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Risk Analysis of Work Accidents in The Building Revitalization Project "Y" City Semarang by PT. X with Fault Tree Analysis (FTA) Method

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Abstract: The construction industry is hazardous due to its tendency to cause accidents. In constructing a multi-storey building, one of the risks that has the potential for work accidents is the risk of falling from a height. This research was conducted on the "Y" building revitalization project in Semarang city. This study aims to analyze the factors that are the basic causes of unwanted events in the project's revitalization using the Fault Tree Analysis (FTA) method. This research is descriptive observational research with analysis based on field observations and supported by literature studies from previous research. The results showed two of the most dangerous risks, namely "workers being hit by falling materials from a height" during advanced structural work, and the risk of "falling from a height" during advanced structural work and installation work. When applying the FTA model, 16 root causes were found for both risks. To minimize these risks, it is necessary to take mitigation measures such as paying attention to one's physical and mental condition before working, always complying with applicable SOPs, and wearing complete PPE.

Keywords: risk analysis, building construction, Fault Tree Analysis

INTRODUCTION

Construction projects are activities where the results are greatly influenced by labor productivity. Every activity in a construction project is interconnected, so if one activity experiences obstacles, other activities in the field will also be affected. The construction activity itself is complex and requires extra attention in its implementation. The three essential elements of construction are cost, quality, and time, including the resources that must be managed, including labor and materials. Human resources, such as workers responsible for technical implementation in the field, play a crucial role in the success of construction projects. Therefore, serious attention to the role of field workers is essential to achieve the set targets. Work targets will be achieved when workers in the field have optimal productivity and appropriate skills. (Alfiyah et al., 2023)

The level of work accidents in Indonesia is still relatively high, with the number increasing every year. Based on data from the Social Security Administration (BPJS), work accident cases increased from 114,235 in 2019 to 177,161 in 2020. The increase in the number of work accident cases is especially apparent in the construction sector (Sulistyaningtyas, 2021). The International Labor Organization (ILO) estimates that there are 430 million occupational accidents and diseases worldwide each year, with 270 million (62.8%) occupational accidents and 160 million (37.2%) occupational diseases, resulting in 2.78 million worker deaths each year. Meanwhile, young workers account for 40% of occupational diseases and accidents. An estimated 3.94% to 4% of a country's GDP is lost economically (ILO, 2003).

Working at height is one of the leading causes of fatal accidents in the construction industry. This work is performed by workers in places that have a difference in height from the ground or water surface, which poses a risk of falls. This can result in serious injury or even death for workers, as well as damage to company assets (Permenaker No. 9, 2016). Working at height in the construction sector has become very serious in many countries. This is due to the high number of fatal accidents due to work at height. According to Ezeoguine (2022), about 50% of fatal accidents in the construction sector are caused by falls from height. In addition, other data shows that in the USA, the

percentage of fatal accidents due to work at height reaches 36.4% (Samantha Brown et al., 2021), while in Australia, the figure is 32% according to SWA (Firdaus & Erwandi, 2023).

Juhindra's research stated that four factors cause work accidents in the construction sector: personal factors, equipment factors, material factors, and environmental factors. Of these four factors, individual factors have the highest percentage as the cause of accidents in construction projects. Some personal factors include worker stress, lack of skills, and carelessness or negligence in carrying out tasks. In every stage of construction project implementation, such as the construction of houses, bridges, and roads, risks are always present, regardless of the project's location. Construction activities have a very high level of risk in various aspects. The size of the project affects the potential dangers that arise, and if not managed properly, this can hinder the smooth running of the project. Therefore, it is important to implement effective risk management to avoid possible risks that will arise during project implementation (Juhindra, 2023).

Revitalization of Building "Y" in Semarang City is a construction project carried out for 180 calendar days, followed by a maintenance period of 360 calendar days by the implementing contractor, PT X. PT X is a construction company located in Semarang City. Since its establishment, the company has become one of the leaders in the construction industry with a primary focus on infrastructure development and large-scale commercial projects. PT X provides various construction services, including: Residential Building Construction, Office Building Construction, Education Building Construction, Other Building Construction, Road Civil Construction, Irrigation and Drainage Network Construction, and Infrastructure and Facilities Construction of Solid, Liquid, and Gas Waste Treatment Systems.

