JURNAL rekayasa mesin
ISSN 2477-6041 articles 36, pp. 1631 – 1642, 2024
Vol. 15. No.3

ANALYSIS OF WORK ACCIDENTS DURING THE PLUMBING INSTALLATION PROCESS USING THE FAULT TREE ANALYSIS METHOD

Sofian Bastuti [1)] ✉, Rini Alfatiyah [1)]

[1)] **Industrial Engineering Department**
Universitas Pamulang, Jalan Raya Surya Kencana No. 1 Pamulang, 15417 Indonesia
dosen00954@unpam.ac.id
dosen00347@unpam.ac.id

Abstract

The plumbing installation process often harbors potential risks that can lead to workplace accidents. Considering the serious consequences of workplace accidents both in terms of health and economy, there are six types of workplace accidents in the plumbing installation process: foot crushed by a pipe, hand cut by a cutting tool blade, eyes exposed to welding smoke, burnt by hot welding slag, sparked by friction between iron and a cutting blade, and leg scratched by the edge of a pipe. This study aims to analyze workplace accident incidents during the plumbing installation process using the Fault Tree Analysis (FTA) method with the hope of identifying the root causes of the accidents and formulating recommendations to improve work safety. The FTA method allows for the development of a systematic model that illustrates the cause-and-effect relationships of system failures and their components. The primary advantage of using FTA is its ability to provide a comprehensive understanding of complex accident scenarios by breaking them down into simpler basic events. The novelty of this research lies in its application of FTA specifically to the plumbing installation process, which has not been extensively explored in previous studies. The results identified that the cause of eyes exposed to welding fumes led to 11 basic events, while the mocus analysis revealed 7 basic events with 11 failure combinations.

Keywords: *Plumbing Installation Process, Work Accidents, Root Causes, Systematic Model, Fault Tree Analysis.*

1. INTRODUCTION

In the construction industry, work safety is a crucial aspect that not only impacts employee welfare but also the efficiency and success of a project [1–3]. In the development of a building or infrastructure, plumbing installation represents one of the critical components that determine the quality and long-term safety of a project [4, 5]. However, this installation process often harbors potential risks that can lead to workplace accidents [6]–[8]. Given the serious consequences of workplace accidents, both in terms of health and economic impact, a thorough analysis of the causes and contributing factors to the occurrence of workplace accidents becomes paramount [9]–[11]. Despite the implementation of numerous preventive measures, incidents of workplace accidents in the plumbing installation process still frequently occur, causing losses for both workers and companies [12]–[14].

Corresponding Author:
✉ **Sofian Bastuti**
Received on: 2024-03-17
Revised on: 2024-08-15
Accepted on: 2024-08-22

DOI: 10.21776/jrm.v15i3.1823

Recent studies have increasingly focused on using various methods to analyze and prevent workplace accidents in the construction industry. For instance, Bakeli and Hafidi (2020) employed a Fault Tree Analysis (FTA) approach for managing safety risks in construction projects [1]. Cahyani et al. (2023) analyzed occupational health and safety risk factors in building construction using FTA, highlighting the importance of systematic risk identification [2]. Andriani et al. (2022) examined factors causing construction work accidents in high-rise building projects through FTA, providing insights into common failure points [3]. Zermane et al. (2022) conducted a risk assessment of fatal accidents due to work at heights activities using FTA, underscoring the method's effectiveness in hazard identification [6]. Lastly, Sakar et al. (2022) applied a fuzzy bow-tie methodology to assess risks in confined spaces aboard ships, demonstrating the versatility of risk analysis tools in various contexts [15].

Fault Tree Analysis (FTA) is a structured and comprehensive risk analysis method that enables the identification of various potential causes of a failure or accident event [16]–[18]. Through this systematic approach, FTA assists in unraveling the complexity of conditions or events that could lead to workplace accidents [18, 19]. By mapping and analyzing the cause-and-effect relationships among risk factors, this method provides deep insights into how and why accidents can occur, as well as aids in the development of effective prevention strategies.

This approach allows for the development of a systematic model that can describe the cause-and-effect relationships of system failures and their components [20, 21]. By identifying critical points and potential failures in the plumbing installation process, this study aims to provide insights on preventive measures and recommendations to enhance work safety and efficiency. Consequently, the results of this analysis are expected to serve as a guide for practitioners, project supervisors, and other relevant parties in implementing risk control strategies and improving workplace safety standards in construction projects, particularly those related to plumbing installation.

