2022 European Conference on Computing in Construction
Ixia, Rhodes, Greece
July 24-26, 2022

UTILIZING SIMULATION TO PREDICT OPTIMUM NUMBER OF PROJECTS

Ahmed Elnady[1], Yaroslav Broda[1], Ahmed Hammad[1], Hamidreza Golabchi[1], and Yasser Mohamed[1]
[1]University of Alberta, Edmonton, Canada

Abstract

Contractors strive to generate profit from utilizing the available resources. This paper introduces a hybrid model of Discrete Event and Monte Carlo Simulations using SIMPHONY Software to model the operational interdependencies of the construction projects at the work packages level using the common pool of resources. The developed model considers organizational financial and equipment resources to help contractors forecast the optimum number of projects to bid for at the planning phase. A case of Bid/No-Bid in building houses is used to validate the model. The main contribution is in the methodology of applying operational techniques in making strategic decisions.

Introduction

Countries offered affordable housing for equality. These housing projects are a good opportunity for contractors to profit. While, selecting the number of projects to bid for is affected by multiple factors, the main goal of a contractor is to successfully deliver the project to maximize the generated profit. Preparation for the upcoming bids consumes time and money; contractors seek to award the maximum available bids without crossing their capacity limit, which is the optimum workload level (number of project). Contractors might exceed this optimum value while trying to avoid losing a chance for profit. Hence, contractors in a need for a model to assist this crucial and strategic decision.

Contractors mostly work on concurrent projects using the same resources including cash, that is another constraint for the decision. Though, avoiding overutilization and underutilization of resources drives organization cash performance. This work considers the conflict between concurrent projects, limited capacity, and maximizing profit. The aim is to support decision-makers in such limited time with multiple constraints environment. This will help in maintaining higher returns from their investment.

Problem Statement

In a complex and uncertain environment like construction projects, decisions can be very risky with significant consequences. They can put companies in negative outcomes like financial distress. In this context, the problem captured by this work is to facilitate the decision process in such dynamic and complex environments as construction projects. This decision process is aiming to maximize the profit return from the investment of the company's fixed resources. The more assigned projects, the higher the return, and the more conflicts and obligations. Hence, it is important to find the optimal number of projects that give higher returns while eliminating conflicts arising from managing these projects. To model this problem, Discrete Event Simulation (DES) and Monte Carlo Simulation (MCS) are used and coded on SIMPHONY.4.6.0.329 software.

The model is validated using a case of a construction company in the process of deciding how many projects to bid for in a new mega project of building affordable houses. This project has a scope of building 100 houses in a new city and is going to be launched in June 2022, and the government is planning to deliver it in one year.

The company has limited resources available for this project and wants to maximize profit from these resources. The more assigned and successfully delivered projects within the time, the more profit the company will gain. Hence, this model is going to answer the question of "How many projects the company can bid on to maximize the return from its resources?".

It is worth to mention that, this work is not attempting to study the factors affect the bidding decision such as the suitability of project to the organization portfolio nor the competition environment of the bidding phase.

Literature review

Bidding for a project is a multi-dimensional problem, and has been investigated from various perspectives: interest of the company in the project to Bid or Not, the competitiveness of the company and its ability to win the bid, and from the profit point of view. First, the interest of the company is based on the matching of the company's business model and project characteristics. For example, (Leśniak, Kubek, et al. 2018) developed a model based on fuzzy tools to boost decision makers' efficacy in taking bidding decisions. In the same context, (Bagies and Fortune 2006) provided a study to improve the evaluation of construction projects in the preliminary phase to help decision-makers whether to bid or not for a specific project. Also, the factors contribute to companies' decisions to bid or not are investigated in different countries, like Nigeria (Oyeyipo, Odusami, et al. 2016), and Saudi Arabia (Alsaedi, Assaf, et al. 2019).

