

Risk Analysis in the Implementation of Construction Projects Using Fault Tree Analysis and Risk Matrix

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ABSTRACT

Post-COVID-19 pandemic, the construction industry sector began to experience good recovery and growth due to government support and policies related to infrastructure programs and the existence of the National Capital City (IKN) development project. In line with the prospects and potential in the construction sector, PT XYZ began to develop a business line in the construction business in the last three years. However, the company's performance in this sector has not yet reached the target set by the company. Therefore, one way to evaluate and improve work processes and better work planning is to implement risk management. This study aims to analyze the risks in the implementation of construction projects at PT XYZ using the fault tree analysis method and risk matrix. The results of this study showed that failure or low achievement of business income (project progress) can be caused by several factors, namely Business & Financial, Technical & Operational, K3L & Social, then Legal. There are 36 risks with a classification of 7 intermediate events and 29 basic events. There are three risks in the high-exposure area, namely Limited working capital (BE15), Late/default (IE1), and Limited employer liquidity (BE1). For significant risks, the top 10 risks (basic events) and 3 risks (intermediate events) have a risk exposure value of 4.4 M, which can be reduced to 1.63 M if PT XYZ implements a mitigation plan for the top risks. In addition, PT XYZ must also strengthen and give more authority to the risk committee to weigh the feasibility and readiness of the project implementation to be worked on. The results of this study are expected to contribute to risk management at PT XYZ so that the Company gets the right strategies and policies to improve performance and success in achieving production targets in the construction sector.

Keywords: *Construction, Risk Management, Fault Tree Analysis, Risk Matrix*

INTRODUCTION

Construction projects are one of the most complex and challenging industrial fields, involving various elements such as planning, design, implementation, and supervision (Kerzner, 2025; Tran & Nguyen, 2024; Yap et al., 2019). This complexity is caused by the large number of parties involved, ranging from project owners, contractors, subcontractors, to material suppliers. In addition, construction projects are often influenced by external factors such as weather changes, fluctuations in raw material prices, and regulatory changes. The high involvement of these elements makes construction projects highly vulnerable to various risks (Deng et al., 2014; Winch, 2012). No construction project is free of risks; risks can be faced, managed, or accepted. Risk cannot be denied (El-Hoteiby et al., 2017; Lantham, 1994). Risks faced in construction projects can be technical or non-technical, such as the risk of delays in project completion, errors in planning or implementation, occupational health and safety problems, and financial constraints (Jahidi et al., 2024; Santoso et al., 2022; Tender et al., 2022). If not managed properly, all of these risks can lead to cost overruns, delays in turnaround times, or even total project failure. The success of these projects essentially depends on effective management for planning, monitoring, and scheduling project activities, and taking the necessary actions to accelerate the completion of activities (Keshk et al., 2018).

In recent years, the construction industry sector in Indonesia has experienced quite a lot of ups and downs due to the impact of the *COVID-19 pandemic* (Iqbal et al., 2021; Oey & Lim, 2021). The spread of *COVID-19* in the period 2020-2021 had a negative impact on the running of construction projects (Zamani et al., 2021). Project completion delays, labor difficulties, payment delays, and a slowdown in *real estate* sector revenues are three indicators that show a slowdown during the pandemic (Ogunnusi et al., 2020). Based on the Central Statistics Agency (BPS), the construction services sector is included in the 6 business sectors most affected by the *Covid-19* pandemic, with a decrease in revenue of 87.94%. The construction business sector globally declined at the beginning of the pandemic and has generally begun to show recovery since 2021. The construction sector's growth in Indonesia is still in the recovery stage, and until 2022, the growth is relatively lower compared to economic growth in general.

In this study, the research will focus on the construction business sector of PT XYZ company. The business income here in question is the receivables obtained or absorbed on the value of the project contract obtained. Based on this data, the acquisition of new contract value in construction projects is quite high and is almost in line with the company's target, but has not been balanced with the Company's ability to absorb the value of project contracts into operating income. This is an evaluation for the Company's production and marketing team. First, on the production side so that the method of implementing the work so that the productivity and efficiency of the work can be carried out properly then, then the second on the technical and marketing side to be able to further study the *feasibility* and feasibility of the project in

accordance with the available resources and the last of course the *evaluation of top management* related to the determination of policies and planning that is even more precise.

PT XYZ needs to improve better planning and optimization so that targets can be more relevant and achieved appropriately. One way to optimize the planning process is to properly implement risk management so that the Company can identify risks, assess and evaluate risks to mitigate risks, especially in the construction business sector. The implementation of good risk management will certainly have a good impact on the Company, in accordance with the statement of Abrahamson (1984) to reduce the negative impact of risks and to increase the productivity and effectiveness of project work, the allocation and identification of appropriate risks is a must. Risk management plays a vital role in achieving project objectives because construction projects are very complex and involve a lot of people and various *stakeholders* (Wu & Zhou, 2019).

