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CONSTRUCTION COST OVERRUN RISK ANALYSIS USING MONTE CARLO SIMULATION TECHNIQUE: CASE OF A SIX-STOREY OFFICE BUILDING IN THAILAND

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ABSTRACT

This study aimed to analyze construction cost overrun risks related to design guidelines to prevent possible risks. Construction cost overrun risk in six-storey office building construction projects was emphasized. This research mainly aimed to analyze the construction budget risks from the variance in material costs and wages using the Monte Carlo Simulation technique. This research considered four categories of variables, consisting of the cement price index, steel price index, other material price index (except cement and steel), and consumer price index of Thailand, over 60 months from November 2014 until October 2019, with reference to the Thai Ministry of Commerce. The results showed that the construction cost overruns of a six-storey office building construction with a budget of 248 million Baht was equivalent to 4%, which meant that the risk was equal to 9.9 million Baht. The overall result from this research could assist developers as a reference for project budget management to manage the projects' financial risk, and developers or designers could cite the data for material proportion design to minimize the project construction cost risk.

Disciplinary: Civil Engineering (Construction Project Management).

1. INTRODUCTION

The construction sector is continuously growing, and it is considered as an important strategic industry that drives Thailand's economy and society. The keys to a good construction project are cost, time, and quality. One important factor is "construction cost", which drives the construction project to success or failure (Afzal et al., 2018). Good and accurate cost planning will lead to smooth project management during the construction period (Cho et al., 2010; Shi et al., 2014). Otherwise, if the cost management plan is mistaken, it may result in the project being at risk of

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construction cost overruns from the anticipated budget, which may lead to many problems. Thus, construction cost overrun risk analysis is a method that helps to analyze the risk possibilities, occurred with projects for decision making and reserve planning in case of exceeding the construction budget so the project can be completed (Memon et al., 2011; Sovacool et al., 2014).

Cost overruns are the extra expenses from the anticipated construction budget, which can be due to various factors, including

- Inadequate structure management, which means some parts of the work are missed resulting in a false prediction that leads to a lower budget than needed.
- Lack of clear budget framework for each contract which can lead to uncontrollable costs in alignment with reality.
- Delay of a project which may be caused by changes in construction and installation plan, resulting in increased expenses.
- Change in material price and wage which varies due to economic conditions that affect the costs and profits of the project.
- Bringing new technologies into construction work to improve the quality, resulting in higher costs.
- Unexpected incidents, such as disasters, which cause project disruption resulting in delays and more expenses.

Moreover, Tammahagin (2011) and Yiangyong & Tochaiwat (2014) presented that cost overrun risks in the Thai building construction industry mostly were relevant to the variance in the material price and wages, which will be the main content of this study. To represent one of the main commercial buildings in Thailand's market, a six-storey office building (Figure 1) was chosen as a sample to prove the procedures and appropriate methods in construction cost overrun risk analysis from the variance of the material price and wages.

2. LITERATURE REVIEW

To gain an overall understanding of the theories and principles used in the study, the literature review, therefore, consists of contents related to the material price index and Monte Carlo Simulation (MCS) technique as follows.

2.1 MATERIAL PRICE INDEX

The material price index of this research could be divided into four categories

1. **Cement price index (C)** is the price of products made from cement, consisting of the foundation pile, reinforced concrete, concrete floor, concrete beam, concrete block, rough concrete, concrete paver block, Portland cement, mixed cement, and masonry cement, etc.
2. **Steel price and product index (S)** is the price of all kinds of steel used in construction, consisting of steel bars, deformed bars, round steel, wires used for binding steel, angle steel, and steel pipes, etc.
3. **Material price index (M)** is the price of other construction materials that are non-cement or steel, including all other materials used for construction, consisting of wood, electrical equipment, plumbing, sanitary ware, plastering materials, tiles, and other construction materials.

4. **Consumer price index (I)** is the index illustrating the changes in products and services, which include increased wages and salaries in line with rising product and service prices as wages and salaries affect decisions related to purchasing goods and services. Thus, the consumer price index of the country is set as a representative of the labor cost in this research.