Second, the competitiveness of the company in the market was surveyed in several studies. (Orozco and Serpell 2010) did a survey to extract factors and sub-factors responsible for contracting organizations' competitiveness. They developed an indexed model to evaluate the company's competitiveness through the surveyed factors. Another key study was done by (Tan, Xue, et al. 2017) to evaluate contractors' competitiveness. They studied the management style of the main contractor relationship with subcontractors. They divided the relation into four categories: adverse, compete, collaborate, and partners. They found that a win/win partnership in a long-term relationship is highly recommended for both parties.

Finally, profit margins affect contractors' competitiveness by contributing to projects' price. Cost and competitive profit margin are be estimated at the early stages of tendering phase by different tools, for example, artificial neural network (Matel, Vahdatikhaki et al. 2019).

One of the widely used approach to assess decision-makers is modeling and simulation. This method has been widely utilized in the construction industry as an example in developing more reliable plans, optimizing usage of resources, minimizing total project cost and duration, and improving the overall performance and productivity (AbouRizk 2010).

There are different approaches to model construction projects. One of the widely used approaches is DES that used to model cyclic operations and for analyzing complicated construction systems (AbouRizk and Hajjar 1998). DES modeling is used to analyze operations with certain specifications. And experiment with different alternatives of the project by manipulating different resources used in carrying out different tasks and activities within the project. Also, it replicates multiple runs to converge the results to a confidence interval (Schriber, Brunner, et al. 2013).

In this approach of modeling, the modelers are concerned with important events like starting or ending of activity. For ease of handling and saving time and effort in experimenting with these models, they are coded using computer programs. One of the most successful simulation software is SIMPHONY. It was developed in 1996 to help in developing complex models with an easy and friendly user interface (AbouRizk and Hajjar 1998). Also, Simphony.NET was developed in 2002 and it is a modeling environment to design a model by utilization of icons that represents resources used within a project and how they are used between different activities (AbouRizk and Mohamed 2002). A further great development was introduced in the computer simulation world by developing Simphony.NET 3.5 (AbouRizk 2010).

Simphony.NET was utilized by (Mohamed, Jafari, et al. 2017) in Snow removal operations, for example. They used sensor data of weather, truck speed, and other data to simulate fame work for real-time planning of snow removal operations. Also, (Hu and Mohamed 2013) utilized it in Industrial construction projects in the planning process to be capable of dynamic planning based on upcoming constraints. These models are utilized to help decision-makers in choosing the best fit scenario for the case constraints and within its stochastic environment. DES is integrated with MCS to model variability (uncertainty) in construction projects. As an example (Peleskei, Dorca, et al. 2015) estimated the cost of construction projects using MCS. Also, (Namazian, Yakhchali, et al. 2019) integrated MCS with Bayesian Networks Methods in predicting Projects completion time under Risk.

Input modeling and assumptions

The model as previously mentioned coded using SIMPHONY software and utilizing DES and MCS to represent the stochastic behavior of construction projects and capture the interdependences between the resources and activities acquiring it. Inputs for this model are represented in the company resources and available amount of liquid cash. In addition, the strategy the company is established to be competitive in the market.

The model utilized the previously mentioned inputs to get the optimum workload (the expected number of projects) while maximizing the profit from investing these assets. Some assumptions shape the model behavior. These assumptions are:

- Scheduled maintenance is supposed to be done after the activity finish and takes one day with cost varied uniformly from a cost of one to 8 hours.
- Maintenance at failure, the equipment is supposed to break down using an exponential function with a mean of (30) hours.
- The company will receive cash in monthly payments.
- The company wants to maximize its profit by bidding on the maximum number of projects.
- The general layout of a mock project is available.
- The design has an expected delivery time, a minimum of 2 days, and a maximum of 8 days.
- The company is expected to have net profit ranging from 5% to 10%.
- The maximum waiting time for any activity to be started is one week.
- The moving entity in the model is the number of the ongoing project.
- Overtime is applied when slippage in activity duration is exceeded 20% of the planned time.
- The calendar is 5 days per week and 8 hours per day.
- Delay of any activity due to resources is not exceeding 40 hours.

