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# Agent-Based Modeling of Construction Firms' Organizational Behavior in Public Tenders

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**Abstract:** A key problem of construction firms' management and economy is organization of effective participation in public tenders. The direct executor, who determines the price of the contract, may be interested in obtaining as many contracts as possible. It means that his strategic behavior in tender may be to undervalue each individual offer. At the same time, such a strategy can be a source of risk of project loss because the actual costs may be lower than the price of the contract won. The management of the construction organization is not interested in this. On the other hand, overpricing strategy may lead to a reduction in the number of contracts won, which may not seem effective either for the head or for the executor of such an organization. The article discusses whether the profits of a construction firm can increase by using a more precise method of calculating the estimated cost. The second question is—which staff of a construction firm will benefit from using such methods? The aim of this work is to test these hypotheses with the instrumentality of agent-based modeling. Profit values of construction firms were obtained by the computer simulation of the construction firms' strategic behavior in public tenders. Results of 1500 computer experiments are presented as a decision tree. It can be seen that when using a more precise method, construction firms win tenders almost two times less often. However, they incur losses many times less than with an inaccurate method. If a construction firm made a profit from the contracts won, the profit margin was almost always greater when using the more precise method. Moreover, the results of game-theoretic modeling are given. Values of the objective functions of the executor and head of the construction firm were obtained, taking into account the reward for contracts won and penalty for miscalculating the cost of work. It has been proved that using more precise methods for calculating the estimated cost is beneficial to both the head and the executor. It can be concluded that both hypotheses were confirmed and a precise method for calculating the cost increases the efficiency of a construction firm.

**Keywords:** construction firms; tenders; organizational behavior; multi-agent system; agent-based modeling; computer simulation



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## 1. Introduction

Absolutely all construction firms must participate in the tender for a contract to perform construction and installation works (CIW). Several participants take part in one tender; each of them submits a personal price quote (PQ) which indicates the cost of work unknown to other bidders. Moreover, information about the building object is usually provided in a limited form in the tender. Any distorted information about the object has a direct impact on the finances of the contractor. That is why participatory process of firms in tenders for CIW has a high degree of uncertainty expressed in the lack of understanding about the number of participants, PQ of contestants, and reliable basic data on the construction object.

Three scientific problems were identified in the statement of the control problem of the business process of the construction firm participation in tenders for CIW (Gladkikh

2021). The first problem is the game uncertainty which is expressed in the complexity of forecasting the participation and behavior of contestants in the tender. The second problem is the information uncertainty, because the basic data on the construction object are limited; that is why, in the event of a win, it manifests itself in the difference between the planned and actual volumes of work and their costs. The third problem is the invalidity of existing methods for calculating the estimated cost of CIW. It is expressed in the inability to correct the estimations used by means of decomposing them into select operations, the inability to take into account various constrained conditions and outsourcing of building machines, inadequate calculation of the actual indirect costs of the firm, as well as construction risks that may arise at the site. In addition, the qualifications of staff, who are preparing PQ for the implementation of CIW, as a rule, do not allow adequate choice of prices. That is why, a multi-user information system is needed, which supports the possibility to create a database of in-company prices and, at the same time, has a simple and convenient interface. These things determine the need to develop a decision support system (DSS) designed to reduce uncertainty in tenders. The mechanisms of institutional, motivational, and information control of organizational systems can be used in the business processes of a construction firm participation in tenders.

### *1.1. Literature Review*

Many construction firms around the world take part in various tenders. That is why this business process is actively discussed in the articles. Watta et al. (2009) offered a suite of representative (principal) tender evaluation and contractor selection criteria for use in future research. Hsieh et al. (2004) proposed a fuzzy MCDM approach for planning and designing tender selection in public office buildings. Falagario et al. (2012) offered to use a DEA-cross efficiency approach in public procurement tenders. Lorentziadis (2010) made a post-objective determination of weights of the evaluation factors in public procurement tenders. Samuel Laryea (2011) created quality of tender documents in construction. Cotter and Zenner (1994) presented empirical evidence on the relation between changes in managerial wealth and tender offer characteristics.

Ralph A. Walkling (2009) developed and tested a model for the prediction of tender offer outcomes. Dodd and Ruback (1977) examined the impact of the tender offer on the returns to stockholders of both bidding and target firms. Wilson et al. (2006) analyzed the factors that influence the success of the tendering process within the constraints of a budgetary approval system. Fredo Schotanus et al. (2022) researched a question about the supplier selection with rank reversal in public tenders. Ballesteros-Pérez et al. (2014) presented a stand-alone methodology useful for estimating future competitors' bidding behaviors separately. Towner and Baccarini (2007) explored risk pricing in construction tenders. Stuart D. Green (1989) presented six case studies of tendering practice in order to establish the reasons for apparent disregard for various techniques published for optimizing the net present value of tenders by the use of discounted cashflow theory and linear programming. Doulos et al. (2019) developed a decision support system for assessment of street lighting tenders based on energy performance indicators and environmental criteria.

With the majority of projects procured using design-and-build contracts, Brook, M. explains the contractor's role in setting costs and design statements, to inform and control the development of a project design (Brook 2016). Mehrabani M.N. et al. developed a decision support system (DSS) for the scoring of tenders (STs) based on the group method of data handling model (GMDH) (Mehrabani et al. 2020). The conclusion is that, amongst quantity surveyors, there is recognition of the benefits that e-tendering can bring about but that there are a number of barriers currently acting as a brake on the uptake of e-tendering (Lavelle and Bardon 2009). According to Pablo Ballesteros-Pérez et al., economic scoring formula selection by auctioneers is invariably and, paradoxically, a highly intuitive process in practice, involving few theoretical or empirical considerations, despite having been considered traditionally and mistakenly as objective, due to its mathematical nature. Therefore, Pablo Ballesteros-Pérez et al. presented a taxonomic classification of a wide variety of economic scoring formulas and abnormally low bids criteria gathered in several countries with different tendering approaches (Ballesteros-Pérez et al. 2015). The paper by Jaskowski P. et al. proposed a probability-based method of estimating the optimal bid price (which means a price of maximum expected value of the contractor's profit) in lowest bid tenders (Jaskowski et al. 2019)

### *1.2. Research Statement*

In this paper, we will consider competing construction firms as a multi-agent system which includes two types of agents. The first group of agents includes the following employee staff: the Principal—the head of the commercial department and the Subordinate—a worker of the commercial department, who prepares PQ. Contestants are included in the second group of agents of competing construction firms. In this study, we use the method of agent-based modeling of the organizational behavior of the Subordinate, Principal and Contestants. By means of computer simulation, data were obtained on the objective functions of the Subordinate and the Principal. Objective functions were derived by calculating the estimated cost in two versions: with a random error within 30% and using a more precise method of calculating the estimated cost.

The main construction firms' management and economic problem is effective participation in public tenders. The article researches the problem of making a decision on the choice of the contract price when participating in public tenders. A low contract price may result in the firm's loss on individual projects. A high contract price can lead to losing tenders and lost profits for the organization. The situation becomes more complicated due to the manifestation of the strategic behavior of stuff of construction firms. The direct executor, who determines the price of the contract, may be interested in getting as many contracts as possible. It means his strategic behavior in a tender may consist in undercharging the cost of each individual offer. The top management of the construction organization is not interested in this. On the other hand, an overvaluation price strategy may lead to a declining number of contracts won. It may not seem efficient either for the manager or for the executor of such a firm. Moreover, management may choose an ineffective strategy for rewarding and punishing a subordinate.

