Risk Analysis And Mitigation Strategies For MRT (Mass Rapid Transit) And LRT (Light Rail Transit) Construction Projects In Jakarta

Achmad Fajar Malik[1*], Hermanto Dwiatmoko[2]

[1,2]Magister Teknik Sipil, Universitas Mercu Buana Jakarta, Indonesia
[*] Corresponding author:
Email: achmadfajar2@gmail.com

Abstract.
The construction projects of Mass Rapid Transit (MRT) and Light Rail Transit (LRT) in Jakarta are highly complex and therefore prone to various risks that may affect project performance. Consequently, it is necessary to identify dominant risk patterns, analyze the influence of risks on project performance, and formulate risk mitigation strategies. This study employed the Severity Index (SI) method to determine risk severity, a Risk Matrix to map risk levels, multiple linear regression analysis to examine the influence of risks on project performance in terms of time, quality, and cost, and Fault Tree Analysis (FTA) to identify the root causes of dominant risks. The results identified several dominant risks categorized as high risks in MRT and LRT construction projects in Jakarta. The regression analysis also showed that, partially, material risk had a significant effect on time (Sig. = 0.017), human resource risk had a significant effect on quality (Sig. = 0.018), and economic risk had a significant effect on cost (Sig. = 0.016). The FTA results indicated that the risks with the highest probabilities of occurrence were lack of workforce competency (10.2%), difficulties in project financing (9.6%), and delays in material delivery (5.0%). Risk mitigation strategies should prioritize improving workforce competency, strengthening material management, enhancing project financial control, and improving coordination in managing design changes to improve schedule performance, quality, and cost efficiency in MRT and LRT construction projects in Jakarta.
Keywords: *Risk Management, Project Performance and Risk Mitigation.*

I. INTRODUCTION

The city of Jakarta continues to experience development and improvements in various aspects, especially in improving facilities and infrastructure, particularly public transportation, considering that transportation is a crucial aspect for large cities in the world [1]. The congestion that occurs in Jakarta has a serious impact on air pollution, decreased productivity, and also impacts the psychology of the community. The strategy to overcome this is to develop mass transportation to encourage people to change their urban lifestyle from private vehicles to the use of public transportation [2].*Mass Rapid Transit*(MRT) and*Light Rail Transit*(LRT) has emerged as an innovation and solution that can move people from one place to another in a shorter time.

The Jakarta MRT Phase 2A construction project stretches approximately 6.3 km from the Bundaran HI area to Kota with 7 underground stations. Meanwhile, the Jakarta LRT Phase 1B construction project connects the Velodrome to Manggarai with a total length of 6.4 km consisting of 5 stations. The implementation of the MRT and LRT construction is certainly not without obstacles and challenges. The high level of construction complexity, the Jakarta MRT and LRT projects face various technical and managerial challenges during the implementation process so that they have the potential to affect the performance of time, quality and cost.

A risk source or risk factor in a construction project is defined as any factor that has the potential to cause loss or damage to a project due to a change that is contrary to the initial project conditions or due to an unforeseen situation. Risk factors result in risk consequences through the occurrence of a risk event (*risk event*). A risk event or risk incident is the occurrence of a negative event [3]. In construction projects, risk events or incidents can be described as variations (additions or reductions) in the quality and quantity of work, productivity, performance, and schedules in the form of things like delays, interruptions or payments, or work progress. Meanwhile, risk consequences are the final result of a risk event that causes deviations from the project object. Risk consequences can be seen in terms of project objectives, such as cost, time, quality, and safety (Al-Bahar and Crandall, 1990; Zhang, 2007).

Risk in construction is a consequence of uncertainty and inherent and unavoidable changes that always occur in every aspect and stage. Therefore, in achieving its objectives, relatively complex construction projects need to have a good risk management plan [3]. The impact of project risks can affect productivity, performance, quality, and cost limits, so risk analysis is necessary as a mitigation effort. Risk analysis is an integral part of risk management in PMBOK, which includes risk management planning, risk identification, assessment (qualitative and quantitative), response planning, and risk monitoring. The concept aims to maximize the probability and consequences of positive events (*positive event*) and minimize the probability and consequences of adverse events to project objects [4].

