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Research Article

Monte Carlo Mathematical Model Simulation: An Evaluation of The Probability of Construction Project Acceleration

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Abstract
Complex projects such as road infrastructure require reliability and risk analysis for safety and economic sustainability. This study divides the concept of comprehensive risk identification into several variables with several indicators. Indicators refer to findings that occur in the field during acceleration. The simulation was conducted with the help of the @Risk program in Microsoft Excel using standard settings, and the distribution used was triangular. The population in this study is all project stakeholders related to determining the implementation time of the Djuanda FO construction, which is currently underway in the 46th week. The population consisted of 22 experts who were involved in scheduling the FO Djuanda construction project. Since the population size is limited in the study, all population members were sampled. The sampling technique is census or saturated sampling, in which all population members are used as samples. The respondents asked to complete a questionnaire and answer questions about implementing the FO Djuanda development project. Sampling is limited to top management with expertise in decision-making to determine the duration of project implementation in scheduling. This study obtained interval data, with interval data in the form of a Likert scale (scale 1–5). Based on the research results, risk evaluation can be adopted well through Monte Carlo mathematical model simulation. The risks in the acceleration of the FO Djuanda development project, based on the order of risk levels from the largest to the smallest, are direct costs, work calendar schedule, logistics, external, field constraints, health and safety, indirect costs, community relations, environment, construction contracts, traffic, and construction.

Keywords: Monte Carlo simulation, the Djuanda flyover construction, probability, project acceleration

1. INTRODUCTION

Congestion is a problem that arises due to population growth and density [1]. The high population growth and density usually experienced by developing countries such as Indonesia and it often cause traffic jams. According to official data from the Central Statistics Agency (BPS) in 2023, the population of Indonesia reached 277,534,122 people. A country's population will generally be directly proportional to the number of vehicles circulating in the community, such as data published by BPS that the number of cars in Indonesia in 2023 was 152,565,905. Regarding distribution, Java Island is the most significant contributor to the number of vehicles. The number of motorized vehicle owners is 92,036,868 units or 59.67% of the total number of national motorized vehicles. Meanwhile, the number of cars owned by people in East Java is 19,382,263 vehicles. The construction of the Djuanda Flyover (FO) in Sidoarjo is a synergistic effort between the local government and the PUPR. Ministry to overcome congestion on the Surabaya-Sidoarjo route.

This construction is carried out on a railroad crossing, one of the congestion points. The local government is responsible for land acquisition, while the National Road Implementation Center (BBPJN) is responsible for building the FO structure. This development is expected to improve traffic flow while considering quality, budget, and time. The construction of FO Djuanda is included in the National Strategic Project (PSN) as stated in Presidential Decree No. 80 of 2019. However, due to the COVID-19 pandemic, the 2019 PSN project was delayed and only started to be worked on by the Java-Bali BBPJN under the PUPR Ministry at the end of 2022. The construction of FO Djuanda has a total bridge length of 858 m, consisting of FO A (Sidoarjo-Djuanda) with a height of 435 m and FO B (Djuanda-Surabaya) with a length of 423 m. FO Djuanda has a bridge width of 9 m with 2 lanes, each 3.5 m, a road shoulder, and a parapet as protection. The total cost of building this FO project reached IDR 332 billion. Work began on November 1st 2022 and is targeted to be completed on April 22nd 2024.

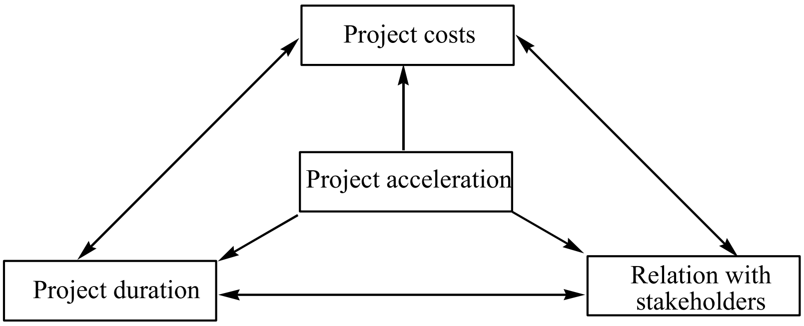


Figure 1. Project acceleration correlation diagram.

Infrastructure projects have a complexity that requires a long-term focus because they involve several risks during the construction and operation phases. Therefore, a multidisciplinary approach is needed, including conducting computer simulations using the Monte Carlo method to design projects that can optimize costs and provide engineering input to control and manage risks [2]. Monte Carlo is a mathematical model for evaluating the probability of accelerating a construction project [3]. The Monte Carlo simulation method has been widely applied to assess economic studies in construction projects; it is a quantitatively feasible method to analyze project risks and uncertainties. Tracy-Widom Distribution for Realistic Modeling: Tracy-Widom distribution is proposed to describe the unique behavior of construction project schedules mathematically [4]. This allows for more realistic modeling of delay risks and interactions between project participants. A study introduces an efficient Monte Carlo simulation procedure for cost estimation in construction projects, which shows superior simulation accuracy and a simplified decision-making tool for assessing construction costs and uncertainties. In Fuzzy Simulation, Monte Carlo can also be applied to risk analysis, namely in the format of Fuzzy Monte Carlo Simulation (FMCS) framework for construction project risk analysis, which handles random and fuzzy uncertainties in the risk assessment model [5]. Bayesian inference with Markov Chain Monte Carlo (MCMC) is also proposed as a universal input model updating the methodology for stochastic simulation models in construction, improving the robustness and practicality of stochastic simulation models.

Monte Carlo is a mathematical model for analyzing uncertainty development, where the goal is to determine how random variations or errors affect the sensitivity, performance, or reliability of the system being modelled [6][7]. Monte Carlo simulation is classified as a sampling technique because the input is generated randomly from a probability distribution for the sampling technique from a natural population. Therefore, the model must choose the input distribution that best fits its data—artificial data generation with a pseudo-random number generator and cumulative distribution of interest. The initial calculation of the Monte Carlo method simulation uses a computer program, namely Microsoft Excel [8], from random numbers based on the input data to then be iterated and calculate the standard deviation, variance, and error values to obtain answers to the problem formulation in this study.

