Occupational Health and Safety Risk Analysis with The Fault Tree Analysis Method

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Abstract. Construction projects are often the most significant contributor to workplace accidents. Many things can happen during construction activities that can cause work accidents. This research aims to identify hazards, find the highest risk that can occur, and determine the primary event using the Fault Tree Analysis Method at Abdurrahman Saleh Air Force Hospital in Malang Regency. This research uses qualitative methods with data collection using questionnaires, interviews, and observations. The questionnaire was distributed to 12 selected respondents based on recommendations from the QHSE Officer. The results of the study were physical, chemical, and psychological hazards. There are 12 low-risk category variables, nine medium-risk, and two high-risk variables. The highest risk variables occurred in the production of rebar & fabrication and plastering work; workers were exposed to electric shock when cutting iron due to high voltage and falling from a height during outdoor plastering work. Basic events are lack of coordination, lack of enthusiasm, lack of motivation, lack of skills, lack of work experience, joking, lack of concentration, fatigue, rushing, lack of OHS members, limited monitoring time, messy work environment, lack of lighting, little workspace, extreme weather, slippery footing, high voltage electricity, tools/machines not functioning correctly, no warning, lack of safety equipment, limited PPE, and workers are not comfortable using PPE

1 Introduction

Development activities in a construction project are often a contributor to work accidents. Based on data from the Social Security Organizing Agency stated by the Minister of Manpower, work accidents in the construction sector increased from 114,000 in 2019 to 177,000 in 2020 [1]. Occupational safety and health issues, especially in the construction industry in Indonesia, still need serious attention from all parties because of the high number of accidents [2]. The construction management sector staff stated that the OHS program in construction projects is still ineffective by the Construction Management Development Agency of the Ministry of Public Works [3]. Therefore, in carrying out construction projects, it is necessary to implement a sound and optimal Occupational Health and Safety program to minimise work accidents.

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Implementing Occupational Health and Safety is an essential factor in construction projects. A safety management system must be implemented on-site to guard against work accidents and protect workers from injuries/accidents [4]. Given that construction projects are dynamic and unique, have limited time and workforce, and unpredictable weather that creates various potential hazards and risks [5]. Work accidents in construction activities in Indonesia often occur due to the non-optimal application of Occupational Safety and Health (OHS). In addition, the construction world's awareness level is also low regarding the importance of Occupational Health and Safety programs.

In construction activities, various sources of hazards can be found. The origins of danger include physical, biological, and psychological hazards to workers. In finding sources of trouble, it is necessary to know what sources of risk will arise [6]. It is required to identify the potential hazards from these sources of danger. After identification, what risks will occur can be arranged so that a risk ranking can be carried out based on the Hazard Identification and Risk Assessment Method.

Every risk that occurs must be analysed so that it can be known what is the main cause of the accident. Analysis of the leading causes of accidents is done using the Fault Tree Analysis Method. The fault tree analysis (FTA) method is a system analysis technique used to determine the root cause and probability of an undesirable event [7]. This technique is expected to identify the underlying cause of the accident so that it can be resolved immediately. Attention from all parties involved in construction is needed to explore the factors that cause accidents and preventive measures that can be taken as evaluation and mitigation of construction occupational safety and health analysis [8].

Based on this description, hazard identification and risk assessment are essential in an ongoing construction project. Risk assessment activities can rank risks from lowest to highest. If the highest risk is known, then the leading cause that causes work accidents will be sought to minimise casualties as minor as possible.

2 Literature Review

2.1 Occupational Health and Safety

Occupational safety and health are considered a concept and endeavour to ensure the integrity and physical and mental well-being of the workforce in particular, as well as humans in general, as a result of work and culture leading to a successful and happy society[9]. Occupational safety reflects a state that is harmless or free from suffering, damage, or loss in the work environment[10]. The most common occupational health and safety issues in the construction industry include falling materials or people from heights, stepping on objects, and being injured by hand tools [11].