The aim of the study is agent-based modeling of organizational behavior of construction firms for the validation of the following hypothesis:

**H1.** *The use of more precise methods of calculating the estimated cost when participating in tenders will increase the profit of the construction firms.*

**H2.** *The use of more precise methods of calculating the estimated cost when participating in tenders will be beneficial to both the Subordinate and the Principal.*

## 2. Theory and Methods

### *2.1. Foundation of Research*

The organizational behavior control theory, formed on the basis of the theory of active systems, has been developed by such researchers as Dmitriy A. Novikov (Novikov 2013), Vladimir N. Burkov, Mikhail V. Goubko, Nikolay A. Korgin (Burkov et al. 2015b), Alexander V. Shchepkin (Burkov et al. 2015a), Anver K. Enalaev (Enalaev and Novikov 2021), Mikhail B. Iskakov (Burkov et al. 2010), Alexander G. Chhartishvilli (Novikov et al. 2018), Vyacheslav V. Kondratev (Burkov et al. 2013), Oleg V. Loginovskiy, Alexander V. Hollay, Aleksandr L. Shestakov, Kristina A. Korenaya (Loginovskiy et al. 2022), et al.

The active systems theory has been widely used in many fields, including construction, where the largest number of researches in this field have been published by Yulia G. Zheglova and Boris P. Titarenko (Zheglova and Titarenko 2020), Sergei A. Barkalov and Olga N. Bekirova (Barkalov et al. 2021), and many others. However, the problem of organizational control of the process of a construction firm participation in tenders has not been explored by means of these methods.

Such specialists as Valeriy I. Telichenko, Galina G. Malykha and Igor A. Dorogan (Telichenko et al. 2017), Dmitrii P. Anufriev and Artem Yu. Holodov (Anufriev and Holodov 2018) investigated the organization and control of construction tenders. Raevskaya et al. (2019) offered to make an expert assessment of the risks of coal mining enterprises by means of fuzzy logic. Borisov et al. (2021) employed a method for fuzzy cognitive modeling of heterogeneous electromechanical systems in controlling innovative design solutions.

The figure below (Figure 1) presents a construction firm as a three-tier organizational system that consists of the following internal elements:

- Principal—in this study, the head of the commercial department (project manager), who manages the business process of preparing and participating in tenders for CIW;
- Subordinate—in this study, employees of the commercial department and estimators who receive assignments from the Principal for the preparation of commercial proposals (hereinafter—CP) for participation in tenders for CIW;
- Controlled object—in this study, the business process of tenders.

and external elements include the Contestant—in this study, other tender participants.

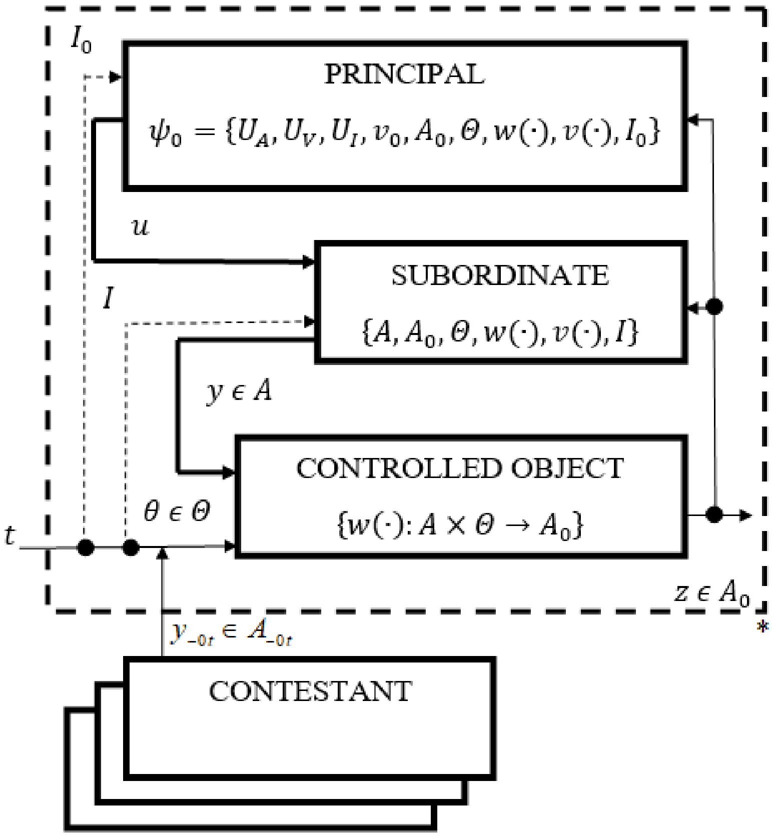


**Figure 1.** The structure of the control system of the construction firm and external contestant. * The zone marked with a dotted line corresponds to the general statement of the organizational behavior control problem (Novikov 2013).

Let us represent the tender as a cortege, as is done in an article by one of the authors (Gladkikh 2021):

$$t = \langle b,\ r_b,\ I_{r_b},\ sp_{r_b},\ d \rangle \tag{1}$$

where $b$ is a building object, $b \in B$, $B$ is a set of construction objects; $r_b$ is CIW present in the tender at the object $b \in B$, $r_b \in R_b$, is a set of all CIW at the object $b$ present in the tender $T_b$ at the object $b$ ($t \in T_b$, $T$—a set of all tenders); $I_{rb}$ is background information in the tender documents for the work $r_b$; $sp_{rb}$ is the start price, in tenders it is also called guaranteed maximum contract price (hereinafter—GMCP), $d$ is date of the tender completion.

When announcing a procurement, the initial information in the tender documentation for CIW $r_b$ at the object $b \in B$ is, as usual, preliminary in nature, i.e., information is incomplete and inaccurate, so that it has uncertainty. Hereinafter, information with uncertainty will be denoted $\overline{I}_{rb}$, and complete and conditionally accurate information—$I_{rb}$, it means $\overline{I}_{rb} \subseteq I_{rb}$.

### 2.2. Methods of Research

To test the effectiveness of using more precise methods to estimate the cost of CIW for the participation of a construction firm in tenders, a computer simulator was created in Microsoft Excel® spreadsheets. Structure of variables relations is shown below (Figure 2). In the simulator, the Subordinate prepares 2 PQ for 1 tender—1 PQ is calculated by means of the basic-index method (B.I.M.), the second PQ is calculated by means of the precise basic-index method (P.B.I.M.).

