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Article

Optimization of completion schedule forecasting in case study of double-double track development project (Package A) using the probabilistic pert method

Leni Sagita Riantini[1], Mohammad Ichsan[2,*], Bambang Trigunarsyah[3], Ayomi Dita Rarasati[1], Nuraziz Handika[1], Chrys Adrian Lolo[1]

[1] Civil Engineering Department, University of Indonesia, Kampus Baru UI, Depok 16424, Indonesia
[2] Digital Business, Binus Business School International Undergraduate Program, Binus University, Jakarta 10270, Indonesia
[3] School of Property, Construction and Project Management, RMIT University, Melbourne 3000, Australia
*** Corresponding author:** Mohammad Ichsan, mohammad.ichsan@binus.edu

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Abstract: This study aims to identify the risk factors causing the delay in the completion schedule and to determine an optimization strategy for more accurate completion schedule prediction. A validated questionnaire has been used to calculate a risk rating using the analytical hierarchy process (AHP) method, and a Monte Carlo simulation on @RISK 8.2 software was employed to obtain a more accurate prediction of project completion schedules. The study revealed that the dominant risk factors causing project delays are coordination with stakeholders and changes in the scope of work/design review. In addition, the project completion date was determined with a confidence level of 95%. All data used in this study were obtained directly from the case study of the Double-Double Track Development Project (Package A). The key result of this study is the optimization of a risk-based schedule forecast with a 95% confidence level, applicable directly to the scheduling of the Double-Double Track Development Project (Package A). This paper demonstrates the application of Monte Carlo Simulation using @RISK 8.2 software as a project management tool for predicting risk-based-project completion schedules.

Keywords: Monte Carlo simulation; quantitative risk; railway infrastructure; scheduling

1. Introduction

Most infrastructure projects are suffering from delays and cost overruns. Studies conducted by Flyvbjerg (2007) and Flyvbjerg et al. (2003) revealed that the projects have major challenges, either cost overruns or delays, which lead to missing out on the identified project benefits. Despite the level of investment in rail construction projects having increased over the years, the evidence indicates that the problem of cost overrun is a worldwide phenomenon for rail infrastructure projects. London's Crossrail Project, Sydney's Lane Cove Tunnel, and Channel Tunnel are examples of transportation projects that experienced delays (Flyvbjerg, 2014).

As in other developing countries (Asiedu and Adaku, 2020; Azolibe and Okonkwo, 2020; Babon-Ayeng et al., 2022; Ebekozien et al., 2023; Isang and Ebiloma, 2023; Manoharan et al., 2022), the phenomenon of Infrastructure projects in Indonesia is unique. Demands for rapid infrastructure development have led them to manage many large projects. Besides being unique, complicated, and expensive, rail construction is usually carried out within a limited time frame, complicated, and uncertain in nature since no two construction projects are ever the same, and most of the projects' elements are site-specific.

This is proven by the implementation of several infrastructure projects that are of particular concern to President Joko Widodo. With the ratification of Presidential Regulation (PP) no. 3/20161, managing infrastructure projects in a relatively large context was finally carried out in Indonesia. This regulation was updated with the ratification of PP No. 58/20172 and, later, PP No. 56/20183. By 2030, the Transportation Ministry's Railways Directorate General aims to have built 10,524 km of rail infrastructure nationwide. Currently, the railways cover 7032 km, and continuous work until 2024 aims to extend them to 7451 km (PricewaterhouseCoopers, 2022). One of the construction projects carried out by the Directorate General of Railways, Ministry of Transportation of the Republic of Indonesia, is the Double-Double Track Development Project (Package A). This project is carried out using the State Sharia Securities (SBSN) funding scheme, which is issued through the Ministry of Finance of the Republic of Indonesia. The project is implemented in two stages, namely Phase I (Fiscal Year 2016 to Fiscal Year 2021) and Phase II (Fiscal Year 2019 to Year 2022). Both Phase I and Phase II experienced numerous obstacles, preventing the project from being completed according to the original schedule. The following table explains the chronology of multi-year contract renewals, which is a significant aspect of the case studies in this research.

Table 1. Chronology of multi-year contract approvals and extensions.

No.	**Date**	**Information**
Package A (Construction of Railway Facilities)		
1	13 June 2014	Multi-Year Contract Agreement (2014–2016)
2	9 December 2016	Multi-Year Contract Extension 1 (2014–2017)
3	14 December 2017	Multi-Year Contract Extension 2 (2014–2019)
4	14 November 2019	Multi-Year Contract Extension 3 (2014–2020)
5	1 January 2021	Multi-Year Contract Extension 4 (2014–2021)
Construction of Railway Facilities (Package A) (Phase II)		
1	19 March 2019	Multi-Year Contract Approval (2019–2021)
2	22 October 2020	Multi-Year Contract Extension 1 (2019–2022)

Source: Internal Documents.