The impact of project risks can impact productivity, performance, quality, and cost constraints. Risk management is a systematic management method to reduce unwanted risks. According to PMI PMBOK (2018), project risk management includes the process of risk management planning, identification, analysis, response planning, response implementation, and risk monitoring on a project. The goal of project risk management is to increase the probability and/or impact of positive risks and to reduce the probability and/or impact of negative risks, in order to optimize the chances of project success.

Risk management is an integrated part, not only in operational and planning processes, but in all processes in an organization to achieve its goals, namely starting from the planning process, organizing, implementing, controlling, evaluating, monitoring, improving, and so on. In addition, risk management is not only needed by certain types of businesses, such as aviation or shipping businesses, but all types of businesses, even broader than businesses, namely all organizations in general [5].

The goal of risk management is to increase the likelihood and impact of positive events and to reduce the likelihood and impact of negative events. Risk management can help optimize the use of resources (costs, time, and labor) to avoid wasteful impacts. Identifying and mapping potential problems early on allows preventative measures to be taken to achieve the project's ultimate goal of increasing the probability of project success and reducing the likelihood of losses [6].

II. RESEARCH METHODS

This study employed a quantitative method with primary data obtained from a questionnaire. The questionnaire, used as a data collection tool, was administered to predetermined respondents. The respondents were the main stakeholders in the Jakarta MRT and LRT construction, namely the owner, contractor, and supervising consultant. Sampling was conducted using the*purposive sampling*, that *purposive sampling*This is done by taking subjects not based on strata, random or region but based on certain objectives [7]. The aim and consideration for taking these subjects/samples is that the sample has mastery over matters related to the development of the railway system.

The research variables consist of seven independent variables (*independent*) which represents the risk factor groups in the MRT and LRT construction projects in Jakarta. The seven variables include material risk (X1), equipment and machinery risk (X2), human resource risk (X3), economic risk (X4), technical risk (X5), environmental risk (X6), and non-technical risk (X7). Each research variable is described in several risk indicators that are used as statement items in the research questionnaire. The preparation of indicators is based on the results of literature studies from various previous studies and is strengthened through the risk identification process in the field in the Jakarta MRT Phase 2 and Jakarta LRT Phase 1B construction projects. Thus, the indicators used not only have a strong theoretical basis, but also describe the actual risk conditions in railway construction projects in Jakarta. Details of the research are presented in Table 1.

The questionnaire data that has met the quality requirements is then analyzed using the method*Severity Index*(SI) to obtain the probability level and impact level of each risk variable.*Severity Index*then mapped using*Risk Matrix*to obtain a risk level classification based on a combination of probability and impact. Multiple linear regression analysis to examine the influence of risk categories on project performance including time, quality, and cost. The results of the regression analysis provide information on the magnitude of the influence of each risk category, both simultaneously and partially, on project performance, so that the most dominant risk factors affecting the achievement of project targets can be identified. Risks that have been identified as dominant risks are then analyzed using the FTA method to determine the root causes of the risk. FTA analysis is carried out by compiling a logical relationship between peak events (*top event*) and the causal factors through logic gates (*logic gate*), thus obtaining a systematic overview of the main sources of risk. The results of the root cause identification serve as the basis for developing more targeted risk mitigation strategies. Thus, this study not only identifies risk levels and analyzes their impact on project performance but also produces recommendations for mitigation strategies that can be implemented to minimize both the opportunities and impacts of risks in MRT and LRT construction projects in Jakarta.