Model layout and description

General

The model consists of three main parts. The network of project activities as shown in Figure 1 is the first part, which is responsible for organizing the flow of model elements and the emerging behavior. The second part is resources, which represents both the available resources of the company and other outside sources if needed as shown in Figure 2. All the resources are in one pool called company resources. Any task acquiring resources from this pool is served on a first in first out basis. The third part is the cash flow and checking points to find if the company is under-utilizing its resources or if the resources are over-utilized to get the optimum load (in this model is the number of projects to bid for) based on this combination.

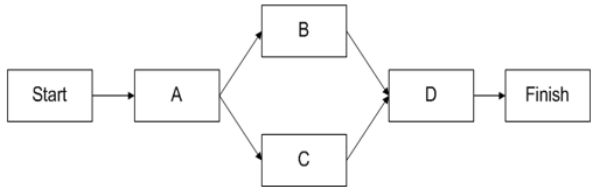

Figure 1 Network Diagram

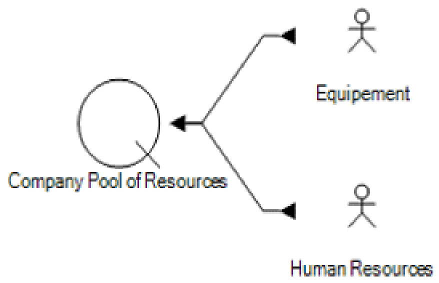

Figure 2 Company pool of resources

All these parts are integrated into each activity of the project. For example, the activity "A" in the network Figure 1 is presented in Figure 3. It starts with setting the time of the ongoing activity to be used in further calculations either inactivity duration or slippage time. Then the required resources for this activity are captured from the company resource pool shown in Figure 2. After that, the activity is going into a cycle of working and checking if it's done or not.

Because of the limited space of the paper, the full model couldn`t be presented but, *Figure 3* captures the workflow of project activities. It shows that after the completion of one activity, the depending activities will start. In this model, the productivity is simulated using a loop that adding a portion of the quantity every step to the total finished quantity of that activity; then every step check if the required quantity of the activity is achieved, then move the entity to the next activity, else holding it till the required quantity is done.

Productivity variation

Crew productivity is not a fixed value. It always changes depending on many variables such as motivation, training, management, and other factors. The time to complete a given quantity is changed randomly every one hour of the simulation time to capture the variability in productivity. The productivity in the model is measured in quantity per hour; hence the hours required to finish the portion (quantity per step) is changing randomly every step and is chosen to have a minimum of 0.75 hours and a maximum of 1.25 hours. This cycle is shown in Figure 4.