Table 1 shows that Phase I work has undergone four multi-year contract extensions. Meanwhile, Phase II has also experienced a multi-year contract extension since its approval on 19 March 2019. This phenomenon occurs not only in this study but also in various other projects managed by the Directorate General of Railways, Ministry of Transportation of the Republic of Indonesia. The issue becomes critical when the forecasted project end dates have slipped as the project risks cannot be controlled properly. The slipped schedule has jeopardized the impact on other project constraints such as project budget and resources, as well as trust in the completion of the project, not to mention the missing project benefits. This study aims to optimize the project completion schedule predictions using the probabilistic PERT method.

2. Literature review

Risk and uncertainties in construction projects.

Uncertainties and risks in a project come not only from external factors like weather and site conditions but also from internal factors such as organizational structure and decision-making processes (Bepari et al., 2024; Siraj and Fayek, 2019). These internal factors can greatly increase the level of uncertainty and prolong the list of risks associated with the project (Adeleke et al., 2018; Kassem et al., 2020). The risk registers in construction projects will be later assessed to know what the impact is on the projects' objectives, such as cost, schedule, and quality, and based on this assessment, some risk responses will be planned and monitored (Project Management Institute, 2019b). One of the responses might be embedded in the form of contingency cost. It refers to a proportion of the construction cost budget allocated as a project component (Project Management Institute, 2017).

Challenges of construction projects in developing countries.

When managing a project, it is crucial to not only track the deviations in time and cost from the planned progress but also accurately assess the project's current status based on the predicted final performance (Barraza et al., 2004). Infrastructure development projects have been facing many challenges, especially in developing countries. Cost overruns (Asiedu and Adaku, 2020; Danisworo and Latief, 2019; Karunakaran et al., 2018) and project delays (Altuwaim and El-Rayes, 2018) are common phenomena in construction projects in developing countries. Only a few of these challenges can be anticipated effectively with accurate forecasting techniques (Ichsan et al., 2024; Isvara et al., 2023; Kwon and Kang, 2019). Therefore, ensuring the accurate schedule completion forecast is essential during the project's execution phase.

Program evaluation and review technique (PERT) and monte carlo simulation.

PERT analysis, also known as probability-based time-series analysis, is a popular technique for project planning and control. This method was first proposed by Booz Allen and Hamilton, as explained in a government report (US Department of the Navy, 1958). In the past, statistically, the PERT analysis was not considered to be simplified using specific estimates but rather involved complex computation (Hartley and Wortham, 1966). However, in recent practices, the estimates are made in a much simpler way using 3 (three) points of estimates. It means that for every project activity, the PERT technique employs three estimates: the longest time to work (pessimistic), the best time to work (most likely), and the quickest time to work (optimistic) as argued by Kwon and Kang (2019) and Lei (2011). The duration of an activity in a PERT network is set by stochastic factors presumed to be independent of each other. The activity duration distribution is known as the PERT-beta distribution (Project Management Institute, 2017, 2019a). **Figure 1** shows that this distribution accommodates the three-point estimates that will be used later for further analysis.

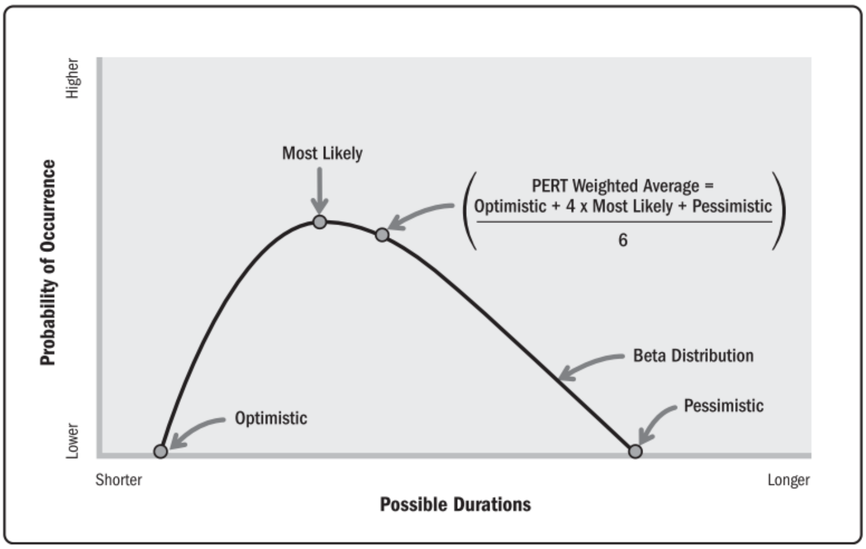

Figure 1. Example of beta distribution (Project management institute, 2019a).