The analysis of workplace accidents using the Fault Tree Analysis (FTA) method not only assists in identifying the direct causes of accident incidents but also provides insights into systemic factors that may contribute. These include weaknesses in training and safety awareness, inadequacies in supervision and maintenance, as well as failures in the implementation of safety standards and protocols [22, 23]. Consequently, this research is not only relevant for enhancing safety on the worksite but also crucial in formulating more effective and comprehensive workplace safety policies.

This study distinguishes itself by applying the Fault Tree Analysis (FTA) method specifically to the plumbing installation process, a niche area that has not been extensively explored in previous research. The novelty of this research lies in its detailed examination of work accidents during plumbing installations, aiming to identify root causes and propose targeted preventive measures. By doing so, it seeks to fill a gap in the literature, offering valuable insights and practical solutions for enhancing workplace safety in this specific aspect of construction projects.

This study aims to analyze incidents of workplace accidents during the plumbing installation process using the Fault Tree Analysis method, with the hope of identifying the root causes of the accidents that occurred and formulating recommendations to improve occupational safety. By understanding the factors contributing to accidents, preventative measures can be taken to reduce the risk of future accidents, thereby creating a safer and more productive work environment.

2. MATERIALS AND METHODS

This research delineates the scope of the plumbing installation process, highlighting its significance in construction projects and pinpointing the myriad of safety challenges it presents [25]–[27]. The study follows a structured methodology as illustrated in the research flowchart (Figure 1).

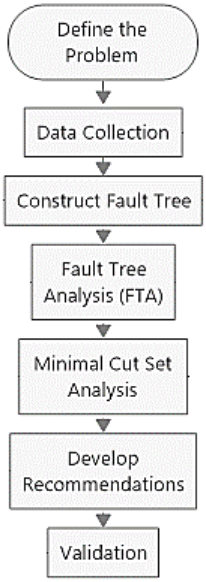

Figure 1. Research flowchart

The research flow is divided into several key stages:

1. Define the Problem: Identify the specific types of workplace accidents in the plumbing installation process.
2. Data Collection: Gather qualitative and quantitative data from case studies, accident reports, and expert interviews.
3. Construct Fault Tree: Develop a fault tree that maps out various potential causes of accidents.
4. Fault Tree Analysis (FTA): Analyze the fault tree using Boolean logic to identify basic events and their interdependencies.
5. Minimal cut set Analysis: Perform minimal cut set (mocus) analysis to identify critical points and failure combinations.
6. Develop Recommendations: Propose targeted preventive measures and recommendations based on the analysis.
7. Validation: Validate the findings through expert reviews and real-world applicability.

Data Collection

The Fault Tree Analysis method is introduced as the cornerstone of the research methodology. Data collection for this study encompasses both qualitative and quantitative approaches:

1. Qualitative Data: Derived from case studies, accident reports, and expert interviews, offering nuanced insights into the real-world dynamics of plumbing installation accidents.
2. Quantitative Data: Involves statistical analysis of accident frequency, severity, and the probability of failure events, providing a robust empirical basis for the fault tree analysis.

Constructing the Fault Tree

The fault tree visually maps out various potential causes of accidents, branching out from a top event (the accident) down to basic events (root causes). Each node in the tree represents a specific type of failure, and through Boolean logic, the interdependencies of these failures are explored to understand how singular or combined factors can lead to the top event.

Calibration/Validation of Tools

To ensure accuracy and reliability, the tools used in the research were calibrated and validated as follows:

1. Calibration: The tools for data collection and analysis, such as interview guides and statistical software, were calibrated against established standards to ensure precision.
2. Validation: The fault tree model and mocus analysis results were validated through expert reviews and comparison with historical accident data to ensure their accuracy and applicability in real-world scenarios.

Identification of Critical Points

The research methodology emphasizes identifying critical points and potential failures within the plumbing installation process. This is achieved through a rigorous analysis of the constructed fault tree, enabling the researchers to pinpoint specific areas of vulnerability and systemic weaknesses that predispose workers to accidents.

Development of Recommendations

Finally, the study leverages the findings from the Fault Tree Analysis to propose targeted preventive measures and recommendations. These are aimed at mitigating identified risks, enhancing training and awareness programs, improving supervision and maintenance protocols, and strengthening the enforcement of safety standards and practices. Through this methodological approach, the research endeavors to contribute valuable insights and practical solutions to the challenges of ensuring safety during the plumbing installation process in construction projects.