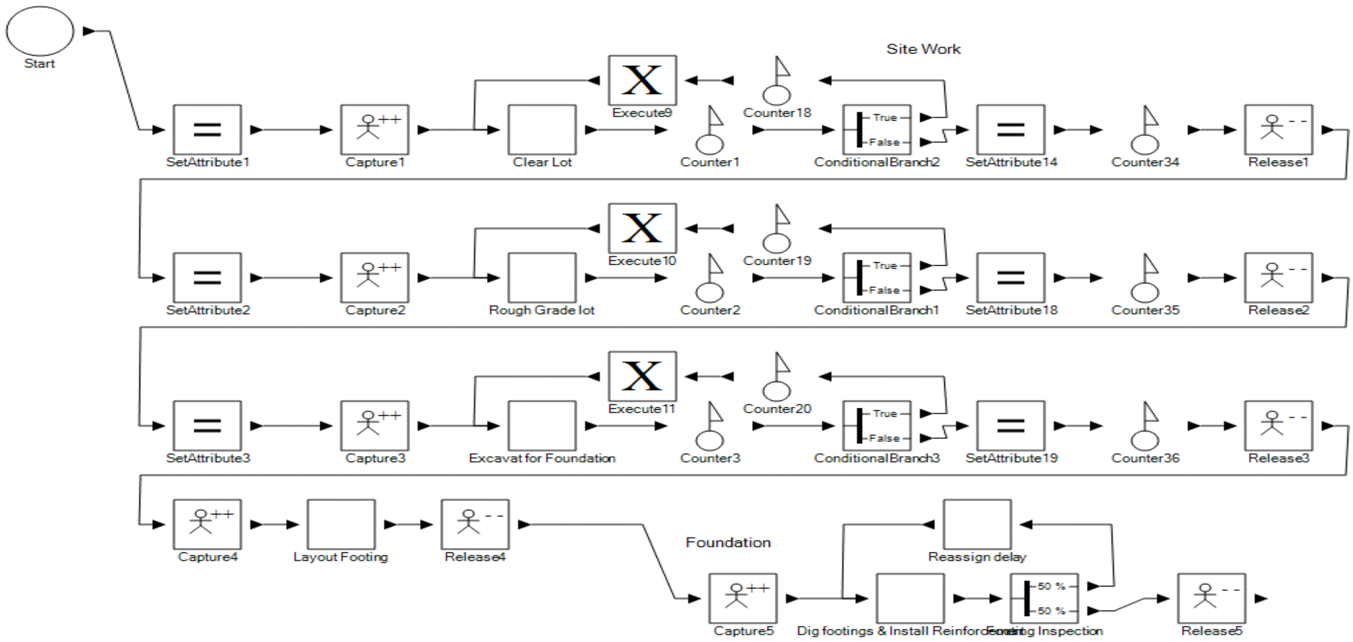

Figure 3 Model Workflow

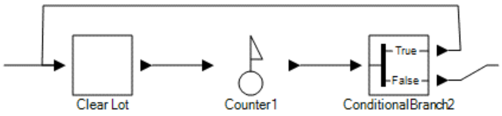

Figure 4: Productivity Loop

In this loop, Figure 4, the activity with stochastic productivity having an upper and lower bound to represent workers' duration in doing the activity. While the counter is accumulating the finished quantity. This finished quantity is sequentially checked in the conditional branch to find if the activity is completely done or needs more time.

Schedule slippage and response

The model can detect if there is slippage in the schedule or not. This is done by comparing between simulation time of the activity and the real-time of this activity as in Figure 5.

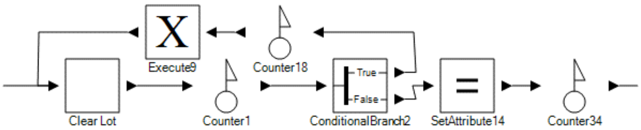

Figure 5 Testing Schedule slippage

In Figure 5, "Counter 18" is calculating the real-time, and "Execute9" is determining if the project time (the consumed time by activity) is greater than the real consumed time, hence the overtime is activated to eliminate the wasted time. "SetAttribute14" and "Counter34" are updating the above-mentioned elements with the project in progress i.e. the number of projects is progressing now. Finally, the model can experiment with maintenance activities either schedule it after the usage of equipment or schedule it after equipment failure. The failure rate is simulated using an exponential function with a mean of 30 hours as mentioned in the assumptions. The mechanism is shown in Figure 6. This mechanism is working by checking whether the equipment has been utilized, if so, the mechanism is scheduling upcoming maintenance after equipment utilizing hours based on the failure rate.

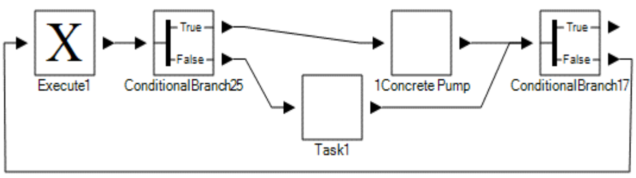

Figure 6 Maintenance at Failure Mechanism

validation and verification

The model is validated by: first, expert opinion that analyzes the structure of the model, variables range, initial conditions, and its behavioral response from a case study. Second, by applying the model on a case of a contracting company deciding on Bid or Not in a mega project of building 100 houses to maximize its profit.

