PLANNING MALAYSIA:
Journal of the Malaysian Institute of Planners
VOLUME 22 ISSUE 6 (2024), Page 171 – 182

BUILDING INFORMATION MODELLING AND MONTE CARLO SIMULATION APPLICATION: ENHANCEMENT MITIGATING RISK OF CONTRACTOR'S SELECTION IN THE CONSTRUCTION PROJECT

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Abstract

Low-bid selection can significantly impact construction delivery, leading to delays, substandard quality, and cost overruns if pricing risks are not considered. This research, however, provides a solution that empowers Quantity Surveyors (QS) to act. They can implement BIM to ensure the accuracy of the prepared pre-tender estimate. Furthermore, the application of Monte Carlo (MC) simulation, using probability distribution, can provide a range of tender prices that can be accepted by the client, thereby mitigating the risk of pricing error by the contractor. As demonstrated in this research, the combination of BIM and MC simulation offers a powerful tool for the construction industry. A case study method through document analysis has been chosen to investigate the patterns of tender prices the bidders offer for a bridge construction project. Then, using a pre-tender estimate as a starting point, MC simulates thousands of probable tender prices in a random sequence based on normal distribution. The outcomes indicate that the clients could avoid the high risk of choosing a contractor based on the lowest tender price in a construction project by using Monte Carlo. Therefore, the research shows that applications of Building Information Modelling and Monte Carlo simulation are not just beneficial but crucial for judgment for clients in the construction industry, and it is up to the stakeholders to implement these findings.

Keywords: Building Information Modelling, Monte Carlo Simulation, Estimate, Bid, Risk Evaluation, Case Study

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INTRODUCTION

The main objective of the tender evaluation is to determine the most economical bid to award the most suitable contractor. The importance of averting project implementation failure is due to the contractor's inability to undertake the work given (Halil, 2007). Even though the government has implemented various guidelines, there is currently a limited practical example of how quantity surveyors (QS) can model the accuracy of the tender price offered. In most cases, a bidder can be awarded using traditional evaluation but not perform acceptably well even with the favourable score they received during the tender evaluation process (Chen et al., 2016; Eke, Elgy, & Wedawatta, 2019). In this case, there is a large disparity between the predicted qualified bidder and actual performance.

Building information modelling (BIM) is a comprehensive information management and analysis application that is becoming increasingly essential in the scope of QS services (Halil, 2020). BIM is a process that fundamentally changes the role of computation by creating a database of the building object in the design, construction, operation, and maintenance (Nawari & Kuenstle, 2015). With the BIM application, 3-D measurement is conducted, and the quantity is obtained directly from visual drawings and transferred simultaneously to the Bill of Quantities format. This will significantly reduce the process from taking off, and there is a lesser probability of human error (Suhot, 2023). The quantity extracted from the drawing model is more accurate than the traditional method. In addition, QS can reduce the risk of producing an inaccurate bill of quantities, which might affect contractors' bidding prices and the QS pre-tender estimate (Olatunji & Sher, 2015).

Monte Carlo (MC) simulation predicts the probability of outcomes of an uncertain event and can be used to model the tender prices. Using MC simulation, the clients have an extra precaution to award the lowest tender if the price offered is not within the acceptable range in the simulation (Brokbals, Wapelhorst, & Čadež, 2019). As a cost advisor to the client, this new approach can improve QS cost advice because a reasonable tender price for the construction project can be determined (Traynor & Mahmoodian, 2019). This method can be applied after the tender evaluation procedure has been carried out, especially in the second stage. This ensures the tender price recommendation is according to the market price and QS's pre-tender estimate. Therefore, the MC simulation is crucial in ensuring the awarded contractor can fulfil the client's needs to complete the project according to the current market cost, time, and quality. Therefore, this research intends to model the realistic tender price in the 2nd stage of tender evaluation. This paper presents the MC simulation model that can evaluate the risk of each submitted tender price based on thousands of bid price simulations; thus, a realistic tender price can be proposed.