Table 1 Research Variables and Risk Identification

Code	Variable Risk	Reference
X1	Material Risk	
X1.1	Inaccuracies in material ordering	[8]
X1.2	Material quality does not match specifications	[8], [9]
X1.3	Delay in material delivery	[2],
X1.4	Loss of material	[10]
X1.5	Changes in the materials used	[11]
X2	Machinery and Equipment Risks	
X2.1	Machine/equipment damage occurred during the work	[8]
X2.2	Lack of machines/work equipment	[2]
X2.3	The condition of the work equipment is not suitable for use	[2]
X2.4	Lost tool	[12]
X3	Human Resource Risk	
X3.1	Lack of workforce competency/skills	[8], [2]
X3.2	Low labor productivity	[8], [9]
X3.3	Lack of workforce discipline	[2]
X3.4	New workforce replacement	[13]
X3.5	Lack of manpower to complete the job	[1]
X4	Economic Risk	
X4.1	Funding difficulties in completing construction	[14] [15]
X4.2	Late payments to contractors	[14]
X4.3	Inaccurate cost estimates/*cost overrun*	[15] [9]
X4.4	Increase in material and labor prices	[16]
X4.5	*Cash flow*troubled company	[8]
X5	Technical Risk	
X5.1	Design changes occur due to adjustments in the field.	[8], [9]
X5.2	Changes to the design of the plan drawings take too long	[12]
X5.3	Lack of supervision in implementation	[8]
X5.4	Inappropriate use of technology and work methods	[17], [18]
X5.5	Difference between specification and implementation	[15]
X6	Environmental Risks	
X6.1	Poor construction waste management process	[19]
X6.2	Work delays due to weather changes	[8], [20]
X6.3	A natural disaster occurred	[2]
X6.4	Pollution that occurs in the work environment	[16]
X7	Non-Technical Risks	
X7.1	Political instability and changes in government policy	[20]
X7.2	Weak communication between project teams	[17], [9]
X7.3	A work accident occurred during the implementation of a construction project	[17]
X7.4	Lack of safety at job sites for workers and construction assets	[15]

III. RESEARCH RESULTS AND DISCUSSION

A questionnaire was administered to 80 respondents, consisting of owners, consultants, and contractors involved in the Jakarta MRT and LRT projects. The questionnaire results served as a reference for analysis and discussion in the next stage. Data analysis was conducted in stages and systematically to ensure that the results obtained had methodological validity and analytical strength. The analysis stage began with instrument quality testing through validity and reliability tests to ensure that each statement item was able to measure the research variables accurately and consistently. Next, classical assumption tests were conducted, including normality tests, multicollinearity tests, and heteroscedasticity tests as requirements in implementing multiple linear regression analysis. Descriptive analysis was then conducted using the*Severity Index*(SI) to determine the probability and impact of each risk variable. The risks were then analyzed using multiple linear regression to determine the extent of the risk variable's influence on project performance. The results of this analysis were then further refined using the method*Fault Tree Analysis*(FTA) to identify the root causes of dominant risks so that appropriate, effective, and applicable mitigation strategies can be formulated for railway construction projects in Jakarta.

3.1 Risk Level Analysis

The risk level is calculated by multiplying the probability and impact values for each risk variable. This approach is based on risk management principles, where the risk level is a function of the likelihood of an event occurring and the magnitude of its impact. This calculation produces a risk score that reflects the actual threat level to project success. The higher the multiplication score, the higher the risk level that should be prioritized for control. The results of the risk level analysis are presented in Table 2 below.

Table 2 Risk Level (Probability x Impact)

