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Analysis of Potential Work Hazard Risk in the Development of the Road Project Using the HIRARC and FTA Methods

Liza Olivia Manurung*, I Nyoman Dita Pahang Putra, Elok Dewi Widowati

Universitas Pembangunan Nasional "Veteran" Jawa Timur

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*Correspondence: Liza Olivia Manurung
Email: lizoliv22@gmail.com

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Abstract: Risk refers to a situation with potential loss or the chance of a loss. Every stage in the construction process inevitably carries potential risk hazards that can threaten the safety of workers, the environment, and the surrounding community. Therefore, a study was conducted to analyse possible risks during mobilising heavy equipment and material vehicles, excavation and embankment work, and blasting work in the X Road construction project. This study employed two methods for risk analysis. The first method involved identifying types of work-related accidents using the HIRARC approach, which included distributing questionnaires to assess each variable's likelihood and severity levels to determine the most significant risk. Then, control measures were applied to the identified risks. After implementing the control measures, a risk reassessment was conducted to assess the level of risk post-control. The identification revealed one dominant variable: heavy equipment overturning from a height. Thus, the analysis continued using the second FTA method to determine the causal factors influencing the risk. The risk was caused by three main factors: human, environmental, and managerial factors, and ten basic events leading to the risk were identified.

Keywords: Risk Analysis, HIRARC, Fault Tree Analysis

Introduction

Infrastructure development is a key driver of national and regional economic growth. Well-developed infrastructure forms the backbone of economic activity, facilitating the smooth flow of goods and services, speeding up distribution processes, and boosting a nation's competitiveness in the global marketplace (Marsus et al., 2020). In this era of globalisation, infrastructure development is not merely about expanding transportation networks but also acts as a strategic instrument for creating better connectivity, improving the quality of life for communities, and reducing economic disparities between regions (Husen & Baranyanan, 2021).

In Indonesia, road infrastructure development has become one of the government's top priorities. This is evident from various national road projects aimed at strengthening interregional connectivity and promoting equitable economic development (Jaladri et al., 2023). One of the strategic projects currently underway is the construction of the X Road, which is designed to improve transportation efficiency in the southern region of Java Island, enhance accessibility, reduce congestion, and increase road user safety. This project is expected to accelerate economic and social mobility while opening new investment opportunities.

However, road infrastructure project development has its share of complex technical and administrative challenges. One of the primary challenges is the risk of workplace accidents, which can threaten the safety of both workers and the surrounding community. As defined by the Minister of Manpower Regulation, a workplace accident is an unplanned and unwanted incident that has the potential to cause harm to individuals and damage to property. Workplace accidents can arise from various factors, including human error, weaknesses in project management, and unforeseen environmental conditions. If not properly managed, these risks can lead to significant physical, financial, and reputational losses (Hanapi et al., 2024; Wardhana, 2021).

As Indonesia enters early 2025, the country faces a serious challenge regarding workplace safety again. The most recent report from the Ministry of Manpower indicates a notable rise in workplace accidents during the first quarter of this year, rising by 9.4% compared to last year. From January to March 2025, 5,632 workplace accident cases were recorded, most of which occurred in the construction, manufacturing, and mining sectors. This surge indicates that despite ongoing efforts to strengthen regulations and implement workplace safety standards, the challenge of creating a safe work environment remains a significant concern (PAKKI, 2025). The construction sector, known for its high-risk work environments, continues to dominate the number of cases, followed by the labour-intensive manufacturing sector and the mining sector, which is fraught with numerous physical and environmental hazards (Adrian).

Factors such as workers' lack of awareness of safety procedures, inadequate field supervision, and negligence in enforcing safety standards are the primary causes of the high accident rates. Additionally, the pressure to meet project deadlines often compromises safety aspects, further complicating risk management in the field. With these numbers on the rise, stakeholders must strengthen the workplace safety culture through continuous training, adopting modern safety technologies, and stricter oversight to reduce workplace accidents in the future (Bramistra, 2024).

To reduce the number of workplace accidents, a systematic and measured risk management approach is required. One of the methods commonly used in the construction industry is Hazard Identification, Risk Assessment, and Risk Control (HIRARC), along with Fault Tree Analysis (FTA). The HIRARC method focuses on identifying potential hazards and developing appropriate control measures, while FTA enables a more in-depth analysis of the causal relationships behind potential undesirable events, allowing for more effective planning of preventive actions (Sufa & Astuti, 2024; Triswandana, 2020).

