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Analysis of the Potential Hazards of Work Accidents Department of Production Using Failure Mode Effect Analysis (FMEA) and Fault Tree Analysis (FTA) Methods in PT. XYZ

Sinyi Retno Mayasi*, Rusindiyanto

Department of Industrial Engineering, Universitas Pembangunan Nasional "Veteran" Jawa Timur, Jl. Rungkut Madya No.1, Gunung Anyar, Surabaya 60294 Indonesia.

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A B S T R A C T

PT. XYZ is a company engaged in the business of white crystal sugar with raw sugar cane in Jombang. As the industrial world develops, companies are required to produce products both in terms of quality and quantity. Therefore, the production process has the potential to experience work accidents. To minimize this from happening, this research identified the potential hazards of work accidents in the production division. The methods used are the Failure Mode Effect Analysis (FMEA) and Fault Tree Analysis (FTA) methods. Using the FMEA method produced 3 potential hazards with the highest RPN values namely potential for exposed hot ashes at the boiler station with an RPN of 33,716. In second place is the potential collapse of the crane at the mill station with RPN 27,192. Then in third place is the potential Explosion of pipes and tanks at the evaporation station with an RPN value of 23.549. With the FTA method, the 3 potential hazards that have been obtained are used as top events and an analysis is carried out to find out the root causes of the potential accidents that occur. The analysis is grouped from human, equipment, and environmental aspects. From the human factor, it is known that the cause was workers who were not concentrating, were negligent, and did not comply with SOPs. The equipment factor comes from the age of the old tool and lack of maintenance. As well as environmental factors, namely high temperature pressure and humidity which can have an impact on corrosion of iron equipment. So that the suggestions that can be given to companies are imposing sanctions on employees who do not comply with the rules, providing job training according to their respective fields, and scheduling regular machine maintenance.

Corresponding Author

Sinyi Retno Mayasi
E-mail: sinyiretnomys@gmail.com

1. INTRODUCTION

In the development of the industrial world, it demands all companies to be more productive in producing high-quality products. Many things are needed to be prepared, including raw materials, machine performance and employee safety which are also very important and influential in the smooth production process. In the development of the industrial world, it demands all companies to be more productive in producing high quality products. Many things are needed to be prepared, including raw materials, machine performance and employee safety which are also very important and influential in the smooth production process. For this reason, occupational safety and health must be implemented in every company to minimize the number of work accidents. According to Wahyuningsih et al. (2021) in her journal, Occupational Safety and Health are all conditions and factors that can have an impact on Occupational Safety and Health for workers and other people in the workplace, which are regulated in the Law of the Republic of Indonesia No.1/ 1970 concerning work safety which defines the workplace as a room or field, closed or open, moving or fixed where the workforce works.

PT. XYZ is a company engaged in the business of white crystal sugar with sugar cane as raw material. In producing sugar, Tjoekir Sugar Factory has six stations namely milling station, refining station, evaporation station, cooking station, spinning and finishing station, and boiler station. Every year PT. XYZ carried out the sugar production process for six months after the sugarcane harvest. Based on data from the company, PT. XYZ in the last five years, namely 2018, 2019, 2020, 2021 and 2022. Based on the report's data, it is known that the largest number of work accidents occurred in 2019 namely 21 work accidents. In the second place, in 2018 there were 16, then in 2020 and 2022 there were 11 work accidents, and then in 2021 there were 10 work accidents. From these data it is categorized into accidents with light, moderate, and severe risks. Based on the results of the interviews, it was also found that the largest percentage of work accident potential was found at the mill station and boiler station.

Taken from several previous research excerpts which became the basis for supporting this research. According to Rizal et al. (2022) the Failure Mode and Effect Analysis (FMEA) method is used to identify all activities related to accident risk and analyze their severity. Companies use FMEA techniques to predict potential errors and failures, assess the consequences of system failures, prioritize which failures must be addressed first, and evaluate errors that have occurred so they can be identified and corrected. Failure priority is obtained by looking for the Risk Priority Number (RPN). The FTA method based on the journal from Ekoanindiyo et al. (2021) states that Fault Tree Analysis is a technique for identifying risks that play a role in the occurrence of failures using the fault tree analysis method. With this method a top-down approach will be carried out. The first is done by estimating the assumed failure or loss of the peak event. then the cause of the top event is broken down into the base failure. This is also supported by the Bukhori and Sholihin (2021) research entitled Proposal for Reducing Work Accident Rates by Applying the FMEA and FTA Methods at PT Jagat Interindo which aims to identify the causes of work accidents which are then given suggestions for improvement according to SOP standards for each work performed. Therefore, this research was conducted to analyze the potential for failure or work accidents at each production station using the FMEA method by looking for a Risk Priority Number (RPN). As well as identifying the root cause of the accident by describing it using the FTA method. So that later recommendations or suggestions can be given to companies to prevent these failures from happening.