Code	Probability (P)	Impact on Time				Impact on Quality				Impact on Costs			
		D	AND	PxD	Category Risk	D	AND	PxD	Category Risk	D	AND	PxD	Category Risk
X1.1	2	3	57%	6	Currently	2	46%	4	Low	2	41%	4	Low
X1.2	2	2	42%	4	Low	4	76%	8	Currently	2	47%	4	Low
X1.3	4	4	80%	16	High	2	38%	8	Currently	3	63%	12	Currently
X1.4	4	3	51%	12	Currently	2	41%	8	Currently	2	46%	8	Currently
X1.5	2	2	45%	4	Low	3	59%	6	Currently	2	43%	4	Low
X2.1	2	3	67%	6	Currently	2	40%	4	Low	3	63%	6	Currently
X2.2	3	3	53%	9	Currently	2	38%	6	Low	2	39%	6	Low
X2.3	2	2	39%	4	Low	2	46%	4	Low	2	43%	4	Low
X2.4	2	2	50%	4	Low	2	37%	4	Low	3	57%	6	Currently
X3.1	4	4	76%	16	High	4	80%	16	High	2	41%	8	Currently
X3.2	4	3	51%	12	Currently	2	42%	8	Currently	4	73%	16	High
X3.3	2	2	44%	4	Low	3	64%	6	Currently	2	38%	4	Low
X3.4	2	2	42%	4	Low	4	75%	8	Currently	2	45%	4	Low
X3.5	4	4	71%	16	High	2	39%	8	Currently	2	44%	8	Currently
X4.1	4	4	77%	16	High	2	44%	8	Currently	4	77%	16	High
X4.2	4	3	64%	12	Currently	2	38%	8	Currently	4	98%	16	High
X4.3	3	2	38%	6	Low	2	39%	6	Low	4	79%	12	High
X4.4	3	2	46%	6	Low	2	44%	6	Low	4	73%	12	High
X4.5	4	2	50%	8	Currently	2	38%	8	Currently	3	57%	12	Currently
X5.1	4	4	81%	16	High	2	46%	8	Currently	2	41%	8	Currently
X5.2	3	4	74%	12	High	2	36%	6	Low	2	41%	6	Low
X5.3	2	2	45%	4	Low	4	71%	8	Currently	2	40%	4	Low

X5.4	-	3	56%	-	-*)	3	59%	-	-	2	40%	-	-
X5.5	-	2	40%	-	-*)	3	55%	-	-	2	41%	-	-
X6.1	2	2	44%	4	Low	2	37%	4	Low	-	-	-	-***)
X6.2	3	3	60%	9	Currently	2	36%	6	Low	3	52%	9	Currently
X6.3	2	2	49%	4	Low	2	35%	4	Low	2	46%	4	Low
X6.4	2	-	-	-	-**)	2	37%	4	Low	2	42%	4	Low
X7.1	2	2	45%	4	Low	2	33%	4	Low	3	50%	6	Currently
X7.2	3	2	49%	6	Low	2	40%	6	Low	2	46%	6	Low
X7.3	3	3	70%	9	Currently	2	35%	6	Low	2	39%	6	Low
X7.4	2	2	44%	4	Low	2	42%	4	Low	3	54%	6	Currently

Is:

**) The probability indicator of the variable is invalid based on the validity test.*

***) The impact indicator on variable time is invalid based on the validity test.*

****) The impact indicator on variable costs is not valid based on the validity test.*

The presence of a variable in the red zone indicates that the risk not only has a relatively high probability of occurrence but also has the potential to cause serious consequences for achieving project targets, both in terms of time, quality, and cost. In the context of project risk management, risks in this category are included in the priority risk group that requires immediate and structured control measures. If the variable is in the red zone due to a very high impact value even though the probability is moderate, this condition indicates that the risk is consequentially critical. This means that even though the frequency of the event is not dominant, the resulting impact can cause significant disruption to the continuity of the project. Conversely, if the position in the red zone is influenced by equally high probability and impact, then the risk is included in the main risk category (*major risk*) which has the potential to occur and also has major consequences.

3.2 Determination of Dominant Risks

3.2.1 Dominant Risk on Impact over Time

The results of the analysis show that the risks that have the highest risk level in the dimension of impact on time include:

1. Delay in material delivery (X1.3)
2. Lack of workforce competency/skills (X3.1)
3. Lack of manpower to complete the job (X3.5)
4. Funding difficulties in completing construction (X4.1)
5. Design changes occur due to adjustments in the field (X5.1)
6. Design changes to plan drawings take too long (X5.2)

These risks indicate that material, labor, funding, and design changes significantly contribute to potential project delays. Conceptually, the time dimension of a construction project is highly sensitive to operational and administrative disruptions, so risks related to technical and financial coordination tend to directly impact the completion schedule of a railway construction project.

3.2.2 Dominant Risks on Impact on Quality

In the quality dimension, the analysis results show that the risks with the highest risk level are:

1. Lack of workforce competency/skills (X3.1)

These findings indicate that the quality of construction work is significantly influenced by the competence of human resources. This risk not only impacts the quality of the work but also has implications for the potential*rework*, cost overruns, and project delays. The fact that this variable also appears as a dominant risk in the time dimension indicates that labor factors are a critical element in the success of railway construction projects.