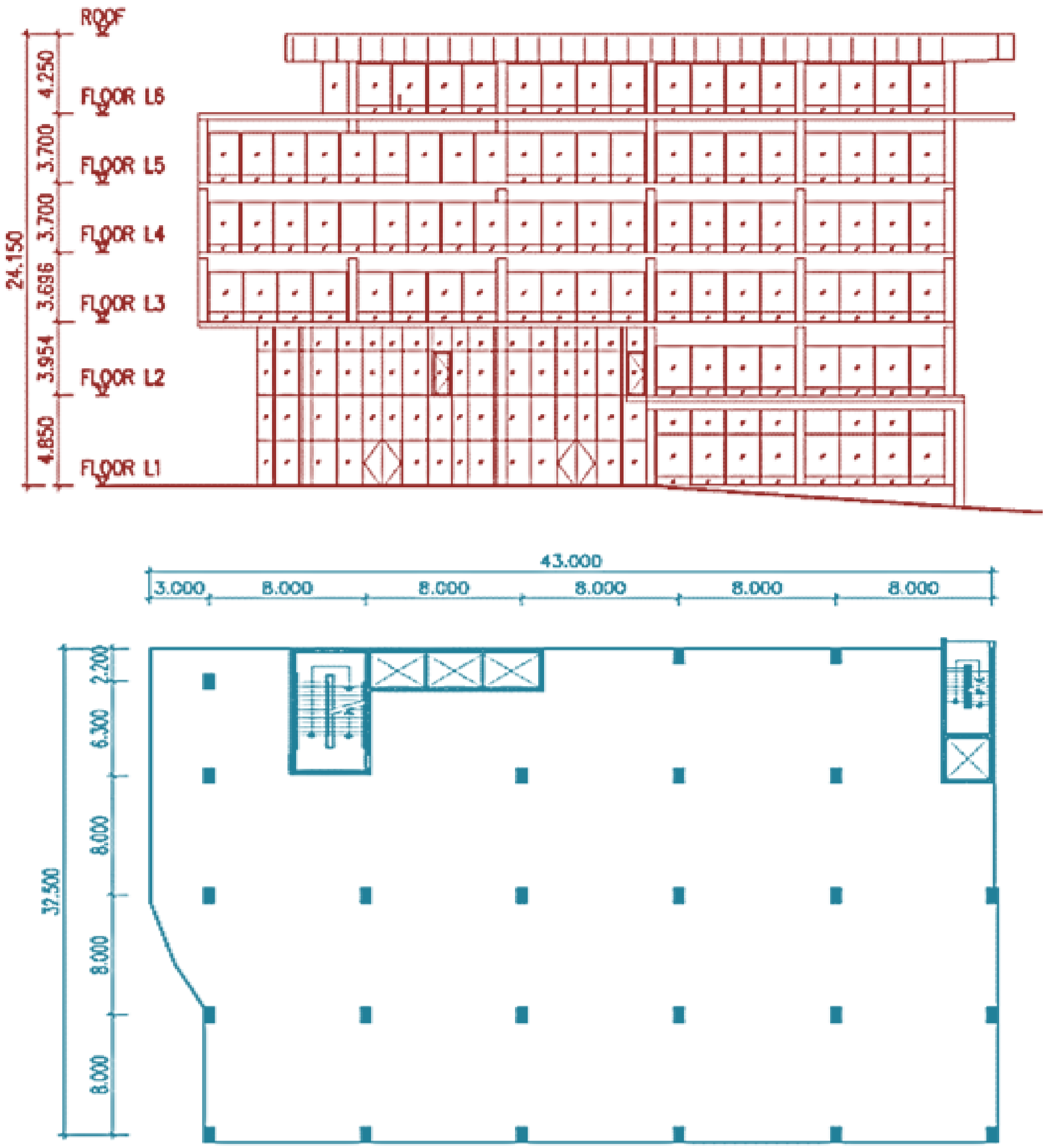


Figure 1: Floor plan and side of building (a) Elevation, (b) Typical Floor Plan

2.2 MONTE CARLO SIMULATION (MCS) TECHNIQUE

The Monte Carlo Simulation (MCS) technique is a popular tool and an essential technique in risk or uncertain incident analysis. This method creates project patterns or policies via computer analysis and then examines the results' probability of obtaining the various variables that are changing at the same time. Generally, probability analysis is a highly effective tool for research or project problem investigation, which does not only have a single solution; however, the randomization of the MCS pattern is also considered another easy-to-use format for probability analysis. This analysis can present the results of risks and uncertainties, which can be explained by the probability distribution. This also includes the use of MCS in construction risk analysis or possibilities in investment decisions (Ahiaga-Dagbui & Smith, 2014; Chang & Ko, 2017).

MCS is defined as a procedure for obtaining an approximate numerical solution using a random set of numbers. It is a coherent estimation of random variables with a known distribution, but the results are too complex to be determined by mathematical methods. Random numbers in many cases are generated by a computer program in accordance with the distribution of the possible assumptions of variances and repeated calculations through the pattern until the form of the distribution is the result. Most of the possibility analysis simulation is to explain if every event can be as described by three characteristics: 1) Optimistic, 2) Pessimistic and 3) Most likely (Mooney, 1997). The MCS procedures can be summarized as follows:

1. Define variances in situation simulation, objectives, and validation of results obtained from the simulation.
2. Anticipate the distribution pattern of the variables in the situation simulation by assigning it to the actual distribution of the data sets (custom distribution).
3. Create random data from a set of variances to simulate situations from forecasting the probability of the data distribution.
4. Calculate the result from the set of variances using the method in 3.
5. Repeat the calculations in steps 3 and 4, at least 1,000 times.
6. Present the results of the data obtained from the calculation via graphs or diagrams showing the probability distribution.