2.2 Hazard Identification and Risk Assessment

OHS risk is a combination of work-related hazardous events or exposures and the severity of injuries and severe health problems that can result from these events or exposures[12]. Hazard Identification and Risk Assessment (HIRA) is a technique for determining the value and risk level of possible occupational hazards by identifying the properties of dangers that may arise and assessing their consequences using a risk assessment matrix [13]. HIRA is a process to determine the existence of a threat, then calculate the magnitude of a risk and determine whether the risk is acceptable or not. The Australian Standard /New Zealand Standard Scale for Risk Management is used for risk assessment.

a. Hazard identification

Finding potential hazards is a step that can provide thorough and detailed information about the risks found. Identification is done by finding anticipated dangers that can endanger the health and safety of employees, those around the workplace, visitors, and the general public [14]. Risk identification is an attempt to find out the risks that may arise in activities carried out by companies or individuals

b. Risk Assessment

The Hazard Identification and Risk Assessment method uses likelihood and severity scales for risk assessment. Risk assessment at low, medium, high, or very high levels is a risk rating. A risk assessment matrix can be determined by correlating the likelihood category results with the severity.

2.3 Fault Tree Analysis

A system analysis approach called Fault Tree Analysis (FTA) is used to identify the underlying causes and possible occurrences of unwanted events [7]. A fault tree is a graphical method to model how faults propagate in a system, that is, how component faults lead to system faults [15]. Large and complex dynamic systems are assessed using fault tree analysis (FTA) to identify and anticipate future problems. A fault tree is a structured logic diagram that shows cause-and-effect relationships among various events in the system [16].

FTA uses rigorous and organised techniques and allows system analysis to model specific arrangements of fault events that can result in unintended events. An unintended incident can be a severe system risk or an accident under investigation with the application of the FTA Method; the technique of using FTA is qualitative, which has two basic notation types, including events and logic gates. The notation of events consists of four symbols as follows [17].

1. an essential event with a circle symbol is a symbol that indicates the occurrence of a hazard or cause of a risk.
2. An intermediate event with a square symbol is a symbol of an activity that requires further analysis.
3. An undeveloped event with a diamond symbol is a symbol that indicates activities that do not allow for further analysis due to a possible lack of information or data.
4. The transfer symbol with a triangle symbol represents a symbol of an activity that still requires further analysis, in addition to the main risk event in the current study.

The notation of logic gates consists of 3 symbols, namely:

1. AND Gate that can happen in case all essential event items occur.
2. OR Gate that can happen in case one or more of the taking after occasion components happen.
3. Voting OR Gate that can happen in case the number of occasions matches the specified conditions.

3 Research Methodology

This research uses qualitative research methods. Qualitative research methods are methods based on the philosophy of post-positivism and are applied to research natural object conditions where researchers act as critical tools, techniques for collecting data by triangulation or combined, data analysis is inductive/qualitative, and research results are more emphasised with meaning than generalisation [18]. Qualitative methods in this study are used for hazard identification and risk assessment using likelihood and severity scales using the Hazard Identification and Risk Assessment method. In contrast, the Fault Tree Analysis method assesses risks that display a combination of events with the highest risk

assessment. Data analysis is fundamental because it answers the research questions and objectives.

Primary data were collected through questionnaires, interviews, and field observations. The questionnaire statement list was explicitly formatted for respondents with answer options using a Likert scale (1-5). In addition, interviews were conducted by conducting direct questions and answers with the Occupational Safety and Health to obtain supporting information for this study. The research variables were obtained from interviews and observations in the field. The number of respondents selected was 12 people who were in the Abdurrahman Saleh Air Force Hospital Construction Project in Malang Regency.

4 Analysis and Discussion

In this study, respondents were selected based on recommendations and suggestions from the QHSE Officer. The respondents selected were staff who were considered experienced and experts in their fields and had good competence in knowledge related to Occupational Health and Safety, so it was expected to get quite good results and not much different from what was expected.

Table 1. Respondent Profile

No	Position	Gender
1	QHSE Officer	Man
2	Inspector 1	Woman
3	Inspector 2	Woman
4	Surveyor	Man
5	Surveyor	Man
6	Drafter	Man
7	Drafter MEP	Man
8	Quantity Survey	Man
9	Quality Control	Man
10	Executor	Man
11	Executor	Man
12	Executor	Man

4.1 Hazard Identification and Risk Assessment Method

The study of risk analysis and assessment in the workplace is used to prevent accidents and diseases caused by work activities, minimise production losses, avoid damage to the company's reputation, and reduce the impact of accidents. [19]. The first step of this study is to identify hazards based on field observations. Observations were made directly on several jobs such as production work of concreting, formwork work, ceramic work, plastering work and ceiling work.