Hazard assessment or work safety risk identification is critical in every new project, task, or job. The main objective is to anticipate various possibilities, including hazards that already exist or may arise during the execution of the work. Once all hazards are identified, control measures can be determined and implemented to reduce or eliminate the risk. A hazard assessment must also be carried out if significant changes to the project, task, or work are in progress (Caesar et al., 2023).

One way to achieve this goal is to identify potential workplace hazards and evaluate the associated risks. (Purnamasari, 2020). Fault Tree Analysis (FTA) is a potential hazard analysis method that serves as an alternative approach to examining failure behavior. Fault tree is a logical diagram that illustrates the relationship between a failure event and its cause. It uses logic gates and events to illustrate how a component's state relates to the system's overall condition. Commonly used logic gates in FTA include: (1) OR gates, (2) AND gates, and (3) inhibitory or conditional gates (Peeters et al., 2018). Identifying these potential risks is expected to significantly reduce or eliminate the possibility of work accidents (Zero Accident). In addition, an efficient risk control strategy can increase workers' sense of safety and security (Sufa & Astuti, 2024).

Risk identification and analysis in this project aims to highlight the main risks associated with work accidents, determine the causes of the most significant incidents through Fault Tree Analysis, and explore methods to overcome or prevent these accidents. Based on the identification of the problem above, the author wants to analyze the risk of work accidents in the revitalization of the Building Project "Y" in Semarang City by PT. X using the FTA (Fault Tree Analysis) Method.

METHODS

This type of research is an observational study using a qualitative and descriptive approach. The method used is the Fault Tree Analysis (FTA) method. This research is descriptive analytical, in which the author describes work conditions in the construction field, then identifies various accident risks that may occur in the construction work stages, and analyzes the factors that cause the risk of work accidents. Data collection is based on direct observation in the field and literature studies from previous studies. With this approach, the research systematically analyzes the basic causes of work accidents and provides mitigation to minimize these risks. The steps of this research are:

- **a.** Identify the risks in each work process through observation and literature study.
- **b.** Determining the most dangerous jobs and risks through observations and literature studies
- **c.** Analyzing the causes of work accidents using the FTA method.

RESULT AND DISCUSSION

Identification of Risks in Each Work Process

Table 1 shows the risks of each work process that are considered potential on the project.

Table 1. Hazard Risk Identification

Work Items	Risk
Advanced structural work	
Transportation of materials to upper floors	Worker hit by material
Concreting	Injured during iron cutting Falling from a height
Formwork	Hand pinched Impaled by a nail Worker's hand hit by wood chips
Casting	Fall from a height Skin irritation Hit by collapsed concrete mold
Wall and floor works	
Hebel wall installation	Exposure to dust from hebel pieces
Plastering	Exposure to sand/cement dust Skin irritation
Ceramic tile installation	Injury from ceramic cutting machine
Installation work (electrical installation, water pipes, ceiling)	Electric shock Falling from height Falling on materials
Finishing	
Indoor finishing (wall painting, interior installation)	Paint inhalation Hand pinched Fall from a height
Outdoor Finishing (exterior painting, rooftop finishing, area cleaning)	Paint inhalation Fall from height

Determination of the Most Dangerous Risks

The author determines the most dangerous risks in the construction work process based on literature studies from previous studies. The following data from prior research findings are shown in Table 2.