LITERATURE REVIEW

Quantity Extraction Using Building Information Modelling

With digitalisation technology, physical data in the form of drawings and plans no longer needs to be printed and dispatched to the respective parties. Data sharing that normally took 2 or 3 days would be accessible via email and cloud sharing (Suhot, 2023). This will empower all consultants to provide faster deliverables in terms of design, estimates, Bill of Quantities (BQ), tender documents, etc (Suhot, 2023). Figure 1 shows Building Information Modelling (BIM)'s AutoCAD Drawing and 3-D Model.

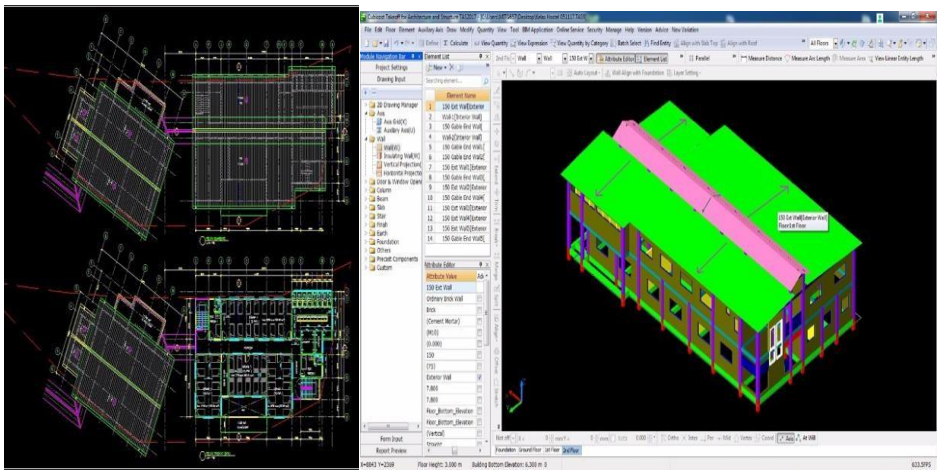

Figure 1: BIM's AutoCAD Drawing and 3-D Model
Source: MiTG (2023)

With digitalisation and 3-D modelling, building components can be rapidly adjusted during the design stage. This will ensure faster cost advice and better value-for-money design for the client. With rapid adjustment and re-use of 3-D models, working intensity is reduced and significantly increased the efficiency of team collaboration (Ali et al., 2018; Nederveen, & Hertogh, 2017). Also, with 3-D modelling, identification of design discrepancies would be easier compared to the current scrutiny of 2-D drawings and will minimise post-contract problems and cost overruns (Honnappa & Padala, 2022). Using BIM, construction quantities can be measured by adhering to the current Standard Methods of Measurement. Several software applications can be used, such as Cubic Cost.

Normally, the BIM applications have a library of descriptions, and the bills of quantities are highly organised and uniform. Depending on the level of

the design phase, the description in the bill quantities can be brief or detailed. During the completion of tender drawings, the description items should be clear and straightforward to understand and this will remove ambiguity and less error in pricing by the contractor (Joe Tidd, 2009; Suhot, 2023). Furthermore, putting the bills of quantities, specifications, and drawing together on one platform by online or physical disk, will reduce errors due to cross-referencing multiple documents currently faced by the contractors (Khosrowshahi & Arayici, 2012). Quantity Surveyor normally measure the cost in the tender price comprising material cost, labour cost, plant cost, overheads, profits and contingencies. All the costs inserted in the bill of quantities should be considered to the current market price. Failure to price according to the current market price would impact the evaluation process either the tender price is accepted or rejected for further process of tender evaluation.

Tender Price

Tender price is a crucial element for the Quantity Surveyor to evaluate in the bidding process. This price is submitted as part of a competitive bidding process, known as tender (Kissi, 2017; Halil, 2007). The tender price is a key factor the clients consider when selecting the winning bid. Kissi (2017) argues that price is a vital variable to consider by the client such as profitability, market condition, product and quality.