Results from the simulation can be shown in graphs or diagrams illustrating the probability distribution according to the result examination set initially (Nakaya, 1999).

3. METHOD

The research methodology consisted of four procedures: principles/tools, data, expected results, and analysis methods as shown in Table 1.

Table 1: Research procedure

Procedures	Principles/tools	Data	Expected Results	Analysis of Procedures
1. Bill of Quantities (BOQ) analysis of 6-story office building	Material Check Form	Cost and proportion analysis of materials in various categories	List and expense proportion for each category of work in project	Analyze the expenses by category
2. Variance analysis of building material price index in four categories	Principles of Variance Analysis	Changes in the material price index in four categories for 60 months	The variance of each category	Analyze the variance
3. Analysis of initial variable distribution	A computer program called ModelRisk	Distribution of four categories of the material price index for 60 months	Distribution of each category	Analyze the distribution
4. Analysis of Construction Cost Overruns Risk	A computer program called ModelRisk	Simulation of the variance of material price index affecting project	Risks of construction cost overruns for six-storey office building project	Monte Carlo Simulation

The data in Table 1 can be explained in detail via the following procedures:

Procedure1 - BOQ analysis of the six-story office building project by dividing the cost of each job category, which was divided into four categories:

concrete, steel, other construction materials (excluding concrete and steel), and wages.

Procedure2 - Variance analysis of construction material price index in four categories by analyzing the variance from November 2014to October 2019 (Bureau of Trade and Economic Indices, 2020).

Procedure3 - Distribution pattern analysis of the initial variables using the ModelRisk program as a tool to help analyze the distribution pattern that is the most suitable for the data set (Habibi, 2017; Vose, 2010).

Procedure 4 - Construction cost overruns risk analysis using MCS via ModelRisk to analyze the relation between construction cost overrun risk and variance of the material price index for both project overall and classified work categories (Habibi, 2017).

4. RESULT AND DISCUSSION

Regarding the data collected from the BOQ of six-storey office building in Bangkok, the results could be divided into three issues.