Table 2. Most Dangerous Risk Variables in Building Construction Work

Research	Findings	Source
Manajemen Risiko Kesehatan dan Keselamatan Kerja Menggunakan Metode HIRARC pada Proyek Pembangunan Gedung Universitas Nahdlatul Ulama Yogyakarta	The study found that the risk assessment with the most dangerous impact was the risk of "falling from a height" during column formwork work.	(Mardhatillah et al., 2024)
Penilaian Risiko Keselamatan dan Kesehatan Kerja pada Konstruksi Bangunan dengan Metode Hirarc	In the study, it was found that the level of risk with a high rating was the risk of "falling from a height" during installation work.	(Yusuf, 2023)
Manajemen Risiko Keselamatan dan Kesehatan Kerja (K3) pada Infrastruktur Gedung Bertingkat	The study found that the most dangerous risk was "material falling from a height and falling on workers" during the upper structure work.	(Yuliani, 2017)
Kajian Pengukuran Tingkat Risiko Keselamatan dan Kesehatan Kerja pada Kegiatan Konstruksi Pembangunan Hotel MidTown Samarinda	In the study, it was found that the risk with a high category was "material falling towards workers" during the work of lifting materials with a tower crane.	(Al Farisi, 2016)

Manajemen Risiko Kesehatan dan Keselamatan Kerja (K3) (Study Kasus pada Pembangunan Gedung SMA Eben Haezar)	In the study, it was found that the risk with the high risk category was "material falling from a height and falling on workers" during the upper structure work.	(Soputan et al., 2014)
Analisis Resiko Kecelakaan Kerja pada Proyek Pembangunan Gedung Kuliah, Laboratorium, dan Bengkel Jurusan Teknik Mesin, Politeknik Negeri Malang dengan Metode Fault Tree Analysis (FTA)	In the study, it was found that 2 out of 34 risks studied, the risk level with a high category is "falling from a height" during casting work and installation work.	(Mahardika et al., 2021)
Penilaian Risiko K3 Kontruksi dengan Meode Hirarc pada Pekerjaan Pembangunan Gedung F3 Fakultas Kedokteran Ilmu Kesehatan Universitas Warmadewa	Risk assessment with the most dangerous impact / high category is "workers falling from a height" on work that uses scaffolding and casting.	(Triswandana & Armaeni, 2020)
Penilaian dan Pengendalian Risiko Kecelakaan pada Pekerjaan Atap di Pembangunan Gedung Bertingkat	Risk assessment with high hazard risk category is "falling from height" in structural work.	(Wibawa & Hidayat, 2019)
Penilaian Risiko Keselamatan dan Kesehatan Kerja dengan Menggunakan Metode Hirarc dan Safety Policy (Studi Kasus Proyek Konstruksi Gedung Ruang Tunggu Kantor Induksi TJBTB)	Risk assessment with the highest hazard is in scaffolding work with the identification of the hazard "falling from height".	(Abryandoko, 2018)
Analisis Risiko Kecelakaan Kerja dengan Metode Job Safety Analysis pada Proyek Konstruksi	Building construction work with the highest risk of "falling from height" during installation work.	(Kadek et al., 2024)

Based on a review of various previous studies as described in Table 2, the risk of work accidents in building construction projects shows that "workers falling on materials" and "falling from heights" are the most dangerous risks, especially in work such as structural construction and installation. In this study, the authors analyzed two risks: the risk of "workers falling on materials" during the construction of advanced structures, and the risk of "falling from a height" during the construction of advanced structures and installation work. This is because, based on observations and literature studies from previous research, these risks are among the most dangerous risks in building construction projects.

Cause Analysis using Fault Tree Analysis (FTA) Model

Fault tree analysis has now become a commonly used method for predicting the probability or frequency of failure in engineering systems, especially related to failure parameters and repair of system components (Andrews & Lunt, 1998). Fault Tree Analysis (FTA) is one of the methods to solve cases when a failure or undesirable event occurs by finding the root causes of the basic events that appear and elaborating on each indication of the "top event" (Rizky, 2003). Fault tree analysis consists of two basic notations, namely "events" and "logic gates", which interconnect events to identify the causes of unwanted events (Alijoyo et al., 2021).