Referring to the benefits of the FO Djuanda development project for road users, the Java-Bali BBPJN is accelerating the project, which is targeted for a functional feasibility test on December 15th 2023. Based on existing conditions, the acceleration of the FO Djuanda development project could have a negative impact if not managed properly. Poor execution and inadequate supervision could result in the imperfection of the FO Djuanda project. Therefore, the researcher conducted a risk analysis in the FO Djuanda project with the acceleration of work using the Monte Carlo Model simulation. MC simulation is part of an advanced risk management approach. The project must carry out several activities, starting from identifying risks and assessing the probability and impact to determine the risk score [9][10]. The novelty of this research is that it provides a structured and systematic flow in dealing with the acceleration of ongoing projects on a large scale of FO development. This study divides the concept of comprehensive risk

Table 1. Respondent list.

No	Service User (Owner)	Supervision Consultant	Service Provider
1	Commitment making official (1 person)	Team leader and supervision (2 persons)	Executive manager (1 person)
2	Coordinator of implementation & head of general administration affairs (2 persons)	Head of division (2 persons)	Head of QA/QC (2 persons)
3	Field supervisor (3 persons)	Technical staff (6 persons)	Technical staff (3 persons)
Total	(6 persons)	(10 persons)	(6 persons)
Total	22 persons		

identification into several variables with several indicators. Indicators refer to findings that occur in the field during acceleration. Thus, the acceleration of the FO Djuanda construction project can be carried out safely, and the project's success can be increased with the analysis. Based on the background described above, this study aims to analyze the Monte Carlo mathematical model simulation on the risk evaluation that occurs in the Djuanda Flyover project with the acceleration of work.

The FO Djuanda project is influenced by various factors, both internal and external. The ranking of risk factors generated from Monte Carlo simulations can have a significant effect on decision making and the acceleration of the FO Djuanda project. The acceleration of the FO Djuanda project obeys a triangular distribution. After reading some literature related to research [11][12] and practice, it is shown that the acceleration of an infrastructure project is influenced by several risk factors that are generally related to project costs, project completion time, and relations with various stakeholders. Moreover, the triangular distribution simulation can predict the probability of project risk level with an accuracy of up to 95% compared to several other probability distributions, for example the left-tailed probability type is only 67.4% in predicting project risk level [13]. Therefore, this article uses a triangular probability distribution to describe the probability of acceleration of the FO Djuanda project (Figure 1).

2. MATERIALS AND METHODS

2.1. Steps in @Risk Simulation

In this study, the simulation was conducted with the help of the @Risk program in Microsoft Excel using standard settings, and the distribution used was triangular. The steps in performing the simulation are as follows open the worksheet containing the summary of the questionnaire results in the Microsoft Excel program and open @Risk. Next, select (block) the data from our questionnaire in a table column of optimistic, pessimistic, and most frequently occurring durations. Next, to test the data distribution, select the distribution fitting menu > distribution to fit. Select any distribution to be tested, namely regular, uniform, and triangular

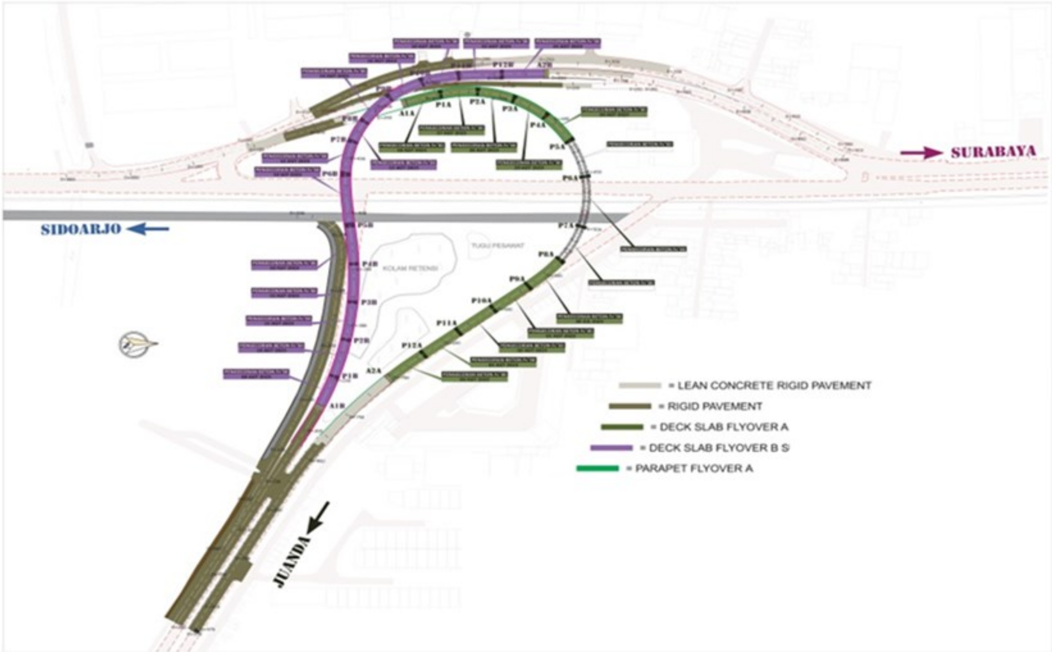


Figure 2. Map of the location of the djuanda flyover development project.

distribution. Then, select the fit menu, and the results show the appropriate distribution. Next, in the Monte Carlo simulation process, the worksheet already contains the job name and optimistic, most frequent, and pessimistic duration. First, create a new column for the simulation result data. Select the defined distribution menu in the simulation result column. A list of available distributions will appear. Next, select the triangular distribution and enter the formula for all jobs in the available column. Next, run the simulation by pressing the start simulation menu. The amount of iteration is determined according to the calculation. Then, adjust it to the standard settings of the @Risk program. After the simulation, the simulation result data will be obtained.

2.2. Population and Sample

The population in this study is all project stakeholders related to determining the implementation time of the Djuanda FO construction, which is currently underway in the 46th week. The study population consisted of 22 experts who were involved in scheduling the FO Djuanda construction project (Table 1). Since the population size is limited in the study, all population members were sampled. The sampling technique is census or saturated sampling, in which all population members are used as samples [14].

In this study, respondents asked to complete a questionnaire and answer questions about implementing the FO Djuanda development project. Sampling is limited to top management with expertise in decision-making to determine the duration of project implementation in scheduling. Thus, a census sampling technique is used with the same population and sample size, namely 22 respondents.

2.3. Research Instruments

This study obtained interval data, with interval data in the form of a Likert scale (scale 1–5).

2.3.1. Validity Test

Validity testing is a test that functions to see whether a measuring instrument is valid or invalid. The measuring instrument referred to here is the questions in the questionnaire. A questionnaire is valid if the questions can reveal something measured by the questionnaire [15][16]. A valid measuring instrument can reveal data accurately and precisely describe the data.