The results obtained were several physical hazards (dust, noise, electric shock, and sun exposure), chemical hazards (diesel exhaust emissions) and psychological hazards (stress/fatigue and lack of work control).

Based on this, it can be seen that there are still hazards that allow work accidents to occur in some of the jobs that have been mentioned. The following is a recapitulation of the risk variables obtained from interviews and observations in the field.

Table 2. Risk Variables

Code	Risk Variables
Reinforcement Production Work (Rebar & Fabrication)	
A1	Fingers are cut by the end of the reinforcement / scratched by the end of the rebar that has been cut.
A2	Workers are exposed to electric shock when cutting irons due to high voltage.
A3	Hit by sharp/blunt objects
A4	Fingers pinched/cut due to sharp iron cutting.
A5	A pile of iron columns/beams falling on workers.
Formwork Work	
B1	Hit by nails/bender/other sharp objects
B2	Falling from a height of >3m during formwork installation
B3	The formwork collapsed due to improper installation.
B4	The loud/noisy noise of Gerindra's machine
Flooring Work	
C1	Fingers are exposed to burrs when cutting ceramics.
C2	Eyes hit by grinding sparks when cutting ceramics.
C3	The worker is hit by material from above/side.
C4	Noisy/loud noise of the grinding machine during cutting
C5	Exposure to dust from ceramic cutting
Plastering Work	
D1	Falling from a height during outdoor plastering work
D2	Falling objects from above or from the side
D3	Eye contact with plastering mortar during installation
D4	Quality error when mixing plastering mortar
Ceiling Work	
E1	Worker falls from a height during ceiling installation/assembly.
E2	Pinched by the ceiling frame
E3	A drill punctured a worker's finger
E4	Falling on the ceiling frame
E5	Workers electrocuted during ceiling work.

As a result of interviews and observations, the risk variables in Table 2 are 23 relevant risk variables. After that, a questionnaire was distributed to 12 selected respondents. The results of the questionnaires that have been allocated will calculate the probability value of each variable. Each risk variable will have a different matter, so the probability value will be calculated one by one using the probability formula.

$$n = \frac{(1xA)+(2xB)+(3xC)+(4xD)+(5xE)}{\Sigma n} \quad (1)$$

After calculating the probability formula of each variable, the next step is risk assessment and risk ranking. At this stage, a risk assessment is carried out based on a combination of the probability category and the impact of the risk. For example, variable A1 has a probability value of 2.7 in the category "Possible "and an impact value of 1.9 in the class "Minor", so the variable is classified as a risk with a "medium" rating. Table 3 presents the risk matrix assessment results based on each variable's risk rating.

Table 3. Risk Matrix Assessment

Probability Level	Consequence Level				
	Negligible	Minor	Moderate	Major	Severe
Almost Certain	Medium	High	High	Extreme	Extreme
Likely	Medium	Medium	High	High	Extreme
Possible	Low	A1,A3,B4,C4	A2,B1	High	High
Unlikely	Low	A5,B1,B3, C1,C2,C3, C5,D2,E2, E3,E4	A4,B2,D4, E1,E5	Medium	High
Rare	Low	D3	Medium	Medium	High

Based on the risk matrix mapping in Table 3, all variables' risk matrix assessment results are obtained. There are three risk rating categories: low, medium, and high. Table 4 presents a complete recapitulation of the risk ranking.

Table 4. Risk Ranking Recapitulation

Code	Probability Value	Category	Impact Value	Category	Rank Risk
A1	2,7	Possible	1,9	Minor	Medium
A2	2,6	Possible	2,8	Moderate	High
A3	2,8	Possible	1,9	Minor	Medium
A4	2,3	Unlikely	2,7	Moderate	Medium
A5	1,8	Unlikely	2,3	Minor	Low
B1	2,4	Unlikely	1,8	Minor	Low
B2	1,8	Unlikely	2,6	Moderate	Medium
B3	1,6	Unlikely	1,8	Minor	Low
B4	2,5	Possible	2,2	Minor	Medium
C1	2,0	Unlikely	2,1	Minor	Low
C2	2,3	Unlikely	1,9	Minor	Low
C3	1,7	Unlikely	1,8	Minor	Low
C4	2,5	Possible	1,8	Minor	Medium
C5	2,2	Unlikely	1,8	Minor	Low
D1	2,5	Possible	2,9	Moderate	High
D2	1,7	Unlikely	2,0	Minor	Low
D3	1,3	Rare	1,9	Minor	Low
D4	1,6	Unlikely	2,5	Moderate	Medium
E1	1,9	Unlikely	2,5	Moderate	Medium
E2	1,5	Unlikely	1,5	Minor	Low
E3	1,8	Unlikely	1,6	Minor	Low