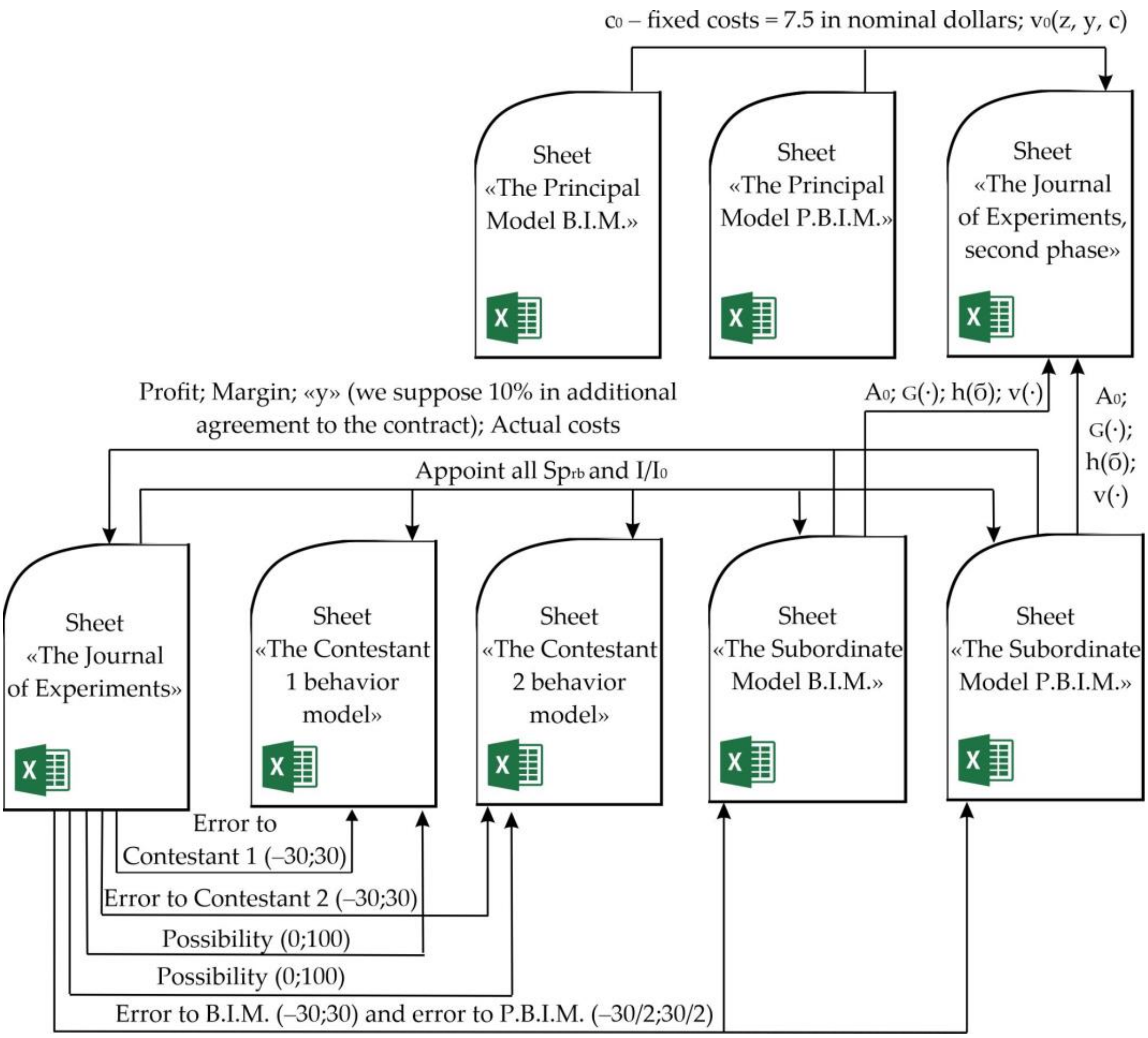


**Figure 2.** Structure of variables relations in the computer simulator developed in Microsoft Excel® 2010 spreadsheets.

The simulator has the following lists: "Experiment Journal", "Subordinate Model (B.I.M.)", "Subordinate Model (P.B.I.M.)", "Contestant 1", "Contestant 2", "Principal Model (P.B.I.M.)", and "Principal Model (B.I.M.)".

The "Experiment Journal" list represents the basic data of the tender, and it also includes the results of all experiments. The Journal consists of columns which are referenced by data from other tabs, specifically: the column "Tender, man-hour/vehicle-hour [working time]"—is a random number generator between 2000 and 10,000, emitting the working time spent on CIW for this tender; $sp_{rb}$ — GMCP, it is formed by multiplying the value from the column "Tender, man-hour/vehicle-hour [working time]" by the cost in nominal dollars—1.9; "Information exhaustiveness about the tender $\left[I;\bar{I}_{rb}\right]$"—is generated by means of a random number generator with a limit from 0 to 100 expressed in a coefficient, in addition, in the same column, unexpected expenses due to incomplete information are determined by a random number generator from 0 to the remainder (obtained by subtracting from 100 the completeness of information expressed numerically (not by a coefficient)); the parameter "Possibility to participate in the tender" presents the share of CIW in the tender, which the firm can do itself. In this study, it was a random number from 0 to 100 expressed as a coefficient (Gladkikh 2022).

These columns represent the basic data about the tender, which are transferred to the tabs with calculations by P.B.I.M., by B.I.M., and with the calculations of both contestants; "B.I.M. Error"—as practice shows, the existing B.I.M. has a significant error expressed by the difference between the actual costs and the estimated cost, which is obtained by this B.I.M., the error is set by a random number generator from −30 to +30; "contestant 1 error" and "contestant 2 error" are determined and set by analogy to the error caused by B.I.M.

The second part of the Experiment Journal consists of a summary of the data tabs for P.B.I.M., B.I.M., Contestant 1, and Contestant 2. Among the summary columns, there are such data as: "B.I.M error"—it transfers error B.I.M. from the relevant tab; "contestant's 1 error" and "contestant's 2 error"—by analogy; profit, margin, y (we suppose 10% in additional agreement to the contract), actual costs, a set of results $A_0$, the Subordinate's reward σ(·) for a win in the tender, the Subordinate's penalty $h(\delta)$ for the incorrectly calculated cost of CIW for the tender, the objective function of the Subordinate, fixed costs $c_0$, and the objective function of the Principal for P.B.I.M. and for B.I.M. (Gladkikh 2022).

### 2.3. Computer Simulator of the Subordinate

The computer simulator of the Subordinate is built by means of the basic data, which are given in the Experiment Journal, in its first stage. The Subordinate model consists of two tabs: "Subordinate Model (P.B.I.M.)" and "Subordinate Model (B.I.M.)". According to the built simulator, "B.I.M. Subordinate Model" consists of the following columns: "$\Phi(R_b;I)$"—the working time indicated in the Experiment Journal multiplied by the cost in nominal dollars 1.25 with tender uncertainty that is generated randomly; "Cost of work [$c_{rb}$]"—this is the function of the cost of work from the estimate with error in B.I.M., which is indicated in the Experiment Journal in the range from −30% to + 30%; "Internal costs of the firm [$c$]"—the actual cost vector, incurred by the organization when performing work $r_b$ for all tenders $t$, it is determined by multiplying the working time by the possibility to participate in the tender, which is indicated in the Experiment Journal, with cost in nominal dollars 1.25. Next are determined the costs that can be met by a subcontracting party (this is the remainder of the possibility to get the job done), after which these values are summed up and the general costs are determined, which the firm will incur when performing CIW in this tender; "Take part or not"—determines whether this firm will take part in this tender or not, this is calculated by means of comparing the value $sp_{rb}$ multiplied by 1.1 (here 1.1 is 10% which can be got if additional work is needed and which may not be formalized in a new tender procedure), and the cost of work by the estimate multiplied by a given margin level, which can take any values from 1.0 to 1.2; "Margin"—can take any value from 1.0 to 1.2; "$y$"—this is PQ which is presented for participation in the tender if the column "Take part or not "specifies "we don't take part", so $y$ has no value, and if participation is relevant, the value $y$ is determined by checking the following results: if the cost of work by the estimate multiplied by the firm's margin is more than $sp_{rb}$ multiplied by 1.1, then the result is $sp_{rb}$, otherwise—the cost of work by the estimate multiplied by the margin is divided by 1.1; "Profit [$\Psi_0$]"– in case of winning in the tender, is determined as the difference between $y$ and unfixed costs $c$ divided by 1.1; "$q_t$ "—Quantity of participants"—varies from 0 to 3 depending on whether the conditions of this tender are suitable for the relevant participants, it means this column determines the correlation of PQ by the firm and two more potential participants; "$y_{1\text{-}0t}$"—this is PQ from the first potential participant to take part in this tender, this value correlates with the contestant's 1 model; "$y_{2\text{-}0t}$ "—this is PQ from the second potential participant to take part in this tender, this value correlates with the contestant's 2 model; "Multiple Subordinate Results [$A_0$]" –is determined as a binary variable, either 0, or 1, depending on whether we take part in the tender, at least one bidder takes part in a tender, and depending on whether we give the least PQ; "σ(·)" is reward for winning, in case of losing, it is 0, in case of winning, it is calculated as a part (from 0.1 to 0.2) of the margin (from 0.05 to 0.2) multiplied by the value of PQ; "$h(\delta)$" is penalty for the inaccurate determination of the expected costs of CIW, calculated by means of finding the share (from 0.1 to 0.2) of the difference between PQ and actual internal costs; $v(\cdot)$—is the objective function of the Subordinate, that is the sum of reward and penalty for participation in the tender (Gladkikh 2022).