In this study, the construction validity test was used. Before conducting the validity test, the existing materials or aspects will be measured based on the theory of what will be obtained in the field, where experts will then be consulted. The experts will be asked for their opinions on the instruments that have been prepared. Then, the experts will give their views on the instrument, whether it can be used without improvement (feasible), whether there is an improvement (feasible, with improvement), or revised (not possible).

2.3.2. Reliability Test

Reliability testing refers to the consistency of measurement results. If the results are consistent, then the instrument is reliable. The reliability testing used in this study is the Cronbach Alpha method. The coefficient of Cronbach Alpha ranges from 0 to 1; for values < 0.6, the instrument is generally considered unreliable.

2.4. Types of Research

Based on the formulation of the problem and the objectives of the research to be achieved, this research combines quantitative and descriptive. The purpose of explanatory research is to provide a picture and a systematic description accurately related to the facts in the field and the phenomena being studied and observed. Meanwhile, quantitative research aims to develop and use mathematical models, theories, and hypotheses related to a phenomenon. The quantitative and qualitative approaches are used. The data presented in the quantitative approach itself is research data in the form of numbers and will produce a category level. The qualitative data presented is obtained in actual conditions and presented and analyzed to provide an overview of the research object.

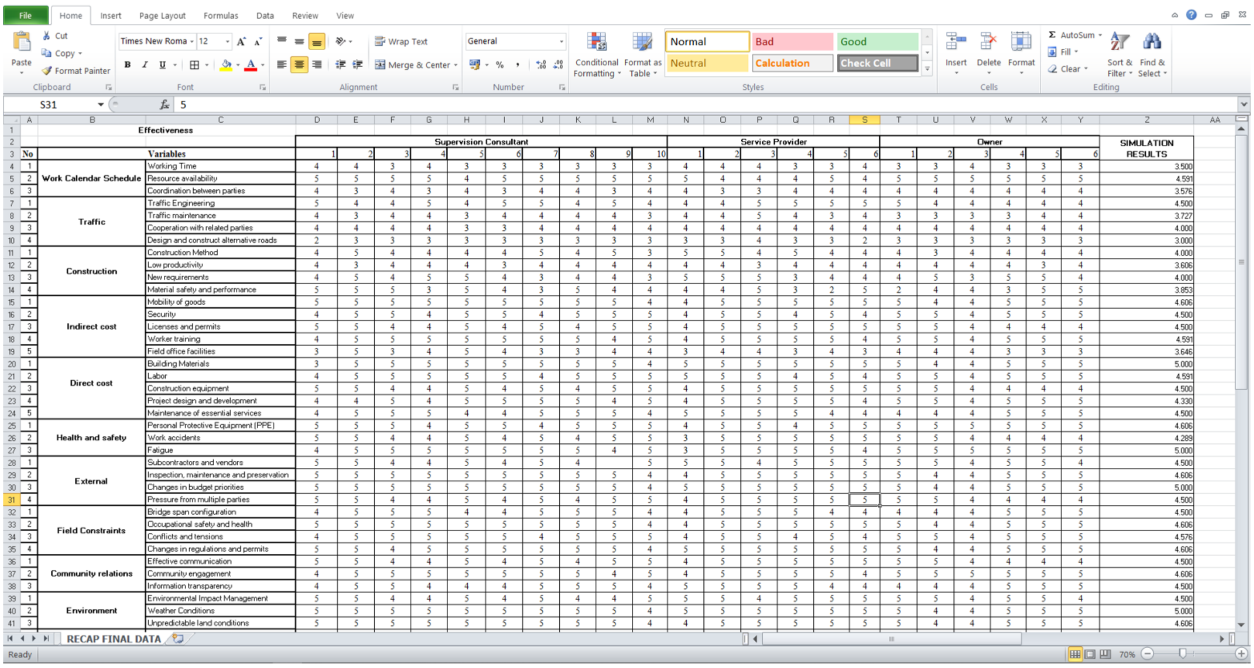
2.5. Location and Time of Research

2.5.1. Research Location

This research was conducted in the Djuanda flyover construction project area. Figure 2 illustrates the construction plan of Djuanda Flyover, designed as a strategic solution to mitigate traffic congestion in the Sidoarjo and Surabaya. This flyover is engineered to enhance mobility efficiency by incorporating an elevated loop ramp, allowing vehicles to move seamlessly without encountering traffic conflicts at the main intersection. The construction progress indicates that several structural components have been completed, including lean concrete rigid pavement, rigid pavement, deck slab flyover A & B, and parapet flyover A, as represented by the color-coded scheme in the diagram. The implementation of this infrastructure is expected to improve road capacity, reduce travel time, and enhance transportation safety in this strategic corridor.