Combining these two methods, this study aims to provide a comprehensive overview of potential risks and accident-causing factors in the X Road construction project. This analysis is expected to enhance the effectiveness of construction risk management, strengthen workplace safety, and ensure smooth project execution, thereby positively contributing to regional economic development and the local community's well-being.

Methodology

HIRARC

This study employs a quantitative research method, distributing questionnaires and facilitating discussions. The questionnaire contains various questions about the risks encountered on the X Road construction project, aiming to gather information about the conditions occurring during the construction project implementation. A construction project is a series of one-time activities, generally short-term, with a clearly defined start and end time. Within these activities is managing project resources to create a structure or building. Projects undertaken within these activities inevitably involve directly or indirectly related parties (Fazis & Tugiah, 2022; Labombang, 2011).

HIRARC is a method for identifying workplace accidents, with risk assessment being a critical component for implementing an Occupational Safety and Health Management System (OSHMS). HIRARC aims to identify potential hazards in each task and examine workplace accidents, then propose corrective actions (Triswandana, 2020). HIRARC consists of three main stages: identifying hazards, assessing risks, and implementing control measures. The hazard identification phase entails examining each work area and recognising potential dangers throughout every work process, including any conditions, incidents, or systems that might result in accidents. (Damayanti & Mahbubah, 2021). A hazard is anything, including a situation or action, that can cause accidents or injuries to people or result in damage or other disruptions (Soehatman, 2010).

Risk Assessment

Risk assessment evaluates the probability of an activity taking place and estimates the possible extent of losses, be it in terms of safety, health, or financial impact, within a defined timeframe (Sufa & Astuti, 2024). The risk assessment refers to the (AS/NZS, 4630:2004). Risk can be measured using two parameters: likelihood and severity.

Table 1: Parameters of "Likelihood of Hazard" Based on AS/NZS 4360 Standard

Likelihood	Description	Rating
Rare (R)	An incident that is likely to occur only under extraordinary/exceptional conditions or after many years (Less than one incident per year)	1
Unlikely (U)	An incident that may occur under certain conditions, but the likelihood is small (rare) (At least one incident per year)	2
Possible (P)	An incident that will occur under several specific conditions (At least one incident per month)	3
Likely (L)	An incident that is very likely to occur (frequently) under almost all conditions (At least one incident per week)	4
Almost Certain (AC)	An incident that is almost certain to occur under all conditions (At least one incident per day)	5

Table 2: Parameters of "Severity" Based on AS/NZS 4360 Standard

Likelihood	Description	Rating
Insignificant	No injury – loss of low monetary value	1
Minor	Minor injury – moderate financial loss requiring immediate first aid treatment on site	2
Moderate	Moderate injury – considerable financial loss requiring medical treatment on-site due to temporary loss of body function	3
Major	Significant injury – high financial loss requiring medical treatment due to total impairment of body function, disrupting production processes	4
Severe	Fatal incident – very high financial loss, involving cases of death, poisoning with major effects, and significant disruption leading to the complete cessation of activities	5

The results of the likelihood and severity assessment can be utilised with the help of a risk assessment matrix to classify the hazard risk levels, as shown in Table 3, based on the (AS/NZS, 4630:2004) standard.

Table 3: Risk Assessment Matrix

Likelihood	Severity				
	1 (Insignificant)	**2 (Minor)**	**3 (Moderate)**	**4 (Major)**	**5 (Severe)**
5 (Almost Certain)	Medium	High	High	Very High	Very High
4 (Likely)	Medium	Medium	High	High	Very High
3 (Possible)	Low	Medium	High	High	High
2 (Unlikely)	Low	Low	Medium	Medium	High
1 (Rare)	Low	Low	Medium	Medium	High

Risk Control

After identifying and evaluating the risks, it is essential to implement risk control measures. Risk control involves procedures designed to recognise, analyse, assess, and address potential risks that could affect a project. The primary goal is to mitigate the adverse effects of these risks by lowering both their probability and severity, ultimately enhancing the project's likelihood of success (Sufa & Astuti, 2024). Regarding occupational health and safety risks, OHSAS 18001 provides risk control measures by reducing the likelihood and severity of risks (OHSAS18001, 2007).