3.2.3 Dominant Risk on Impact on Cost

The results of the analysis on the dimensions of impact on costs, risks with the highest risk level include:

1. Low labor productivity (X3.2)
2. Funding difficulties in construction completion (X4.1)
3. Late payments to contractors (X4.2)
4. Inaccurate cost estimates/*cost overrun*(X4.3)
5. Increase in material and labor prices (X4.4)

These results indicate that financial aspects and labor productivity are the dominant factors influencing potential project cost overruns. Risks related to cash flow and the accuracy of cost estimates significantly impact the financial stability of construction projects.

3.2.4 Comprehensive Identification of Dominant Risks

When viewed as a whole, there are several variables that appear in more than one impact dimension, namely:

1. Lack of workforce competency/skills (X3.1) → impacts time and quality
2. Funding difficulties in completing construction (X4.1) → impacts time and costs

The consistent occurrence of these variables across more than one impact dimension indicates that these risks have a broader exposure than other risks. Thus, these two variables can be categorized as the main dominant risks in this study, as they have a significant influence on more than one project objective (*time – quality – cost*).

3.3 Multiple Linear Regression Analysis

Multiple linear regression analysis was conducted to determine the influence of risk variables on the performance of the Jakarta MRT and LRT construction projects. The independent variables consisted of seven risk groups: material risks (X1), machinery and equipment (X2), human resources (X3), economic risks (X4), technical risks (X5), environmental risks (X6), and non-technical risks (X7). Meanwhile, the dependent variables consisted of three aspects of project performance: impact on time (Y1), quality risks (Y2), and costs (Y3). The analysis was conducted using IBM SPSS software.*Statistics*To obtain a regression model, test the influence of each risk variable, and evaluate the model's ability to explain variations in project performance. Based on the regression analysis conducted on the three dependent variables, the results of the analysis can be summarized in Table 3 below.

Table 3 Results of Multiple Linear Regression Analysis

Dependent Variable	F Test (Sig.)	Significantly Influential Variables (t-Test)	Adjusted R2	Conclusion
Impact on Time	0.350	Material Risk (X1)	0.242	Simultaneously it is not significant, but partially material risk has a significant effect on the impact of time.
Impact on Quality	0.191	Human Resource Risk (X3)	0.240	Simultaneously it is not significant, but partially human resource risk has a significant effect on quality impact.
Impact on Costs	0.502	Economic Risk (X4)	0.180	Simultaneously it is not significant, but partially economic risk has a significant effect on the cost impact.

The results of the simultaneous test (F-test) on the three regression models have a significance value greater than 0.05, so the hypothesis stating that there is a simultaneous influence of all risk variables on project performance cannot be accepted. However, the results of the partial test (t-test) indicate that there are several risk variables that have a significant influence on certain performance aspects. In the regression model of the impact on time, the material risk variable is the only variable that has a significant influence. In the regression model of the impact on quality, the human resource risk variable shows a significant influence. Meanwhile, in the regression model of the impact on cost, the economic risk variable is the only variable that has a significant influence. The other risk variables do not show a significant influence on the three aspects of project performance based on the results of statistical tests.

3.4 Analysis *Fault Tree Analysis* (FTA)

Fault Tree Analysis(FTA) is used as a deductive analysis method (*top-down*) which describes the logical relationship between peak events (*top event*) with various causal events (*basic event*) through AND and OR logic gates. The FTA analysis focuses on three risk indicators, namely X3.1 (Lack of workforce competence/skills), X4.1 (Funding difficulties in completing construction), and X1.3 (Delays in material delivery). These three variables were chosen because they have the highest priority level and represent the human resource risk group, economic risk, and material risk or*supply chain*.

3.4.1 FTA Risk X3.1 – Lack of Workforce Competence/Skills

1. Determination of the Peak Event (Top Event)

*Top event*What occurs in this indicator is a decline in project performance due to a lack of workforce competence. This risk has a significant impact on:

a) Delay in completion of work.

b) Decrease in the quality of work results.

c) Increased costs due to*rework*.