4.1 BILL OF QUANTITIES OF 6-STOREY OFFICE BUILDING

For the BOQ of the six-storey office building project, the researcher performed the analysis by dividing the construction cost into four categories.

Table 2: List and expense proportion for each category

Categories	Concrete (C)	Steel (S)	Materials (M)	Labor (I)	Total Cost
Amount (Baht)	18,184,607.20	14,209,711.57	170,470,371.61	45,117,700.28	247,982,390.66
Percent	7 %	6 %	69 %	18 %	100 %

The analysis result obtained from dividing the construction cost into each work category was to consider the variance of the construction cost for only four variables by referring to the calculation formula of the Escalation Factor (K) of the construction work (Chooprasit, 2001; Jaruwanno, 2011). The work categories were concrete, steel, other materials (excluding concrete and steel), and wages. For the concrete and steel categories, only expenses related to the project were considered. All other materials were classified into the other material category. The analysis result of the BOQ of the six-storey office building project consisted of a list and expense proportion as shown in Table 2, presenting the changes in the construction proportion of each category when changes in the material price occurred, which could lead to construction cost overruns.

4.2 VARIANCE IN MATERIAL PRICE INDEX IN FOUR CATEGORIES

For the study of the material price variances, the researcher cited the material price index from the Ministry of Commerce by collecting data from November 2014 until October 2019 for 60 months. The variance in the material price index that could affect the project is shown in Figure 2.

Regarding the variance result analysis, it was found that the category with the highest variance was steel, while the secondary was concrete. If the variance was considered, the procurement of such materials might be emphasized and prioritized by the risk management over other types. Additionally, when considering the material proportion of each category shown in Table 2, it was found that the proportions of the steel and concrete categories were not as much as the other categories. After many irritations of the MCS, the risk analysis outcome was more accurate, resulting in the ability to effectively control the material prices.

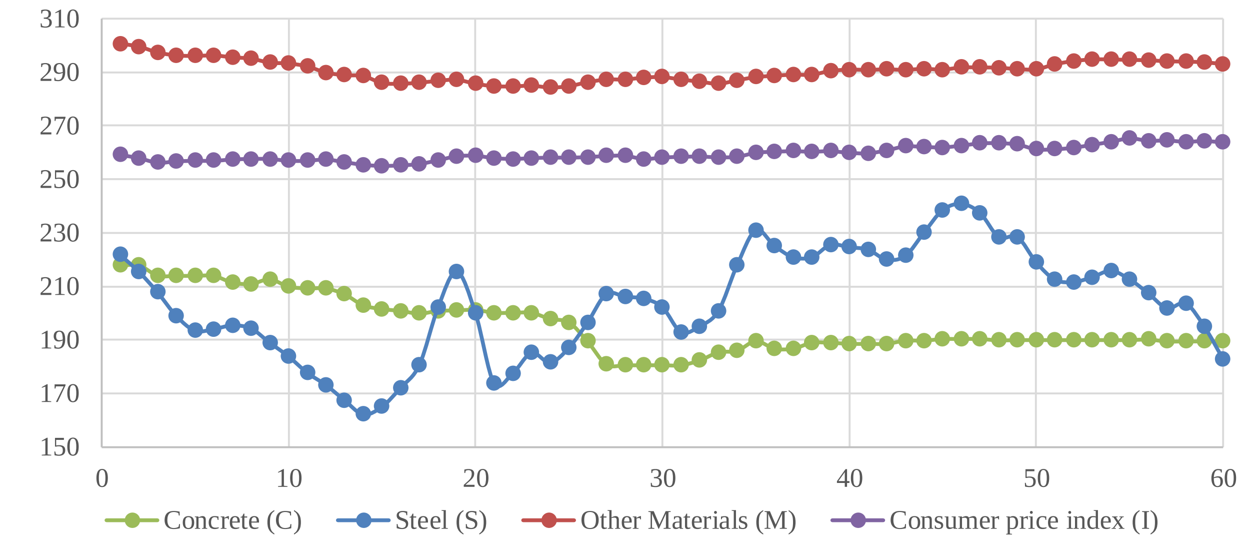


Figure 2: Variances in material price indexes 60 months (November 2014 to October 2019), with October 2019 set as the base.