2. LITERATURE REVIEW

Occupational Safety and Health (K3) is all activities to guarantee and protect the safety and health of workers through efforts to prevent work accidents and work-related diseases. The K3 system really needs to be considered because by implementing a good K3 system, the number of work accidents can be minimized so that every company activity remains smooth and undisturbed (Gianata et al., 2020). The term Occupational Safety and Health varies, some call it Company Hygiene and Occupational Health (Hyperkes) and some are simply abbreviated as OSH (Redjeki, 2016). Triyono et al. (2014) stated the main goal in implementing OSH based on Law no. 1 of 1970 concerning Occupational Safety among others to protect and guarantee the safety of every worker and other people in the workplace, to ensure that every source of production can be used safely and efficiently, and to increase national welfare and productivity. According to Farihah in Mahawati et al. (2021) industrial accidents are incidents of accidents that occur in the workplace, especially in an industrial environment, in the occurrence of industrial accidents there is no element of intent or planning, so if there is an element of sabotage or criminal action it is beyond the meaning of industrial accident. Based on the Regulation of the Minister of Manpower of the Republic of Indonesia Number: 03/MEN/98 Concerning Procedures for Reporting and Investigating Accidents Chapter 1 Paragraph 1 reads: "An accident is an unwanted and unexpected event that can cause human and/or property casualties." Accidents are triggered by activities at work. Such conditions may be caused by certain work activities of the individual, or by the activities of other people at work (Umniyyah et al., 2020).

According to Aprilliani et al. (2022) that people who experience work accidents must complain and suffer a lot, while other workers share in their grief. Occupational accidents will cause injury, disability or even death. Wahyudi in Simarmata et al. (2022) says there are three main factors that cause work accidents, namely: humans (actors who often make mistakes, whether intentional or not), the environment (related to a work environment that does not comply with safety standards), and equipment. (the location of the machine and the design of the equipment must be designed taking into account the safety of workers).

The success of an OSH risk management process is largely determined by the ability to determine or identify all the potential hazards that exist in each stage of work activities. If all hazards have been completely identified, it means that the organization/company will be able to carry out comprehensive management. The purpose of identifying potential hazards is to reduce the chance of accidents, provide an understanding of all parties regarding potential hazards, as input in determining appropriate prevention and security strategies, and provide information on sources of danger to the parties concerned (Aprilliani et al., 2022).

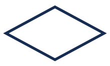
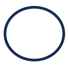
Based on journal excerpts Ihsan & Nurcahyo, (2022), the FMEA method is a method designed to identify and understand failure modes and the causes of these failures, as well as the effects caused by the system for the process of a particular product and assess the risks associated with the identified failure modes, effects, and causes, as well as focus on control measures. In this FMEA method, the Risk Priority Number (RPN) will be calculated for each work accident risk variable that may occur. The RPN value is obtained from the multiplication of Severity (S), Occurrence (O), and Detection (D). From the RPN value, it will produce a level of risk from the work. Jobs with the highest RPN score have a high level of risk, and will then receive top priority in carrying out preventive and curative actions. According to Rizal et al. (2022) the calculation of the RPN value is based on the following: (i) Severity indicates the seriousness of the consequences. The scale or rating used in this study is based on the severity scale. This standard describes the potential impact of occupational injury, illness, social and psychological hazards and hazards to machinery and equipment. (ii) Occurance is the measured failure rate (probability of work accident) especially related to the work performed. (iii) Detection is a measure of the ability to detect or control failures (potential work accidents) that may occur. Points are given to assess these three aspects, namely a scale of 1-10 or a scale of 1-5.