According to the built simulator, the "Subordinate Model P.B.I.M." consists of similar costs. The only difference are the following columns: "The cost of work [$c_{rb}$]"—this is the function of the cost of work by the estimate, which is calculated by means of the new P.B.I.M., P.B.I.M. has the smallest degree of error, because the error of P.B.I.M. is reduced by 2 times in relation to the error of B.I.M., which is indicated in the Experiment Journal; "$y$" is PQ calculated based on P.B.I.M., it is different from the value of PQ that is based on B.I.M., not only because the error in calculations is reduced by 2 times in computer simulation, but also because $y$ takes into account the margin, which varies from 1.0 to 1.2, and the computer simulator takes into account $y$ that has the highest value (Tables 1–3).

So, as shown in the Tables 1–3, in the computer simulator of the Subordinate Model B.I.M. and P.B.I.M., there were different values $y$, but the computer simulator of the Experiment Journal takes into account the data with the highest values that are directly dependent on the margin in PQ.

To account for different y of potential subordinates $y_{1\text{-}0t}$ and $y_{2\text{-}0t}$ there were created the Contestants Behavior Models $y_{1\text{-}0t}$ (Table 4) and $y_{2\text{-}0t}$ (Table 5).

**Table 1.** Fragment of the spreadsheet list “Subordinate Model B.I.M.”.

| $\Phi(R_b;I)$ Cost Function with Uncertainty in Tenders | The Estimated Cost of Work [$c_{rb}$] Allows for an Error within 30% (12—Error B.I.M.) | | Internal Costs of the Firm [$c$]—The Actual Cost Vector, Incurred by the Firm When Performing Work $r_b$ for All Tenders $t$. | | | Take Part or Not | Margin | $y$ | Profit [$\Psi_0$] | $q_t$—Quantity of Participants | $y_{1\text{-}0}$ | $y_{2\text{-}0}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5906.25 | 5197.5 | 12 | 3150.0 | 2598.75 | 5748.75 | 1 | 1.00 | 4725.0 | −1023.75 | 3 | 5218.98 | 7087.0 |
| 5906.25 | 5197.5 | 12 | 3150.0 | 2598.75 | 5748.75 | 1 | 1.05 | 4961.25 | −787.5 | 3 | 5218.98 | 7087.0 |
| 5906.25 | 5197.5 | 12 | 3150.0 | 2598.75 | 5748.75 | 1 | 1.10 | 5197.5 | −551.25 | 3 | 5218.98 | 7087.0 |
| 5906.25 | 5197.5 | 12 | 3150.0 | 2598.75 | 5748.75 | 1 | 1.15 | 5433.75 | didn’t win | 3 | 5218.98 | 7087.0 |
| 5906.25 | 5197.5 | 12 | 3150.0 | 2598.75 | 5748.75 | 1 | 1.20 | 5670.0 | didn’t win | 3 | 5218.98 | 7087.0 |

**Table 2.** Fragment of the spreadsheet list “Subordinate Model P.B.I.M.”.

| $\Phi(R_b;I)$ Cost Function with Uncertainty in Tenders | The Estimated Cost of Work [$c_{rb}$] allows for an Error within 1/2 from Computer Simulator of the Subordinate Model «B.I.M.» (6—Error P.B.I.M.) | | Internal Costs of the Firm [$c$]—The Actual Cost Vector, Incurred by the Firm When Performing Work $r_b$ for All Tenders $t$. | | | Take Part or Not | Margin | $y$ | Profit [$\Psi_0$] | $q_t$— Quantity of Participants | $y_{1\text{-}0}$ | $y_{2\text{-}0}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5906.25 | 5551.88 | 6 | 3150.0 | 2598.75 | 5748.75 | 1 | 1.00 | 5047.16 | −178.98 | 3 | 5218.98 | 7087.0 |
| 5906.25 | 5551.88 | 6 | 3150.0 | 2598.75 | 5748.75 | 1 | 1.05 | 5299.52 | didn’t win | 3 | 5218.98 | 7087.0 |
| 5906.25 | 5551.88 | 6 | 3150.0 | 2598.75 | 5748.75 | 1 | 1.10 | 5551.88 | didn’t win | 3 | 5218.98 | 7087.0 |
| 5906.25 | 5551.88 | 6 | 3150.0 | 2598.75 | 5748.75 | 1 | 1.15 | 5804.23 | didn’t win | 3 | 5218.98 | 7087.0 |
| 5906.25 | 5551.88 | 6 | 3150.0 | 2598.75 | 5748.75 | 1 | 1.20 | 6056.59 | didn’t win | 3 | 5218.98 | 7087.0 |

**Table 3.** Fragment of the spreadsheet list “Journal of Experiments”.

| Possibility to Participate in Tender. The Closer to 1, the Higher Possibility to Get the Job Done | | Error B.I.M. | Contestant 1 Error | Contestant 2 Error | Profit P.B.I.M. | Profit B.I.M. | Margin P.B.I.M. | Margin B.I.M. | y (We Suppose 10% in Additional Agreement to the Contract) P.B.I.M. | y (We Suppose 10% in Additional Agreement to the Contract) B.I.M. | Actual Costs P.B.I.M. | Actual Costs B.I.M. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.56 | 3150.0 | 12 | 19 | −20 | −178.98 | −551.25 | 1 | 1.1 | 5047.16 | 5197.5 | 5748.75 | 5748.75 |

**Table 4.** Fragment of the spreadsheet list "Contestant 1 Behavior Model".

| $\Phi(R_b;I)$ Cost Function with Uncertainty in Tenders | Possibility to Participate in Tender. The Closer to 1, the Higher Possibility to Get the Job Done | The Estimated Cost of Work [$c_{rb}$] allows for an Error within 30% (19—Contestant 1 Error) | | Internal Costs of the Firm [$c$]—The Actual Cost Vector, Incurred by the Firm When Performing Work $r_b$ for All Tenders $t$. | | | Take Part or Not | Margin | $y$ | Profit [$\Psi_0$] | $q_t$—Quantity of Participants |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5906.25 | 0.71 | 4784.06 | 19 | 3993.75 | 1712.81 | 5706.56 | 1 | 1.2 | 5218.98 | didn't win | 3 |
| 5906.25 | 0 | 4784.06 | 19 | 0 | 5906.25 | 5906.25 | 1 | 1.2 | 5218.98 | didn't win | 3 |
| 5906.25 | 0.17 | 4784.06 | 19 | 956.25 | 4902.19 | 5858.44 | 1 | 1.2 | 5218.98 | didn't win | 3 |
| 5906.25 | 0.06 | 4784.06 | 19 | 337.5 | 5551.88 | 5889.38 | 1 | 1.2 | 5218.98 | −670.4 | 3 |
| 5906.25 | 0.7 | 4784.06 | 19 | 3937.5 | 1771.88 | 5709.38 | 1 | 1.2 | 5218.98 | −490.4 | 3 |

**Table 5.** Fragment of the spreadsheet list "Contestant 2 Behavior Model".

| $\Phi(R_b;I)$ Cost Function with Uncertainty in Tenders | Possibility to Participate in Tender. The Closer to 1, the Higher Possibility to Get the Job Done | The Estimated Cost of Work [$c_{rb}$] allows for an Error within 30% (−20—Contestant 2 Error) | | Internal Costs of the Firm [$c$]—The Actual Cost Vector, Incurred by the Firm When Performing Work $r_b$ for All Tenders $t$. | | | Take Part or Not | Margin | $y$ | Profit [$\Psi_0$] | $q_t$—Quantity of Participants |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5906.25 | 0.07 | 7087.5 | −20 | 393.75 | 5492.81 | 5886.56 | 1 | 1.1 | 7087.5 | didn't win | 3 |
| 5906.25 | 0.37 | 7087.5 | −20 | 2081.25 | 3720.94 | 5802.19 | 1 | 1.1 | 7087.5 | didn't win | 3 |
| 5906.25 | 0.66 | 7087.5 | −20 | 3712.5 | 2008.13 | 5720.63 | 1 | 1.1 | 7087.5 | didn't win | 3 |
| 5906.25 | 0.87 | 7087.5 | −20 | 4893.75 | 767.81 | 5661.56 | 1 | 1.1 | 7087.5 | didn't win | 3 |
| 5906.25 | 0.21 | 7087.5 | −20 | 1181.25 | 4665.94 | 5847.19 | 1 | 1.1 | 7087.5 | didn't win | 3 |