Lowest Tender Price VS Lowest Tender Price from the Competitive Tender Price

The lowest tender price always becomes a debate in the construction sector. Most of the researchers revealed that selecting the contractor from the lowest tender contribute to the project delay and cost overrun. Understanding how the Quantity Surveyor selects the contractor in the construction project is crucial. Normally, Quantity Surveyor will recommend to the client a suitable contractor based on the lowest tender price offered by the contractor from the competitive price. The competitive price was determined after the process of tender evaluation process. Public Work Department in Malaysia exercises a good approach in the tender evaluation process to determine a suitable competitive tender price using the cut-off method (Halil, 2007). Through normal distribution curve, outliers that offer the tender price too low and too high will be removed for further evaluation. From this stage, the bidders failed to produce a reasonable tender offer based on the current market price. Therefore, the price recommended to the client is normally the lowest from the competitive tender price. The research was conducted to identify which range of competitive tender prices the client will award the project to the bidders. Monte Carlo will guide the client on which tender price should be awarded to the contractor. Therefore, it will guide the client on which tender price should be awarded to an appropriate contractor in the construction project.

Predicting Tender Prices using Monte Carlo Simulation

Monte Carlo Simulation is a statistical technique that generates random variables for modelling risk or uncertainty in the research (Brokbals et al., 2019). This technique suits and benefits various clients, such as the public and private sector, in evaluating a realistic budget for the proposed project (Halil et al. 2020). The Monte Carlo technique is simply a way of sampling from a distribution to provide a range of solutions that QS can use to advise the client. In this case, it provides the forecast of cost for the sample it has chosen (Shaffie & Jaaman, 2016). During the evaluation phase, Monte Carlo simulation techniques can determine an appropriate tender price for the proposed project. Even though tender evaluation exercises in the federal government department may use the "cut-off method" known as the less-than-average bid method in the academic (Awwad & Ammoury, 2019), this paper proposes another approach using Monte Carlo, which is crucial for decision-making for tender selection during the pre-contract stage.

Applying the Monte Carlo simulation, the client and QS can justify the project tender price based on the identified risk in selecting an appropriate contractor. This ensures that the right price contractor will be selected accordingly and recommended to the client in the tender report. In this case, MC simulation can solve incomplete information using the probability function, allowing decision-makers to understand better risk and uncertainty (Shaffie & Jaaman, 2016). Therefore, by using Monte Carlo, the contractor's incompetence in the construction project could be avoided by the client. In addition, the client could avoid the risk of selecting an inaccurate tender price for their construction project. The benefits of BIM and MC simulation are crucial in the tendering phase, ensuring accuracy on the quantity take-off and predicting the tender price for the construction project. Therefore, decision-making to select an appropriate contractor at a reasonable cost for construction projects can be obtained (Halil et al., 2022).

Selection of Tenderers

In the construction industry, tender selection is a process of selecting a contractor from a list of several tenderers in whom the employer has the confidence to execute the construction contract based on the following criteria (Halil, 2007);

a. A competitive tender price,
b. Suitable construction period,
c. Experience track record,
d. Financial commitment,
e. Technical knowledge.

In recommending a contractor, QS must consider the employer satisfaction requirement, namely, procuring the highest quality construction product and the best value for money (Eke et al., 2019). Based on the above explanation, BIM and Monte Carlo Simulation employed by QS will reduce the inappropriate selection of contractors for construction projects. Regarding accuracy, quantity, and price, BIM and Monte Carlo simulation can simulate the decision-making process for clients and QS at the tendering stage. Therefore, the risk of the client appointing an inappropriate contractor and the mistake of quantity calculation in the tender document could be avoided by using these software applications in construction projects.

Risk Evaluation During Process of Decision-making

During the tender evaluation, choosing the right contractor is crucial to be awarded in the construction project. Therefore, the recommended list of contractors is crucial for the client. Explicitly considering risk during tender evaluation is crucial for the client to select the best price for the contractor. By using MC, the best price for the tender awarded is forecasted. Samuel (2013) mentioned in his research that a rigorous methodology is based on key performance indicators and risk analysis for predicting the significant potential contract risks at the tender evaluation stage. A final bidder is selected for the award based on the lowest risk rather than the lowest tender price.