According to Haslindah in Setyaningsih (2021) Fault Tree Analysis (FTA) is a fault tree analysis that can be simply described as an analytical technique. The fault tree itself can be interpreted as a graphical model involving various parallels and combinations of pilot errors that will result in the occurrence of the previous unwanted event. According to Priyanta in Adityanto et al. (2019), there are five stages to conducting an analysis with Fault Tree Analysis (FTA), which are as follows: (i) Defining the problem and boundary conditions of a system under review, (ii) Fault Tree graphical model depiction, (iii) Looking for a minimum cut set from the Fault Tree analysis, (iv) Performing a qualitative analysis of the

Fault Tree, (v) Performing a quantitative analysis of the Fault Tree.

According to Clemens in Wibisono (2021), Cut set is a combination of forming on a fault tree where if all happens will cause the top event to occur. Cut set is used to evaluate the fault tree diagram and in get by drawing a line through the blocks in the system for denotes the minimum number of failed blocks that cause the whole system to fail. The search for the minimum cut set is done with the help of the laws of Boolean algebra. The symbols used in FTA will be presented in Table 1.

Table 1. Symbols in fault Tree Analysis

Symbol	Definition
	Top Event
	Logic Event OR
	Logic Event AND
	Transferred Event
	Undeveloped Event
	Basic Event

3. RESEARCH METHOD

This study combines qualitative and quantitative data processing. Qualitative processing, namely by identifying and analyzing the potential hazards that exist at the production station of PT. XYZ. As for quantitative processing, namely by calculating the RPN using the Failure Mode Effect Analysis (FMEA) method and calculating probability using the Fault Tree Analysis (FTA) method. Data were obtained through interviews and distributing questionnaires. The research method can be seen in Fig. 1.

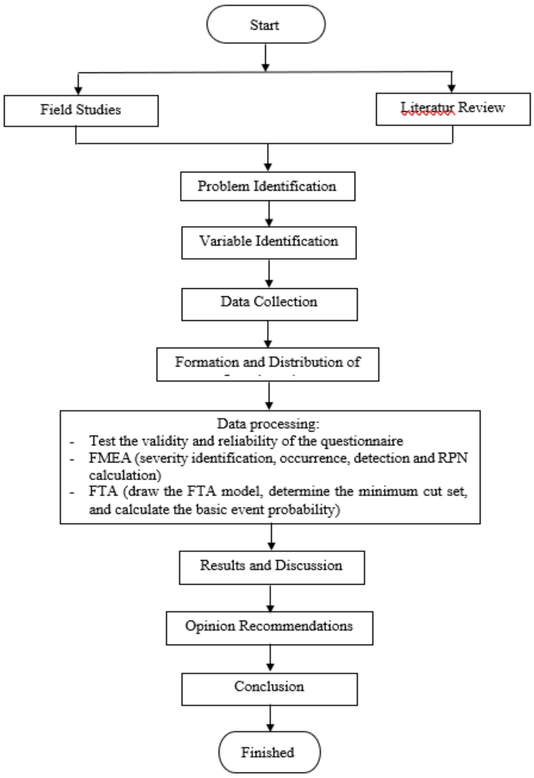


Fig. 1. Flow chart analysis stage
(Source: processed data, 2023)

4. RESULT AND DISCUSSION

Based on the results of data collection obtained at PT. XYZ is known data on the number of work accidents in the production process for the last 5 years. The following data on the number of work accidents can be seen in Fig. 2.

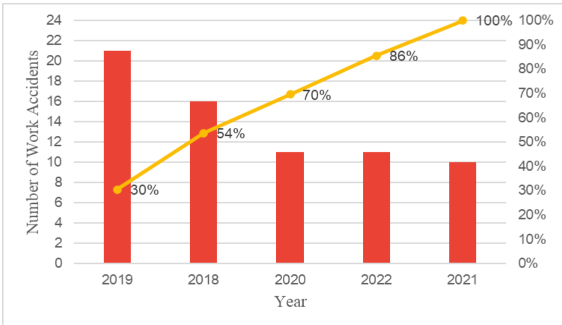


Fig. 2. Pareto diagram work accident PT. XYZ last 5 years
(Source: processed data, 2023)

The Pareto diagram in Figure 2, shows that from the last five years of PT. XYZ, 2019 was the year with the highest number of work accidents with a percentage 30 % with a total of 21 cases. This data will be used as a consideration in this study to assist the process of identifying potential hazards in the production process.