4.3 DISTRIBUTION PATTERN OF INITIAL VARIABLES

The distribution pattern of the initial variables was obtained using data from the change in the material price index from the Ministry of Commerce over the past 60 months. After that, the distribution pattern comparison process was utilized through VOSE ModelRisk as a user interface. The program displayed possible distribution patterns of the data set as shown in Figure 3.

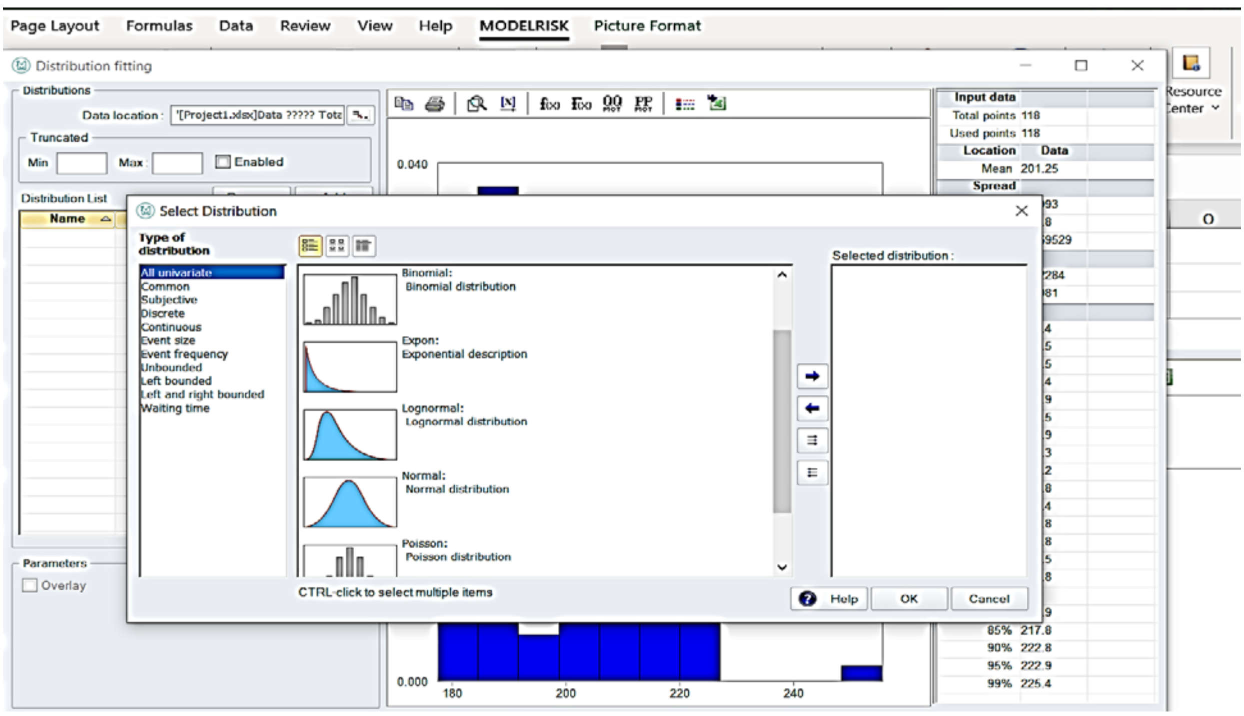
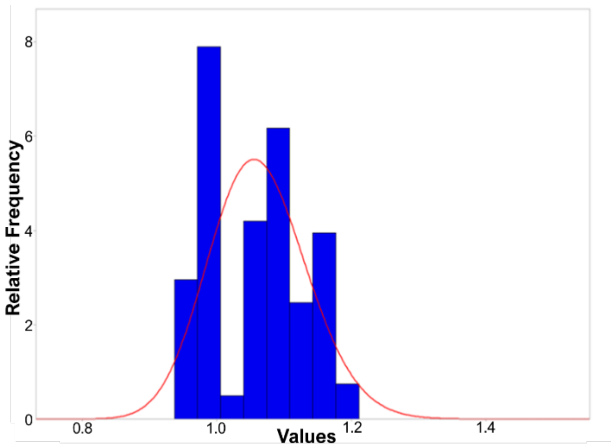
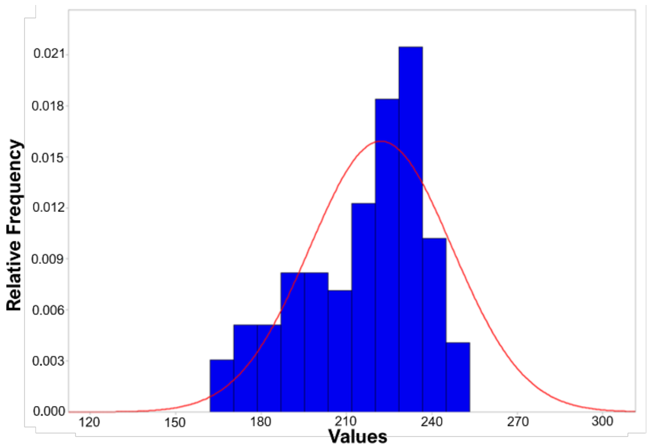


