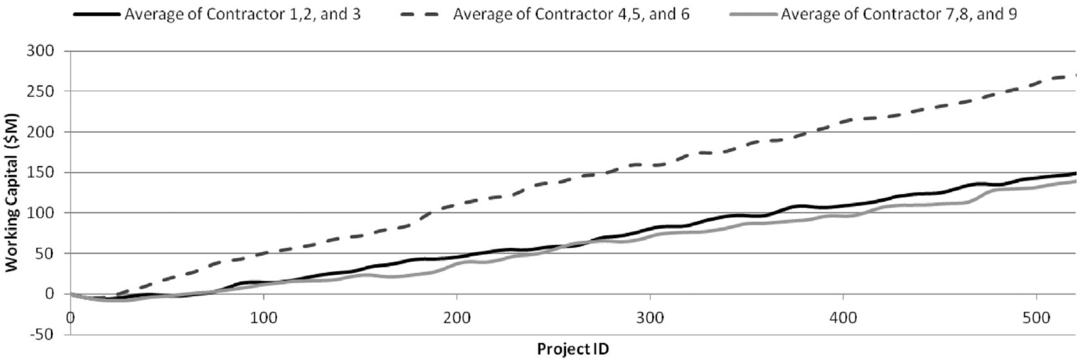

Fig. 2. Financial performance of contractors in the experiment set 1 under scenario 1.

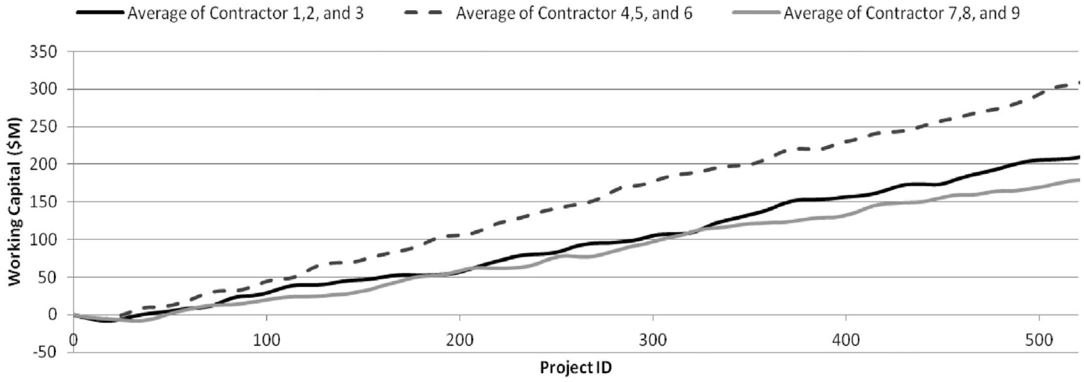

Fig. 3. Financial performance of contractors in the experiment set 1 under scenario 2.

Fig. 5 shows the success rate of contractors throughout the simulation period. The success rate of a contractor *i* is defined as per the following equation:

$$\mathit{Success\ rate}_i = \frac{\#\text{of won projects by i}}{\mathit{total}\#\text{of projects i has bid on}}. \tag{4}$$

This figure confirms that moderately risk averse contractors, on average, outperform other contractors. Moreover, there exists a convergence to a somehow constant success rate for each contractor after 2–3 years (in the simulation time scale). It is worth noting that the result in Fig. 5 is obtained from several simulation runs of experiment 1 under scenario 2.

4.2. Experiment set 2

The results of the second set of experiments, as reflected in Fig. 6, show that contractors #6, 7, 8, 9 and 10 who considered "Need For Work" as one of the criteria for determining their markup have a better financial performance in comparison with the contractors who did not (#1, 2, 3, 4, and 5). This could be explained by the fact that these contractors lower their markup strategically depending on their need for work and financial situation which allow them to acquire new projects when they have their resources idle, despite that it might be at the expense of lower expected profits. Specifically, this flexibility is of more help to contractors when risk level of projects is low and market competition is intense. It is worth noting that this experiment set is conducted with the same risk aversion degree for all contractors in order to isolate the "Need for Work" effect on contractors' growing capital. Fig. 6 shows the results obtained for moderate risk aversion level. However, the simulation was repeated another two times, once with mild risk aversion condition for all contractors and the other with extreme risk attitude. Both scenarios showed similar results.