To facilitate the risk identification process, the author will use *the Fault Tree Analysis method*. *Fault Tree Analysis* (FTA) is a method in risk management used to systematically and logically analyze system failures. FTA also has several advantages, such as making it easier to visualize problems (systematic and logical), root identification, and compatibility with other methods. Koivisto (2009) revealed that FTA and other risk assessment processes can be integrated to facilitate decision-making. The integration or combination of risk assessment methods such as Risk Matrix, *Fishbone Diagram* (FD), *Fault Tree Analysis* (FTA), and *Real Time Data* (RTD) results in a new and more comprehensive evaluation method (Ikhwan et al., 2021). Therefore, in this study, it is planned to use a combination of FTA with a risk matrix so that risk identification can be easily visualized and can be analyzed qualitatively and quantitatively (Na et al., 2025; Spasenic et al., 2022).

The results of this research are expected to improve risk management, make it easier for top management to make decisions, and ensure that the strategies and policies implemented will have a positive impact on the company.

The objectives of this research are to identify potential risks that may occur during the execution of construction projects, assess the probability and impact of these risks on project success, and develop appropriate risk management strategies that can enhance performance and achieve revenue targets in the construction sector. These goals aim to provide a comprehensive understanding of risk factors and effective mitigation to ensure project success and financial performance.

The benefits of this study are expected to have both practical and academic impacts. Practically, it will help PT XYZ identify critical construction risks to meet business revenue and profit targets in line with the Company's Work Plan and Budget (RKAP). The research also offers valuable insights into how risk management contributes to revenue achievement during construction processes, aiding management in making informed decisions and policies.

Academically, the study provides a reference for future research, contributing to the broader knowledge base on risk management in construction project execution.

METHOD

This research employed a systematic methodology to analyze risk management in construction projects at PT XYZ, covering research design, data collection, risk identification, quantification, aggregation, risk ranking, and mitigation planning. The study's design included three main phases: risk identification using Fault Tree Analysis (FTA), risk assessment via expert judgment and historical data analysis, and risk ranking using FTA combined with risk matrices. Data collection incorporates primary data from structured interviews and surveys with key management personnel and secondary data from company documents and project reports. Risk identification involves categorizing existing, new, and emerging risks through document reviews and expert interviews, followed by mapping causes with FTA. Quantification assigns numerical probabilities and impacts to risks based on historical data and expert evaluation, following guidelines from Indonesia's Ministry of State-Owned Enterprises. Risk aggregation consolidates lower-level events into overall risk profiles using FTA AND/OR gate logic. Risks are then ranked by exposure level through qualitative and quantitative calculations, with risk levels classified from low to high according to preset criteria. Finally, mitigation strategies are developed to effectively reduce risk probabilities or impacts within budget constraints, prioritizing interventions that maximize risk reduction cost-effectively to improve business process efficiency and project success.

RESULTS AND DISCUSSION

Research Data

The analysis and discussion in subchapter 4 concern the profile of the company or project being researched and the profile of the respondent. The company profile or project to be discussed is the construction project carried out by PT XYZ, especially on road and land projects. The profile of the respondents in this study involved *senior managers* and *project coordinators*.

Identification of Risks

Risk identification is a stage to determine the risks that can occur due to internal and external factors in implementing construction projects. The risk identification process was carried out by studying the literature related to risks in construction projects and reports on the results of the risk register (*Risk Register*) on the implementation of construction projects at PT XYZ then interviews with experts in the field of risk as well as several *project managers* and *senior managers* at PT XYZ. The results of the risk identification were then coded to facilitate the analysis process. The results of risk identification can be seen in Table 4.1.

The FTA method was a deductive top-down analysis method. In this study, FTA, the causes of failure in low operating income (Construction Project Progress) began by classifying the factors causing failure, namely Business and Financial, Technical and Operational, K3L, and Social, and then Legal. Based on the classification of the failure factors, the main causes of failure are identified.

In this FTA method, knowing the factors that cause failure is necessary. The method of analyzing the potential failure of low business income (construction project progress) is an FTA tool with a top-down approach that starts from the top level event that has been defined, then looks for the causative events to the most basic events, so that the most basic events are obtained from the causes of potential work accidents that occur in the project. The following are the steps, procedures, and approaches using FTA as a tool to analyze and evaluate failure modes as follows:

1. Identify possible top events obtained based on interviews and literature studies.
2. Identify the first level of contributors by adding conditions or events that can contribute to or cause the occurrence of top events.
3. Assign logic gates according to events occurring at the same time and place (AND) or one of the possible events (OR). The movement of forming branches on the fault tree shows the effect of the top event
4. Identify the second-level contributor and define logical symbols to connect the events that might be the cause of the first-level contributor's failure mode.
5. Set a logic gate for the second-level contributor.
6. Repeat or resume. Develop a strategy to correct the combination of events to prevent the occurrence at the top of the event from happening again.