Using MC simulation, a probabilistic model can predict the significant potential contract risks at the tender evaluation stage (Brokbals et al., 2019). A better and more reliable system of tender evaluation is needed to predict the future performance of an awarded contractor, theoretically reducing risk, time, cost overruns, and quality defects.

RESEARCH METHOD

In this research, the method adopted is a case study approach. Creswell and Creswell (2018) describe the approach as exploring events that have occurred in the past. The selected case-study project is 'Bridge Construction', a bridge construction located in Selangor. However, the project's full name is not revealed for confidential reasons. The authors have investigated the pattern of tender prices from the project document. The document analysis for a case study should not be underestimated because it provides accurate information which cannot be collected through observations and interviews (Piaw, 2012). The following are the steps of the method adopted;

1. Compute the initial investigation (Document Analysis).
2. Determine correlations.
    a. Between Estimate Line Items
    b. Between Risk Drivers
    c. Between line items and risks
3. Build a model.
4. Run MC Simulation.
5. Analyse the result.

The availability of sufficiently large data plays a significant role in correctly determining the most suitable forecasting techniques. A major advantage associated with large data collection is the ability to provide the forecaster with a fairly large selection of forecasting techniques (Lazim, 2020).

This study's MC simulation predicts the estimated range and gives confidence for the project development (Halil et al., 2020). The analysis of the tender price pattern was explored to determine an appropriate tender price for the contractor award in the construction project.

RESULTS AND DISCUSSION

This project uses open tendering. A total of thirty (30) numbers of contractors participated in this tender. After the process of tender evaluation, only eight (8) contractors are recommended to the client. The process of tender evaluation using the cut-off method. Halil (2007) describes the cut-off method implemented by Public Works Department as a tool to analyse the tender price according to deviation from the mean weighted by 1.18. The formula for the cut-off method (1) is as follows:

$$cut\ off\ price = Mean - 1.18 * \text{Standard deviation}$$

$$= \frac{1}{2}\sum_{i=1}^{n} x_i - \left\{1.18 * \left[\frac{1}{N-1}\sum_{i=1}^{n}(x_i - \bar{x})^2\right]^{\frac{1}{2}}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Table 1 shows the list of the final recommended tenderers and their prices based on the case study.

Table 1: The list of the sampling

List of Contractors	Tender Price (MYR)
A	24,600,000.00
B	24,668,232.00
C	25,978,855.00
D	26,351,000.00
E	27,158,693.00
F	27,376,572.00
G	27,523,794.00
H	28,000,000.00

Source: Authors (2024)

From the above Table 1, the critical question is how to identify the best tender price from eight (8) contractors proposed to the client? Here, MC can help the final decision-making process for the client, to identify the best tender prices. In this case, the analysis was carried out using an MC simulation to identify the possible range of tender prices.

i) A sample of one

The sample of tender price data is evaluated, and an attempt should be made to imagine the distribution of the parent population to get an idea of the price from the sample population. The estimated price could have come from anywhere in the distribution of the parent population. The sample mean provides evidence concerning the value of a population mean based on (2). In this case, the population mean can be assumed to follow normal distribution as an approximation. However, a few other distributions can be used, such as Weilbul, Lognormal and Gamma (Ballesteros-Pérez et al., 2021). In this study, it is assumed that the sampling distribution of the sample mean is a normal distribution for samples (any size) drawn from a normal population and is approximately normal for large samples drawn from any population. The sampling distribution has a formula as follows;

$$mean\ sample = \mu\bar{x} = \mu \quad \text{..... (2)}$$

$$sample\ variance = \sigma\bar{x} = \frac{\sigma}{\sqrt{n}} \quad \text{..... (3)}$$

Where:
μ and σ = the mean and variance of the population from which random n samples are generated.