3. RESULTS AND DISCUSSION

3.1. Result

The fault tree analysis utilizes workplace accident data obtained from the plumbing installation process. The data gathered represents workplace accidents that occurred over a one-year period. From this simulation, a total of six workplace accident incidents were recorded. The accidents are as follows:

1. Foot crushed by a pipe
2. Hand cut by the blade of a cutting tool
3. The eyes are exposed to welding fumes
4. Burnt by hot welding slag
5. Sparked by friction between iron and the cutting blade
6. Leg scratched by the edge of a pipe

Determination of the Top Event

The top event is a failure or error that will be identified in detail. The list of top events for workplace accidents can be viewed in Table 1

Table 1. List of top event workplace accidents

No	Types of Accidents	Frequency
1	The eyes are exposed to welding fumes	12
2	Hand cut by the blade of a cutting tool	5
3	Sparked by friction between iron and the cutting blade	5
4	Burnt by hot welding slag	3
5	Leg scratched by the edge of a pipe	5
6	Foot crushed by a pipe	2

The steps for determining intermediate events and basic events are based on the standard safety plan, observations, and interviews regarding the causes of workplace accidents with workers and company management. The top event is derived from the classification of workplace accidents that have a high frequency of occurrence during the plumbing installation process.

Fault Tree Analysis Diagramming

The next step is to perform the fault tree analysis diagramming. The construction of the fault tree analysis begins from the top event, then moves to intermediate events, and down to basic events, in accordance with the results previously obtained. The diagramming also involves determining logic gates. A logic gate is a logical model represented in the form of symbols (And Gate or Or Gate) that connects events in the first and second contributions. The fault tree analysis diagram is annotated with letters and numbers to facilitate the focus analysis work. This analysis aims to find the hidden causes of workplace accidents. Below are the results from the fault tree analysis diagramming.

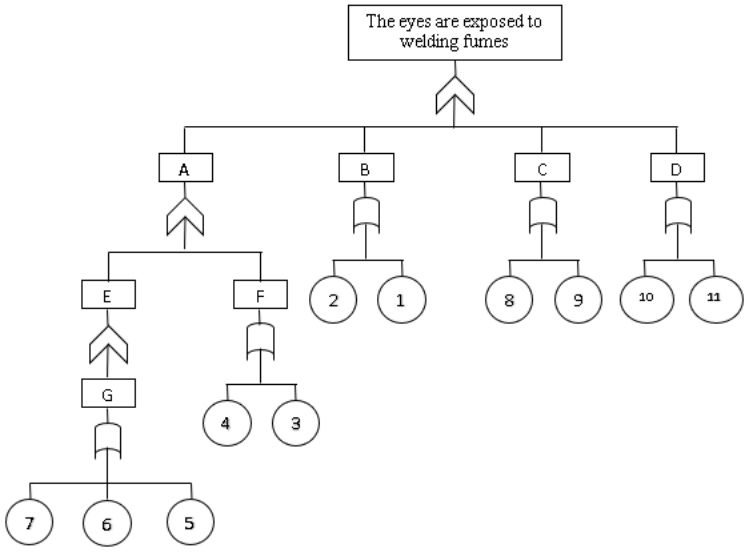

Figure 2. FTA diagramming with mocus analysis

Information:

A: Employee Factors
B: Management Factors
C: Environment Factors
1: Excessive targets
2: Violating the regulations
3: Indifferent towards the use of PPE
8: Insufficient Information
9: There are no sanctions
10: There are no safety tools

D: Equipment Factors	4: Neglecting PPE	11: Inadequate tools
E: In haste	5: Poor lifestyle choices	
F: Lack of Understanding of Welding SOP	6: Insufficient Rest	
G: Excessively Fatigued	7: Lacking enthusiasm for work	

The results of the fault tree analysis for the cause of eyes exposed to welding smoke can be seen in Table 2

Table 2. Minimal cut set for eyes exposed to welding smoke

No	Minimal *Cut Set*
1	Excessive targets
2	Violating the regulations
3	Indifferent towards the use of PPE
4	Neglecting PPE
5	Poor lifestyle choices
6	Insufficient Rest
7	Lacking enthusiasm for work
8	Insufficient Information
9	There are no sanctions
10	There are no safety tools
11	Inadequate tools