2. Identification*Basic Event*

Causes between (*intermediate event*) is broken down into basic events:

A1. Lack of regular training programs

A2. Absence of technical certification according to project specifications

B1. Non-competency-based workforce selection

B2. Recruitment targets that are too fast without competency evaluation

C1. Lack of field supervision

C2. Work standards are not consistently enforced

3. Quantitative Analysis

Table 4 Probability Calculation X3.1 Quantitative Analysis of FTA

Variables	Total Score	Shoes	Probability Value
Impact on Time			
X3.1	302	6392	0.047
Impact on Quality			
X3.1	319	5473	0.058

Since both dimensions have high categories, the aggregate probability is calculated using the OR approach:

$P(TE) = 1 - (1 - Pw)(1 - Pm)$ .... (1)

$P(TE) = 1 - (1 - 0.047)(1 - 0.058) = 0.102$

Thus, the probability of a peak event occurring is 10.2%.

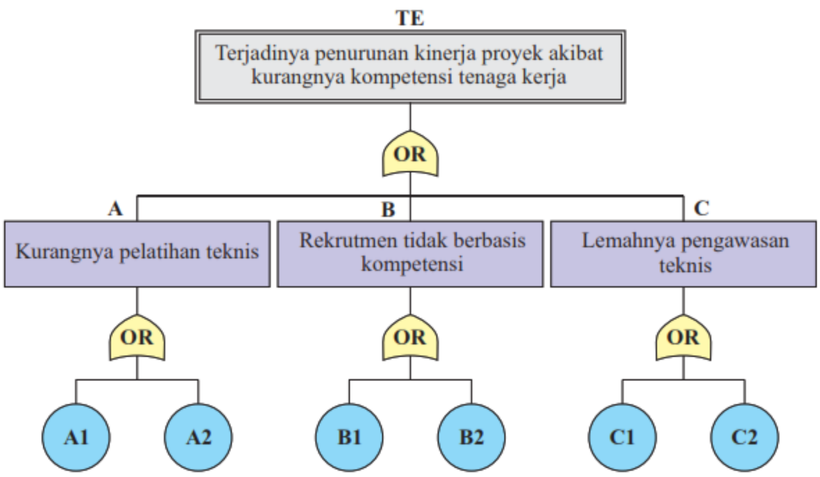

Fig. 1 Risk FTA Diagram X3.1

3.4.2 FTA Risk X4.1 – Funding Difficulties in Construction Completion

1. Determination of Peak Events (*Top Event*)

*Top event*In this analysis, the risk is the delay in project implementation due to funding difficulties. This risk impacts:

a) Delay in completion of work.
b) Increased construction costs.

2. Identification*Basic Event*

Identification*basic event*among others:

D1. Financial planning is not mature
D2. There was a cost overrun (*cost overrun*)
E1. Incomplete administrative documents
E2. Multi-level payment approval process
F1. Late payment from the owner

3. Quantitative Analysis

Table 5 Probability Calculation X4.1 Quantitative Analysis of FTA

Variables	Total Score	Shoes	Probability Value
Impact on Time			
X4.1	309	6392	0.048
Impact on Costs			
X4.1	309	6056	0.051

$P(TE) = 1 - (1 - 0.048)(1 - 0.051) = 0.096$ .... (2)

The probability of a peak event is**9,6%**.