Code	Probability Value	Category	Impact Value	Category	Rank Risk
E4	1,8	Unlikely	1,7	Minor	Low
E5	1,6	Unlikely	2,8	Moderate	Medium

Table 4 states there are 12 low-risk category variables, nine medium-risk variables, and two high-risk variables. After obtaining the results of the risk category ranking results, the next step will be to identify the cause of the accident using the Fault Tree Analysis Method using the highest risk.

4.2 Fault Tree Analysis Methods

The depiction of the Fault Tree Analysis Diagram begins with finding a project's top event or peak failure. Based on the data processing results from filling out questionnaires on the Abdurrahman Saleh Air Force Hospital Development Project, the three highest risk values were obtained based on HIRA calculations. The top events that occur include:

1. Workers are exposed to electric shock when cutting irons due to high voltage
2. Falling from a height during plastering work outside the room

After the top event is known, the next step is to determine the factors that cause work accidents. Based on this, four Intermediate Event factors were obtained: human, management, environmental, and technical. The following depicts the Top Event in the production work of rebar and fabrication: workers exposed to electric shock when cutting iron due to high voltage.

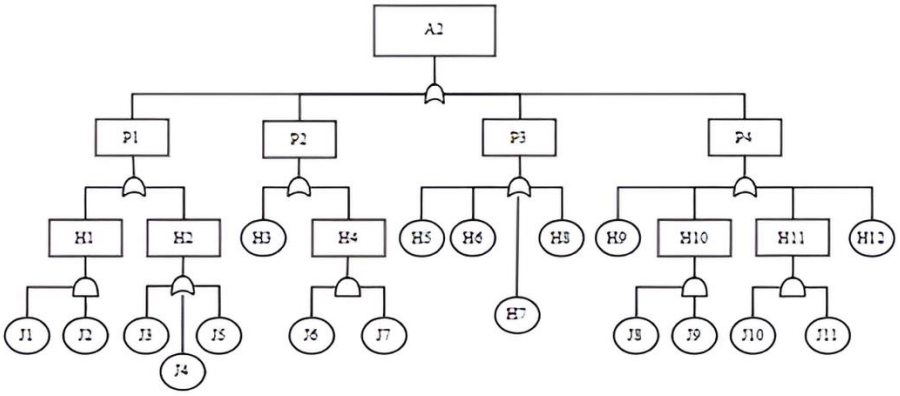

Fig. 1. Top Event Worker was electrocuted during iron cutting due to high voltage.

After the depiction in the Fault Tree Analysis Method, the results of the primary event/cause of the work accident that is the most basic and no longer possible to be traced back based on the acquisition of the highest risk variable results can be seen.

Table 5. FTA Method Description: The Worker was electrocuted during iron cutting due to high voltage.

Event	Description	Event	Description
A2	Workers were electrocuted during iron cutting due to high voltage.	H10	Not by procedures
P1	Human factor	H11	Workers do not use PPE
P2	Management factors	H12	High voltage electricity
P3	Environmental factors	J1	Lack of enthusiasm

P4	Technical factors	J2	Lack of motivation
H1	Mental and physical problems	J3	Joking
H2	Lack of caution	J4	Lack of concentration
H3	Lack of coordination between stakeholders	J5	Rushing
H4	Lack of monitoring	J6	Lack of K3 members
H5	Cluttered work environment	J7	Limited monitoring time
H6	Lack of lighting	J8	No warning
H7	Limited working space	J9	Lack of safety equipment
H8	Extreme weather	J10	A limited number of personal protective equipment
H9	Machines not working properly	J11	Workers are not comfortable using PPE

The results of the depiction of the Fault Tree Analysis Method at the risk of fabrication and rebar production work are workers exposed to electric shock when cutting iron due to high voltage obtained 16 essential events. The minimum cut set on the job can be seen in Table 6

Table 6. Minimum Cut Set of Workers Exposed to Electric Shock During Iron Cutting Due to High Voltage.