The fault tree analysis results revealed that the cause of eyes exposed to welding smoke led to 11 basic events, while the mocus analysis identified 7 basic events with 11 failure combinations. These results were categorized into two causes of accidents: unsafe actions and unsafe conditions. Of the 11 failure combinations, the primary causes of workplace accidents related to eyes exposed to welding smoke were employee factors, with two key causes being lack of motivation and insufficient rest. Below is the table of combinations of factors causing workplace accidents as identified by the mocus analysis for eyes exposed to welding smoke, which can be seen in Table 3

Table 3. Mocus combination for eyes exposed to welding fumes

Factor	No. *Basic Event*	*Basic Event*	*Unsafe Action*	*Unsafe Condition*	*Basic Event Combination*
Employee	1	Excessive targets	-	√	1
	2	Violating the regulations	-	√	2
	3	Indifferent towards the use of PPE	√	-	3
	4	Neglecting PPE	√	-	4
	5	Poor lifestyle choices	√	-	5
Management	6	Insufficient Rest	√	-	6
	7	Lacking enthusiasm for work	-	√	7
Environment	8	Insufficient Information	-	√	8
	9	There are no sanctions	√	√	9
Equipment	10	There are no safety tools	-	√	10
	11	Inadequate tools	√	√	11

Handling and Prevention of Workplace Accidents

Handling and prevention before the occurrence of workplace accidents are viewed from two aspects, namely:

1. Management Aspect
    a. Providing explanations about the dangers of common workplace accidents in the process line.

b. Addressing these issues by offering education (training) and explanations to workers or employees about accidents and work safety.

2. Technical Aspect

a. Supplying personal protective equipment (PPE) such as safety shoes, gloves, helmets, safety glasses, and providing first aid kits for initial treatment of workplace accidents.

b. Imposing strict penalties for those who neglect occupational health and safety (OHS) standards.

Handling and prevention after the occurrence of workplace accidents are viewed from two aspects, namely:

1. Management Aspect

a. Providing medical treatment, examinations, and care for workers injured in workplace accidents until they recover fully.

b. Offering compensation to workers who suffer from workplace accidents, whether temporarily or permanently disabled.

2. Technical Aspect

a. Identifying workplace accidents if they occur during the process line and providing first aid for workplace accidents.

b. Conducting investigations into the causes of workplace accidents to prevent recurrence.

Handling and prevention of workplace accidents can be viewed in Table 4

Table 4. Handling and prevention of workplace accidents

No	Types of Accidents	Before Workplace Accidents				After a Workplace Accident			
		Management Aspect		Technical Aspect		Management Aspect		Technical Aspect	
		A	B	A	B	A	B	A	B
1	The eyes are exposed to welding fumes	√	-	√	-	√	√	√	√
2	Hand cut by the blade of a cutting tool	-	√	√	-	√	√	√	√
3	Sparked by friction between iron and the cutting blade	-	-	√	-	√	√	√	√
4	Burnt by hot welding slag	√	-	√	-	√	√	√	√
5	Leg scratched by the edge of a pipe	-	-	√	-	√	√	√	√
6	Foot crushed by a pipe	-	-	√	-	√	√	√	√

By examining the root or fundamental causes of workplace accidents, which cannot be further identified due to the lack of necessary information (basic event) obtained from the fault tree analysis diagramming, the handling and prevention of workplace accidents in the plumbing installation process are approached from two perspectives: management aspect and technical aspect.

1. Management Aspect

a. Conducting safety talks, meetings, education, patrols, and morning briefings in the process line area.

b. Monitoring the assembling process and employees, conducting accident inspections, and simulating emergency situations.

c. Providing information about roles, including job functions, authority, and responsibilities.

2. Technical Aspect

a. Identifying and providing occupational health and safety equipment (such as signs, first aid kits, and personal protective equipment).

b. Carrying out occupational health and safety inspections, including monitoring the discipline of personal protective equipment use according to established regulations and environmental aspects.

c. Monitoring the effectiveness of corrective actions and prevention of workplace accidents.

From the two aspects mentioned above, the handling and prevention before workplace accidents concerning the top event produced by the company, namely eyes exposed to welding smoke, involve examining each basic event from the fault tree analysis diagram. Thus, the handling and prevention before workplace accidents concerning the factors causing workplace accidents can be seen in Table 5.