4.3. Experiment set 3

While considering "Need for Work" is a reasonable strategy for contractors, the extent to which this consideration should be accounted for in the markup percentage has not been studied in the literature. The experiment set presented in this section addresses this gap through having five different groups of contractors in the market who perceive the importance of "Need for Work" consideration differently and thus allocate different boundaries to this criterion in their markup functions. Fig. 7 shows the experiment results where the growing capitals for the five groups of contractors are presented versus the project Id. It is observed that contractors 1 and 2 who do not take their need for work into consideration in their markup decisions performed the worst, whereas, contractors 7 and 8 who adopted a need for work upper margin of 3% had the best financial performance. Contractors 5 and 6 came in the second rank with using an upper limit of 2%. As for contractors 9 and 10 who discounted their markup up to 4%, they increased their chance of winning the project while decreasing the profit margin radically. On the other hand, contractors 3 and 4 who discounted up to 1% were most probably not able to immediately secure a contract when they need it. Based on the aforementioned, it can be concluded that considering "Need for Work" strategically and discounting the markup up to 2–3% is the optimal policy for contractors in a competitive market on the long run. All contractors whose working capitals are shown in Fig. 7 were assigned a moderate risk aversion degree. It should be noted again that this experiment was conducted under different contractors' risk behavior (slightly and extremely risk averse) and the results were consistent regardless of the risk attitude.

4.4. Summary of research findings

The aforementioned conducted experiments and scenarios revealed several findings which can be of significant use to contractors, their

Fig. 4. Financial performance of contractors in the experiment set 1 under scenario 3.