Under the critical value approach, the significance level α is predetermined. The value of α corresponds to the total area of the critical region. In this case, it can be the other region of confidence interval (95%), which may decide the minimum and maximum value of the tender price range.

ii) Result

The result shown in Figure 2 indicates 1000 trials = n random samples using MC simulation to forecast the most appropriate tender prices that can be considered by the client. Table 2 shows the most suitable tender price at RM26,254,635.04, assuming the average price is the equilibrium market price. However, the range of competitive tender prices of RM 23.38 million (minimum) to 29.34 million (maximum), the client can be advised of the decision - based on the result indicated by the MC simulation. There will be a risk for the client if choosing a price below or higher than the confidence level. Using MC, the client can evaluate the best tender price that should be awarded to the contractor in the construction project. Samuel (2013) indicates that awarding contracts solely on the lowest price could lead to the overall project risk while selecting a price higher than the limit may affect the client's budget. Therefore, MC guides the client in identifying the best tender price from the final list of contractors in the construction project (Brokbals et al., 2019).

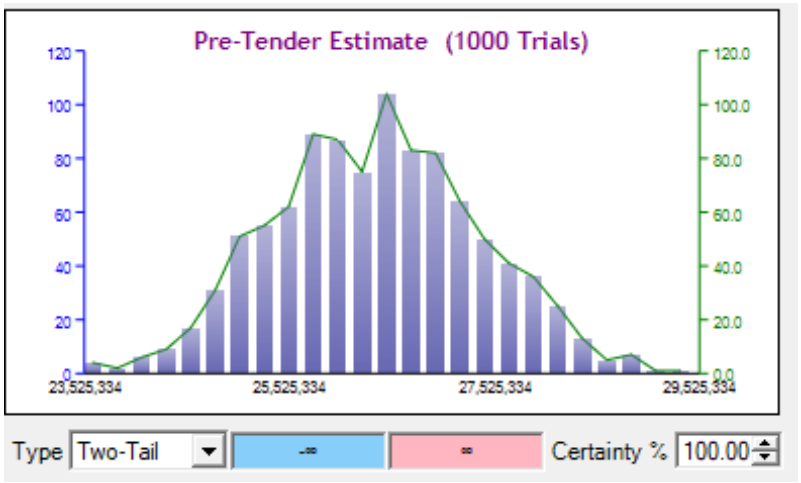

Figure 2: The distribution of the MC simulation
Source: Authors (2024)

Table 2: The outputs of the MC simulation

Statistics	Result
Number of Trials	1000
Mean	26,254,635.0360
Median	26,269,281.0679
Standard Deviation	991,375.2618
Variance	982,824,909,680.4960
Coefficient of Variation	0.0378
Maximum	29,338,444.9742
Minimum	23,370,158.4235
Range	5,968,286.5507
Skewness	0.0574
Kurtosis	-0.2450

Source: Authors (2024)

CONCLUSION

The finding reveals that selection and risk identification using Monte Carlo simulation establishes the best price offered evaluated and the confidence price level. Therefore, risky decision-making can be avoided when selecting the lowest or highest bidder. Preparing tender estimates using BIM and tender evaluation analysis with Monte Carlo simulation is crucial for the Quantity Surveyor and client in construction projects. During the tender evaluation process, the price is the primary factor of influence in the contract award. In this case, the evaluation of tender price risk, which is through MC simulation, is crucial. Building Information Modelling can measure the quantity of construction work accurately. Meanwhile, Monte Carlo Simulation can simulate the price range, which equates to the risk of the tender price selection during the process of tender evaluation exercise at the pre-tender stage. Innovation in Building Innovation Modelling and Monte Carlo simulation offer the best practices when providing the Quantity Surveyor's scope of services. From the study, turning risk into opportunity relies on an analytical method. Monte Carlo simulation can fulfil a key role in increasing the quality of decision–making and help the client make better decisions to award the project to the contractor in the construction project.

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Received: 21st June 2024. Accepted: 10th September 2024