The event notation consists of 4 symbols, including (Alijoyo et al., 2021):

1. Circle (basic event) - this symbol indicates the cause of the risk, meaning that the circle represents the root or source of a risk event and requires no further analysis.
2. Square (intermediate event) - this symbol depicts an event that still requires additional analysis, usually followed by a logic gate to indicate the next event.
3. Square (undeveloped event) - this symbol signifies that the event cannot be analyzed further due to lack of data or information.
4. Triangle (transfer symbol) - is a symbol of an event that still requires further analysis, outside of the main risk event in the current analysis.

The event notation symbols are presented in Figure 1.

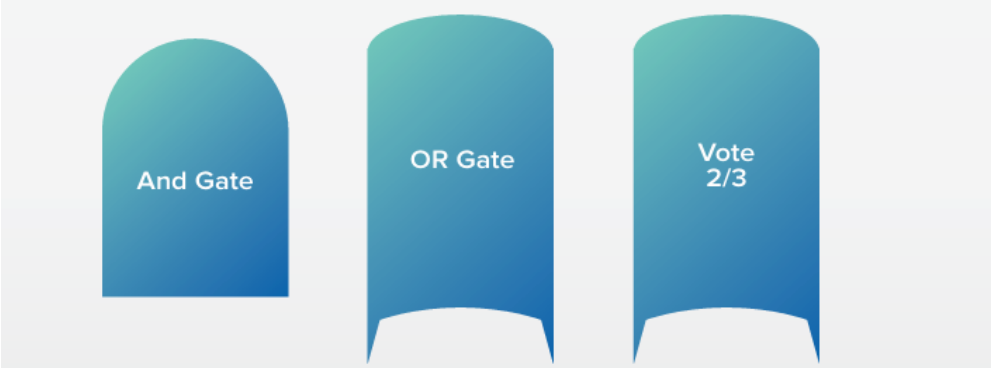

Figure 1. Event Notation Symbols (Alijoyo et al., 2021)

Logic gate notation consists of 3 symbols, including (Alijoyo et al., 2021):

1. AND Gate – a risk event can occur only if all the input events below it occur.
2. OR Gate – a risk event can occur if one or more of the input events below it occur.
3. Voting OR Gate – an event can occur if the number of events occurring meets the necessary conditions. In the example image below, an event can occur if there are at least two causes that must occur. If the Voting OR Gate contains 1/3, then at least one cause must occur.

The logic gate notation symbol is presented in Figure 2.

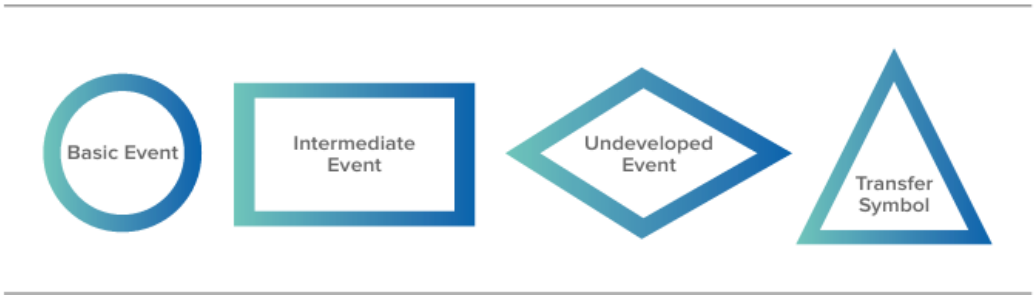

Figure 2. Logic Gate Notation (Alijoyo et al., 2021)

To find out the basic cause of the risk of "workers being hit by materials," the results of the FTA analysis are shown in Figure 3.