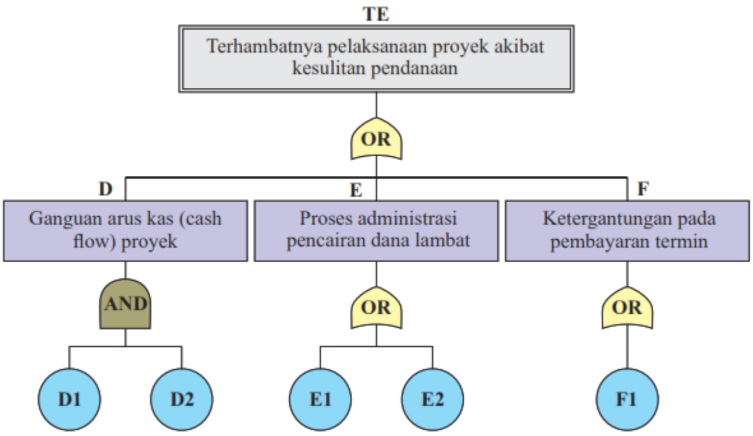

Fig. 2 Diagram FTA Risiko X4.1

3.4.3 FTA Risk X1.3 – Delay in Material Delivery

1. Determination of Peak Event (*Top Event*)

*Top event*This is the risk of materials arriving late at the project site. This risk impacts the project's time performance.

2. Identification*Basic Event*

Identification*basic event*among others:

G1. *Supplier overload*
G2. Production delays
H1. Distribution bottlenecks
H2. Extreme weather
I1. Inaccurate material requirement calculations
I2. The material approval process takes too long.

3. Quantitative Analysis

Table 6 Calculation of Probability Analysis X1.3 Quantitative Analysis of FTA

Variables	Total Score	Shoes	Probability Value
Impact on Time			
X1.3	318	6392	0.050

P(TE) = 0.050 .... (3)

The probability of a peak event is**5,0%**.

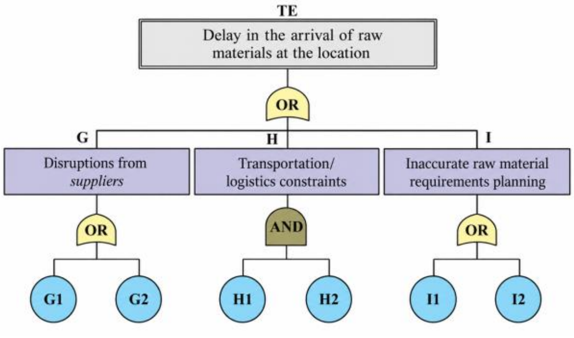

Fig. 3 FTA Diagram of Risk X1.3

3.5 High Category Risk Management and Mitigation Strategy

Risk management in the Jakarta MRT and LRT construction projects must be systematic, structured, and prioritized. Management and mitigation strategies were developed through expert interviews and literature review. Based on the results of the risk matrix and FTA analysis, the following table presents risk responses and mitigation strategies.

Table 7 Priority Risk Responses (High Risk and Risk Monitoring)

Variable Risk	Risk Response	Mitigation (concrete steps)	Reference
X3.1 – Lack of workforce competency/skills	*Mitigate* (Reducing Risk)	Competency-based recruitment, training programs*on-site*& certification, mentorship, increased supervision & QC, productivity KPIs.	Support: training studies and productivity improvement [21]
X4.1 – Funding difficulties in completing construction (*cash-flow problems*)	Mitigation and (partial) transfer of some risks via bank*guarantees/ retentions.*	Planning*cash-flow* And *forecasting*, *contingency fund*, accelerating the claims process, monitoring terms.	Working capital management and*payment systems* [22].
X1.3 – Delay in material delivery (*supply-chain delay*)	Mitigation and transfer via supplier*contracts/ insurance*. Sharing risks through procurement contracts	*Procurement planning*critical schedule based, *multiple supplier strategy*, *tracking*material delivery,*buffer stock*for general materials.	Recommendation *resiliency* and mitigation*supply-chain*in construction [23].
X3.5 – Shortage of manpower	Mitigation (through HR planning and control)	Manpower planning based on project schedule, reserve workforce database,*cross training*(training workers to be able to handle other jobs)	Construction HR management support and planning practices [24].
X5.1 – Design changes due to field adjustments	Mitigation and control (Avoid changes that can be prevented through careful design).	Design validation before construction, comprehensive DED (thorough survey before finalization).	Support for impact studies*design changes* on *cost/time* [25].
X5.2 – Design changes to plan drawings take too long	Mitigation and control (focus on accelerating and controlling the approval process)	*Digital approval workflows*, SLA for drawing revisions, use of BIM or collaborative platforms, appointment of a design coordinator.	Study of workflow improvement and design digitalization [26].
X3.2 – Low labor productivity	Share with subcontractor work guarantee).	Daily productivity monitoring, training to improve efficiency, incentive schemes, lean methods, and productivity comparisons.	Literature support construction productivity and HR interventions [27].