Monte Carlo simulation is a stochastic technique employed in risk analysis and is known for its acknowledged precision (Purnus and Bodea, 2013). The term "three-point estimations" is well-known in Monte Carlo simulation that is conceptualized by PERT. The study obtained three estimates (optimistic, most likely, and pessimistic) for all preliminary project variables, including duration, volume of work, productivity, calendar, and resources. When compared to several other methods, Monte Carlo Simulation is perhaps the simplest and most suitable approach for incorporating precise information regarding uncertainty. Monte Carlo simulations can generate project plans and produce output through distributions and Earned Value metrics, including turnaround time and cost (Ichsan et al., 2024; Isvara et al., 2023; Qazi et al., 2021; Yoon and Yu, 2019).

PERT applications in construction projects.

Many researchers and practitioners developed the PERT method to test various approaches based on probability distributions for practicality over the course of each project activity. PERT is one of the evaluation methods that shows dependency linkages between activities by examining activity-on-arrow networks; as a result, it can characterize logical dependencies between occurring activities (Hajdu, 2013). PERT is one method that planners can use to consider the time and money required to estimate a project duration with a certain degree of accuracy. In their study, Hajdu and Bokor (2016) opined that there are no appreciable differences in the outcomes when different activity duration distributions are used (Hajdu and Bokor, 2016). The accuracy of the three-point estimate has a substantially greater impact on the distribution of project durations (Maulana and Kurniawan, 2019). PERT is used in road and highway construction projects to evaluate the scheduled end date (Kehinda et al., 2017). Meanwhile, the fuzzy PERT was used to forecast completion dates (Hsiau and Lin, 2009; Nemaa and Aswed, 2021). Furthermore, sensitivity analysis in PERT networks has been applied to highway construction and cable-stayed projects (Hajdu and Bokor, 2016). Meanwhile, in mega infrastructure projects, PERT has been used to estimate project completion time and duration estimates (Lee et al., 2018; Liu et al., 2021). In building construction projects, PERT is also used to evaluate projects under risk and uncertainties (Handoko and Gondokusumo, 2019; Hendradewa, 2019; Mariana and Wijaksono, 2021).

3. Data and methods

The research utilizes a quantitative approach since it measures risk severity and prioritization, as well as forecasts the duration of identified activities related to the identified risks using PERT and Monte Carlo simulation, utilizing @RISK 8.2 software for the analysis. The research stage commences with the initial steps of identification and risk assessment. The research instrument employed in this procedure involves the utilization of a questionnaire meticulously crafted by the researcher and subsequently validated by a designated expert.

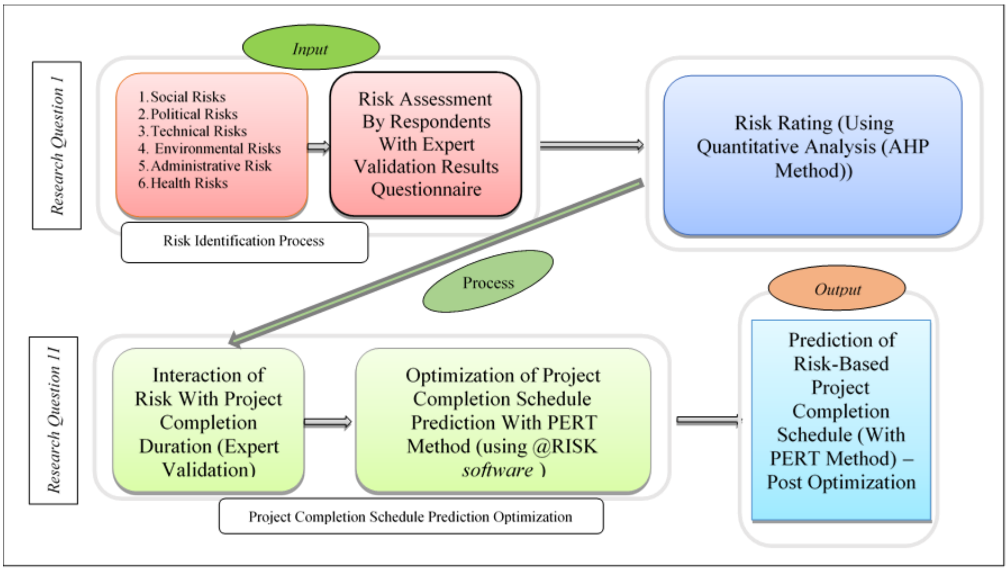

Figure 2. Research process.