Risk Assessment

Risk Quantification

The results of the risk identification aim to determine the level of risk by considering the level of likelihood of risk occurrence and the degree of impact generated by the main risk. The results of filling out the questionnaire that have been submitted and calculated the total risk value can be seen in Table 1 Risk Quantification Results.

Table 1. Risk Quantification Results

No	Risk	Risk Code	Possibility	Impact	TR
Intermediate Events					
1	Late / Default	IE 1	4.00	4.93	19.72
2	Overbudget	IE 2	3.33	4.27	14.22
3	Over volume	IE 3	3.27	3.20	10.46
4	Delays in work progress	IE 4	3.87	4.27	16.52
5	Administrative backup fulfillment inconsistency	IE 5	2.73	2.67	7.29

No	Risk	Risk Code	Possibility	Impact	TR
6	Demo/Crime	IE 6	2.13	2.73	5.81
7	Claims/Lawsuits	IE 7	3.00	3.20	9.60
Basic Events					
8	Limitations of employer liquidity	BE 1	3.47	4.73	16.41
9	Incompleteness of billing documents	BE 2	2.60	2.93	7.62
10	Changing of offices	BE 3	2.20	2.00	4.40
11	The minutes of the receipt of work results have not yet been published	BE 4	2.80	2.60	7.28
12	Rising material prices	BE 5	3.20	3.47	11.10
13	There are work items that have not been calculated	BE 6	3.00	2.93	8.79
14	Repair/ reject/ defect	BE 7	2.60	3.20	8.32
15	Partial procurement	BE 8	2.93	3.20	9.38
16	Limited suppliers, uncompetitive prices	BE 9	3.27	3.07	10.04
17	Failure of the working method	BE 10	2.53	2.93	7.41
18	Material quality incompatibility	BE 11	2.87	2.93	8.41
19	Inaccuracies of data from employers and/or results of initial field surveys	BE 12	3.07	2.60	7.98
20	Unforeseen Condition	BE 13	2.67	2.87	7.66
21	Delay in land discussion	BE 14	3.00	2.73	8.19
22	Working capital limitations	BE 15	4.53	4.40	19.93
23	Limited number of work tools	BE 16	4.20	3.40	14.28
24	Delays in material procurement	BE 17	3.67	3.13	11.49
25	Damage to work tools	BE 18	2.53	2.87	7.26
26	Delay in the procurement of spare parts	BE 19	3.47	3.20	11.10
27	Low performance of subcontractors	BE 20	3.27	3.33	10.89

No	Risk	Risk Code	Possibility	Impact	TR
28	Limited number and competence of personnel	BE 21	3.67	3.53	12.96
29	Limited competence and awareness of personnel	BE 22	3.27	3.40	11.12
30	Limitations of field supervision	BE 23	3.20	3.33	10.66
31	Non-compliance with K3 standards	BE 24	2.73	2.80	7.64
32	Non-compliance with environmental standards	BE 25	2.87	2.80	8.04
33	Rejection from the local community	BE 26	2.13	2.00	4.26
34	Fatality	BE 27	2.00	3.20	6.40
35	Environmental pollution	BE 28	1.93	2.33	4.50
36	Delay in fulfilling obligations to 3rd parties	BE 29	3.13	3.33	10.42

The impact value and the risk probability calculated above will be distributed on the risk map matrix. The distribution of risk on the risk map can be seen in Figure 4.6: Results of the Risk Map based on Risk Assessment.