Figure 3: The user interface of distribution pattern comparison for the data set.

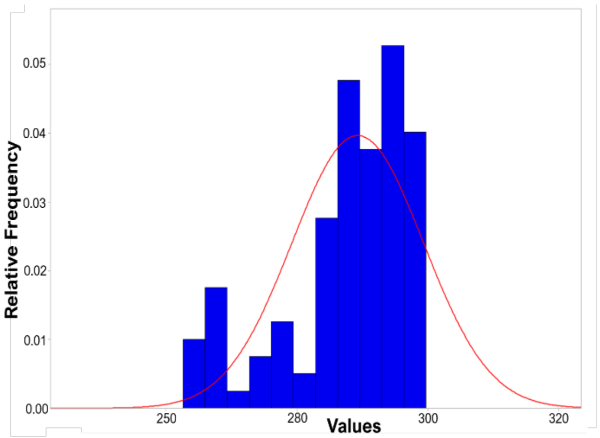
Figure 3 presents the user interface of the distribution pattern comparison of the possible set of data selected by the program. The suitability of the data presentation was not equal. Therefore, the program processed the set of data and possible distribution patterns to find the most suitable pattern by sorting the most appropriate patterns from top to bottom. The distribution pattern of the initial variables processed by ModelRisk for the cement price index distribution was a log-normal distribution, while the pattern of the steel price index, index distribution, and distribution pattern of the consumer price index of the country had normal distributions, as shown in Figure 4.



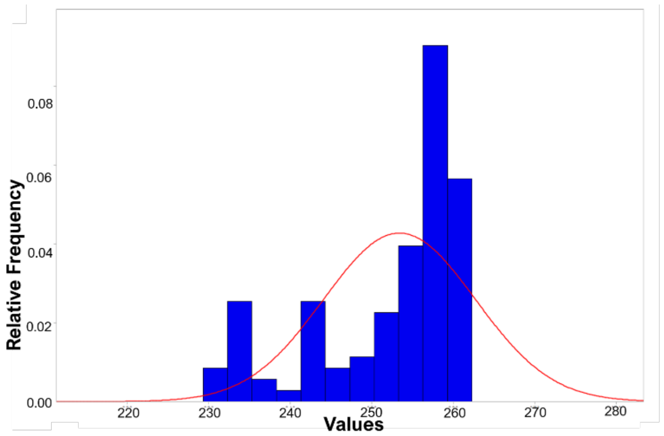
Log-normal distribution pattern of the cement price index



b) Normal distribution pattern of the steel price index



Normal distribution pattern of the material price index



Normal distribution pattern of the consumer price index

Figure 4: Distribution patterns of four categories price index

The processing of the ModelRisk helped to quickly identify the most suitable distribution pattern through the Fit Model system, which was very useful when compared to the analysis by continuously sampling the distribution pattern to find the most suitable pattern for the data. Obtaining the appropriate distribution pattern could reduce errors or deviations in the analysis results and increase the accuracy of the simulation so that the risk analysis results for the construction cost overrun were most precise since the different patterns of the results from the MCS method were dissimilar and might lead to incorrect risk analysis results.