Table 5. Eyes exposed to welding fumes accident

No	*Basic Event*	Handling and Prevention Before Workplace Accidents					
		Management Aspect			Technical Aspect		
		A	B	C	A	B	C
1	Excessive targets	√	-	√	-	-	-
2	Violating the regulations	-	√	-	√	√	-
3	Indifferent towards the use of PPE	√	-	√	-	-	√
4	Neglecting PPE	-	-	-	√	-	-
5	Poor lifestyle choices	-	-	√	√	√	√
6	Insufficient Rest	√	√	√	-	-	√
7	Lacking enthusiasm for work	√	√	-	-	-	√
8	Insufficient Information	√	-	√	-	-	-
9	There are no sanctions	√	-	√	-	-	√
10	There are no safety tools	-	√	√	-	√	-
11	Inadequate tools	√	-	-	√	-	-

From the information above, it is evident that in the handling and prevention of workplace accidents involving eyes exposed to welding fumes, viewed from two technical aspects, the variety of options undertaken by company management is both necessary and crucial:

1. Management Aspect

a. Conducting safety talks, meetings, education, patrols, and morning briefings in the process line area to facilitate coordination among workers and between workers and the site manager.

b. Monitoring the process line and workers, performing workplace accident inspections, and simulating emergency situations.

c. Providing explanations about job roles, including job functions, authority, and responsibilities.

2. Technical Aspect

a. Carrying out identification and inspections of occupational health and safety, including monitoring the discipline of using personal protective equipment according to applicable regulations.

b. Identifying and providing occupational health and safety equipment, first aid kits, and personal protective equipment.

c. Monitoring the effectiveness of corrective actions and the prevention of workplace accidents.

From all the measures for handling and preventing workplace accidents related to the above top event, viewed from two aspects, the measures for handling and prevention before workplace accidents that must be implemented by the company are:

1. Management Aspect:
   a. Conducting safety talks, meetings, education, patrols, and morning briefings in the process line area to facilitate coordination among workers and between workers and the site manager.
   b. Monitoring the process line and workers, conducting workplace accident inspections, and simulating emergency situations.
2. Technical Aspect:
   a. Monitoring the effectiveness of corrective actions and the prevention of workplace accidents.
   b. Implementing identification and inspections of occupational health and safety, including supervising the disciplined use of personal protective equipment according to established regulations.

3.2. Discussion

The scientific discussion is as follows:

1. The study identified six main types of workplace accidents in the plumbing installation process. The Fault Tree Analysis revealed that eyes exposed to welding fumes were the most frequent accident type. The primary causes included employee factors such as lack of motivation and insufficient rest.
2. Compared to previous studies, this research provides a more detailed examination of the specific types of accidents in plumbing installations. Studies by Bakeli and Hafidi (2020) and Cahyani et al. (2023) focused on broader construction safety, while this study narrows down to the niche area of plumbing installation.
3. The findings highlight the importance of both management and technical interventions to prevent workplace accidents. Proper training, the provision of PPE, and strict enforcement of safety regulations can significantly reduce accident occurrences. The study also emphasizes the need for regular rest periods and motivation strategies to enhance employee safety.
4. Strengths and Limitations
   a. Strengths: The study's strength lies in its specific focus on plumbing installation, providing detailed insights that can be directly applied to improve safety in this area.
   b. Limitations: One limitation is the reliance on historical accident data, which may not capture all potential risks. Future research could involve real-time monitoring and broader data collection to enhance the findings.

4. CONCLUSIONS.

This study utilized Fault Tree Analysis (FTA) to identify the root causes of workplace accidents during plumbing installation, revealing that eyes exposed to welding fumes were the most frequent accident type due to factors such as lack of motivation and insufficient rest among employees. The theoretical contribution of this research lies in its novel application of FTA to the plumbing installation process, providing a detailed examination of specific

accident types and their causes. The findings emphasize the importance of both management and technical interventions, such as proper training, provision of personal protective equipment (PPE), and strict enforcement of safety regulations, to prevent workplace accidents. The study's limitations include reliance on historical accident data, which may not capture all potential risks, suggesting that future research could benefit from real-time monitoring and broader data collection. Overall, this research contributes to new knowledge in the domain by offering targeted preventive measures and practical solutions for enhancing workplace safety in plumbing installation projects.

REFERENCES

[1] T. Bakeli and A. A. Hafidi, "A fault tree analysis (Fta) based approach for construction projects safety risk management," *Proc. Int. Conf. Ind. Eng. Oper. Manag.*, no. August, pp. 1889–1901, 2020.