Case study

The case utilized in this paper represents a construction company specialized in building houses of around 2200 square feet (sq ft) with a cost of around $200 per sq ft. The company is facing a decision-making problem in choosing the number of projects to bid on in a new mega project. This project is building 100 houses in a new city and is going to be launched in June 2020 and the government is planning to deliver it in one year. The company has limited resources available for this project and wants to maximize profit. The more assigned and completed projects on schedule and to an acceptable quality, the more profit the company will gain.

The project has some constraints that decide to determine the number of houses the company should bid on more complex than are mentioned previously in the assumptions. In addition, the final design of each house is different from others. While a mock design is available.

Table 1 Company Resources

Equipment	Quantity
FE Loader	2
Grader	2
Steel wheel roller	2
Dozer	2
Excavator	2
Grout Pump	2
Hydraulic crane	2
Concrete pump	2

The model is tested to represent the relations with the fixed durations given from the mock project shown in Table 2. Then the quantities, resources, and cost of resources are estimated using the RSMEANS based on the given fixed duration of each activity. Quantities were back-calculated from durations based on production rates in RSMEANS(2006). These estimated resources, quantities, and costs are utilized in the model. After that, the model is tested to check that duration and budget are mapping the given plan. Finally, Monte Carlo Simulation is utilized in the model to represent the stochastic reality of crew productivity variability and equipment failure.

Table 2 project Work Breakdown Structure

Code	Task Name	Duration	Predecessors
0	Mock project	104 days	
1	Site Work	6 days	
2	Clear Lot	3 days	
3	Rough grade lot	1 day	2
4	Excavate for foundation	2 days	2,3
5	Foundation	19 days	
6	Layout footings	1 day	4
7	Dig Footings & Install Reinforcing	1 day	6
8	Footing Inspection	0 days	7
9	Pour footings	1 day	8

Code	Task Name	Duration	Predecessors
10	Build Block Foundation	15 days	9
11	Foundation Certification	0 days	10
12	Waterproofing and Drain Tile	1 day	11
13	Rough Carpentry	30 days	
14	Set Steel	1 day	12
15	1st Floor Deck Framing	4 days	14
16	1st Floor Wall Framing	4 days	15
17	Set Roof Trusses	2 days	16
18	Frame Roof and instalments	12 days	17
19	Frame Basement and holding blocks	7 days	18,23
20	Concrete Slabs	6 days	
21	Basement Slab Preparation	2 days	15
22	Slab Inspection	1 day	21
23	Pour Basement Slab	1 day	22
24	Prep Garage Slab	1 day	23
25	Pour Garage Slab	1 day	24
26	H.V.A.C.	9 days	25
27	Plumbing Rough-in	8 days	15
28	County Plumbing Rough-in Inspection	0 days	27
29	Electric Rough-in	19 days	18
30	Specialty Rough-ins	5 days	29
31	County Framing Inspection	0 days	30FS+1 day
32	Roofing	8 days	18
33	Insulation	5 days	31
34	Finishing and cleaning	26 days	33
35	Final Building Inspection	0 days	34

Scenarios

The model is built to abstract different scenarios in dealing with upcoming projects to facilitate the decision-making process and maximize the return while experiencing the best utilization of resources. In addition, helps in deciding how many projects the company can manage simultaneously with the same pool of resources. The resources of the company from equipment are modeled to be fixed with quantities mentioned in Table 1. Then four scenarios are simulated. The first one is scheduling maintenance of working equipment after every completed task is done using this equipment with one shift working hours. The second scenario is utilizing overtime when needed to overcome the slippage in the schedule. The third scenario is the maintenance of equipment at failure with one shift of labor working hours. The fourth one is utilizing overtime with maintenance at failure. These different scenarios are tested to get the most profitable policy for the company. Finally, experimenting with the model to get the number of projects that the company can handle using its resources and within the other constraints mentioned before.