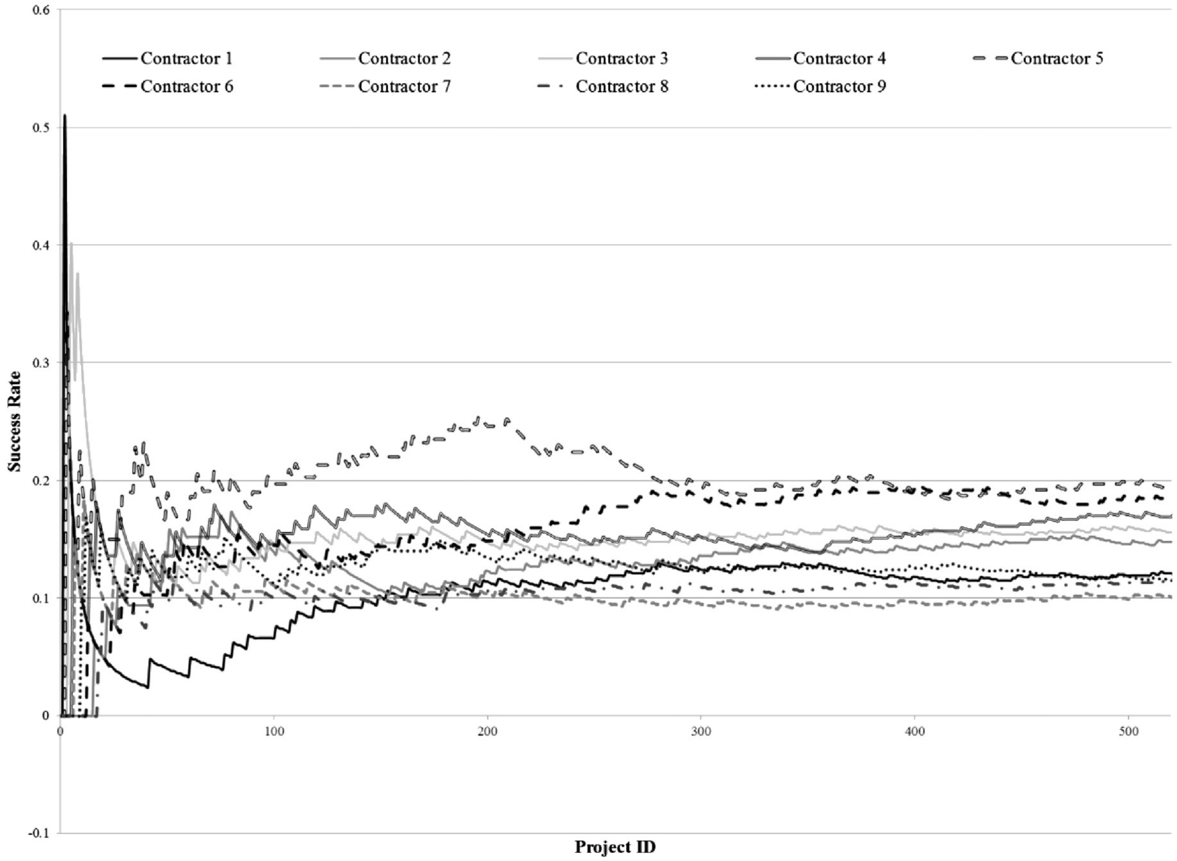

Fig. 5. Contractors' success rate under scenario 2.

understanding of the construction market and their shaping of their bidding strategies. Disregarding the need for work component, it was shown that moderately risk averse contractors consistently outperform other contractors in all market conditions including all levels of project risk whereas extreme risk aversion is the least effective strategy under all circumstances. Another interesting and not so intuitive observation is that the higher the projects' risk and uncertainty within the market, the more competitive slightly risk averse contractors are where they tend to exhibit a close financial performance to moderately risk averse contractors. This implies that in a riskier market, a contractor can afford to be more risk tolerant and still maintain a profitable business.

Furthermore, the study showed that a contractor who takes into consideration his need for work in his markup choice has a significantly better financial performance on the long term than one who does not. Based on the simulations studying different consideration levels for the need for work component, it was observed that 2 to 3% markup decrease accounting for the contractor's need for work led to higher contractor's chance of financial growth. A higher discount may allow the contractor to win more projects but will have a detrimental effect on his finances. Therefore, the optimal policy can be concluded to be moderation in both dimensions of risk attitude and need for work. At the limit, not considering need for work and being extremely risk averse appeared to be the least effective strategy a contractor can adopt. Thus, a contractor needs to be cautious when discounting his markup to account for his need for work in such a way to create a balance between earning enough profit and securing the needed amount of projects. Finally, the results obtained from all sets of experiments converged towards the same observation of a market equilibrium reached under

Table 4
Contractors' working capital in the experiment set 1 under scenarios 1, 2, and 3.

Working capital ($M)						
	Scenario 1	Δ% with the best performance	Scenario 2	Δ% with the best performance	Scenario 3	Δ% with the best performance
Contractor 1	237	−25%	170	−54%	294	−28%
Contractor 2	90	−72%	292	−22%	299	−27%
Contractor 3	155	−51%	198	−47%	345	−16%
Average of Contractors 1, 2, 3	**161**	**−49%**	**220**	**−41%**	**313**	**−24%**
Contractor 4	260	−18%	346	−7%	321	−21%
Contractor 5	318	0%	271	−27%	382	−6%
Contractor 6	269	−15%	372	0%	408	0%
Average of Contractors 4, 5, 6	**283**	**−11%**	**330**	**−11%**	**371**	**−9%**
Contractor 7	163	−49%	207	−44%	202	−50%
Contractor 8	167	−47%	158	−58%	234	−43%
Contractor 9	112	−65%	194	−48%	224	−45%
Average of Contractors 7, 8, 9	**147**	**−54%**	**186**	**−50%**	**220**	**−46%**

The bold values are basically the average of the three above values.
The underlined value shows the highest value in a scenario.