Computer simulator of the first contestant $y_{1\text{-}0t}$ (Table 4) consists of the following columns: "$\Phi(R_b;I)$"—consists of the working time, shown in the Experiment Journal, multiplied by cost in nominal dollars 1.25 with uncertainty in tender, which is indicated in the Experiment Journal; the parameter "Possibility to participate in tender" presents the share of CIW in the tender, which the firm can do itself. In this study, it was a random number from 0 to 100 expressed as a coefficient; the "cost of work [$c_{rb}$]"—this is the function of the cost of work from the estimate with an error in B.I.M., which is indicated in the Experiment Journal in the range from −30% to + 30%; "Internal costs of the firm [$c$]"—the actual cost vector, incurred by the organization when performing work $r_b$ for all tenders $t$, it is determined by multiplying the working time by the possibility to participate in tender, which is indicated in the Experiment Journal, with cost in nominal dollars 1.25. Next, the costs are determined that can be met by a subcontracting party (this is the remainder of the possibility to get the job done), after which these values are summed up and the general costs are determined, which the firm will incur when performing CIW in this tender; "Take part or not" determines whether this firm will take part in this tender or not, this is calculated by means of comparing the value $sp_{rb}$ multiplied by 1.1 (here, 1.1 is 10%, which can be obtained if additional work is needed and which may not be formalized in a new tender procedure) and the cost of work by the estimate multiplied by a given margin level which can take any values from 1.05 to 1.2; "Margin"—for the first contestant its value is 1.2; "$y$"—this is PQ which is presented for participation in the tender, if the column "Take part or not" specifies "we don't take part", $y$ has no value, and if participation is relevant, in this case, the value $y$ is determined by comparing the following results: if the cost of work by the estimate multiplied by the firm's margin is higher than $sp_{rb}$ multiplied by 1.1, than the result is $sp_{rb}$, otherwise—the cost of work by the estimate multiplied by the margin is divided by 1.1; "Profit [$\Psi_0$]"—in case of winning in tender, it is determined as the difference between $y$ and internal costs $c$ divided by 1.1; "$q_t$—Quantity of participants"—varies from 0 to 3 depending on whether the conditions of this tender are suitable for the relevant participants, that is, this column determines the PQ correlation of a potential contestant, second contestant (Table 5), and our PQ created on the basis of the B.I.M (Gladkikh 2022).

Columns have similar functions at the computer simulator of the second contestant $y_{2\text{-}0t}$ (Table 5), but the margin of the second contestant is 10%.

### *2.4. Computer Simulator of the Principal*

Computer simulation of the Principal consists of basic data determined in the Experiment Journal, at its first stage (Gladkikh 2022). The model of Principal is located in the lists named the "Model of Principal (P.B.I.M.)" and the "Model of Principal (B.I.M.)". According to the built simulator, the "Model of Principal (P.B.I.M.)" and the "Model of Principal (B.I.M.)" have identical calculations which are based on the data in tabs "Subordinate Model P.B.I.M." and "Subordinate Model B.I.M.". Lists, the "Model of Principal (P.B.I.M.)" and the "Model of Principal (B.I.M.)", consist of the following columns: "$c_0$"—fixed cost, expressed in const 7.5 in nominal dollars (as the working time in this computer simulation varies from 6000 to 10,000 pcs., and the cost of work for a potential Contractor is 1.25 in this research, then cost of a typical tender is 7500 in nominal dollars, of which fixed costs for the participation of a construction firm in tenders are 0.1%); "$v_0$"—the objective function of the Principal, that is, net profit which is determined as the difference between PQ and actual indirect costs. In the calculations, actual indirect costs are reduced by 1.1 times (it is believed that these costs will be taken into account in the additional agreement), and also reduced by the objective function of the Subordinate and fixed costs (Gladkikh 2021):

$$v_0(\mathbf{z},\ \mathbf{y},\ \mathbf{c}) = \mathbf{z}\cdot(\mathbf{y}-\mathbf{c}) - \Phi(\mathbf{z},\ \mathbf{y}) - h(\mathbf{z}\cdot(\mathbf{y}-\mathbf{c})) - c_0, \tag{2}$$

where $v_0$ is the objective function of the Principal, which in this study will mean the profit of a controlled construction firm; $z$ is the result of participation in the tender $t$ for a construction firm; $y$ is the proposed price of the contract; $\mathbf{c}$ is the vector of the actual costs incurred by the firm for the performance of work $r_b$ on all tenders **t**, if $z_t = 0$, then we will hold $c_t = 0$, $c_t \in \mathbf{c}$; $h(\delta)$ is the penalty function; $c_0$ is the fixed costs of the firm.

Data from the "Subordinate Model (P.B.I.M.)", "Subordinate Model (B.I.M.)", "Model of Principal (P.B.I.M.)", "Model of Principal (B.I.M.)" are copied in the Experiment Journal, to its second stage (Table 6).

**Table 6.** The Journal of Experiments, second stage.

| Actual Costs P.B.I.M. | Actual Costs B.I.M. | $\sigma(\cdot)$ P.B.I.M. | $h(\delta)$ P.B.I.M. | v(·) P.B.I.M. | $c_0$—Fixed Costs = 7.5 in Nominal Dollars P.B.I.M. | $v_0$(z. y. c) P.B.I.M. | $\sigma(\cdot)$ B.I.M. | $h(\delta)$ B.I.M. | $v(\cdot)$ B.I.M. | $c_0$—Fixed Costs = 7.5 in Nominal Dollars B.I.M. | $v_0$(z. y. c) B.I.M. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5748.75 | 5748.75 | 0 | −140.32 | −140.32 | 7.5 | −46.16 | 103.95 | −110.25 | −6.3 | 7.5 | −29.84 |

This example shows (Table 6) the objective function of the Principal with the rates of winning and the penalty for the Subordinate at 0.2 and 0.2, respectively. Examples will be shown below with other values of the control parameters of the Principal.

## 3. Results

### *3.1. Results of Agent-Based Modeling*

As a rule, a large construction firm participates in 50 to 150 tenders a month. That is why, within 1.5 to 2.0 years, the firm will take part in 1500 tenders. So, in this research 1500 experiments were conducted (Figure 3).

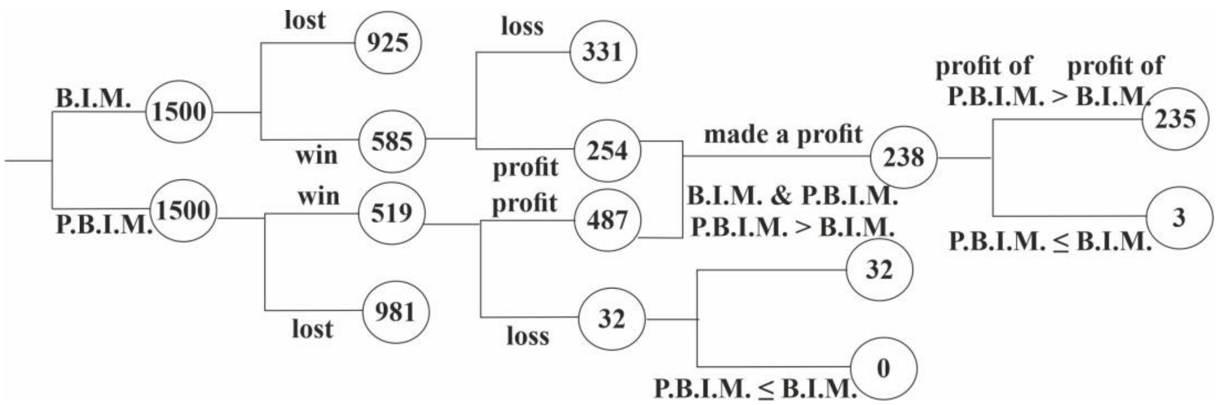


**Figure 3.** Results of the 1500 simulations.

Figure 3 shows that the construction firm participated in 1500 tenders. It won 519 tenders, but 487 tenders out of them were profitable when using P.B.I.M. The construction firm won 925 tenders but only 254 tenders out of them were profitable when using B.I.M. It was also checked how many profitable tenders matched in B.I.M. and P.B.I.M. There were 238 such tenders, of which 235 tenders gave more profit when using P.B.I.M. and only 3 gave profit when using B.I.M.