Regarding the distribution pattern analysis of the four variables, there were two patterns: normal distribution and log-normal distribution. The distribution pattern of the initial variables had

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different monthly price index data, which caused the histogram to collect data for each category with different shapes. However, when the distribution pattern was considered, some work categories also had the same distribution pattern relatedness. The distribution pattern of each index was connected to the probability simulation process. After 1,000 randomization irritations, the set of the data was chosen at random by the analysis assistance program following the distribution of the analyzed data. The random results depended on the distribution pattern of the initial variables in each work category and addressed the analysis using the ModelRisk as an analysis tool.

4.4 CONSTRUCTION COST OVERRUN RISK FOR SIX-STOREY OFFICE BUILDING

The program displayed possible distribution patterns of the data set as shown in Figure 3. The analysis of the construction cost overrun risk for the project was the result of the comparison between the altered material price for the project and the construction budget, and the possible risk is simulated via the MCS method and construction budget of the project. The variances for all four material price indexes for 60 months period were the initial variables for the probability simulation. The variance of the material price index was set according to the distribution pattern analyzed via the ModelRisk to obtain the overrun cost for the six-storey office building project, and the program matched them randomly according to the number of rounds specified. The changes in the total construction cost and continuous change in each category could be seen according to the constants of the categories, which increased and decreased from the original construction budget. This research was randomized 10,000 times, and the analysis results are shown in Figure 5.