Source: Current Research.

Once the risk identification procedure is completed, the subsequent step involves creating a risk matrix utilizing the findings from a questionnaire filled out by selected respondents using the Analytical Hierarchy procedure (AHP) method. **Figure 2** provides an overview of the research process.

3.1. Data collection and measurement

This study observed individuals who were highly and directly engaged with the double-double track project. To solve the problems raised in this study, researchers used a technique called purposive sampling. This technique was selected because the data needed to be collected from respondents with specific educational backgrounds and experience working on railway projects. The respondents were divided into two groups: subject matter experts and individuals who have been working on the double-track project for a minimum of 3 years. The respondents are requested to provide their assessment of the risks using the Analytical Hierarchical Process (AHP) that has been suggested by Saaty (1987) in order to establish weighting factors that are used for further risk assessment, which aims for risk prioritization. The data were collected using structured questionnaires that were distributed via emails or hardcopy to respondents. For the AHP, a scale from 1 to 9 (1 = Equally important; 9 = very high importance) was selected in order to make pairwise comparisons of factors. For qualitative risk assessment, a scale from 1 to 5 was used for assessing risks in terms of probability (1 = very seldom; 5 = very often) and impact (1 = very small; 5 = very big).

3.2. Data analysis

When the AHP analysis was performed, the data was analyzed using Microsoft Excel, where later the weighting factors and consistency ratio as well as consistency index were calculated. Furthermore, a qualitative risk assessment was performed using Microsoft Excel to identify prioritized risks. Once the risk ratings and main risk factors impacting the project's timeline were determined, additional modeling was conducted using the @RISK 8.2 software from palisade.com to provide an optimal estimate for the project's completion timetable. This process involves correlating the primary risk factors with the duration obtained from secondary data in the case study project. The assessment and validation process were carried out by the same experts as in the previous step. The outcome of this process is an approximate assessment in the form of a three-point estimate, which includes a pessimistic, most-likely, and optimistic estimate. The expert's estimation of the length is assessed by simulating it using @RISK 8.2 software, which incorporates the PERT distribution. This simulation allows for determining an estimated duration with a specific level of confidence.

4. Results and discussions

The data was collected from 26 respondents (domain practitioners) and 3 respondents (domain experts). After the experts and respondents were determined, the next process involved having the experts validate the draft questionnaire prepared by the researcher. The purpose of this validation is to assess the variables and sub-variables included in the study through a questionnaire, ensuring validity and objectivity. The validation process for experts was carried out through direct interviews/approaches, allowing researchers to freely communicate and discuss with the intended experts to obtain detailed and accurate information, responses, and input. Following the experts' responses and inputs as a form of validation, the finalized questionnaire design was obtained, as shown in **Table 2**, and then distributed to the respondents for assessment. The assessment in this questionnaire includes 2 aspects, namely, an assessment of the intensity of the impact of risk and an assessment of the probability of risk.

The questionnaire validated by the experts was first tested by 5 individuals chosen for a pilot survey. The goal is to assess the level of understanding of potential respondents regarding the questions in the questionnaire. The researchers randomly selected these 5 individuals from the 26 predetermined potential respondents. After the pilot survey confirmed that all five prospective respondents could understand the questions, the questionnaire was distributed to each selected respondent according to their areas of expertise. After respondents completed the questionnaire, the researchers carried out further data processing using the Analytical Hierarchy Process (AHP) method to obtain a risk rating and determine the dominant risk factor causing delays in the completion schedule.

Table 2. Variables and sub-variables of expert validation results (example: railroad works).

Activity: Land Clearing			
X1	Technical Risks	X1.1	Unskilled Labor
		X1.2	Availability of Working Land
X2	Social Risks	X2.1	Vandalism
X3	Administration Risks	X3.1	Changes in Organizational Structure/Personnel Turnover
		X3.2	Delay in Submitting Documents
		X3.3	Delay in Document Approval
		X3.4	Coordination with Stakeholders (Railway company, provincial government, etc.)
X4	Economic Risks	X4.1	Price of Tools/Materials
		X4.2	Delay in Payment Process (Wages, Tools/Materials, etc.))
		X4.3	Project Activity Costs That Don't Go According to Plan
X5	Environmental Risks	X5.1	Environmental Pollution
		X5.2	Weather Factors
X6	Safety and Health Risks	X6.1	Work Accidents
		X6.2	COVID-19 Pandemic
		X6.3	Natural Disasters/Force Majeure
Activity: Surveying/Staking Out			
X1	Technical Risks	X1.1	Change in Scope of Work/Design Review
		X1.2	Unskilled Labor
		X1.3	Less Effective/Efficient Work Methods
		X1.4	Availability of Working Land
X2	Social Risks	X2.1	Vandalism
X3	Administration Risks	X3.1	Changes in Organizational Structure/Personnel Turnover
		X3.2	Delay in Submitting Documents
		X3.3	Delay in Document Approval
		X3.4	Coordination with Stakeholders (Railway company, provincial government, etc.)
X4	Economic Risks	X4.1	Increased Price of Tools/Materials
		X4.2	Delay in Payment Process (Wages, Tools/Materials, etc.))
		X4.3	Project Activity Costs That Don't Go According to Plan
		X4.4	Availability of Budgets to Employers
X5	Environmental Risks	X5.1	Weather Factors
X6	Safety and Health Risks	X6.1	Work Accidents
		X6.2	COVID-19 Pandemic
		X6.3	Natural Disasters/Force Majeure