Table 5
Contractors' market share in the experiment set 1 under scenarios 1, 2, and 3.

Market share			
	Scenario 1	Scenario 2	Scenario 3
Contractor 1	12.3%	10.6%	10.9%
Contractor 2	9.0%	11.9%	10.9%
Contractor 3	10.9%	10.9%	12.3%
Average of Contractor 1, 2, 3	**10.7%**	**11.1%**	**11.4%**
Contractor 4	12.9%	12.3%	11.9%
Contractor 5	13.1%	12.1%	13.1%
Contractor 6	12.9%	13.4%	12.3%
Average of Contractor 4, 5, 6	**13.0%**	**12.6%**	**12.4%**
Contractor 7	9.6%	9.8%	9.6%
Contractor 8	10.2%	9.2%	9.4%
Contractor 9	9.0%	9.6%	9.4%
Average of Contractor 7, 8, 9	**9.6%**	**9.5%**	**9.5%**

The bold values are basically the average of their three above values.

competitive bidding where all contractors have gained enough information about their competitors and adjusted their strategies accordingly.

4.5. Verification & validation

Verification is the process of determining whether the programming implementation of the abstract model is correct whereas validation is the process of determining whether the conceptual model is a reasonably true representation of the real world for the purpose of answering the research questions [28]. In other words, verification is concerned with solving the problem right while validation is concerned with solving the right problem [44]. There are numerous methods with different levels of rigor for verification and validation of simulation models, particularly agent-based models. Depending on the type of the model and available data, a method may be applicable for verification and validation; a model should be verified and validated to the degree needed for the model's intended purpose or application [36]. The agent-based simulation platform used in this study, AnyLogic, allows the user to breakdown the model into several computation steps and verify the programming component of each step due to its capability of collecting information on any parameter or process at any time through the simulation. For some specific bidding cycles in several simulation runs, the corresponding calculations of all the process steps were computed manually, compared and verified with the model calculation.

One of the most prevalent validation methods is "model-to-model comparison" where the results of the simulation are compared with previous studies on the subject. As mentioned previously, results of the first set of experiments were aligned with the literature [3,25,26]; moderately risk averse contractors outperform other contractors in competitive markets given any level of project risk. Kim and Reinschmidt [25,26], using an evolutionary model in which contractors choose their markup according to their risk attitude and project uncertainty, showed that moderately risk averse contractors are more successful than the others. Also, Awwad et al. [3] reached the same conclusion. They developed an agent-based environment where contractors use a mathematical model that integrates utility theory and Friedman's model (1956) to determine an optimal markup according to contractors' risk attitude and the market competition. Another validation method used in this study was parameter variability (sensitivity analysis) where we closely examined how uncertainty in the values of the main input parameters can impact the model output. In addition, different distributions were used for project budget, estimated duration, actual cost, and actual duration in addition to the fact that all experiments were conducted under different scenarios in order to make sure results are consistent. For example, experiment sets 2 and 3 were conducted with three different contractors' risk attitudes.