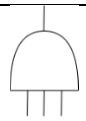
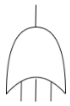
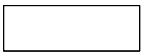
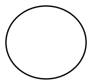
1. Elimination: Removing hazards and risks entirely by avoiding the involvement of human labour in hazardous activities.
2. Substitution: Replacing processes, operations, materials, or equipment with alternatives that are either non-hazardous or less hazardous.
3. Engineering Controls: Implementing controls through equipment and workplace design to ensure construction safety and provide protective measures.
4. Administrative Controls: Managing risks by regulating procedures, work permits, job safety analysis, and enhancing workers' competence through training and supervision.
5. Personal Protective Equipment (PPE): Utilising the correct personal protective equipment and safety tools to protect workers from possible hazards.

FTA

FTA is used to explore the root causes of the most critical identified risks. This method aims to provide a clearer insight into existing hazards and the appropriate mitigation strategies needed to improve safety and ensure the construction project's success. In general, risk is characterised as the combination of the likelihood of an event occurring and the magnitude of its possible consequences. It represents the potential for loss, highlighting situations where exposure to harm exists. Moreover, risk is closely linked to uncertainty, emphasising its inherently unpredictable nature. (Purba et al., 2022).

FTA is a powerful method for pinpointing risks that may lead to failure. It follows a top-down structure, beginning with a presumed failure event—the top event—and methodically tracing the contributing factors down to the fundamental causes, known as basic events. The FTA method can identify and illustrate the relationships among various causal factors in a fault tree diagram, making it easier to understand and further analyse potential risks (Wicaksono & Yuamita, 2022). The following are the standard fault tree symbols used to facilitate analysis; the symbols can be seen in Table 4 (Kececioglu, 1991):

Table 4: FTA Symbols

Symbol	Name	Description
	And Gate	This event occurs if all "Input events" simultaneously cause the event above.
	Or Gate	The event above this symbol will occur if any "Input Events" happen, even if only one can cause the event above.
	Top Event, Intermediate Event	The main event must be explained in more detail, including the incident or event.
	Basic Event	An event that does not require further development or elaboration.

Result and Discussion

Project Overview

The X Road construction project is a broader national road development initiative segmenting Java and Bali islands. This project stretches along the southern coastline of Java Island, spanning a minimum of five provinces, including Banten, West Java, Central Java, the Special Region of Yogyakarta, and East Java. The total planned length is 4,373 kilometres, with an estimated completion time of 540 days.

Data Analysis

The data analysis in this study includes analysis using the HIRARC method and FTA. In the HIRARC approach, hazard identification was carried out for several activities, such as heavy equipment and material vehicle mobilisation, cut and fill operations, and blasting. This resulted in 13 hazard identifications obtained through a literature study method. This was followed by a risk assessment using a likelihood and severity values scale. The risk assessment is categorised into four levels: low, medium, high, and very high. The identified risk variables for the X Road construction project, based on the literature review, are presented in Table 5 as follows:

Table 5: Identification of Job Hazards

Activity	Hazard Identification	Code
Heavy equipment and material vehicle mobilisation	Struck by a heavy equipment manoeuvre	A1
	Air pollution (dust)	A2
	Collision with project vehicles	A3
	Worker trapped/crushed/hit by heavy equipment	A4
	Tripped or stumbled over materials during loading/unloading	A5
Cut and Fill Work	The worker slips/falls into an excavation hole	B1
	Heavy equipment overturns from a height.	B2
	Landslide of soil or materials	B3
	Air pollution (dust)	B4
	Excavation holes without signs or barriers	B5
Blasting Work	Air pollution (dust)	C1
	Noise from drilling and blasting activities	C2
	Flying rock	C3

Risk Assessment

Following the identification of workplace hazards, a risk assessment was carried out using a parameter table to evaluate the associated risk levels. This assessment was based on two parameters: severity and likelihood. The risk assessment aimed to analyse the potential risk of accidents and identify the causes and the impacts associated with each accident risk. The results of the likelihood and severity evaluations were further classified using a risk assessment matrix based on the (AS/NZS, 4630:2004). According to the HIRARC evaluation results, 0% of hazards were classified as low risk, three hazards (23%) were classified as medium risk, 10 hazards (77%) were classified as high risk, and 0% were classified as very high risk, as shown in Table 6. The percentage distribution of hazard categories for the X Road construction project has been simplified and illustrated in Figure 1.