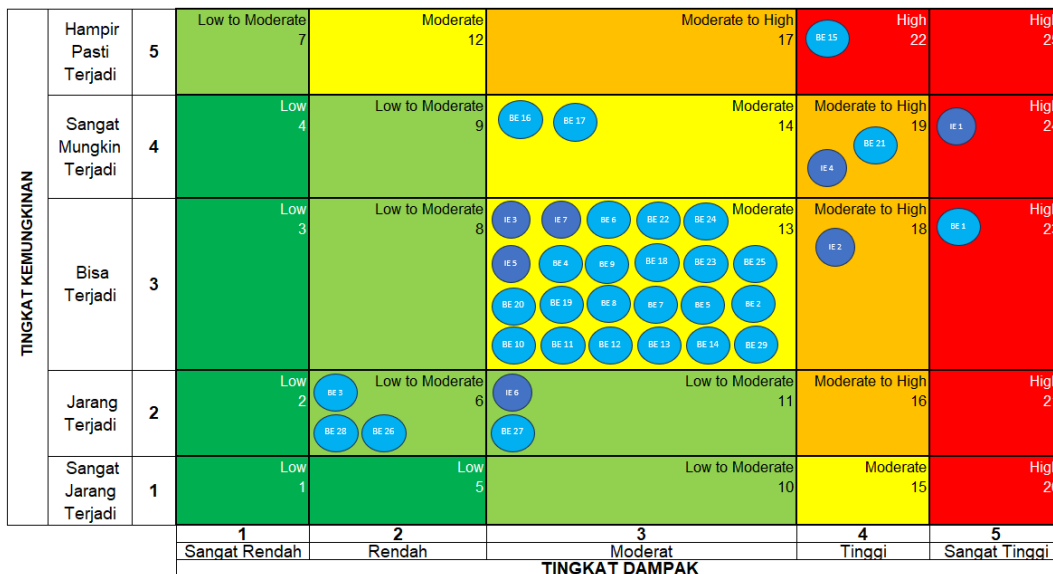


Figure 1. Risk Map Results based on Risk Assessment

In Figure 1, the distribution results of each risk can be seen in the exposure area. Based on the distribution of risk values on the risk map, it can be seen that there are several risk events

in high-exposure areas, namely Limited working capital (BE15), Late/default (IE1), and Limited employer liquidity (BE1)

Risk Aggregation

Risk aggregation refers to consolidating risk exposure from the bottom level (*basic event*) of a business hierarchy to the top level risk profile (*top event*). The risk aggregation process can be started by grouping each risk with an AND and OR gate relationship, which in aggregation has a different approach to affect higher events. Risks that have an *AND gate* relationship with the risk probability level 1 will be multiplied by the risk probability level 2 up to the risk probability level i, while for risks that have an *OR gate* relationship the risk probability level 1 will be added by the risk probability level 2 to the risk probability level i.

Risk aggregation is carried out for each *top event* & *intermediate event*, which is as follows:

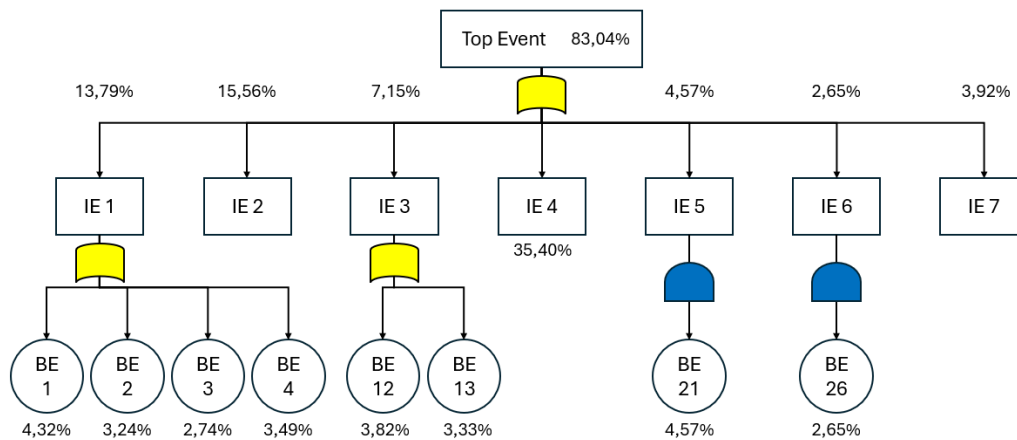


Figure 2. Risk Aggregation on FTA Top Event chart, Failure to achieve or low operating income (Project Progress) in Construction Projects

Based on the results of risk aggregation, it is known that the main failure that is the focus of the analysis in this study as a top event has a probability of 83.04%, there are 7 *intermediate events* with the OR gate indicating that one of the *intermediate events* can cause the occurrence of a top event which each had a contribution of IE 1 (13.79%), IE 2 (15.56%), IE 3 (7.15%), IE 4 (35.40%), IE 5 (4.57%), IE 6 (2.65%) and IE 7 (3.92%). IE 4 is an *intermediate event* that has the largest contribution and/or probability, which is 35.40% of the risk.

Each *intermediate event* is caused by *basic events*, which show the root cause with individual probabilities, including IE 1 caused by BE 1 with a probability of 4.32%, BE 2 with a probability of 3.24%, BE 3 with a probability of 2.74%, and BE 4 with a probability of 3.49% which is connected to the OR gate. Furthermore, IE 3 is caused by BE 12 and BE 13, which have a

probability of 3.82% and 3.33% respectively. IE 5 is caused by BE 21 with a probability of 4.57%, and IE 6 is caused by BE 26 with a probability of 2.65%.