[2] H. Crisia Cahyani, H. Hardi Purba, and B. Susetyo, "Analyze of Occupational Health and Safety Risk Factors and Human Resource Quality on the Implementation of Building Construction using Fault Tree Analysis," *Adv. Res. Civ. Eng.*, vol. 5, no. 1, pp. 31–42, 2023.

[3] N. D. Andriani, I. Wayuni, and B. Kurniawan, "Analisis Faktor Penyebab Kecelakaan Kerja Konstruksi Pada Proyek Highrise Building dengan Metode Fault Tree Analysis (FTA)," *Pro Heal. J. Ilm. Kesehat.*, vol. 4, no. 2, pp. 235–241, 2022.

[4] S. Bastuti and R. Alfatiyah, "Safety Riding Analysis Using the PDCA Concept for Plumbing Fitting Industry Employees in Tangerang," *J. Ilm. Tek. Ind.*, vol. 21, no. 2, pp. 135–141, 2022, doi: 10.23917/jiti.v21i2.18151.

[5] R. Andhika, A. Rahma, A. Hasanudin, and I. I. Ntroduction, "Risk Assessment Analysis in Boiler System with Hazard and Operability Study (HAZOP)," vol. 6869, pp. 213–220, 2023, doi: 10.23917/jiti.v22i2.22875.

[6] A. Zermane, M. Z. Mohd Tohir, M. R. Baharudin, and H. Mohamed Yusoff, "Risk assessment of fatal accidents due to work at heights activities using fault tree analysis: Case study in Malaysia," *Saf. Sci.*, vol. 151, no. March, p. 105724, 2022, doi: 10.1016/j.ssci.2022.105724.

[7] C. Sakar, M. Buber, B. Koseoglu, and A. C. Toz, "Risk analysis for confined space accidents onboard ship using fuzzy bow-tie methodology," *Ocean Eng.*, vol. 263, no. July, p. 112386, 2022, doi: 10.1016/j.oceaneng.2022.112386.

[8] I. M. Siregar, A. Larasati, and A. Muid, "Analysis of the Implementation of Hazard Identification , Risk Assessment and Risk Control (HIRARC) in the Work Environment Against Work Accidents (Case Study of PT XYZ)," vol. 6869, 2021, doi: 10.23917/jiti.v22i2.22810.

[9] P. Fithri, Nofriyanti, A. Hasan, and I. Kurnia, "Risk Analysis for Occupational Safety and Health in Manufacturing Company Using FMEA and FTA Methods: A Case Study," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1003, no. 1, 2020, doi: 10.1088/1757-899X/1003/1/012073.

[10] M. N. Iskandar, Qurtubi, and C. Basumerda, "Risk Analysis in Occupational Safety and Health (OSH) by Using FMEA and FTA Method," *2021 Int. Conf. Decis. Aid Sci. Appl. DASA 2021*, pp. 496–501, 2021, doi: 10.1109/DASA53625.2021.9682232.

[11] I. Ramdani *et al.*, "A Risk Analysis Of Occupational Safety Levels For Operatorson Company X Using A Hazop Method With An Fta Approach Pjaee, 17 (5) (2020) A Risk Analysis OF Occupational Safety Levels For Operatorson Company X Using A Hazop Method With An Fta Approach A Risk," *s J. Archaeol. Egypt/Egyptology*, vol. 17, no. 5, pp. 735–745, 2020.

[12] Y. J. Ahn, Y. U. Yu, and J. K. Kim, "Accident cause factor of fires and explosions in tankers using fault tree analysis," *J. Mar. Sci. Eng.*, vol. 9, no. 8, 2021, doi: 10.3390/jmse9080844.

[13] Z. Spasenic, D. Makajic-Nikolic, and S. Benkovic, "Integrated FTA-risk matrix model for risk analysis of a mini hydropower plant's project finance," *Energy Sustain. Dev.*, vol. 70, pp. 511–523, 2022, doi: 10.1016/j.esd.2022.08.024.

[14] W. Qiao, Y. Liu, X. Ma, and Y. Liu, "A methodology to evaluate human factors contributed to maritime accident by mapping fuzzy FT into ANN based on HFACS," *Ocean Eng.*, vol. 197, no. January, p. 106892, 2020, doi: 10.1016/j.oceaneng.2019.106892.