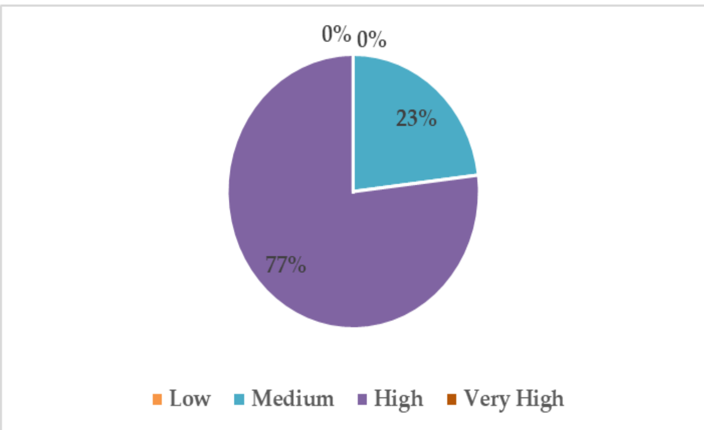


Figure 1. Categories of Hazards

Table 6: Recapitulation of Risk Assessment

Activity	Hazard Identification	Code	Likelihood	Severity	Risk Matrix
Heavy equipment and material vehicle mobilisation	Struck by a heavy equipment manoeuvre	A1	2	3	Medium
	Air pollution (dust)	A2	5	2	High
	Collision with project vehicles	A3	2	5	High
	Worker trapped/crushed/hit by heavy equipment	A4	2	5	High
	Tripped or stumbled over materials during loading/unloading	A5	2	4	Medium
Cut and Fill Work	The worker slips/falls into an excavation hole	B1	3	2	Medium
	Heavy equipment overturns from a height.	B2	4	4	High
	Landslide of soil or materials	B3	4	3	High
	Air pollution (dust)	B4	5	2	High
	Excavation holes without signs or barriers	B5	4	4	High
Blasting Work	Air pollution (dust)	C1	5	2	High
	Noise from drilling and blasting activities	C2	5	2	High
	Flying rock	C3	5	3	High

Risk Control

Risk control measures must be implemented after the risks have been assessed and their hazard categories identified. Risk control aims to minimise the negative impacts of these risks by reducing both the likelihood and the severity, thereby increasing the chances of project success. Data were collected through questionnaires and interviews, and the steps for implementing risk control measures for the identified risks are presented in Table 7, based on the consideration of the five risk control hierarchies: elimination, substitution, engineering controls, administrative controls, and PPE.

Table 7: Recapitulation of Risk Control

Activity	Hazard Identification	Risk Control Measures	
Heavy equipment and material	Struck by a heavy equipment manoeuvre	**1. Engineering Control** a. Install "Heavy Equipment Manoeuvre Area" signs	**2. Administrative Control** a. Assign traffic controllers/ flagmen

Activity	Hazard Identification	Risk Control Measures		
vehicle mobilisation	Air pollution (dust)	**1. Engineering Control** a. Conduct regular watering on access roads	**2. PPE** a. Masks b. Safety goggles	
	Collision with project vehicles	**1. Engineering Control** a. Install "Caution: Vehicle Entry and Exit" signs b. Conduct regular inspections to ensure vehicles are in good condition	**2. Administrative Control** a. Ensure that equipment operators are adequately trained and certified (possess SIO certification) b. Assign traffic controllers/ flagmen	
	Worker trapped/crushed/ hit by heavy equipment	**1. Engineering Control** a. Install signs and barriers in the working area b. Position field guides	**2. Administrative Control** a. Prohibit work within the heavy equipment operating area b. Conduct a job safety analysis for the worksite	**3. PPE** a. Safety shoes b. Project Helmet c. Project Vest
	Tripped or stumbled over materials during loading/unloading	**1. Engineering Control** a. Clear the related area	**2. PPE** a. Safety shoes b. Project Helmet	
Cut and Fill Work	The worker slips/falls into an excavation hole	**1. Engineering Control** a. Install signs and barriers around excavation holes	**2. PPE** a. Safety shoes b. Project Helmet	
	Heavy equipment overturns from a height	**1. Engineering Control** a. Heavy equipment must be in good condition (with equipment feasibility certification) b. Install signs and barriers along slopes	**2. Administrative Control** a. Operators must operate equipment properly b. Operators must be certified as heavy equipment operators (possess SIO certification)	
	Landslide of soil or materials	**1. Engineering Control** a. Install signs and barriers around excavation areas or material stockpiles	**2. Administrative Control** a. Prohibit work activities around excavation pits or stockpile areas	
	Air pollution (dust)	**1. PPE** a. Masks b. Safety goggles		