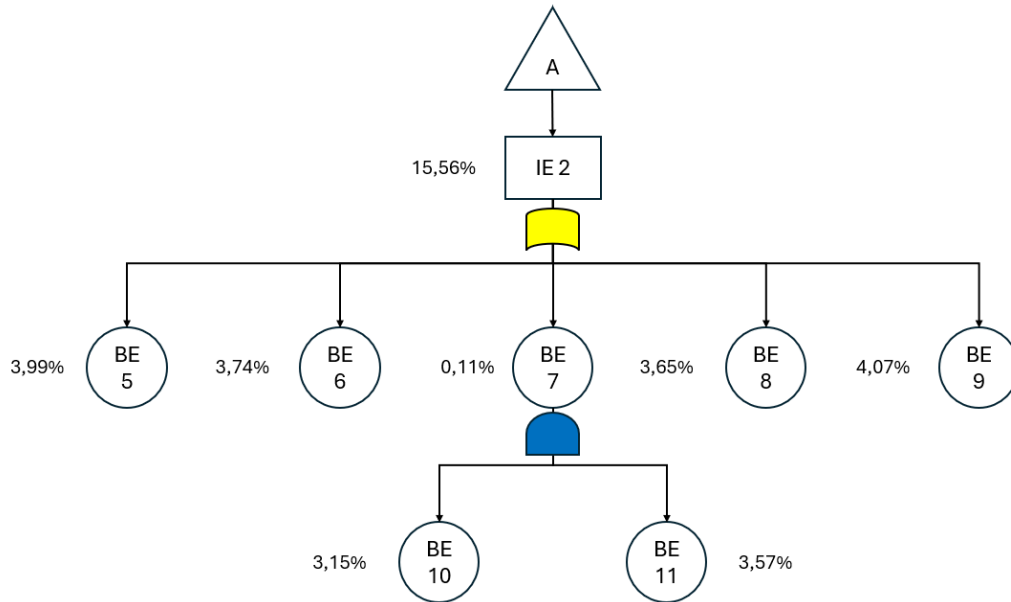


Figure 3. Risk Aggregation on the Chart: *Fault Tree Analysis, Intermediate Event 2, Overbudget*

In the image above, IE 2 which is connected by Gate A as a causal logic that explains the occurrence of Intermediate Event 2 has a root cause with the OR gate including BE 5 with a probability of 3.99%, BE 6 with a probability of 3.74%, BE 8 with a probability of 3.65%, BE 9 with a probability of 4.07%, and BE 7 with a probability of 0.11% which is connected to the AND gate which has a root cause of BE 10 and BE 11 with probability respectively 3.15% and 3.57%, respectively. BE 9 is the root cause with the highest probability of causing IE 2.

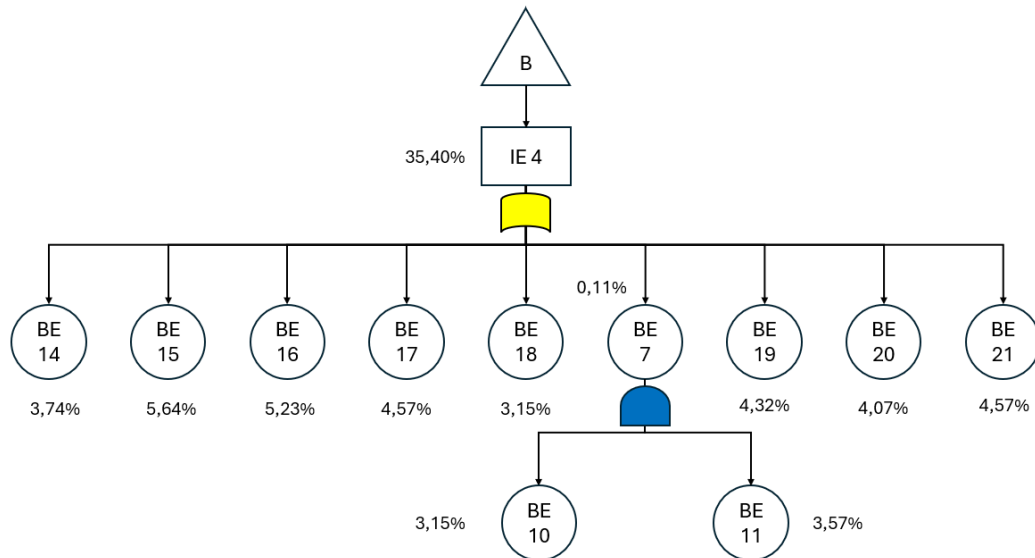


Figure 4. Risk Aggregation Chart, *Fault Tree Analysis, Intermediate Event 4, Delay in work progress*