Table 2. (*Continued*).

Activity: Excavation/Heap Work			
X1	Technical Risks	X1.1	Change in Scope of Work/Design Review
		X1.2	Unskilled Labor
		X1.3	Technical Specifications That Are Not Met or Undergone Changes
		X1.4	Less Effective/Efficient Work Methods
		X1.5	Availability of Working Land
X2	Social Risks	X2.1	Vandalism
X3	Administration Risks	X3.1	Changes in Organizational Structure/Personnel Turnover
		X3.2	Delay in Submitting Documents
		X3.3	Delay in Document Approval
		X3.4	Coordination with Stakeholders (Railway company, provincial government, etc.)
X4	Economic Risks	X4.1	Increased Price of Tools/Materials
		X4.2	Delay in Payment Process (Wages, Tools/Materials, etc.))
		X4.3	Project Activity Costs That Don't Go According to Plan
		X4.4	Availability of Budgets to Employers
X5	Environmental Risks	X5.1	Weather Factors
X6	Safety and Health Risks	X6.1	Work Accidents
		X6.2	COVID-19 Pandemic
		X6.3	Natural Disasters/Force Majeure
Activity: Establish Sub Ballast			
X1	Technical Risks	X1.1	Change in Scope of Work/Design Review
		X1.2	Delay in Material Fabrication Process
		X1.3	Unskilled Labor
		X1.4	Technical Specifications That Are Not Met or Undergone Changes
		X1.5	Less Effective/Efficient Work Methods
		X1.6	Availability of Working Land
X2	Social Risks	X2.1	Vandalism
X3	Administration Risks	X3.1	Changes in Organizational Structure/Personnel Turnover
		X3.2	Delay in Submitting Documents
		X3.3	Delay in Document Approval
		X3.4	Coordination with Stakeholders (Railway company, provincial government, etc.)
X4	Economic Risks	X4.1	Increased Price of Tools/Materials
		X4.2	Delay in Payment Process (Wages, Tools/Materials, etc.))
		X4.3	Project Activity Costs That Don't Go According to Plan
		X4.4	Availability of Budgets to Employers
X5	Environmental Risks	X5.1	Environmental Pollution
		X5.2	Weather Factors
X6	Safety and Health Risks	X6.1	Work Accidents
		X6.2	COVID-19 Pandemic
		X6.3	Natural Disasters/Force Majeure

The first step in the analysis using AHP is to create a pairwise comparison matrix (**Table 3**). Then, proceed by creating a comparison matrix in pairs by adopting a scale for assessing risk impact intensity and risk probability.

Table 3. Impact intensity and probability assessment matrix.

	5	**4**	**3**	**2**	**1**
5	1.00	3.00	5.00	7.00	9.00
4	0.33	1.00	3.00	5.00	7.00
3	0.20	0.33	1.00	3.00	5.00
2	0.14	0.20	0.33	1.00	3.00
1	0.11	0.14	0.20	0.33	1.00
Total	1.79	4.67	9.53	16.33	25.00

After the scoring matrix is created, the next step is normalizing it. The normalization process involves dividing the numbers in each column by the total number of that respective column (**Table 4**).

Table 4. Normalization of the impact matrix and risk probability.

	5	**4**	**3**	**2**	**1**
5	0.560	0.642	0.524	0.429	0.360
4	0.187	0.214	0.315	0.306	0.280
3	0.112	0.071	0.105	0.184	0.200
2	0.080	0.043	0.035	0.061	0.120
1	0.062	0.030	0.021	0.020	0.040
Total	1.000	1.000	1.000	1.000	1.000

Table 5. Calculation of impact intensity weighting and risk probability.