Activity	Hazard Identification	Risk Control Measures		
	Excavation holes without signs or barriers	**1. Engineering Control** a. Install signs and barriers around excavation holes		
Blasting Work	Air pollution (dust)	**1. PPE** a. Masks b. Safety goggles		
	Noise from drilling and blasting activities	**1. PPE** a. Earplugs b. Ear muffs		
	Flying rock	**1. Engineering Control** a. Control the direction of the blast b. Set the delayed blasting time c. Provide free space so that materials are directed sideways	**2. Administrative Control** a. Set a safety distance of approximately ±500 meters from the blasting site	**3. PPE** a. Project Helmet

Residual Risk Assessment (Post-Control Risk)

After implementing risk control measures, this residual risk assessment was conducted to reanalyse the potential accident risks and identify the causes and impacts associated with each accident risk. The evaluation was based on two parameters: severity and likelihood. According to the results of the residual risk evaluation, there were six hazards (46%) classified as low risk, six hazards (46%) classified as medium risk, one hazard (8%) classified as high risk, and no hazards (0%) classified as very high risk, as shown in Table 8. The percentage distribution of hazard categories for the X Road construction project has been simplified and illustrated in Figure 2.

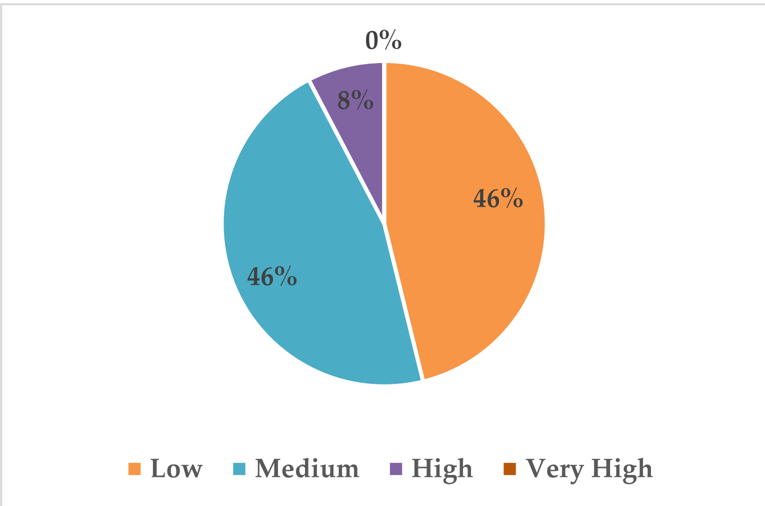


Figure 2. Categories of Hazards

Table 8: Recapitulation of Residual Risk Assessment

Activity	Hazard Identification	Code	Likelihood	Severity	Risk Matrix
Heavy equipment and material vehicle mobilisation	Struck by a heavy equipment manoeuvre	A1	2	1	Low
	Air pollution (dust)	A2	4	1	Medium
	Collision with project vehicles	A3	1	4	Medium
	Worker trapped/crushed/hit by heavy equipment	A4	2	2	Low
	Tripped or stumbled over materials during loading/unloading	A5	1	2	Low
Cut and Fill Work	The worker slips/falls into an excavation hole	B1	2	2	Low
	Heavy equipment overturns from a height.	B2	3	3	High
	Landslide of soil or materials	B3	3	1	Low
	Air pollution (dust)	B4	4	1	Medium
	Excavation holes without signs or barriers	B5	3	1	Low
Blasting Work	Air pollution (dust)	C1	4	1	Medium
	Noise from drilling and blasting activities	C2	3	2	Medium
	Flying rock	C3	4	1	Medium

Table 9 summarises the risk level assessment before control measures and the residual risk evaluation after implementing those controls. Variables with residual risk levels equal to or higher than their initial assessments are considered dominant, indicating a need for further analysis using the FTA method to uncover their root causes. The collected data found that heavy equipment overturning from a height (B2) emerged as the dominant hazard during the cut-and-fill work phase.