In the image above, IE 4 which is connected by Gate B as a causal logic that explains the occurrence of Intermediate Event 4 has a root cause with the OR gate including BE 14, BE 15, BE 16, BE 17, BE 18, BE 19, BE 20, BE 21 with a probability of 3.74%, 5.64%, 5.23%, 4.57%, 3.15%, 4.32%, 4.07%, 4.57%, and BE 7 with a probability of 0.11% which is connected to the AND gate which each has a root cause of BE 10 and BE 11 with a probability of 3.15% and 3.57%, respectively. BE 15 with a probability of 5.64% is the root cause with the highest probability of causing IE 4.

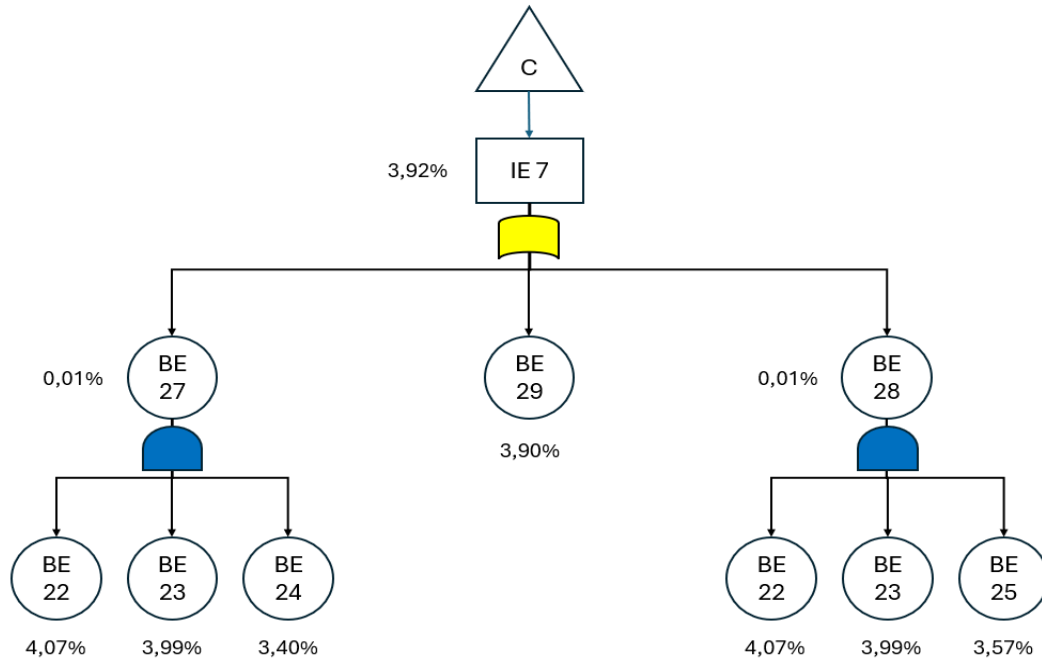


Figure 5. Risk Aggregation Chart, *Fault Tree Analysis, Intermediate Event 7, Claims/ Lawsuits*

In the image above, IE 7 which is connected by Gate C as the causal logic that explains the Intermediate Event 7 event has a root cause with the OR gate including BE 29 with a probability of 3.90%, BE 27 with a probability of 0.01% which is connected to the AND gate which each has the root cause of BE 22, BE 23 and BE 24 with a probability of 4.07% each, 3.99% and 3.40%, as well as BE 28 with a probability of 0.01% which is connected to the AND gate which has the root cause of BE 22, BE 23 and BE 25 respectively with a probability of 4.07%, 3.99% and 3.57% respectively. BE 29 is the root cause with the highest probability of causing IE 7.

Risk Rating

Based on the results of the risk quantification above, the risk calculation formula is ranked based on the rank of the 10 *highest basic events, consisting of 3 intermediate events*, which can be seen in the *following* Fault Tree Analysis chart.