	5	**4**	**3**	**2**	**1**	**Total**	**Priority**	**Percentage**
5	0.560	0.642	0.524	0.429	0.360	2.514	0.503	50.29%
4	0.187	0.214	0.315	0.306	0.280	1.301	0.260	26.03%
3	0.112	0.071	0.105	0.184	0.200	0.672	0.134	13.44%
2	0.080	0.043	0.035	0.061	0.120	0.339	0.068	6.78%
1	0.062	0.030	0.021	0.020	0.040	0.174	0.035	3.47%
Total	1.000	1.000	1.000	1.000	1.000	5.000		

After the weighting calculation is carried out, as shown in **Table 5**, meanwhile the **Table 6** shows the obtained weighting factor.

Table 6. Weight value for impact intensity assessment and risk probability.

	Very big (5)	**Big (4)**	**Medium (3)**	**Small (2)**	**Very Small (1)**
Weighted Value	0.503	0.260	0.134	0.068	0.035

The next stage of this quantitative analysis is to calculate the consistency index (CI), which is obtained by first determining the value of the Eigenvectormatrix as shown in **Table 7**.

Table 7. Eigenvector values.

0.503	1.00	3.00	5.00	7.00	9.00	=	2.742
0.260	0.33	1.00	3.00	5.00	7.00	=	1.413
0.134	0.20	0.33	1.00	3.00	5.00	=	0.699
0.068	0.14	0.20	0.33	1.00	3.00	=	0.341
0.035	0.11	0.14	0.20	0.33	1.00	=	0.176

Furthermore, the result of the multiplication is divided by the value of the weights that have been obtained as values in Eigenvectormatrix as shown in **Table 8**.

Table 8. Eigenvector values.

2.742	:	0.503	5.453
1.413	:	0.260	5.428
0.699	:	0.134	5.199
0.341	:	0.068	5.024
0.176	:	0.035	5.086
Total			26.191

Based on the above calculations, the maximum eigenvalues can be obtained as follows:

$$\lambda \text{ Max} = \frac{\Sigma}{n} = \frac{26.191}{5} = 5.238$$

After the maximum Eigenvalue is obtained, it can be calculated the consistency index value with the following formula and respective result:

$$\text{Consistency Index (CI)} = \frac{(\lambda \text{ Max} - n)}{(n-1)} = (5.238 - 5)/(5 - 1) = 0.060$$

The final stage of this quantitative analysis is calculating the consistency ratio. The consistency ratio is obtained by the following formula:

$$\text{Consistency Ratio (CR)} = \frac{0.060}{1.12} = 0.0531\ (5.31\%)$$

After obtaining the consistency ratio and confirming that the calculations are acceptable, the next process is to calculate the local value to assess the intensity of the risk impact and the probability of risk. The local value is calculated by multiplying the number of respondents who assessed the intensity of the risk impact as well as the probability of risk by the weight value obtained for each. There were 26 respondents (samples) used to determine the local value based on their inputs of the risk's probability and impact rating. Then, the result of such multiplication is divided by the total number of respondents who filled out the questionnaire for each scope of work. After the entire process of quantitative analysis using the AHP method is carried out, the risk rating is obtained as follows:

Table 9 shows that there are two dominant risk factors that have the highest rating in terms of their probabilities and impacts on the project, which are (1) Coordination with stakeholders and (2) Change in scope of work/design review. These results were validated by the designated experts, and the two dominant risks are viewed as relevant and often occur in the project. Coordination with stakeholders is a dominant risk due to the project's complex administration process, and the guidance for coordination between the railway operator and its sub-sector entities, the local provincial government, the contractors, and sub-contractors during project execution was not clear. Moreover, the risk of change in the scope of work/design review may occur due to additional work, additional variation orders, and the rejection of the design from certain stakeholders.

Table 9. Dominant risk for every scope of work.

Scope of Work	Dominant Risk Variables	Value of Risk Factors	Risk Level
Track Works	VAR00007—Coordination with Stakeholders (Railway company, provincial government, etc.)	0.525	Moderate Risk
Railway Bridge Structure Work	VAR00073—Coordination with Stakeholders (Railway company, provincial government, etc.)	0.606	Moderate Risk
Station Building Works	VAR00081—Change in Scope of Work/Design Review	0.529	Moderate Risk
Operation Facility Work	VAR00026—Coordination with Stakeholders (Railway company, provincial government, etc.)	0.597	Moderate Risk

After identifying the dominant risk factors for each scope of work as described in the previous discussion, the next step is answering the second research question of this study, namely, the optimization strategy for predicting the completion schedule. The first step is to link the dominant risk factors with the duration of completion of each work activity on a critical path in accordance with the project schedule obtained as part of the secondary research data.

Table 10. Assessment of estimated duration by experts.