Table 2. Identification of potential hazards of sugar production

No	Stations	Potential Hazards
1	Milling	a. Collapse of the crane b. Stuck in the drive chain
2	Purification	a. Inhalation of phosphoric acid b. Touched hot pipe
3	Evaporation	a. Noise worker b. Explosion of pipes and tanks
4	Crystallization	a. Exposed to hot sugar liquid b. Sugar spilled on the production floor
5	Rounds and finishes	a. Got electric shock b. Panels explosion
6	Boiler	a. Exposed to hot water vapor b. hot ash exposure burns

Source: results of interviews with workers

Table 2 above is the result of interviews conducted with PT. XYZ regarding some potential work accident hazard assistance in the sugar production process which consists of 6 work stations. From each station, 2 potential hazards are taken which are considered to have a high risk according to workers. The results of this request will be assessed using the FMEA method.

In the FMEA method, before assessing the level of severity, occurrence, and detection, the scale and criteria for each are determined to make it easier for workers to fill out the questionnaire. The determination of these criteria is also based on the results of a mutual agreement with workers. The following criteria for severity, occurrence, and detection can be seen in Table 3, Table 4, and Table 5.

Table 3. Severity level criteria

Scale	Level	Criteria
1	Minor	Events can be ignored and do not cause harm
2	Low	Small incident, small financial loss and no serious impact
3	Moderate	Moderate incident, financial loss, and moderate injury (no permanent disability injury)
4	High	High impact events, major financial losses, and major injuries (permanent disabilities)
5	Very High	Events with very high effect, huge financial loss, and potential loss of life

Table 4. Occurrence level criteria

Scale	Level	Criteria
1	Unlikely	Rarely happens, almost never happens
2	Low	Events occur with low frequency, have never happened and may happen. Occurs 1 time in 1 period
3	Moderate	Events occur with moderate frequency, should have happened or might have happened. Happens 1-3 times in 1 period
4	High	Events occur with high frequency, can occur easily. Occurs more than 3 times in 1 period
5	Very High	Events occur with very high frequency and occur frequently. Almost repeated every month in 1 period

Table 5. Detection level criteria

Scale	Level	Criteria
1	Very High	Events that have a very high chance of control or failure detection capability
2	High	Events that have a high probability of control or failure detection capability
3	Moderate	Events that have a moderate probability of control or failure detection capability
4	Low	Events that have a low chance of control or the company's ability to detect failure
5	Unlikely	Events that have very low failure detectability or controllability almost do not occur.

Source: results of discussions with workers

After determining the assessment criteria for each aspect, 44 workers filled out questionnaires which were distributed evenly across 6 stations, so that the number of respondents at each station was around 7-8 people. before entering into the RPN calculation, it first conducts validity and reliability tests on the 12 potential hazards identified according to each aspect. The validity and reliability test values can be seen in Table 6 and Table 7 below.

Table 6. Hazard potential validity test results

Variable	**Potential Hazards**	**Pearson Correlation**	**r_{table}**	**Information**
Severity	S1	0,579	0,2973	Valid
	S2	0,670	0,2973	Valid
	S3	0,707	0,2973	Valid
	S4	0,710	0,2973	Valid
	S5	0,598	0,2973	Valid
	S6	0,556	0,2973	Valid
	S7	0,797	0,2973	Valid
	S8	0,490	0,2973	Valid
	S9	0,740	0,2973	Valid
	S10	0,778	0,2973	Valid
	S11	0,696	0,2973	Valid
	S12	0,472	0,2973	Valid
Occurance	O1	0,766	0,2973	Valid
	O2	0,651	0,2973	Valid
	O3	0,552	0,2973	Valid
	O4	0,783	0,2973	Valid
	O5	0,571	0,2973	Valid
	O6	0,625	0,2973	Valid
	O7	0,589	0,2973	Valid
	O8	0,403	0,2973	Valid
	O9	0,715	0,2973	Valid
	O10	0,722	0,2973	Valid
	O11	0,641	0,2973	Valid
	O12	0,699	0,2973	Valid
Detection	D1	0,830	0,2973	Valid
	D2	0,806	0,2973	Valid
	D3	0,825	0,2973	Valid
	D4	0,811	0,2973	Valid
	D5	0,806	0,2973	Valid
	D6	0,726	0,2973	Valid
	D7	0,822	0,2973	Valid
	D8	0,762	0,2973	Valid

Variable	Potential Hazards	Pearson Correlation	r_{table}	Information
	D9	0,876	0,2973	Valid
	D10	0,805	0,2973	Valid
	D11	0,620	0,2973	Valid
	D12	0,710	0,2973	Valid

Table 7. Hazard potential reliability test results

Variable	*Cronbach's Alpha*	Information
Severity	0,760	Reliable
Occurance	0,757	Reliable
Detection	0,775	Reliable

Based on Table 6, it can be seen that all potential hazards are declared valid so that the instrument can be used in measuring this study. while in Table 7, it is known that all variables are acceptable because they have a value of more than 0.5 (Cronbach's alpha (α) value > 0.5), so the instrument can be declared reliable.