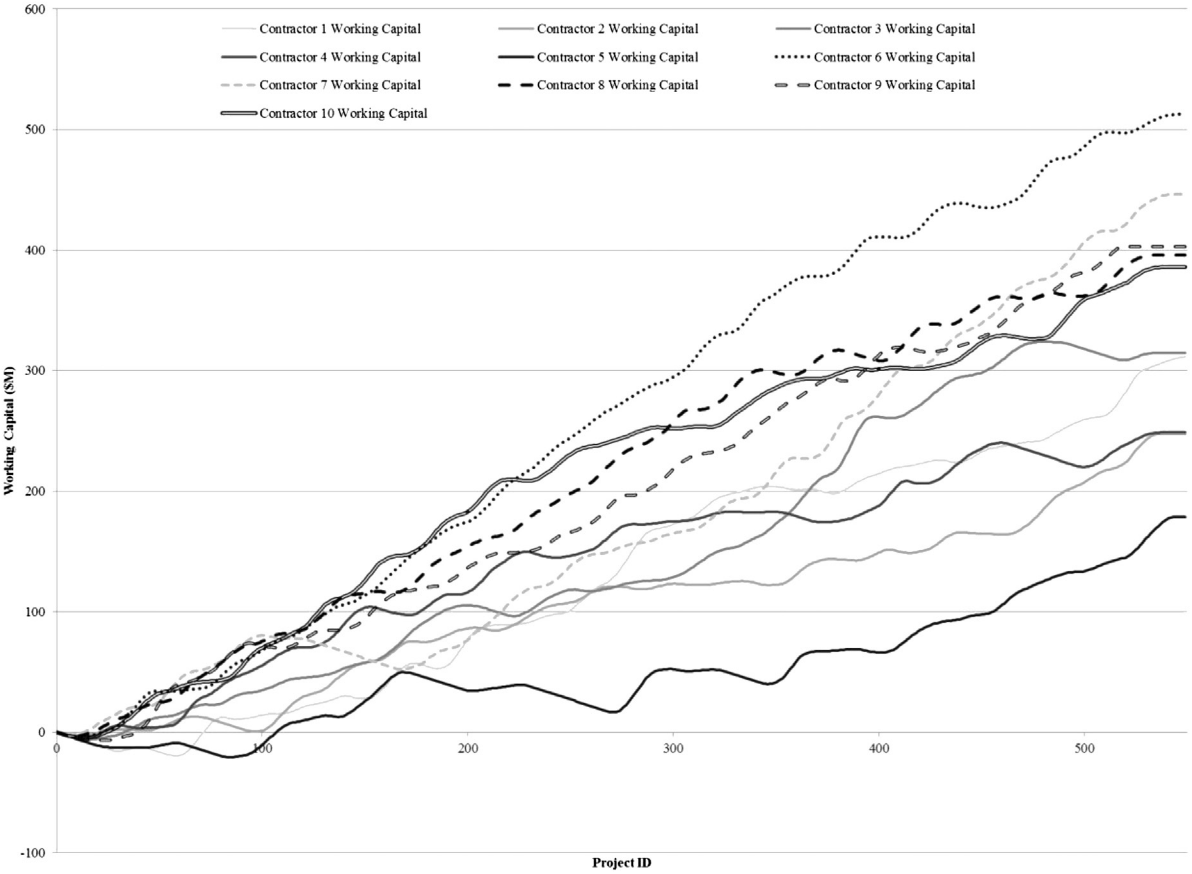

Fig. 6. Working capital of moderately risk averse contractors in the experiment set 2.