[15] H. Li, M. Liang, F. Li, J. Zuo, C. Zhang, and Y. Ma, "Operational safety risk assessment of water diversion infrastructure based on FMEA with fuzzy inference system," *Water Supply*, vol. 22, no. 10, pp. 7513–7531, 2022, doi: 10.2166/ws.2022.322.

[16] M. Takahashi, Y. Anang, and Y. Watanabe, "A safety analysis method for control software in coordination with FMEA and FTA," *Inf.*, vol. 12, no. 2, pp. 1–31, 2021, doi: 10.3390/info12020079.

[17] P. Kilian *et al.*, "Best Practices for Advanced Modeling of Safety Mechanisms in an FTA," *IEEE Access*, vol. 11, no. March, pp. 60109–60129, 2023, doi: 10.1109/ACCESS.2023.3284751.

[18] M. Barozzi, S. Contini, M. Raboni, V. Torretta, V. Casson Moreno, and S. Copelli, "Integration of Recursive Operability Analysis, FMECA and FTA for the Quantitative Risk Assessment in biogas plants: Role of procedural errors and components failures," *J. Loss Prev. Process Ind.*, vol. 71, no. March, p. 104468, 2021, doi: 10.1016/j.jlp.2021.104468.

[19] F. Ihirwe, D. Di Ruscio, K. Di Blasio, S. Gianfranceschi, and A. Pierantonio, "Supporting model-based safety analysis for safety-critical IoT systems," *J. Comput. Lang.*, vol. 78, no. May 2022, p. 101243, 2024, doi: 10.1016/j.cola.2023.101243.

[20] V. Bolbot, G. Theotokatos, E. Boulougouris, G. Psarros, and R. Hamann, "A Novel Method for Safety Analysis of Cyber-Physical Systems-Application to a Ship Exhaust Gas Scrubber System," *Safety*, vol. 6, no. 2, 2020, doi: 10.3390/safety6020026.

[21] N. Hosseini, S. Givehchi, and R. Maknoon, "Cost-based fire risk assessment in natural gas industry by means of fuzzy FTA and ETA," *J. Loss Prev. Process Ind.*, vol. 63, no. October 2019, p. 104025, 2020, doi: 10.1016/j.jlp.2019.104025.

[22] K. Zhou, G. Huang, S. Wang, and K. Fang, "Research on Transportation Safety of Hazardous Chemicals Based on Fault Tree Analysis(FTA)," *ICITM 2020 - 2020 9th Int. Conf. Ind. Technol. Manag.*, pp. 206–209, 2020, doi: 10.1109/ICITM48982.2020.9080360.

[23] D. Birch, T. Bradley, D. S. Birch, and T. H. Bradley, "Development of a Human Factors Hazard Model Using HEP / FTA / ETA," 2023.

[24] M. Bao, S. Ding, and G. Li, "Classification and Control of Key Factors Affecting the Failure of Aviation Piston Turbocharger Systems Using Model-Based System Safety Analysis," *Int. J. Aerosp. Eng.*, vol. 2021, pp. 20–24, 2021, doi: 10.1155/2021/9710515.

[25] N. Tri Atmoko, E. Bilak Lopo, M. Chamim, and H. Lilih Wijayanto, "Analisis Pengaruh Arus Pada Pengelasan Bertingkat (Multilayer Welding) Terhadap Struktur Mikro, Kekerasan Dan Kuat Tarik Sambungan Material Astm a106," *J. Rekayasa Mesin*, vol. 14, no. 1, pp. 205–212, 2023, doi: 10.21776/jrm.v14i1.1210.

[26] R. Bintarto, M. S. Ma'arif, D. Widhiyanuriyawan, T. D. Widodo, R. Raharjo, and N. A. Purnomo, "Pengaruh Laju Alir Tungsten in-Ert Gas Terhadap Kekuatan Tarik

Dan Kejut Pada Sambungan Las Tig Baja Galvanis Dan Alu-Minium 5052 Dengan Filler Al-Si 4043," *J. Rekayasa Mesin*, vol. 14, no. 1, pp. 1–12, 2023, doi: 10.21776/jrm.v14i1.656.

[27] A. Ariyanto *et al.*, "Rancang Bangun Prototipe Preparasi Material Resistance Spot Welding," *J. Rekayasa Mesin*, vol. 14, no. 2, pp. 725–733, 2023, doi: 10.21776/jrm.v14i2.1466.