### *3.2. Result of Game Theory Modeling*

Under the assumption of the maximum goodwill of the Subordinate to the Principal, several experiments were carried out, in which values of rewards and penalty rates of the Subordinate were changed:

1. The reward of the Subordinate = 0.1 and the penalty of the Subordinate = 0.1;
2. The reward of the Subordinate = 0.15 and the penalty of Subordinate = 0.15;
3. The reward of the Subordinate = 0.2 and the penalty of the Subordinate = 0.2;
4. The reward of the Subordinate = 0.1 and the penalty of the Subordinate = 0.15;
5. The reward of the Subordinate = 0.1 and the penalty of the Subordinate = 0.2;

6. The reward of the Subordinate = 0.15 and the penalty of the Subordinate = 0.1;
7. The reward of the Subordinate = 0.15 and the penalty of the Subordinate = 0.2;
8. The reward of the Subordinate = 0.2 and the penalty of the Subordinate = 0.1;
9. The reward of the Subordinate = 0.2 and the penalty of the Subordinate = 0.15.

Changes of the Subordinate's objective function were determined for each variant.

This research was conducted using B.I.M. (Figure 4) and P.B.I.M. (Figure 5) and gave the following results:

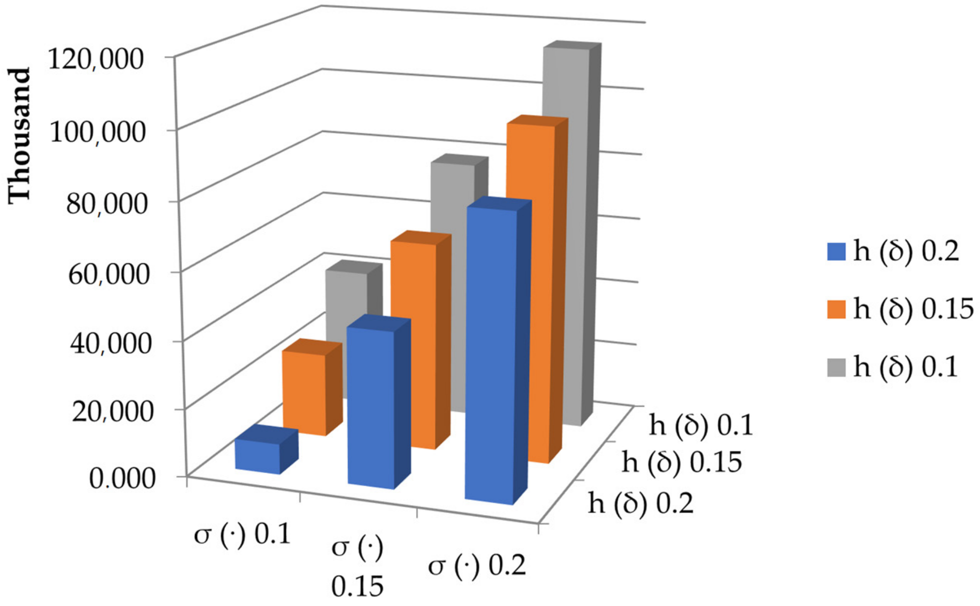


**Figure 4.** The Subordinate's objective function using B.I.M. with different Principal's control parameters of the stimulation and loss functions.

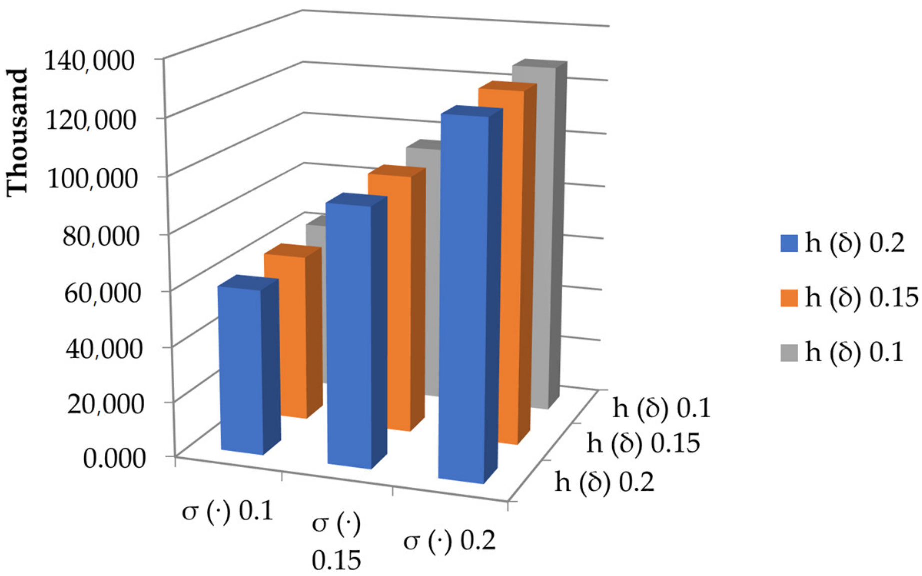


**Figure 5.** The Subordinate's objective function using P.B.I.M. with different Principal's control parameters of stimulation and loss functions.

Figure 4 shows that when the reward function is minimum 0.1 and the penalty function is maximum 0.2, then the Subordinate's objective function will be small, it will take on the value 9, 053.82 nominal dollars. When the reward function is maximum 0.2, and the penalty function is minimum 0.1, the Subordinate will receive income in the amount of 114, 933.31 nominal dollars. However, these are the data obtained using B.I.M. Below are the data obtained using P.B.I.M. (Figure 5):

According to the bar chart (Figure 5), the Subordinate's objective function of 59,754.89 in nominal dollars is positive with the minimal reward 0.1, and maximum value of the penalty function 0.2. This is 50,701.07 nominal dollars more than the value of the objective function using B.I.M. The maximum value of the Subordinate's objective function using P.B.I.M. is 128,295.51 nominal dollars. It is made with a reward of 0.2 and penalty of 0.1, and this is 13,362.20 nominal dollars more than the result achieved with B.I.M. It means that the Subordinate will make more profit when its PQ will be calculated using P.B.I.M. than using B.I.M. Putting it otherwise, making fewer errors in calculations, the Subordinate will make more profit. It is clear that for the Subordinate, the most beneficial value of the reward function will be 0.2, and of the penalty—0.1, but the system of reward and penalty is regulated by the Principal itself, that is why we will determine the result after analyzing the obtained data of the Principal's objective function.

However, to make a more detailed experiment and to obtain a model of the maximum goodwill of the Subordinate to the Principal, other norms of the Subordinate's reward and penalty were exploited.

According to the results, bar charts of changes in the Principal's objective function were created from the given parameters of reward and penalty (Figures 6 and 7).