No	Cut Set	No	Cut Set
1	JI+J2	8	H6
2	J3	9	H7
3	J4	10	H8
4	J5	11	H9
5	H3	12	J8+J9
6	J6+J7	13	J10+J11
7	H5	14	H12

The depiction of the Fault Tree Analysis Method on the second highest risk variable, namely plastering work falling from a height during outdoor plastering work, can be seen in Figure 2.

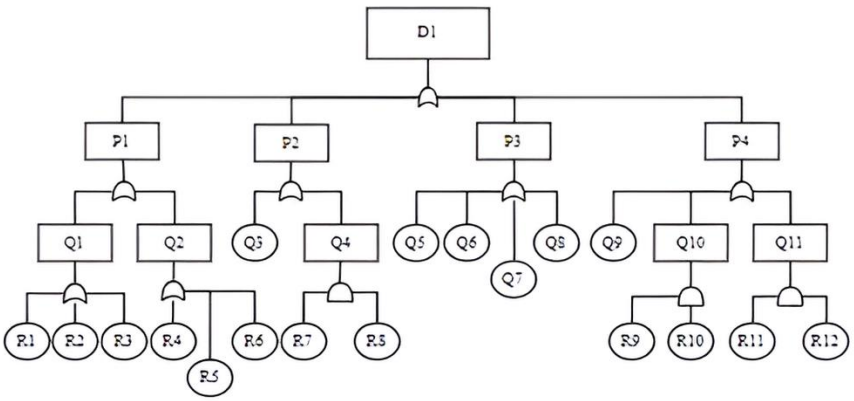

Fig. 2. Top Event Fall from Height during Outdoor Plastering Work

Table 7. Description of the FTA Method Falling from a Height during Outdoor Plastering Work

Event	Description	Event	Description
C1	Falling from a Height During Outdoor Plastering Work	Q10	Not by procedures
P1	Human factors	Q11	Workers do not use PPE
P2	Management factors	R1	Lack of skill level
P3	Environmental factors	R2	Lack of work experience
P4	Technical factors	R3	Fatigue
Q1	Mental and physical problems	R4	Joking
Q2	Lack of caution	R5	Lack of Concentration
Q3	Lack of coordination between stakeholders	R6	Rushing
Q4	Lack of monitoring	R7	Lack of OHS members
Q5	Cluttered work environment	R8	Limited monitoring time
Q6	Slippery footing due to rain	R9	No warning
Q7	Limited workspace	R10	No height safety
Q8	Extreme weather	R11	A limited number of personal protective equipment
Q9	Tools not working properly	R12	Workers are not comfortable using PPE

The results of the Fault Tree Analysis diagram on the highest risk variable resulted in 17 basic event combinations. These essential events are listed in Table 8.

Table 8 . Minimum Cut Set Falling From Height Outdoor Plastering Work Time

No	Cut Set	No	Cut Set
1	R1	9	Q5
2	R2	10	Q6
3	R3	11	Q7
4	R4	12	Q8
5	R5	13	Q9
6	R6	14	R9+R10
7	Q3	15	R11+R12
8	R7+R8		

5 Conclusion

Hazards that can occur in the Abdurrahman Saleh Air Force Hospital construction project are physical, chemical, and psychological hazards. There are 12 low-risk category variables,9 medium-risk variables, and 2 high-risk variables. The highest risk occurs in rebar and fabrication production work and plastering work. Basic events of the two highest risk variables are lack of enthusiasm, lack of motivation, lack of skill level, lack of work experience, joking, lack of concentration, fatigue, hurry, lack of coordination, lack of OHS members, limited monitoring time, cluttered work environment, lack of lighting, limited workspace, extreme weather, slippery footing, high voltage electricity, tools / machines not functioning correctly, no warning, lack of safety equipment, limited number of personal protective equipment and workers are not comfortable using PPE.

We are grateful for the support of several respondents and resource persons in the Abdurrahman Saleh Air Force Hospital development project in Malang Regency. The publication of this paper was supported by a research grant from ITN Malang research grant with ITN.04.006.011/I.LPPM/2023.

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