2.5.2. Research Time

The research will be carried out during the



No		Variables	Supervision Consultant 1	2	3	4	5	6	7	8	9	10	Service Provider 1	2	3	4	5	6	Owner 1	2	3	4	5	6	SIMULATION RESULTS
1	Work Calendar Schedule	Working Time	4	4	3	4	3	3	3	3	3	3	4	4	4	3	3	4	3	3	4	3	3	3	3.500
2		Resource availability	5	5	5	5	4	5	5	5	5	5	5	4	4	4	5	4	5	5	5	5	5	5	4.591
3		Coordination between parties	4	3	4	3	4	3	4	4	3	4	4	3	3	4	4	4	4	4	4	4	4	4	3.576
1	Traffic	Traffic Engineering	5	4	4	5	4	5	5	4	5	4	4	4	5	5	5	5	5	4	4	4	4	4	4.500
2		Traffic maintenance	4	3	4	4	3	4	4	4	4	3	4	4	5	4	3	4	3	3	3	3	4	4	3.727
3		Cooperation with related parties	4	4	4	4	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4.000
4		Design and construct alternative roads	2	3	3	3	3	3	3	3	3	3	3	3	4	3	3	2	3	3	3	3	3	3	3.000
1	Construction	Construction Method	4	5	4	4	4	4	5	4	5	3	5	5	4	5	4	4	4	3	4	4	4	4	4.000
2		Low productivity	4	3	4	4	4	3	4	4	4	4	4	4	3	4	4	4	4	4	4	4	3	4	3.606
3		New requirements	4	5	4	5	5	4	3	4	4	3	5	5	5	3	4	4	4	5	3	5	5	4	4.000
4		Material safety and performance	5	5	5	3	5	4	3	5	4	4	4	4	5	3	2	5	2	4	4	3	5	5	3.853
1	Indirect cost	Mobility of goods	5	5	5	5	5	5	5	5	5	4	4	5	5	5	5	5	5	4	4	5	5	5	4.606
2		Security	4	5	5	4	5	5	4	5	5	5	4	5	5	4	5	4	5	5	4	5	5	5	4.500
3		Licenses and permits	5	5	4	4	5	4	5	4	5	5	4	5	5	5	5	5	5	5	4	4	4	4	4.500
4		Worker training	4	5	5	5	5	5	5	5	4	5	4	5	5	5	5	4	5	5	4	5	5	5	4.591
5		Field office facilities	3	5	3	4	5	4	3	3	4	4	3	4	4	3	4	3	4	4	4	3	3	3	3.646
1	Direct cost	Building Materials	3	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	4	4	5	5	5	5.000
2		Labor	4	5	5	5	5	5	4	5	5	5	5	5	5	4	5	4	5	5	4	5	5	5	4.591
3		Construction equipment	5	5	4	4	5	4	5	4	5	5	4	5	5	5	5	5	5	5	4	4	4	4	4.500
4		Project design and development	4	4	5	4	5	5	5	5	4	5	4	5	5	5	5	4	5	5	4	5	5	5	4.330
5		Maintenance of essential services	4	5	5	5	4	4	5	5	5	4	5	5	5	5	4	4	4	4	4	5	5	5	4.500
1	Health and safety	Personal Protective Equipment (PPE)	5	5	5	4	5	5	4	5	5	5	4	5	5	4	5	5	5	5	5	5	5	5	4.606
2		Work accidents	5	5	4	4	5	4	5	4	5	5	3	5	5	5	5	5	5	5	4	4	4	4	4.289
3		Fatigue	4	5	5	5	5	5	5	5	4	5	3	5	5	5	5	4	5	5	5	5	5	5	5.000
1	External	Subcontractors and vendors	5	5	4	4	5	4	5	4		5	5	5	4	5	5	5	5	5	4	5	5	4	4.500
2		Inspection, maintenance and preservation	5	5	5	5	5	5	5	5	5	4	4	5	5	5	5	5	5	4	4	5	5	5	4.606
3		Changes in budget priorities	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	4	4	5	5	5	5.000
4		Pressure from multiple parties	5	5	4	4	5	4	5	4	5	5	4	5	5	5	5	5	5	5	4	4	4	4	4.500
1	Field Constraints	Bridge span configuration	4	5	5	5	4	4	5	5	5	4	4	5	5	5	4	4	4	4	4	5	5	5	4.500
2		Occupational safety and health	5	5	5	5	5	5	5	5	5	4	4	5	5	5	5	5	5	4	4	5	5	5	4.606
3		Conflicts and tensions	4	5	5	5	5	5	4	5	5	5	4	5	5	4	5	4	5	5	4	5	5	5	4.576
4		Changes in regulations and permits	5	5	4	5	5	5	5	5	5	4	5	5	5	5	5	5	5	4	4	5	5	5	4.606
1	Community relations	Effective communication	5	5	4	4	5	4	5	4	5	5	4	5	5	5	5	5	5	5	4	4	4	4	4.500
2		Community engagement	4	5	5	5	5	5	5	5	4	5	4	5	5	5	5	4	5	5	5	5	5	5	4.606
3		Information transparency	4	5	5	4	4	4	5	5	5	4	5	5	5	5	4	4	4	4	4	5	5	5	4.500
1	Environment	Environmental Impact Management	5	5	4	4	5	4	5	4	4	5	5	5	4	5	5	5	5	5	4	5	5	4	4.500
2		Weather Conditions	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	4	4	5	5	5	5.000
3		Unpredictable land conditions	5	5	5	5	5	5	5	5	5	4	4	5	5	5	5	5	5	4	4	5	5	5	4.606

Figure 3. Data that was tested.

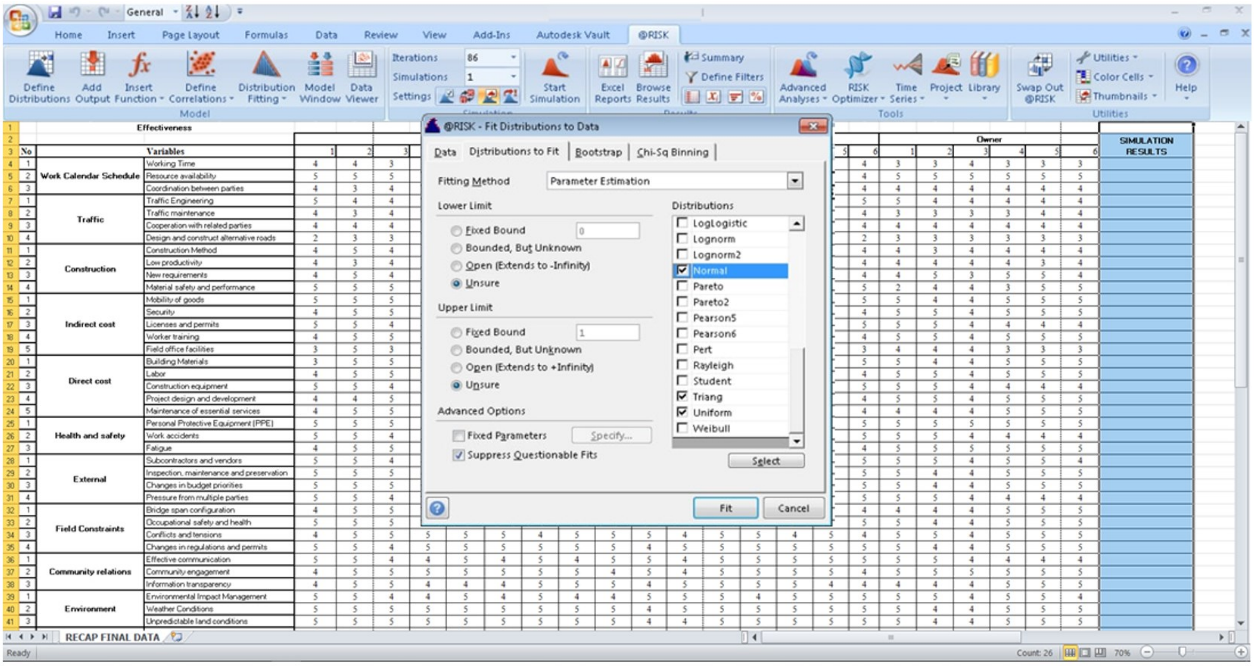


Figure 4. Determination of the tested distribution.

project, from the 46th week until completion.