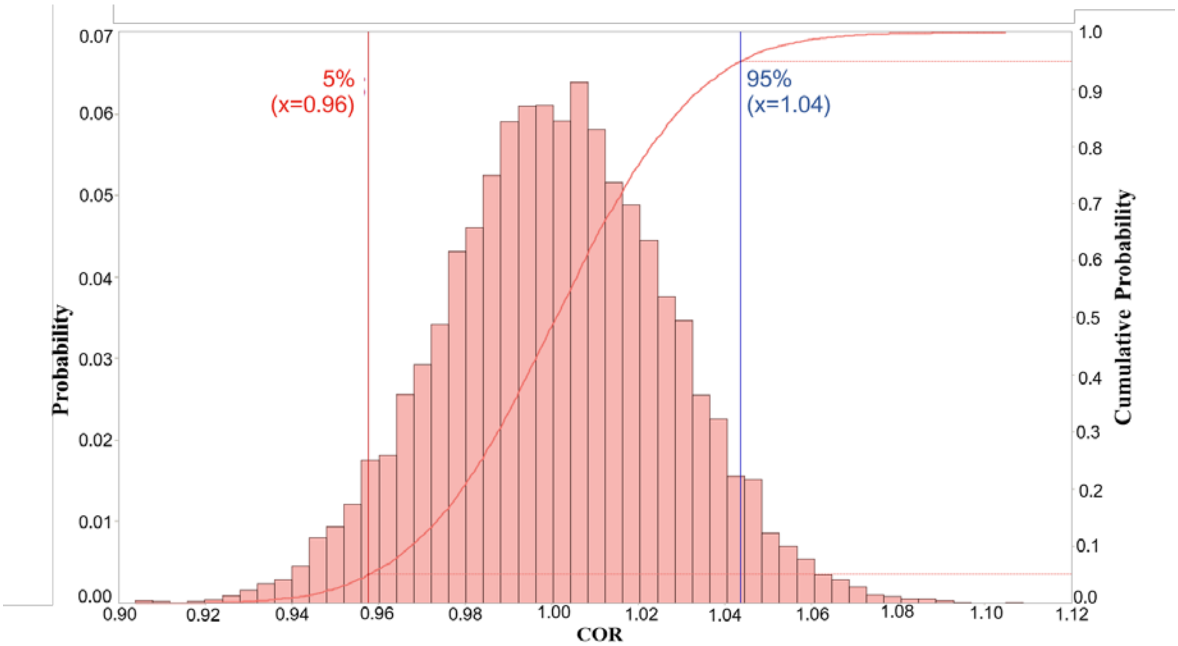

Figure 5: Cumulative frequency and simulation histogram

According to Figure 5 and the analysis of each category, it was found that the price variance in Thailand was quite large, which directly affected the project budget. It was also found that the overrun of the budget at the optimistic 95th percentile was equal to 1.04, representing 4%, which meant that the risk value is 9,919,295 Baht. Therefore, the results did not only reflect that the material price variances and wages were important to the construction of the building, but it also showed methods for risk analysis used as a practical guideline for further projects in the future.

4.5 DISCUSSION

The construction cost overrun risk analysis for the six-storey office building through Monte Carlo Simulation using ModelRisk helped in the analysis of the material variance factors and wages based on data from the variance in the history of the price index over the past 60 months. It was found that after 10,000 rounds of simulation, the total construction cost of the project was 247,982,390 Baht. The most likely variance in the material price index for the overrun cost was 1.04, reflecting an allowance at 4%, which meant, the construction cost overrun risk value was 9,919,295 Baht. However, when comparing the result to Tammahagin (2011), in which the cost overrun risk value for a 23-storey condominium was 6%, the 2% difference in the correction (COR) values could be due to different building categories, office building and residential building as these have dissimilar components, for example, the number of bathrooms per building area or passenger lifts. Besides, the difference in the height certainly affected the unequal composition of the material and construction cost proportion. Nevertheless, a 2% difference was not a large difference, and preliminary analysis could be performed to reveal that the study results reflected an appropriate method for an efficient analytical process.

However, the construction cost overrun risk analysis was beneficial for the best budget management to allocate the budget to cover all possible risks for all factors that could cause the cost overruns, which are similar to the results of Yiangyong & Tochaiwat (2014). Nevertheless, if the factors affecting the construction costs could be increased, such as inadequate structure management, the lack of a clear budget framework for each contract, could lead to delays, bringing new technologies to construction and unexpected incidents, the construction cost risks, which could be more accurately analyzed (Aziz et al., 2013; Vu et al., 2016).

5. CONCLUSION

This study has analyzed the construction cost overrun risk for a six-storey office building construction project, using construction budget risks from the variance in material costs and wages via the Monte Carlo Simulation technique. This study focuses on four variables, including the cement price index, steel price index, other material price index (except cement and steel), and consumer price index of Thailand, over 60 months from 2014-2019, announced by the Thai Ministry of Commerce. The results showed that for the case study of a six-storey office building with a budget of 248 million Baht, the construction cost overruns was 4%, equaling risk 9.9 million Baht. The overall result from this research is useful for developers as a reference for project budget management to manage the projects' financial risk, and developers or designers could cite the data for material proportion design to minimize the project construction cost risk.

6. AVAILABILITY OF DATA AND MATERIAL

Data can be made available by contacting the corresponding author.

7. ACKNOWLEDGEMENT

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8. AUTHOR RESPONSIBILITIES

Damrongsak Rinchumphu conceived and planned the experiments. Chonticha Karnjanamukdar and Kasina Uboncharoen carried out the experiments and contributed to sample preparation. Damrongsak Rinchumphu, Chonticha Karnjanamukdar, and Kasina Uboncharoen and Wacharapong Prasarnklieo contributed to the interpretation of the results. Damrongsak Rinchumphu took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis, and manuscript.

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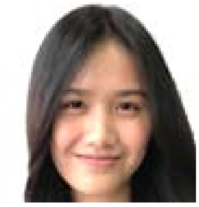

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