Output analysis

The four basic scenarios are utilized first to have a vision of how the project performance will be based on the company management style and productivity of labors. The results of the four scenarios are shown in Table 3. From the results of one run, it`s clear that utilizing maintenance at failure will reduce the cost of the project but on the other hand, it will increase project duration because of progress interruptions due to equipment breakdown. The cost in scheduled maintenance is higher by 11.59% than maintenance at failure in one shift and by taking the overtime effect; it will be still higher but by 5.4%. Time in scheduled maintenance is less by 5.4% than the maintenance at failure, while after taking the effect of overtime the percentage will be reduced to 2.3%. The model is then tested with 1000 runs for the same scenario to get the convergence and confidence of results. The mean result of 1000 runs revealed that applying the strategy of equipment maintenance at breakdowns is increasing the schedule but also, decreasing project cost; the benefit from this strategy is cost reduction. On the other hand, applying overtime to control the schedule slippage will increase the cost but another side is maintaining approximately the same duration of the project. Hence, the company is decided to strictly utilize over time in activities that will face delay more than 20%; also, will utilize maintenance at the failure to benefit from the reduced project time. This strategy is applied considering other constraints and assumptions mentioned above to answer the main question "How many projects could the company bid on to maximize the benefits and best utilization of resources?"

Table 3 Time and Cost of One Project

Scenario	One Project_ One Run		One Project_ One Thousand Run	
	Cost ($)	Time (hour)	Mean Cost ($)	Mean Time (hour)
One shift _ Schedule Maintenance	217,875	999	220,000	998
Overtime _ Schedule Maintenance	233,634	988	235,000	999
One shift _ Maintenance at failure	192,617	1,053	200,000	1,035
Overtime _ Maintenance at failure	219,032	1,016	221,000	1,000

By utilizing what-if scenarios, the first trial was what if the company applied for 40 projects? Is it will possible with the limited equipment? Will enough cash be available to push the project forward?

All trials are illustrated in Figure 7 and Figure 8. By analysis of these results, it is found that for 40, 30, and 20 projects the time to finish these projects will be more than 1920 working hours i.e. more than one year. That violates the government's constraints of delivering the whole project in one year. Then, by analyzing the 10 projects' case, it`s clear that all constraints are met but there is abundance in the time of the project in addition to the waiting time of activities to resources. At the point of 15 projects, the duration is within the limit of one year, but the waiting time has exceeded the limit of one week (40 hours). So, the number of projects decreased to be 14 projects. All conditions are met at the point of 14 projects. Hence, the company can bid on 14 projects to maximize utilization of its resources.

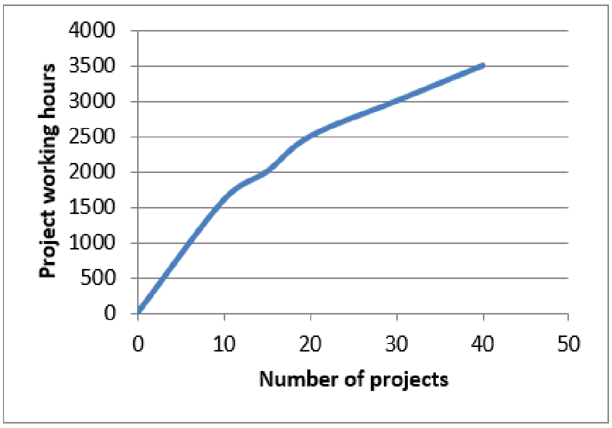

Figure 7 Number of projects with their total hourly durations

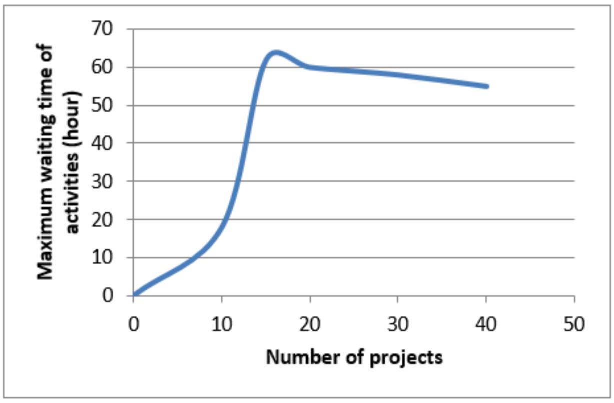

Figure 8 Number of projects with a maximum waiting time of activities for resources