Activities	Dominant Risk	Assessment of Estimated Duration by Experts		
		Pessimistic	Most-Likely	Optimistic
Track Demolition Permits and LAA Existing Track IV and V Lines	Coordination with Stakeholders	40	32	25
Track Demolition Work and LAA Lines IV and V Exist		56	49	42
Bore Pile As 6-7-8 D-E-F	Change in Scope of Work/Design Review	14	11	9
Bore Pile As 6-7-8 G-H		10	7	5
Bore Pile As 6-7-8 I-J		10	7	5
Bore Pile As 6-7-8 K-L-M		14	11	9
Pile Cap As 6-7-8 D-E-F		42	39	35
Column As 6-7-8 D-E-F		35	31	28
1st Floor Beams As 6-7-8 D-E-F		30	26	22
HCFP & Plate As 6-7-8-9		35	31	28
Top Floor Column As 6-7-8-9-K-L-M		30	26	22
Beam & Plate Top Floor As 6-7-8-9-K-L-M		37	33	29
Install Platform Wall & Drainage East Side line III & IV New (P.08–P.14)		21	24	21
East Side Platform Floor Casting		5	7	5
Shelter Installation		16	21	17

Table 10. (*Continued*).

Activities	Dominant Risk	Assessment of Estimated Duration by Experts		
		Pessimistic	Most-Likely	Optimistic
Testing & Safety Assessment	Coordination with Stakeholders	30	37	31
Disassemble Money Orders & Upper Flow Electricity (LAA)		21	24	21
Utility Test-Pit in Central P.12 Area		2	5	3
Job Portal P.18-MP.01	Change in Scope of Work/Design Review	36	50	38
P.12 East Portal Jobs		38	52	40
Work of the Lower Structure P.11 East		50	57	50
P.11 East Portal Jobs		38	52	40
Erection 6 PCI Girder for Overpass (P.08–P.09)	Coordination with Stakeholders	12	19	13
Setting Up platform Mount P.09	Change in Scope of Work/Design Review	7	10	7
Erection 3 PCI Girder for Platform Mount 3 Elevated	Coordination with Stakeholders	6	10	7
Erection Segment Box Girder P.18–P.19		54	61	55
Erection Segment Box Girder P.17–P.18		54	61	55
P.14–P.17	Change in Scope of Work/Design Review	21	24	21
P.17–P.21		28	31	28
P.19–P.21		10	13	10

The list of activities on the critical track is fully obtained from the available secondary data, namely the Double-Double Track Development (Package A) project schedule. The process, as stated in **Table 10**, is the result of expert assessments based on experience and current field conditions. After determining the dominant risk factors related to each work activity, the researchers then asked the experts to provide a predictive assessment of the duration for completing each work activity on the critical path because of the dominant risk factors associated with it.

The next stage was to conduct simulations using the PERT distribution in the @RISK 8.2 software. In the simulation, researchers used an iteration of 100,000 times so that the data obtained can be guaranteed its accuracy. Simulation was carried out for the duration of every work activity on the critical path. After the simulation was completed, a percentage of the confidence level can be used to interpret the results. In this case, researchers used 90%, 95%, and 99% percentages to compare the duration results. However, for the final conclusion, researchers used a 95% confidence level, 5% is the fault tolerance commonly used by researchers, with the intention that there is a 5% chance that the final result is not exactly what was expected (Gigerenzer et al., 2004).

Based on **Table 11**, the results of the post-optimization completion schedule prediction for the case study of the Double-Double Track Development (Package A) project would be on 30 March 2024, with a confidence level of 95%. This result was analyzed based on the dominant risk factors that influence the critical path activities of the project. As a comparison, based on the project's secondary data, its existing completion schedule (before optimization) was supposed to be on 29 December 2023.

Thus, there is a 93-day deviation between the existing and the post-optimization duration.

Table 11. Dominant risks associated with activities on critical lines.