3. RESULTS AND DISCUSSIONS

3.1. Respondent Data

Data was collected by distributing questionnaires to related parties, namely the owner, supervision consultant, and service provider in the FO Djuanda Development project. The number of parties is as follows: 6 owners, 10 supervision consultants, and 6 service providers, with a total of 22 respondents. In this study, the questionnaires were distributed by top management on the owner, supervision consultant, and service provider side of the FO Djuanda development project. The questionnaires were distributed for approximately one week. At the same time, researchers also conducted interviews with respondents to provide information related to the research, especially those related to scheduling and risk factors that existed during the project. The results showed that the respondents in this study consisted of owners 27%, with a total of 6 respondents; supervisory consultants, 46%, with 10 respondents; and service providers, 27%, with 6 respondents.

The last education is a reference for each respondent to have suitable qualifications and qualities. It is known that the majority of respondents in this study were S1 graduates, 77% of whom had 17 respondents. Meanwhile, the smallest number of respondents were masters graduates, namely 13%, with 5 respondents. Experience in the construction sector also influences the provision of answers. It is known that the respondents in this study were the most respondents with more than 15 years of work experience, which is 55%, with a total of 12 respondents. For 11–15 years of experience, it is 27%, with a total of 6 respondents. At the same time, the lowest number of respondents is 5–10 years of work experience, which is 18%, with a total of 4 respondents.

3.2. Monte Carlo Simulation Method

The steps used are to obtain the standard deviation value according to the following data;

$$\sigma = \sqrt{\frac{(x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{(4124 - 4297.5)^2 + (4471 - 4297.5)^2}{22-1}} = 54 \quad (1)$$

then, determine the margin of error, Eq. 2.

$$\varepsilon = Z\,x \sqrt{\frac{p(100-p)}{n}} = 1{,}96\ x \sqrt{\frac{22(100-22)}{22}} = 17 \quad (2)$$

while the number of iterations needed is obtained by the equation 3.

$$N = \left(\frac{3\sigma}{\varepsilon}\right)^2 = \left(\frac{3\ x\ 54}{17}\right)^2 = 86\ \text{iteration} \quad (3)$$

Next, the number of iterations is obtained through calculations entered into the @Risk program. The following is an example of data processing steps using the @Risk program. Open the summarized questionnaire data and select (block) data to be tested. Figure 3 presents a structured questionnaire data summary in Microsoft Excel, designed for analysis using the @Risk add-in. It includes various effectiveness criteria such as work schedule, productivity, coordination, costs, health and safety, external factors, and field constraints, rated by users, contractors, and owners. The final column displays results, representing a statistical evaluation. Utilizing Monte Carlo simulations in @Risk, this data enables probabilistic risk analysis to assess uncertainties, optimize resource allocation, and accelerate project completion by identifying potential delays and improving decision-making efficiency.

Select the distribution fitting menu; In the distribution to fit menu, select the distribution to be tested, namely the triangular distribution; Next, select the fit menu.

Figure 4 displays the "Fit Distribution to Data" menu in @Risk, which is essential for selecting the most appropriate probabilistic distribution for risk analysis and project forecasting using Monte Carlo simulation. The selection of triangular, uniform, and normal distributions is preferred due to their simplicity, ease of interpretation, and flexibility across various project scenarios. Triangular distribution is suitable for judgment-based estimations with minimum, maximum, and mode parameters, Uniform distribution is applied in situations with limited information where all values within a range have equal probability, while normal distribution is ideal for naturally distributed data, such as project duration and costs. In this image, the parameter estimation method is used to fit the distribution to the dataset, with lower limit and upper limit options configurable to align with real-world constraints before applying the selected distribution through the "Fit" button. By choosing the appropriate distribution, Monte Carlo simulation in @Risk enables more accurate probabilistic analysis, facilitates data-driven decision-making, and optimizes project planning by effectively assessing risks and uncertainties.

Next, the results will come out. Figure 5 displays the @Risk software interface with the define distribution window open, showing a triangular distribution (Triang 3.6, 4.4, 4.4) for "Dataset 6," which is being applied in a Monte Carlo simulation to model risk and uncertainty in project effectiveness variables. The distribution is defined by minimum (3.6), most likely (4.4), and maximum (4.4) values, indicating a skewed shape favoring

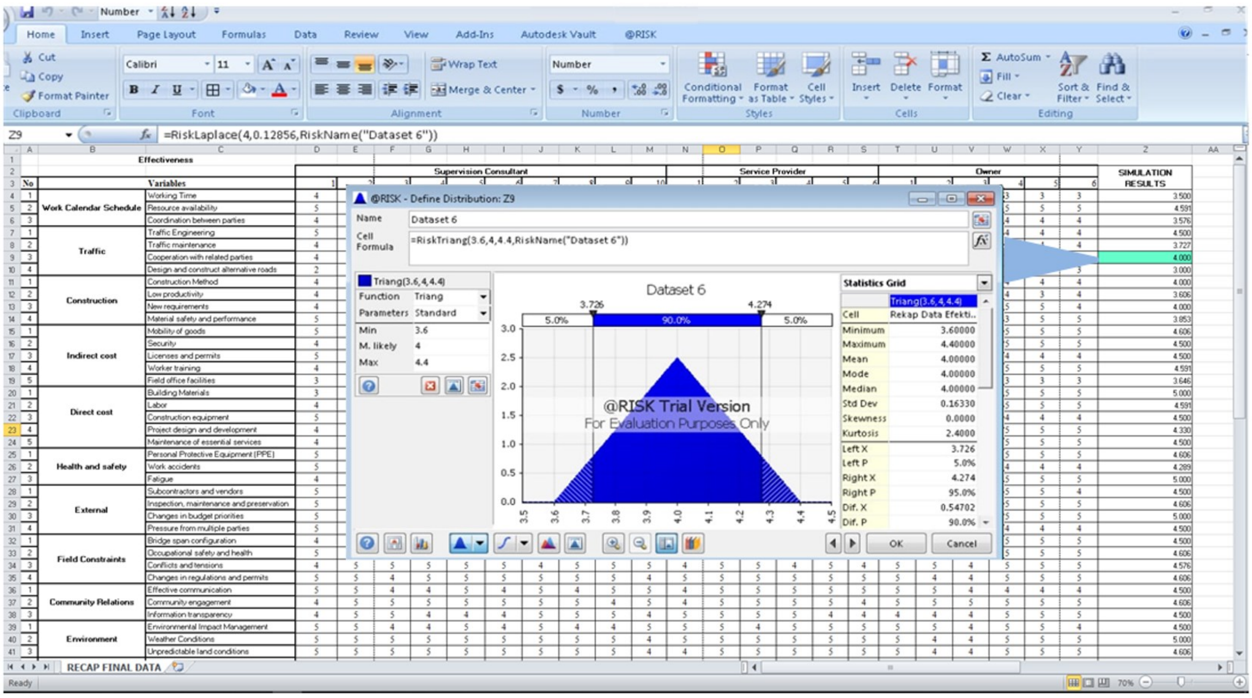


Figure 5. Triangular distribution test results.