X4.2 – Late payments to contractors	Risk transfer through contract clauses and banking instruments.	Realistic payment schedules, automatic billing and progress certification, use of escrow accounts/holding accounts/bank guarantees, expedited administrative approvals.	Study of payment delays and administrative solutions [28].
X4.3 – Inaccurate cost estimates /*Cost overrun*	Avoiding risks	Data-driven estimates (historical database), contingency planning, sensitivity analysis, periodic re-estimation, contract type selection (lump sum and cost-plus).	Review of cost overrun factors and controlling recommendations [29].
X4.4 – Increase in material & labor prices	Transfer through clause*pass-through*if the contract allows it.	Early purchase, price escalation clause, hedging contract, futures contract.	Material market literature / inflation and*procurement strategies* [18].
X1.4 – Material loss (monitoring)	Avoiding risks	Inventory digitalization (RFID/barcode), controlled access to stores, cycle counting, security and auditing, insurance for material theft.	Study support*inventory control*and materials*handling* [30].
X4.5 –*Cash-flow*troubled companies (monitoring)	Transfer of risk through guarantees or support of the parent company	Corporate working capital management, banking facilities/*credit lines*, cost control,*project-level cash forecasting*.	Study of cash flow & working capital management in construction [22].

IV. CONCLUSION

Based on the results of the analysis and discussion regarding the risks in the MRT and LRT construction projects in Jakarta, the following conclusions can be drawn:

4.1 High Category Risk in Railway Projects in Jakarta

Based on the results of the analysis*Severity Index*(YES) And *Risk Matrix*, six risks were found to be included in the high risk category, namely delays in material delivery (X1.3), lack of workforce competence and skills (X3.1), insufficient number of workers to complete the work (X3.5), funding difficulties in completing construction (X4.1), design changes due to adjustments in the field (X5.1), and the length of the process of changing the plan drawings (X5.2). Thus, the dominant risk patterns in the MRT and LRT projects in Jakarta do not only come from the technical aspects of construction, but are also influenced by interrelated managerial and administrative factors.

4.2 The Impact of High Category Risk on Time, Quality, and Cost Performance

Based on the results of multiple linear regression analysis, it was obtained that the partial test results showed that there were risk categories that had a significant influence on each project performance indicator. In time performance, the material risk category (X1) had a significant influence with a significance value of 0.017 (<0.05), so that disruptions in material procurement and distribution were the main factors influencing delays in project completion. In quality performance, the human resource risk category (X3) had a significant influence with a significance value of 0.018 (<0.05), which indicated that workforce competence and skills were the main factors in maintaining the quality of construction work. Meanwhile, in cost performance, the economic risk category (X4) had a significant influence with a significance value of 0.016 (<0.05), so that the funding conditions and financial management of the project were the most determining factors in increasing implementation costs. These results indicate that each dimension of project performance is influenced by different risk categories so that risk control strategies need to be formulated specifically according to the characteristics of each risk.

4.3 Risk Management and Mitigation Strategy

Based on the results of the integration of multiple linear regression analysis and FTA, the risk mitigation strategy is focused on risks that have a high level of severity, have been proven to have a significant impact on project performance, and have a dominant root cause. The FTA results indicate that the lack of workforce competency (probability 10.2%), funding difficulties in completing construction (9.6%), And Delays in material delivery (5.0%) are a priority risk that requires immediate action. Therefore, recommended mitigation strategies include improving workforce competency through training and certification, strengthening procurement planning and material supply chain control, improving project cash flow management, accelerating the design change coordination process, and strengthening coordination between stakeholders during project implementation. These strategies are expected to reduce potential delays, maintain construction quality, control project costs, and increase the success of the MRT and LRT projects in Jakarta.

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