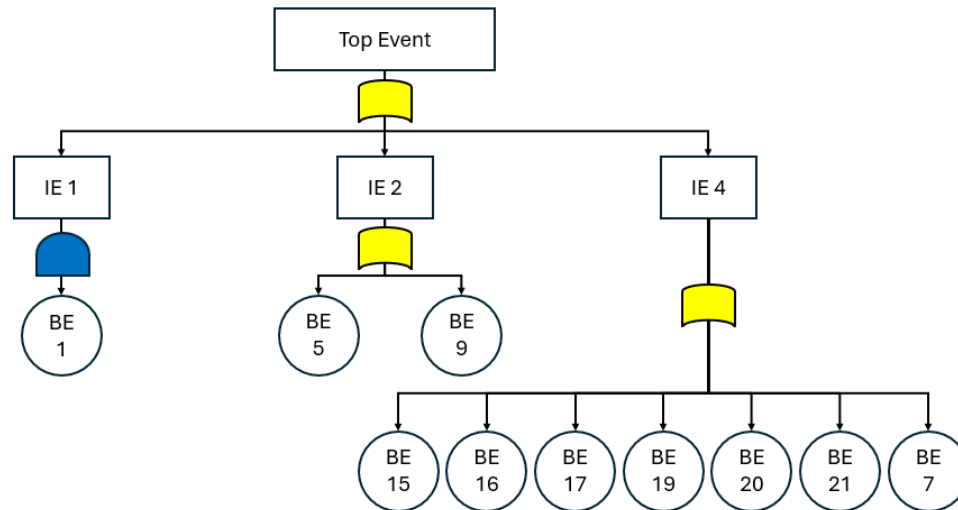


Figure 6. Chart *Fault Tree Analysis* on 10 *Basic Event Top*

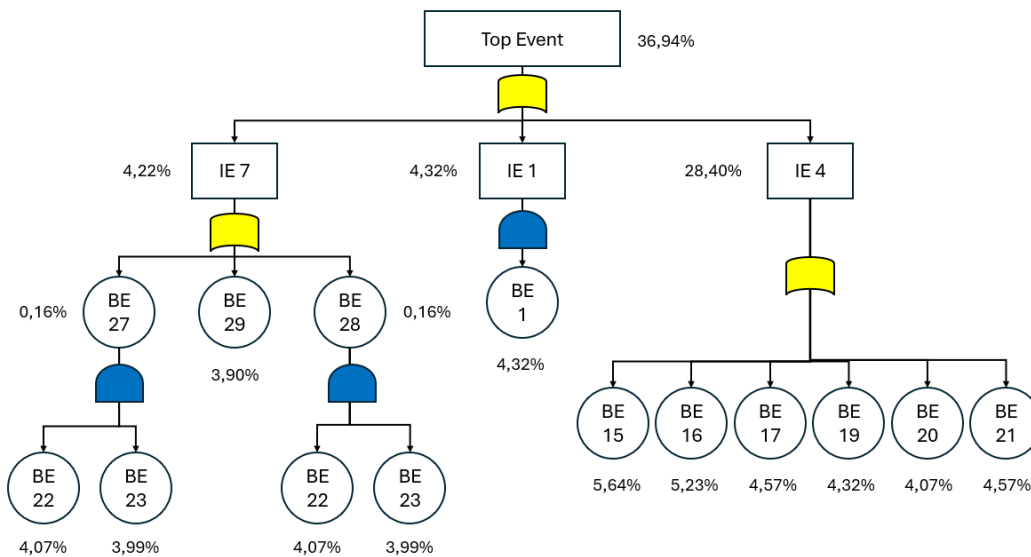


Figure 7. Risk Aggregation Chart: *Fault Tree Analysis* on the Top 10 Highest Basic Events

In the FTA Top Risk image above, which shows the hierarchy analysis of the causes of failure to the root of the problem, it shows that *the Top Event*, which is the main focus of the FTA analysis, is caused by 3 *intermediate events*, including IE 1 with a contribution to the *top event* of the *basic event*, namely BE 1 through the AND gate with a probability of 4.32%, IE 4 with a contribution to *the top event* of 28.40% which is connected to 6 basic events through the OR gate including BE 15, BE 16, BE 17, BE 19, BE 20, and BE 21 with a probability of 5.64%, 5.23%, 4.57%, 4.32%, 4.07%, and 4.57%, and finally IE 7 with a contribution to *the top event* of 4.22% connected through the OR gate caused by 3 *basic events* among them are BE 27 and BE 28 with a probability of 0.16%

connected to BE 22 and BE 23 through the AND gate which have a probability of 4.07% and 3.99% respectively and BE 29 with a probability of 3.90%. IE 4 accounts for almost 76.88% of the total probability of *Top Event* so the mitigation focus should be directed to this *intermediate event* where BE 15, BE 16, BE 20 and BE 21 are the biggest root causes in IE 4, the ability to manage and mitigate this *basic event* will have a significant impact in reducing the risk of *Top Event*. Risk ranking is based on the amount of *risk exposure* value of each risk presented in the following table:

Table 2. Risk Rating Table

No	Risk	Risk Code	Probability	Impact Rating	Risk Exposure (M)
1	Working capital limitations	BE 15	90.60%	4.40	0.50
2	Late / Default	IE 1	80.00%	4.93	0.49
3	Limitations of employer liquidity	BE 1	69.40%	4.73	0.41
4	Delays in work progress	IE 4	77.40%	4.27	0.41
5	Limited number of work tools	BE 16	84.00%	3.40	0.36
6	Limited number and competence of personnel	BE 21	73.40%	3.53	0.33
7	Delays in material procurement	BE 17	73.40%	3.13	0.29
8	Limited competence and awareness of personnel	BE 22	65.40%	3.40	0.28
9	Delay in the procurement of spare parts	BE 19	69.40%	3.20	0.28
10	Low performance of subcontractors	BE 20	65.40%	3.33	0.27
11	Limitations of field supervision	BE 23	64.00%	3.33	0.27
12	Delay in fulfilling obligations to 3rd parties	BE 29	62.60%	3.33	0.26
13	Claims/ Lawsuits	IE 7	60.00%	3.20	0.24

After the results of risk identification were known, a risk analysis was carried out. It concluded that there are 3 intermediate events consisting of the top 10 basic events that impact Low Operating Income (Construction Project Progress), which is likely to be 36.94% and has a risk exposure of 4.40 M or 35.02% of the Company's total risk limit.

The identified key risk events and their mitigations at PT XYZ include: (1) Working capital limitations (90.6% probability, 0.5M exposure) requiring alternative funding sources, optimized cash flow management, and early payment term requests; (2) Delayed or failed payments (80% probability, 0.49M exposure) mitigated by client payment ability assessments, penalty clauses, and automated invoice collection; (3) Client liquidity constraints (69.4% probability, 0.41M

exposure) addressed via due diligence and negotiated payment terms; (4) Project progress delays (77.4% probability, 0.41M exposure) managed with detailed scheduling, regular monitoring, and contingency planning; (5) Equipment shortages (84% probability, 0.36M exposure) resolved by renting or acquiring equipment and inventory monitoring; (6) Personnel quantity and competency gaps (73.4% probability, 0.33M exposure) mitigated by recruitment, training, and rotation; (7) Material procurement delays (73.4% probability, 0.29M exposure) managed through schedule monitoring, long-term contracts, and alternative suppliers; (8) Personnel competency and awareness issues (65.4% probability, 0.28M exposure) addressed with training and certification; (9) Spare part procurement delays (69.4% probability, 0.28M exposure) mitigated by needs lists, contractual delivery priorities, and spare part reserves; (10) Subcontractor underperformance (65.4% probability, 0.27M exposure) managed by strict selection, service agreements, and supervision; (11) Limited field supervision (64% probability, 0.27M exposure) handled with quality control, defect handling procedures, and material compliance; (12) Delays in fulfilling third-party obligations (62.6% probability, 0.26M exposure) mitigated by secure payment terms; and (13) Legal claims (60% probability, 0.24M exposure) managed by robust contract clauses and legal advisory services.

Risk Mitigation

A process to reduce or control the impact and likelihood of risk so that the risk does not have too much of an impact on the organization or project. Risk mitigation measures are essential in risk management, as they help reduce the potential for loss or damage resulting from risk.

CONCLUSION

The conclusions of this study indicate that the failure to achieve business revenue (progress in construction projects) can be caused by several risk factors, including business and financial aspects, technical and operational issues, health, safety, environment, and social aspects, as well as legal factors. A total of 36 risks were identified related to the failure of revenue achievement in the construction and earthwork projects at PT XYZ, classified into 7 Intermediate Events (IE) and 29 Basic Events (BE). Risk assessment revealed that the top 10 risks include three with high exposure: delayed or failed payments (IE1), limited liquidity of the client (BE1), and limited working capital (BE15). Risk mitigation plans were developed for these top risks, which account for a total risk exposure of 4.4 billion IDR or 35.02% of PT XYZ's risk limit of 12.55 billion IDR. Appropriate risk management strategies to improve performance and revenue success include accelerating asset divestment to improve liquidity and working capital, exploring alternative financing, assessing client payment capacity before contract signing, imposing penalty clauses for payment delays, collaborating with strategic partners for equipment resources, and regularly monitoring equipment inventory. Implementation of these mitigations can reduce risk

exposure from 4.4 billion to 1.63 billion IDR. Operationally, this research serves as a reference framework for risk management planning in road construction projects, while strategically it supports strengthening PT XYZ's risk management committee for aligned decision-making and integrated marketing and production. The study's limitations include respondent fatigue due to heavy project workloads, which affects questionnaire accuracy. Future research is recommended to conduct surveys when respondents have sufficient time and information for optimal results.

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