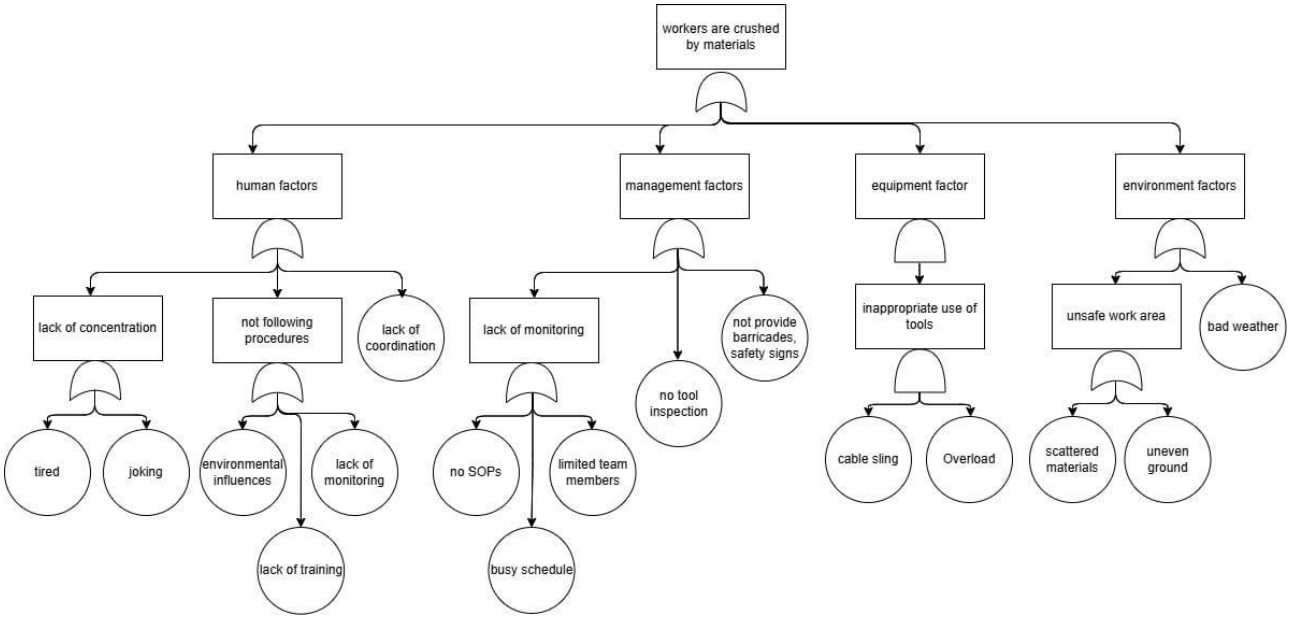

Figure 3. FTA Model The risk of workers are crushed by material

In Figure 3, a top event is "workers are crushed by material". Four factors affect the risk of such accidents, namely human factors, management factors, equipment factors, and environmental factors. The basic causes of personal factors are fatigue, joking, environmental influences, lack of training, lack of supervision, and lack of coordination. The basic causes of management factors are no SOP, busy schedule, limited number of team members, no equipment inspection, and not providing barricades and safety signs. The basic causes of the equipment factor are cable sling and overload. The basic causes of environmental factors are scattered materials, uneven ground, and bad weather. Based on the FTA accident, "workers are crushed by material" resulted in 16 basic event combinations. The basic events are as listed in the minimum cut set in Table 3. The minimum cut set is a list of minimal conditions that are sufficient and necessary for the peak event (John Andrews, 1998).

Table 3. Minimum Cut Set of Workers are Crushed by Material

Minimum Cut Set
Tired
Joking
Environmental Influence
Lack of training
Lack of monitoring
Lack of coordination
No SOPs
Busy schedule
Limited team members
No tool inspection
No provide barricades, safety signs
Cable sling
Overload
Scattered material
Uneven ground
Bad weather

To find out the basic cause of the risk of "falling from a height," the results of the FTA analysis are presented in Figure 4.