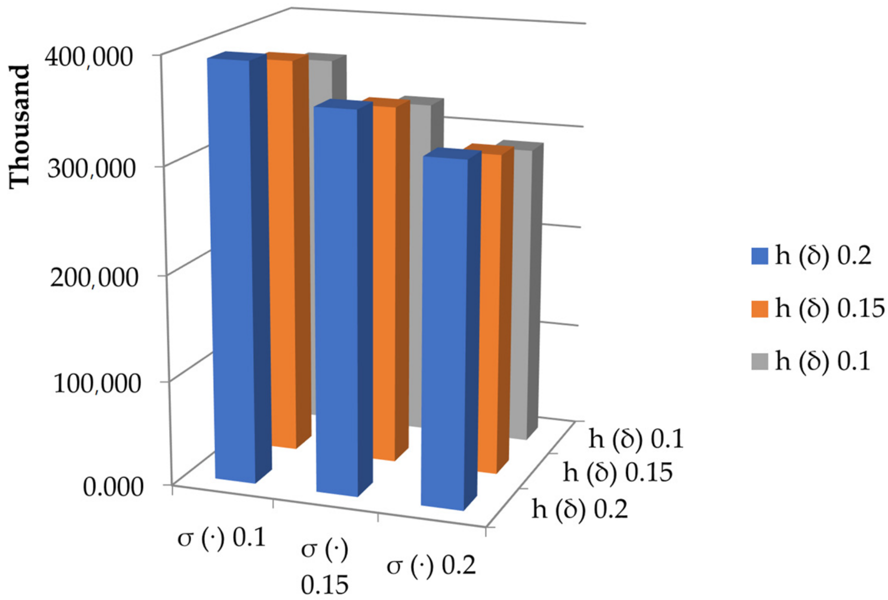


**Figure 6.** The Principal's objective function values using B.I.M. with different parameters of stimulation and loss functions.

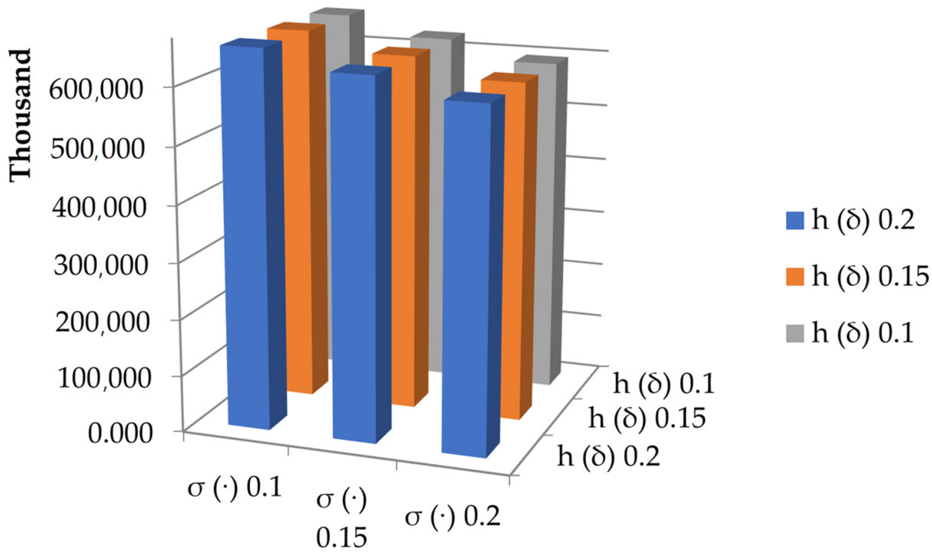


**Figure 7.** The Principal's objective function using P.B.I.M. with different parameters of stimulation and loss functions.

As it is shown in the bar chart (Figure 6), when the reward function is minimal 0.1 and the penalty function is maximal 0.2, then the Principal's objective function is 393,790.56 in nominal dollars. When the value of the reward function is maximal 0.2 and the value of the penalty function is minimal 0.1, then the Principal's objective function is 287,911.08 in nominal dollars. Let us compare the data with the values obtained by using P.B.I.M in the calculation of PQ. (Figure 7).

In Figure 7, the Principal's objective function is 663,378.81 in nominal dollars with the minimal value 0.1 of the Subordinate's reward function and the maximal value 0.2 of the Subordinate's penalty function. This is 269,588.25 in nominal dollars more than at the same values using B.I.M. When the value of the Subordinate's reward function is maximal 0.2 and the value of the penalty function is minimal 0.1, then the Principal's objective function is 594,838.19 in nominal dollars. This result is 306,927.11 in nominal dollars more than the result obtained with B.I.M.

So, the values of the objective function obtained with P.B.I.M. are almost twice as large as the values obtained with B.I.M. Using a more precise method promotes the most efficient activity of the firm.

Summing up, it should be concluded that it is more profitable for the Principal to charge the Subordinate the maximum value of penalty for the wrong PQ calculation and the minimum value of the reward for the right calculation of the CIW cost on the object. To analyze the objective functions of the Subordinate and the Principal, Table 7 was formed, from which one can see how values of the objective functions of the Subordinate and the Principal change from the constant parameters of the reward and penalty functions. Values of the Table 7 were obtained as a result of using B.I.M.

**Table 7.** Correlation of the Subordinate's objective functional and the Principal's objective functional using B.I.M. with the same parameters of the reward and penalty system.

| Parameter | $h(\delta)$ 0.2 | $h(\delta)$ 0.15 | $h(\delta)$ 0.1 |
|---|---|---|---|
| **б(·) 0.1** | 9053.82/ 393,790.56 | 25,191.43/ 377,652.95 | 41,329.04/ 361,515.34 |
| **б(·) 0.15** | 45,855.95/ 356,988.43 | 61,993.56/ 340,850.82 | 78,131.17/ 324,713.21 |
| **б(·) 0.2** | 82,658.09/ 320,186.30 | 98,795.70/ 304,048.69 | 114,933.31/ 287,911.08 |

As can be seen from Table 7, the difference between the maximum value 0.2 and the minimum value 0.1 of the reward at fixed penalty is 74 thousand nominal dollars—it is the objective functional of the Subordinate. As for the Principal—the difference between the value of the objective functional with a maximum reward 0.2 and a minimum reward 0.1 at a fixed penalty is 74 thousand nominal dollars. It means that the Principal obtains more profit with changing the Subordinate's objective function just by means of reducing the Subordinate's reward and by increasing its value of penalty.

The data of Table 7 show that the Subordinate's and the Principal's reward is collectively constant, which means there is a zero-sum game. Selection of the system with the minimal rate of reward and the maximum rate of penalty is a more profitable strategy for the Principal. Of course, the Subordinate's objective functional takes the minimal value with that system of reward, but it is positive, it means that it is still beneficial for the Subordinate to do its job.

The above bar chart provides values of the Subordinate's and the Principal's objective function, which clearly show the advantage of using P.B.I.M. over B.I.M. when calculating PQ for the participation of a construction firm in tenders. Let us compare in the table form values of the Subordinate's and the Principal's objective functions with P.B.I.M. (Table 8).

**Table 8.** Correlation of the Subordinate's and the Principal's objective functional using P.B.I.M. with the same parameters of the reward and penalty system.

| Parameter | $h(\delta)$ 0.2 | $h(\delta)$ 0.15 | $h(\delta)$ 0.1 |
|---|---|---|---|
| **б(·) 0.1** | 59,754.89/ 663,378.81 | 61,219.18/ 661,914.53 | 62,683.47/ 660,450.24 |
| **б(·) 0.15** | 92,560.91/ 630,572.79 | 94,025.20/ 629,108.50 | 95,489.49/ 627,644.21 |
| **б(·) 0.2** | 125,366.93/ 597,766.77 | 126,831.22/ 596,302.48 | 128,295.51/ 594,838.19 |

Based on the data from Table 8, it should be noted that with a reward of 0.1, the Principal's objective function varies from 663 to 660 thousand nominal dollars. When a reward is 0.15, the Principal's objective function reduces by about 33 thousand nominal dollars (from 663 to 630 thousand nominal dollars). Finally, when the rate of reward is 0.2, the value of the Principal's objective function changes from 598 to 595 thousand nominal dollars; this is a large reduction from the basic value, by 65 thousand nominal dollars (from 663 to 660 thousand nominal dollars). That is why it should be noted that the Subordinate's reward of 0.1 becomes more profitable for the Principal. Let us analyze the value of the Subordinate's objective functional with similar values of the reward system. So, with the value of 0.1, the Subordinate's reward varies from 60 to 63 thousand nominal dollars, with the value of 0.15, the Subordinate's reward varies from 93 to 95 thousand nominal dollars, and finally, with the value of 0.2, the Subordinate's reward varies from 125 to 128 thousand nominal dollars. So, the difference of the Subordinate's reward from its largest value to its minimum one is compliant with that of the Principal—the same 65 thousand nominal dollars.