Activities (Critical Path)	Confidence Level			Duration After Optimization	
	90%	95%	99%	Begin	Finish
Track Demolition Permits and LAA Existing Track IV and V Lines	36	37	38	Sun 26/09/21	Mon 01/11/21
Track Demolition Work and LAA Lines IV and V Exist	53	53	55	Tue 02/11/21	Fri 24/12/21
Bore Pile As 6-7-8 D-E-F	12	13	13	Thu 27/01/22	Tue 08/02/22
Bore Pile As 6-7-8 G-H	8	9	9	Tue 18/01/22	Wed 26/01/22
Bore Pile As 6-7-8 I-J	8	9	9	Sun 09/01/22	Mon 17/01/22
Bore Pile As 6-7-8 K-L-M	12	13	13	Sun 26/12/21	Sat 08/01/22
Pile Cap As 6-7-8 D-E-F	41	41	41	Mon 07/03/22	Sat 16/04/22
Column As 6-7-8 D-E-F	32	33	34	Sun 17/04/22	Fri 10/06/22
1st Floor Beams As 6-7-8 D-E-F	28	28	29	Sat 11/06/22	Fri 08/07/22
HCFP & Plate As 6-7-8-9	32	33	34	Sat 09/07/22	Wed 10/08/22
Top Floor Column As 6-7-8-9-K-L-M	28	28	29	Thu 11/08/22	Wed 07/09/22
Beam & Plate Top Floor As 6-7-8-9-K-L-M	35	35	36	Thu 08/09/22	Wed 12/10/22
Install Platform Wall & East Side Drainage	23	23	23	Sat 26/11/22	Sat 07/01/23
East Side Platform Floor Casting	6	6	7	Sun 08/01/23	Fri 13/01/23
Shelter Installation	18	19	20	Sat 14/01/23	Wed 01/02/23
Testing & Safety Assessment	33	34	35	Thu 02/02/23	Tue 07/03/23
Disassemble Money Orders & Upper Flow Electricity (LAA)	23	23	23	Wed 08/03/23	Thu 30/03/23
Utility Test-Pit in Central P.12 Area	3	3	4	Fri 31/03/23	Sun 02/04/23
Job Portal P.18 - MP.01	42	44	46	Sun 17/09/23	Mon 30/10/23
P.12 East Portal Jobs	44	46	48	Sun 25/06/23	Wed 09/08/23
Work of the Lower Structure P.11 East	53	54	55	Thu 04/05/23	Mon 26/06/23
P.11 East Portal Jobs	44	46	48	Sat 17/06/23	Tue 01/08/23
Erection 6 PCI Girder for Overpass (P.08–P.09)	15	16	17	Thu 20/10/22	Fri 04/11/22
Setting Up platform Mount P.09	8	9	9	Sat 05/11/22	Sun 13/11/22
Erection 3 PCI Girder for Platform Mount 3 Elevated	8	8	9	Mon 14/11/22	Mon 21/11/22
Erection Segment Box Girder P.18–P.19	58	59	59	Wed 08/11/23	Thu 25/01/24
Erection Segment Box Girder P.17–P.18	57	58	59	Wed 08/11/23	Wed 24/01/24
P.14–P.17	23	23	23	Fri 26/01/24	Sat 17/02/24
P.17–P.21	30	30	30	Sun 18/02/24	Mon 18/03/24
P.19–P.21	12	12	12	Tue 19/03/24	Sat 30/03/24

The deviation provides important information for the project manager to control the project. The project manager can control the project's schedule by predicting its completion time using the forecasting analysis. The forecasting process is based on the dominant risk factor's quantitative analyses using a probabilistic approach. Therefore, they may be able to plan for the project's extension of time by proposing the post-optimization schedule results as its basis.

5. Conclusion

Based on the data processing and discussion of the research that has been carried out, the following research conclusions can be obtained. The dominant risk factors resulting in delays in completion schedules on the Double-Double Track Development Project (Package A) are "Coordination with Stakeholders" for the scope of work of the Rail Road, Railway Bridge Structure, and Operating Facilities as well as "Change in of Scope of Work/Review Design" for the scope of work of the Station Building. Both factors are part of the internal risk factors of a construction project, as stated by Bepari et al. (2024) and Siraj and Fayek (2019).

The risk factor of coordination issues with stakeholders is a dominant risk due to the complex administrative process in the project and the lack of clear instructions or guidance for coordination between the stakeholders during project execution. These issues occurred not only in the internal stakeholder coordination but also with the external stakeholders of the project. Therefore, developing clear communication and coordination guidelines is necessary. Moreover, the risk of change in the scope of work or design is the other significant factor that caused the project to experience delays. Additional work, additional variation orders, and the rejection of the design from certain stakeholders are the causes of this risk. To mitigate this risk, a detailed and prompt change order process must be implemented, supported by an intensive stakeholder engagement and communication process to reduce delays in such changes or additional work.

The post-optimization completion schedule prediction using the Program Evaluation and Review Technique (PERT) method for the case study of the Double-Double Track Development Project (Package A) resulted in a completion date of 30 March 2024, with a confidence level of 95%. The result of this study is highly useful in determining the project's schedule end date.

This study provides the methods and approach for controlling the project's schedule, particularly for projects with high complexities and involving various stakeholders. By using a risk analysis approach synthesized with probabilistic quantitative analysis, the current schedule can be predicted more accurately. This study only focuses on one specific case of a railway construction project, but it can provide insights into managing schedules for other types of infrastructure construction projects.

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