higher probabilities near the maximum value. The probability density function graph highlights that 90% of the data is concentrated in the central region, with 5% falling on the lower and upper extremes, while the statistics grid presents key metrics such as mean, median, standard deviation, skewness, and kurtosis to characterize the dataset. The @Risk formula applied within Excel integrates this distribution for probabilistic risk analysis, aiding in project decision-making by modeling uncertainties in factors such as scheduling, costs, coordination, and external influences, ultimately optimizing project planning and risk management strategies. The complete results of the computer simulation using the Monte Carlo method are presented in Table 2.

Based on the ranking in Table 2, the most risky variables that affect the implementation of the acceleration of the Djuanda FO development project based on the risk level (TR) from the highest to the lowest are: direct costs (TR = 20.45), work calendar schedule (TR = 19.01), logistics (TR = 18.93), external (TR = 18.74), field constraints (TR = 18.72), health and safety (TR = 18.61), indirect costs (TR = 18.18), community relations (TR = 17.49), environment (TR = 17.41), construction contracts (TR = 16.89), traffic (TR = 15.79), and construction (TR = 13.89). In this project, regarding the evaluation of scheduling and acceleration risks in the Djuanda FO development project, several research implications can be drawn for further development in project management, primarily related to scheduling and risk management in construction projects.

The results of the ranking of several risk factors in the acceleration of the FO Djuanda project can be illustrated with a triangle probability that summarizes three key factors that affect the probability of acceleration of the FO Djuanda project. This includes project costs consisting of direct costs namely costs incurred for building materials, construction equipment, project design and development, essential service maintenance and labor, indirect costs, and logistics. Project duration consisting of work calendar schedules namely those related to working time, resource availability, and coordination between parties and construction. Relations with various stakeholders including investors related to construction work contracts, with the police and transportation agencies related to regulating vehicle flow and reducing congestion on roads affected by the construction of FO Djuanda, and with employees especially related to occupational health and safety are essential. Furthermore, the relation with various external parties such as vendors and subcontractors who supply building materials and with the surrounding community affected by the FO Djuanda construction project such as land compensation and their health due to various pollution resulting from the FO Djuanda construction project activities are also crucial. Air pollution caused by NOx gas that reacts with O_2, O_3, and unburned hydrocarbons in car engines could produce peroxyacetyl nitrate (PAN) which causes sore eyes and respiratory problems, as well as with the environment caused by the disposal of various waste produced in the FO Djuanda construction project activities that can pollute the soil, water, and air. Moreover, air pollution caused by CO_2 gas, whether emitted by project vehicles or due to traffic jams caused by the Djuanda FO construction project activities, can worsen the accumulation of CO_2 in the stratosphere where the asymmetric vibrations of CO_2 molecules can absorb infrared radiation of 2,349 cm^{-1} which is in the center of the absorption band (red, 2,100–2,400 cm^{-1}) as a heat radiation band, thus causing global warming and climate change [17].

An infrastructure project is usually comprehensively studied first using various engineering applications including Monte Carlo methods, which are almost always accompanied by the random nature of input variables. This is due to the randomness arising from the environment, material structure, construction process, maintenance or many other sources, which need to be properly and accurately accounted [18]. Project time and cost are some very crucial items that must be calculated precisely and accurately in a construction project. Monte Carlo simulation can be used to estimate time and cost in construction projects with relatively accurate results [7][19]. For example, Monte Carlo simulation predicts an 80% probability that a large-scale project can be completed with a total construction period of 22.54 months and a total cost of 3.0923 million yuan [11].

Monte Carlo simulation can be an excellent tool for analyzing the potential impact of changes or

Table 2. The risk level of each variable.

Variables		Effectiveness	Frequency	Risk Level	Average	Rank
	Working time	3.50	4.89	17.12		
Work Calendar Schedule	Resource Availability	4.59	4.85	22.27	19.01	2
	Coordination between parties	3.58	4.93	17.65		
	Traffic Engineering	4.50	4.50	20.25		
	Traffic Maintenance	3.73	4.00	14.91		
Traffic	Cooperation with Related Parties	4.00	4.00	16.00	15.79	11
	Designing and Developing Alternative Roads	3.00	4.00	12.00		
	Construction Method	4.00	4.00	16.00		
	Low Productivity	3.61	2.47	8.92		
Construction	New Requirements	4.00	4.00	16.00	13.89	12
	Material Safety and Performance	3.85	3.80	14.63		
	Mobility of Goods	4.61	4.25	19.57		
	Security	4.50	4.29	19.29		
Indirect Costs	Licensing and Permits	4.50	3.50	15.75	18.18	7
	Worker Training	4.59	4.50	20.66		
	Field Office Facilities	3.65	4.29	15.65		
	Building material	5.00	4.26	21.28		
	Labor	4.59	4.76	21.83		
Direct Costs	Construction Equipment	4.50	4.40	19.80	20.45	1
	Project Design and Development	4.33	4.35	18.84		
	Essential Service Maintenance	4.50	4.55	20.49		
	Personal Protective Equipment (PPE)	4.61	3.29	15.16		
Health and Safety	Work accident	4.29	4.24	18.18	18.61	6
	Delay	5.00	4.50	22.50		