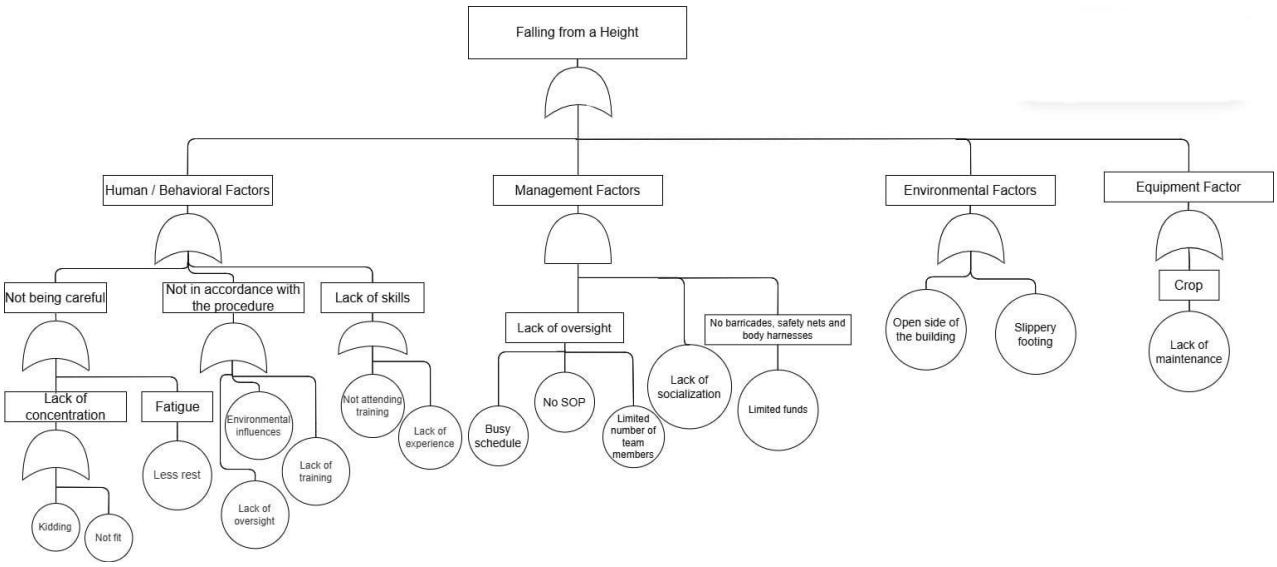

Figure 4. FTA Model Risk of Falling from Height

Figure 4 shows a top event, "falling from a height". Four factors affect the risk of such accidents: human factors, management factors, environmental factors, and equipment factors. The basic causes of personal factors are joking, not fit, lack of rest, environmental influences, lack of training, not attending training, and lack of experience. The basic causes of management factors are busy schedules, no SOPs, limited team members, lack of socialization, and limited funds. The underlying causes of environmental factors are open sides of buildings and slippery footing. The basic cause of the equipment factor is a lack of maintenance. Based on the FTA, the "fall from height" accident resulted in 16 basic event combinations. The basic events are as listed in Table 4.

Table 4. Minimum Cut Set of Falls from Height

Minimal Cut Set
Kidding
Not fit
Less rest
Lack of supervision
Not following training
Environmental influence
Lack of training
No training
Lack of experience
Tight schedule
No SOP
Limited number of team members
Less socialization
Limited funds
Open side of the building
Slippery footing
Lack of maintenance

Accident Risk Prevention

The preventive measures that can be taken based on the results of the FTA (Fault Tree Analysis):

1. From the human factor, the prevention that can be done is to pay attention to one's physical and mental condition to stay concentrated while working, always comply with applicable procedures, and attend training properly to improve skills in providing training.

2. Management can increase the number of team members in the workplace, develop good work safety SOPs, and provide high-quality and complete PPE that is comfortable for workers to wear.
3. For the work environment to remain safe, cleaning the work area regularly is necessary.
4. For equipment, a thorough inspection must be carried out before work so that the tools used remain safe when working.

CONCLUSION

1. The results of determining the work with the most dangerous risks in the project are "workers crushed by materials" during advanced structural work, and the risk of "falling from a height" during advanced structural work and installation work.
2. The FTA results of the causes of the accident of workers falling on materials resulted in 16 basic event combinations, and the accident of falling from a height resulted in 16 basic event combinations.
3. Each construction project has its own causal factors and combinations, so that the FTA model can vary. However, these differences are usually not too significant given the relatively similar characteristics of construction work.

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