Table 9: Recapitulation of Risk Assessment and Residual Risk Assessment

Code	Risk Assessment			Residual Risk Assessment		
	Likelihood	Severity	Risk Matrix	Likelihood	Severity	Risk Matrix
A1	2	3	Medium	2	1	Low
A2	5	2	High	4	1	Medium
A3	2	5	High	1	4	Medium
A4	2	5	High	2	2	Low

Code	Risk Assessment			Residual Risk Assessment		
	Likelihood	Severity	Risk Matrix	Likelihood	Severity	Risk Matrix
A5	2	4	Medium	1	2	Low
B1	3	2	Medium	2	2	Low
B2	4	4	High	3	3	High
B3	4	3	High	3	1	Low
B4	5	2	High	4	1	Medium
B5	4	4	High	3	1	Low
C1	5	2	High	4	1	Medium
C2	5	2	High	3	2	Medium
C3	5	2	High	4	1	Medium

FTA

The FTA method is conducted when the risk variable, even after control measures, shows no reduction or remains the same as the risk level before control implementation. The main goal of this method is to identify the underlying causes of workplace accidents related to the risk variable. The causes of these accidents are thoroughly analysed to determine the contributing factors behind the identified risks. This analytical method involves several stages, including identifying the Top Event, determining the causal factors of the accident, and defining both the intermediate and basic events.

The HIRARC analysis identifies a significant and dominant potential hazard: heavy equipment overturning from a height during cut and fill operations. Based on the HIRARC study, the hazard that will be analysed using the FTA method is the overturning of heavy equipment from a height, with its causal factors categorised into three main aspects: human factors, management factors, and environmental factors, as illustrated in Figure 3. Based on Figure 3, the top event in the fault tree analysis is the overturning of heavy equipment from a height. This top event leads to 11 intermediate events and 10 basic events, all linked through logical 'OR' and 'AND' gates. Potential hazards during cut and fill operations include the overturning of heavy equipment, which can be triggered by various factors, such as:

1. Lack of knowledge and experience
2. Lack of concentration
3. Rushing during work
4. Insufficient rest
5. Tight work schedule
6. Underestimating procedures
7. Absence of training
8. Strong winds and heavy rain

9. Extreme worksite conditions
10. Inadequate lighting

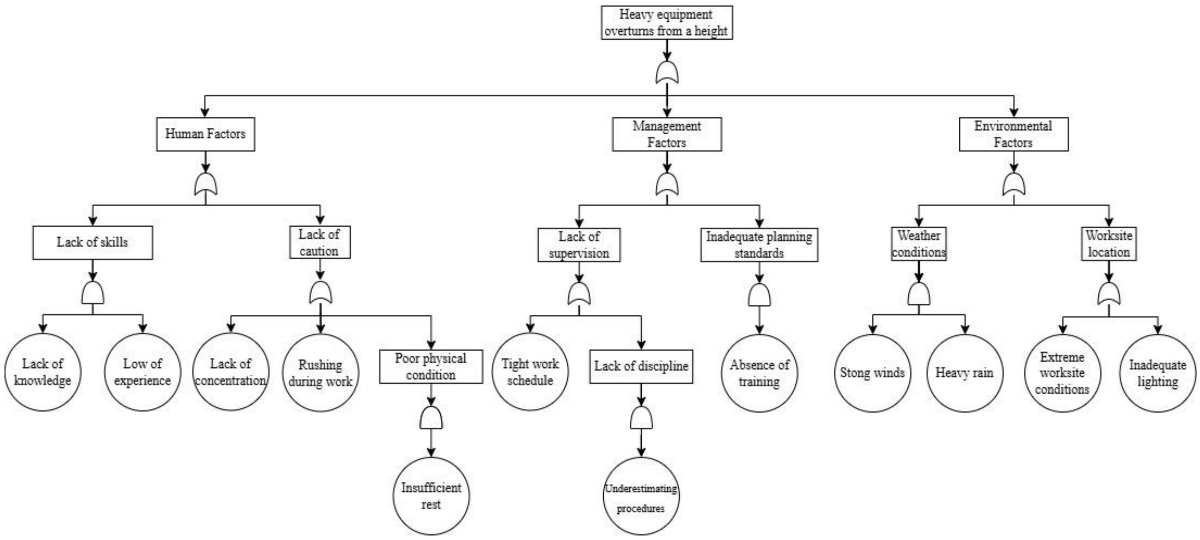


Figure 3. Heavy equipment overturns from a height

Conclusion

Based on the research results using the HIRARC method on the X Road construction project, the most dominant hazard risk identified is heavy equipment overturning from a height, categorised as high risk. The primary causes of this accident stem from three aspects: human factors, management, and environmental conditions. The FTA revealed 10 basic events, including lack of knowledge and experience, concentration, rushing, insufficient rest, tight work schedules, underestimating procedures, absence of training, heavy rain and strong winds, extreme working areas, and inadequate lighting.

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