Table 2. *Cont.*

Variables		Effectiveness	Frequency	Risk Level	Average	Rank
External	Subcontractors and Vendors	4.50	3.00	13.50	18.74	4
	Inspection, Maintenance, and Preservation	4.61	4.29	19.77		
	Changes in Budget Priorities	5.00	4.29	21.46		
	Pressure from Several Parties	4.50	4.50	20.25		
Field Constraints	Bridge Span Configuration	4.50	3.50	15.75	18.72	5
	Occupational Health and Safety	4.61	4.29	19.77		
	Conflict and Tension	4.58	4.29	19.62		
	Changes in Regulations and Licensing	4.61	4.29	19.74		
Relations with the Community	Effective Communication	4.50	3.50	15.75	17.49	8
	Community Involvement	4.61	3.58	16.47		
	Information Transparency	4.50	4.50	20.25		
Environment	Environmental Impact Management	4.50	3.25	14.62	17.41	9
	Weather Conditions	5.00	3.29	16.46		
	Undeveloped Land Conditions	4.61	4.59	21.15		
Logistics	Mobility of Building Materials	4.61	4.06	18.69	18.93	3
	Girder Factory Location	5.00	4.15	20.73		
	Area Accessibility	5.00	3.48	17.38		
Construction Contract	Changes in Scope of Work	4.61	4.00	18.42	16.89	10
	Contract Contradiction	4.61	3.18	14.66		
	Contract Time and Cost Estimates	4.61	3.15	14.49		
	Permits and Regulations	5.00	4.00	20.00		

modifications made to a complex project [20], such as the accelerated construction of the Djuanda flyover. However, even though Monte Carlo simulation has a quality level that correlates with the input data. This strengthens the more limited application in the early design phase, while in the details and implementation of the design phase, facts that are in accordance with the reality found in the field are needed, for example using three-dimensional models and numerical analysis [12]. Regardless of that, result of the computer simulation using the Monte Carlo method which places the cost variable as the highest risk in accelerating the Djuanda flyover construction project are in line with the results that the Monte Carlo simulation can be used to assess the financial feasibility and investment risk in an infrastructure project [2]. Moreover, Monte Carlo simulation containing probability distributions obtained from expert assessments can be applied to evaluate and calculate the probability of total project costs [21]. The cost of a project can also be estimated and calculated using a combination of Monte Carlo simulation and Markovian simulation cost projection (MSCP) methods [22].

Monte Carlo simulation can be used to identify key items that must be focused on because they have a significant impact on the total cost of the project and to make efficiencies in project items that, if made efficient, will not disrupt the smooth running of the project and the quality of the project results, to prevent project cost overruns [23]. Changes made midway through an infrastructure project will certainly have a significant impact on project costs, and will certainly also have implications for changes to the project schedule [16][24], re-adjustments to the project's work schedule time [25], and updates to the project work agreement with the contractor [26], and investors, because for investors it is very important to have certainty, both regarding costs, time and sustainability [27].

Changes in construction and infrastructure projects will certainly affect traffic flow and vehicle volume density on the road, which can have a negative impact on the environment [28]. This is contrary to the design of sustainable infrastructure development engineering which seeks to shorten project completion time, cut project costs so that the use of environmentally unfriendly construction materials can be minimized, and reduce CO_2 emissions, both due to the flow of project vehicles and the impact of congestion caused by the project, so that CO_2 gas that can last for 200 years in the stratosphere and can cause global warming can be significantly reduced [29].

Some implications of the research that can be formulated as follows. First, Risk-Based Scheduling Model: By minimizing risk, further research can be directed at developing a scheduling model that integrates risk analysis. This model can help project managers make more informed and strategic decisions regarding project acceleration and risk mitigation. This is as re-inforced by the fact that Monte Carlo simulations related to the ranking of risk factors, especially those related to investment and financial planning, are fundamental considerations for effective management decisions with sustainability goals [30]. Therefore, for managers and owners of large infrastructure projects, risk rating factors, especially those related to project costs, must be known in advance in as much detail and as accurately as possible [31]; Second, Risk Management in Project Acceleration: The findings on 12 risk variables that affect project acceleration provide a basis for in-depth research on each variable. Research can be conducted to understand the specific impact of each variable and develop effective mitigation strategies. The results of the Monte Carlo simulation, including in the context of this research 12 risk variables, can greatly assist project managers in rearranging project schedules, costs, and so on so that the project can run smoothly with the best quality results [32].

4. CONCLUSIONS

Based on the research results, risk evaluation can be adopted well through Monte Carlo mathematical model simulation. The risks in the acceleration of the FO Djuanda development project, based on the order of risk levels from the largest to the smallest, are direct costs, work calendar schedule, logistics, external, field constraints, health and safety, indirect costs, community relations, environment, construction contracts, traffic, and construction. Suggestions for further research include using other analysis tools that can answer the problem formulation and can be used to compare data from this study.

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Conflicts of Interest

The authors declare no conflict of interest.

REFERENCES

[1] R. Wijaya, J. M. Kerta, and R. Hedwig. (2013). "Influences of wireless traffic toward wifiperformance at BINUS square - Jakarta". *Internetworking Indonesia Journal.* **5** : 37-41.

[2] M. Ehrlich and R. L. K. Tiong. (2012). "Improving the Assessment of Economic Foreign Exchange Exposure in Public–Private Partnership Infrastructure Projects". *Journal of Infrastructure Systems.* **18** (2): 57-67. 10.1061/(asce)is.1943-555x.0000069.

[3] L. D. Nguyen, D. H. Phan, and L. C. M. Tang. (2013). "Simulating Construction Duration for Multistory Buildings with Controlling Activities". *Journal of Construction Engineering and Management.* **139** (8): 951-959. 10.1061/(asce)co.1943-7862.0000677.

[4] J. D. Vlok and J. C. Olivier. (2012). "Analytic approximation to the largest eigenvalue distribution of a white Wishart matrix". *IET Communications.* **6** (12): 1804-1811. 10.1049/iet-com.2011.0843.

[5] L. Yu, Y. P. Li, and G. H. Huang. (2016). "A fuzzy-stochastic simulation-optimization model for planning electric power systems with considering peak-electricity demand: A case study of Qingdao, China". *Energy.* **98** : 190-203. 10.1016/j.energy.2016.01.021.

[6] F. Al-Sahar. (2019). "Practical Analysis and Response for Risks Using Monte Carlo Simulation on Construction Manufacturing". *IOP Conference Series: Materials Science and Engineering.* **661** (1). 10.1088/1757-899x/661/1/012132.

[7] C. A. Peleskei, V. Dorca, R. A. Munteanu, and R. Munteanu. (2015). "Risk Consideration and Cost Estimation in Construction Projects Using Monte Carlo Simulation". *Management.* **10** : 163-176.

[8] F. Santos, S. F. Garcia, and C. Acosta. (2022). "Comparison of the Different Project Management Software used for a Commercial Project in the Philippines: A Case Study". *2nd International Conference in Information and Computing Research (iCORE).* 177-183. 10.1109/iCORE58172.2022.00051.