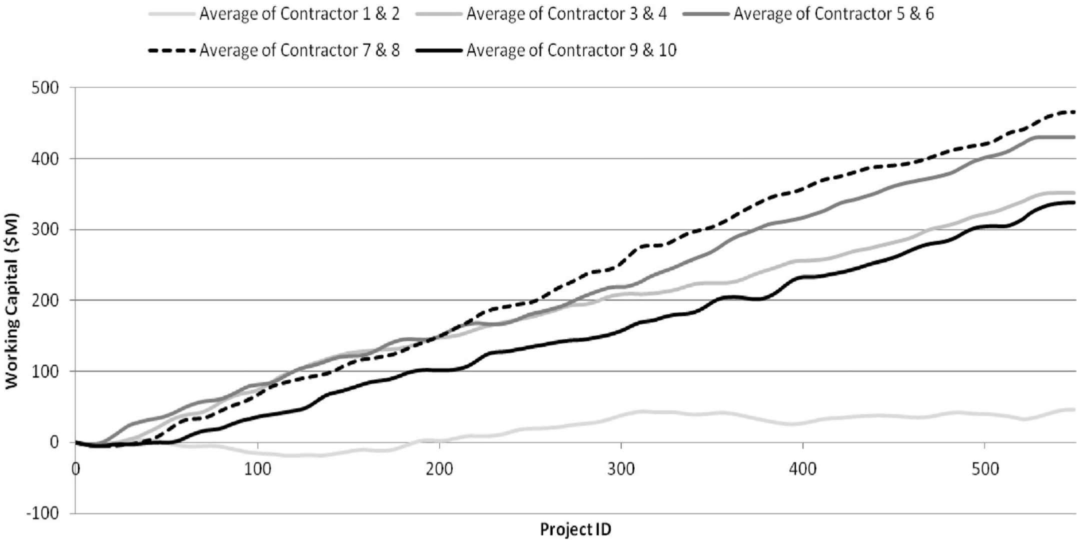

Fig. 7. Working capital of moderately risk averse contractors in the experiment set 3.

The simulation model developed in this study, like any other simulation model, is based on some assumptions. One important assumption was that contractors have access to other contractors' bidding history. With respect to validation of model assumptions, it is worth mentioning that many contractors have a specific unit in their business development, typically a Research & Development department, that is in charge of collecting market information, tracking and analyzing their competitors. On the other hand, it was assumed that all contractors have the same size, initial working capital, cost estimation accuracy, construction management skills, expertise, and G&A costs in order to avoid any possible impact of these factors on the results. Concerning validation of the markup determination, the selection of these three additive and independent criteria is supported by a thorough literature review presented in the related work and methodology sections of the paper. As for the structural validation of the simulation, the bidding process used in the simulation model imitates the actual bidding process happening in reality.

5. Conclusion and future works

Markup decision can massively impact a contractor's financial performance because the primary channel of securing work in the construction industry is still through a variety of competitive bidding mechanisms. The presented study used agent-based modeling as an appropriate framework for analyzing and investigating the impact of risk behavior and need for work on construction contractors' performance in a competitive bidding environment. Prior to applying agent-based modeling in this study, the authors had first to conduct an extensive literature review in order to build a rule-based and descriptive markup decision model that replicates the behavior of contractors. The developed model built on previous analytical and empirical studies about contractors' bidding parameters and markup considerations and combined all these attributes and functions into a comprehensive agent-based model that reflects many of the complexities of the bidding process. Different combinations of risk behavior, need for work and market competition were simulated and their implications on the contractor's business and the market as a whole were observed and analyzed. This model can serve as a virtual simulation lab that can be used by any potential user (contractor, consultant or owner) to evaluate and compare different bidding strategies, markup behaviors, and bid tendering approaches and to learn about resulting emergent market patterns. In particular, this study provided contractors with invaluable insights into the impact of considering need for work on their financial performance and to what extent this consideration should be taken into account. It was shown that moderation in both dimensions of risk allowance and need for work is the optimal bidding strategy for contractors in competitive environments. At the limit, this model can be used by a contractor to compare different markup functions that he may wish to adopt in order to evaluate which would most benefit his business on the long run.

The authors suggest that future works can focus on adaptive risk attitude in two main directions. The first step is to study contractors' organizational culture and risk behavior in order to find out whether and when contractors change their risk attitude. This would help identifying what information and signals contractors look for in the market or their organization in order to act more or less risk averse. Second, new methodologies such as reinforcement learning can be used to help contractors design the optimal dynamic strategy according to their organization, competition, and market conditions. This strategy can be later experimented and compared against other strategies in the virtual lab designed and developed by the authors using agent based modeling. Furthermore, some of the assumptions used in this paper can be enhanced in the future version of the model. For instance, the number of contractors in the market was kept fixed in this study and there was no newcomer or quitter from the market. Also, the size of a contracting firm was considered constant throughout the simulation while it is not always the case in reality. In future studies, new behaviors for contractors such as entry, exit, expansion, contraction, alliance, and merging can be defined and added to the model if aligned with the purpose of the research. As we tried to apply a variety of validation methods, validation of the model through expert judgment is still crucial [6]. As part of future work, the simulation model can be validated by comparing its results with real case studies or by presenting it to and getting feedback from practitioners and professionals in the field of construction bidding.

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