## 4. Discussion and Conclusions

### *4.1. Research Limits*

A computer simulator of a multi-agent system with several assumptions and limitations was created in this study. General assumption means that public tenders have three participants: the Subordinate and only 2 Contestants. The Subordinate model was created in two versions: the Subordinate model B.I.M. and the Subordinate model P.B.I.M. The Subordinate model P.B.I.M. computer simulator had half the error of the Subordinate model B.I.M. computer simulator. The error of the latter was within 30% limit. Computer simulators of Contestant 1 and Contestant 2 have the error in same range.

A significant assumption of this study is that several parameters have values in nominal dollars. Such parameters are:

(1) coefficient 1.9 used in the calculation of $sp_{rb}$. It means the maximum value of working time cost in nominal dollars;
(2) coefficient 1.25 used in the calculation of $\Phi(R_b;I)$. It means construction firms' working time cost in nominal dollars;
(3) coefficient 7.5 used in the calculation of $C_0$. It means fixed cost in nominal dollars.

The variable Margin has a few values (1.00; 1.05; 1.10; 1.15; 1.20) used in five scenarios. These values are multiplicative coefficients and mean by what percentage the Subordinate could increase the cost of CIW at the PQ. In the computer simulators of Contestant 1 and Contestant 2, the multiplicative coefficients were 1.20 and 1.10 accordingly. In reality, this coefficient may take any values.

Denominator 1.1 is used for the calculation of the following variables: Profit [$\Psi_0$]; PQ [$y$] (if the cost of CIW is less than $sp_{rb}$), and the objective function of the Principal $v_0$. Denominator 1.1 means a 10% reduction in the cost corresponding to cases with an addendum to the contract. In reality, this value may be any other.

Other assumptions and limitations correspond to using random number generators with the following parameters:

(1) "Tender, man-hour/vehicle-hour [working time]"—is a random number generator between 2000 and 10,000, emitting the working time spent on CIW for this tender;
(2) "Information exhaustiveness about tender $\left[I; \overline{I}_{rb}\right]$"—is generated by means of a random number generator with a limit from 0 to 100;
(3) Parameter "Possibility to participate in tender" presents the share of CIW in the tender which the firm can do itself. In this study, it was a random number from 0 to 100.

There are the following assumptions and limitations used in the gaming simulation of strategic behavior of the Principal and the Subordinate. In this study, the Principal has nine strategies of reward in case of winning in public tenders and penalty in case of losing during the CIW implementation. These strategies correspond to the Cartesian product of the vector with values of reword for winning—(1.10; 1.15; 1.20) and the vector with values of penalty—(0.90; 0.85; 0.80). In reality, the Principal has an unlimited number of strategies.

### 4.2. Research Perspectives

The result of this study is that the use of more precise methods of calculating the estimated cost will improve the effectiveness of the construction firm. The dependence between the precision of estimated pricing and profit can be identified in further research. It means agent-based modeling can be performed with different coefficients of accuracy in determining the estimated cost.

It was already noted above that three scientific problems were identified in the study (Gladkikh 2021). In this work, both hypotheses referred only to the third problem, which is "Inaccurate determination of the estimated cost at the stage of preparation for the participation in a tender". Therefore, it is possible to formulate hypotheses related to the other two problems, then research the impact of information about the possible behavior of competitors on the choice of contract price and on the profit of a construction firm. It is also possible to investigate the impact of the accuracy of basic data for construction projects on the choice of contract price and the profit of construction firms.

To research the problem "the presence of game uncertainty, which is expressed in complex forecasting the participation of competitors in the tender $t$ and their prices $y_{-0t}$ for CIW", the following hypotheses can be deduced:

- can statistics on the participation of competitors in tenders help determine such a contract price that the probability of winning the tender is acceptable?
- will the profits of construction firms increase when using statistical data on participation in public tenders, if they have to pay money for this information?

To investigate the problem "the information uncertainty in the basic data (the estimated cost is determined based on these data) leads to inaccurate pricing", the following hypotheses can be deduced:

- can expert systems, which appraised the quantity of information in the tender, make a sufficient correction to the estimated cost so that the order is profitable with an acceptable probability?
- will the profit of the construction firm increase when using expert data, if it has to pay money for this information?

Testing these hypotheses is an interesting avenue for future research.

### *4.3. Research Conclusions*

#### 4.3.1. Confirmed H1

Figure 3 shows that the firm participated in the same tenders, but it used different means to estimate the CIW cost. So, according to Figure 3, if the firm uses the existing B.I.M., it will win in 585 tenders, of which it will make a profit in 254 tenders and a loss in 331 tenders. Inversely, according to the computer simulator, on the chance of using the new P.B.I.M. in PQ calculation, the firm will win 519 times, of which it will make a loss 32 times and a profit 487 times. This large difference is due to the fact that P.B.I.M., which has two times less error, was used in the estimation of the CIW cost, this will make the firm's activities approximately 68% more efficient, which confirms the need to introduce a more precise method in the calculation of the estimated cost of work in the business process of preparing a PQ for the participation of construction firms in tenders.

#### 4.3.2. Confirmed H2

When comparing the objective function of the Subordinate, which is obtained with B.I.M., with the Subordinate's objective functional, which is obtained with P.B.I.M., at the maximum value 0.2 of the penalty and the minimum value 0.1 of the reward, the difference will amount to 51 thousand nominal dollars. The difference of the Principal's objective functional with the same parameters will amount to 270 thousand nominal dollars. Indeed, the obtained results show the superiority of the more precise method P.B.I.M. over the method B.I.M. which has a higher degree of error. When the Subordinate and the Principal use P.B.I.M. in their PQ calculations, they will make a bigger profit than when using B.I.M.

For the Subordinate, it was not beneficial to win many contracts by reducing PQ if it uses a more precise method. It means that it was profitable to choose other strategies of behavior when participating in tenders, including making riskier offers, without fear of receiving a large penalty on the results of participation in tenders. This resulted in a 6.6-fold increase in the Subordinate's reward with the most favorable strategy to the Principal, with the Principal's reward increasing by 68% (Table 8).

Thus, as a result of computer simulation of the construction firm participation in tenders as a contestant, it was shown that it is beneficial for both the Principal and the Subordinate to use more precise methods. This fact sustains the need to integrate an appropriate DSS into the business process of preparing PQ for the participation of construction firms in tenders.

Both hypotheses H1 and H2 have been confirmed. Some researchers came to similar solutions in their works (Bakr 2019), (Ellis et al. 2021), (Sayed et al. 2020), (Subiyanto and Suyoto 2020), (Hanák et al. 2020), (Niewerth et al. 2022), and (Jaskowski et al. 2019).

**Author Contributions:** Conceptualization, A.A.; methodology, A.A.; software, V.G.; validation, A.A. and V.G..; formal analysis, V.G.; investigation, V.G.; resources, V.G.; writing—original draft preparation, V.G.; writing—review and editing, A.A. and V.G.; visualization, V.G.; supervision, A.A.; project administration, A.A. All authors have read and agreed to the published version of the manuscript.

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