[9] L. M. F. Silva, A. C. R. de Oliveira, M. S. A. Leite, and F. A. S. Marins. (2020). "Risk assessment model using conditional probability and simulation: case study in a piped gas supply chain in Brazil". *International Journal of Production Research.* **59** (10): 2960-2976. 10.1080/00207543.2020.1744764.

[10] K. Walędzik and J. Mańdziuk. (2018). "Applying hybrid Monte Carlo Tree Search methods to Risk-Aware Project Scheduling

Problem". *Information Sciences.* **460-461** : 450-468. 10.1016/j.ins.2017.08.049.

[11] X. Chen, L. Cheng, G. Deng, S. Guan, and L. Hu. (2021). "Project duration-cost-quality prediction model based on Monte Carlo simulation". *Journal of Physics: Conference Series.* **1978** (1). 10.1088/1742-6596/1978/1/012048.

[12] F. Alves Cantini Cardozo, D. Peixoto Cordova, and C. Otávio Petter. (2022). "Risk analysis by Monte Carlo simulation in underground rock excavation projects". *Dyna.* **89** (221): 24-30. 10.15446/dyna.v89n221.97628.

[13] F. Amirah, A. Shukri, and Z. Isa. (2023). "Monte Carlo Simulation Based Approach to Quantify Risks for Construction Project Uncertainty Analysis using Probabilistic Estimates in Risk Assessment". *Journal of Pharmaceutical Negative Results.* **13** : 366-376.

[14] M. Setiawan, W. D. Ruspitasari, and I. K. Ningrum. (2020). "The role of mediation on product innovation and market orientation related to both entrepreneurial orientation and competitive advantage". *International Journal of Innovation, Creativity and Change.* **13** : 622-639.

[15] H. Yasin, M. Usman, H. Rashid, A. Nasir, A. Sarwar, and I. A. Randhawa. (2017). "Guidelines for Environmental Impact Assessment of JHAL flyover and underpass project in Faisalabad". *Geology, Ecology, and Landscapes.* **1** (3): 205-212. 10.1080/24749508.2017.1363972.

[16] R. M. Choudhry, M. A. Aslam, J. W. Hinze, and F. M. Arain. (2014). "Cost and Schedule Risk Analysis of Bridge Construction in Pakistan: Establishing Risk Guidelines". *Journal of Construction Engineering and Management.* **140** (7). 10.1061/(asce)co.1943-7862.0000857.

[17] E. Yuniarti, L. A. S. M. Exposto, I. Dewata, F. A. D. Nugraha, and A. Alfitri. (2024). "Health and Environmental Pollution: A Literature Review". *Kesmas National Public Health Journal.* **19** (5). 10.21109/kesmas.v19isp1.1102.

[18] J. Eliáš, M. Vořechovský, and V. Sadílek. (2020). "Periodic version of the minimax distance criterion for Monte Carlo integration". *Advances in Engineering Software.* **149**. 10.1016/j.advengsoft.2020.102900.

[19] D. Pant and K. Srinivas. (2019). "Cost Estimation of Construction Project Using Monte Carlo Simulation". *IOSR Journal of Mechanical and Civil Engineering.* **16** : 13-19

[20] W. E. Back and L. C. Bell. (1995). "Monte Carlo Simulation as Tool for Process Reengineering". *Journal of Management in Engineering.* **11** (5): 46-53. 10.1061/(asce)0742-597x(1995)11:5(46).

[21] Y. Chen, S. Chen, C. Hu, L. Jin, and X. Zheng. (2020). "Novel Probabilistic Cost Estimation Model Integrating Risk Allocation and Claim in Hydropower Project". *Journal of Construction Engineering and Management.* **146** (8). 10.1061/(asce)co.1943-7862.0001893.

[22] J. Du, B.-C. Kim, and D. Zhao. (2016). "Cost Performance as a Stochastic Process: EAC Projection by Markov Chain Simulation". *Journal of Construction Engineering and Management.* **142** (6). 10.1061/(asce)co.1943-7862.0001115.

[23] Z. Bouayed. (2016). "Using monte carlo simulation to mitigate the risk of project cost overruns". *International Journal of Safety and Security Engineering.* **6** (2): 293-300. 10.2495/safe-v6-n2-293-300.

[24] E. Eshtehardian and S. Khodaverdi. (2016). "A Multiply Connected Belief Network approach for schedule risk analysis of metropolitan construction projects". *Civil Engineering and Environmental Systems.* **33** (3): 227-246. 10.1080/10286608.2016.1184492.

[25] J. Batselier and M. Vanhoucke. (2015). "Empirical Evaluation of Earned Value Management Forecasting Accuracy for Time and Cost". *Journal of Construction Engineering and Management.* **141** (11). 10.1061/(asce)co.1943-7862.0001008.

[26] M.-H. Kim and E.-B. Lee. (2019). "A Forecast Model for the Level of Engineering

Maturity Impact on Contractor's Procurement and Construction Costs for Offshore EPC Megaprojects". *Energies*. **12** (12). 10.3390/en12122295.

[27] X. Zhu. (2018). "Rural Infrastructure PPP Project Risks Analysis Based on Monte Carlo Method". *Proceedings of the 2018 3rd International Conference on Education, E-learning and Management Technology (EEMT 2018)*. 10.2991/iceemt-18.2018.26.

[28] W. Fawcett, I. R. Urquijo, H. Krieg, M. Hughes, L. Mikalsen, and Ó. R. R. Gutiérrez. (2015). "Cost and Environmental Evaluation of Flexible Strategies for a Highway Construction Project under Traffic Growth Uncertainty". *Journal of Infrastructure Systems*. **21** (3). 10.1061/(asce)is.1943-555x.0000230.

[29] S.-n. Sun and Z.-b. Su. (2011). "Parametric vibration of submerged floating tunnel tether under random excitation". *China Ocean Engineering*. **25** (2): 349-356. 10.1007/s13344-011-0029-2.

[30] A. Senova, A. Tobisova, and R. Rozenberg. (2023). "New Approaches to Project Risk Assessment Utilizing the Monte Carlo Method". *Sustainability*. **15** (2). 10.3390/su15021006.

[31] F. Allahi, L. Cassettari, and M. Mosca. (2017). "Stochastic risk analysis and cost contingency allocation approach for construction projects applying Monte Carlo simulation". *Lecture Notes in Engineering and Computer Science*. **2229** : 385-391.

[32] M. K. Sharma. (2020). "Monte Carlo Simulation Applications for Construction Project Management". *International Journal of Civil Engineering and Technology (Ijciet)*. **11** (2). 10.34218/ijciet.11.2.2020.010.