Conclusions

Construction projects are managed in a dynamic environment with nonlinear interrelations between activities and resources. The uncertainties regarding project outcomes increase the complexity of the decision-making process. In such environment, decision-making based on mental models will lack sophistication and will lead to sub-optimal outcomes. Hence, the presented model enables decision-makers to simulate strategic decisions. Results prove that this model helps decision-makers to map their mind and clear their vision to make the best decision within interdependent constraints. Also, the results revealed that the feedbacks from changes in the nonlinear interrelations between activities cannot easily be estimated using traditional tools like the Critical Path Method or Program Evaluation Technique.

On the other hand, this model exhibit limitations such as excluding the competition in the bidding phase that can be eliminated in future researches. In addition, the methodology of DES is limited in representing the full dynamics of construction behavior and would be enhanced by a hybrid DES and continuous simulation. Finally, the limited policies tested are another limitation in this model.

This model could have further improvement by utilizing continuous simulation with DES to fully capture the project behavior, and by utilizing the Markov chain to represent the productivity of crew in different working hours.

References

(2006). Metric Construction Cost Data 64th Edition. Kingston, RSMeans COnstruction Publishers & Consultants.

AbouRizk, S. (2010). "Role of simulation in construction engineering and management." Journal of Construction Engineering and Management 136(10): 1140-1153.

AbouRizk, S. and Y. Mohamed (2002). Optimal construction project planning. Proceedings of the Winter Simulation Conference, IEEE.

AbouRizk, S. M. and D. Hajjar (1998). "A framework for applying simulation in construction." Canadian Journal of Civil Engineering 25(3): 604-617.

Alsaedi, M., S. Assaf, et al. (2019). "Factors affecting contractors' bidding decisions for construction projects in Saudi Arabia." Buildings 9(2): 33.

Bagies, A. and C. Fortune (2006). Bid/no-bid decision modelling for construction projects. Procs 22nd Annual ARCOM Conference, Birmingham.

Hu, D. and Y. Mohamed (2013). Time-stepped, simulation-based scheduling system for large-scale industrial construction projects. 2013 Winter Simulations Conference (WSC), IEEE.

Leśniak, A., D. Kubek, et al. (2018). "Fuzzy AHP application for supporting contractors' bidding decision." Symmetry 10(11): 642.

Matel, E., F. Vahdatikhaki, et al. (2019). "An artificial neural network approach for cost estimation of engineering services." International Journal of Construction Management: 1-14.

Mohamed, E., P. Jafari, et al. (2017). Data-driven simulation-based model for planning roadway operation and maintenance projects. 2017 Winter Simulation Conference (WSC), IEEE.

Namazian, A., S. H. Yakhchali, et al. (2019). "Combining Monte Carlo Simulation and Bayesian Networks Methods for Assessing Completion Time of Projects under Risk." International journal of environmental research and public health 16(24): 5024.

Orozco, F. and A. Serpell (2010). A model at the construction firm level of interrelationships of competitiveness factors and indexes. TG74-Special Track 18th CIB World Building Congress May 2010 Salford, United Kingdom, Citeseer.

Oyeyipo, O., K. T. Odusami, et al. (2016). "Factors affecting contractors' bidding decisions for construction projects in Nigeria." Journal of Construction in Developing Countries 21(2): 21-35.

Peleskei, C. A., V. Dorca, et al. (2015). "Risk Consideration and Cost Estimation in Construction Projects Using Monte Carlo Simulation." Management (18544223) 10(2).

Schriber, T. J., D. T. Brunner, et al. (2013). Inside discrete-event simulation software: how it works and why it matters. 2013 Winter Simulations Conference (WSC), IEEE.

Tan, Y., B. Xue, et al. (2017). "Relationships between main contractors and subcontractors and their impacts on main contractor competitiveness: an empirical study in Hong Kong." Journal of Construction Engineering and Management 143(7): 05017007.