After all the instruments are declared valid and variable, the calculation of the RPN 12 potential hazards can be carried out. From the data collection that has been obtained from the respondents' answers, the average value of each component of severity, occurrence, and detection is taken to calculate the RPN value of the entire potential hazard. The RPN calculation results can be seen in table 8.

Table 8. RPN for potential hazards in the production process

No	Stasiun	Potential Hazards	Severity	Occurrence	Detection	RPN
1	Milling	a. Collapse of the crane	4,273	2,523	2,523	**27,192**
		b. Stuck in the drive chain	3,901	1,637	1,932	12,357
2	Purification	a. Inhalation of phosphoric acid	3,295	2,568	2,340	19,812
		b. Touched hot pipe	3,159	2,386	2,318	17,476
3	Evaporation	a. Noise worker	2,705	2,977	2,046	16,470
		b. Explosion of pipes and tanks	4,273	2,205	2,5	**23,549**
4	Crystallization	a. Exposed to hot sugar liquid	3,57	1,931	2,25	15,509
		b. Sugar spilled on the production floor	2,568	1,909	1,909	9,360
5	rounds and finishes	a. Got electric shock	3,5	1,840	2,046	13,179
		b. Panels explosion	3,818	1,682	1,977	12,697
6	Boiler	a. Exposed to hot water vapor	3,705	2,432	2,4409	21,703
		b. Hot ash exposure burns	3,95	2,977	2,864	**33,716**

Based on the RPN calculation results for potential hazards in the production process in Table 8, it can be seen that the potential hazard that has the highest risk of failure is the potential for hot ash exposure burns at the boiler station with an RPN of 33,716. In second place is the potential collapse of the crane at the mill station with RPN 27,192. Then in third place is the potential Explosion of pipes and tanks at the evaporation station with an RPN value of 23.549.

Of the three potential hazards identified as having the highest RPN, identification will be carried out using the FTA method to find the root cause. This potential hazard will be used as a top event. The results of the FTA diagram for each top event can be seen in Fig. 3, Fig. 4, and Fig. 5.

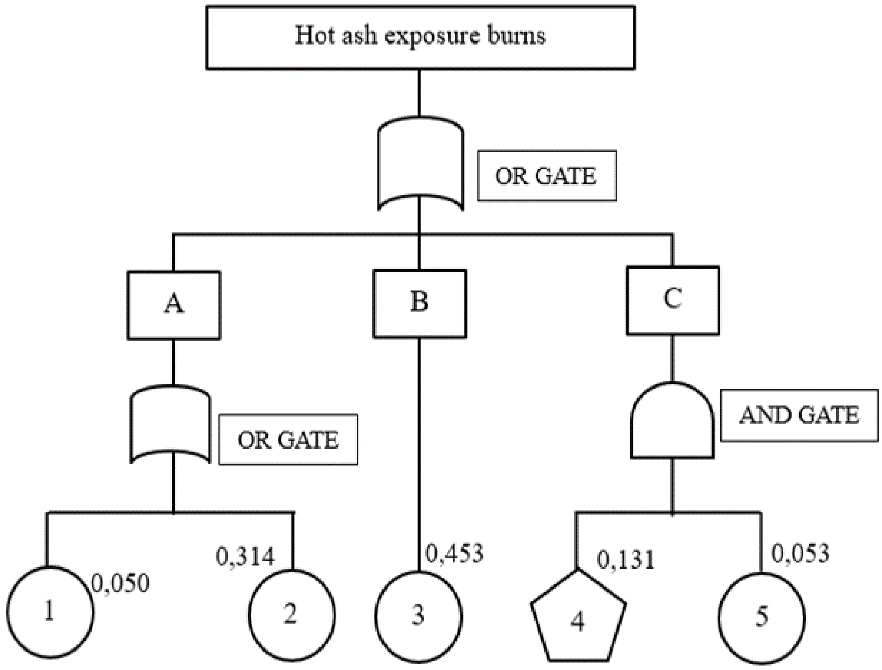


Fig. 3. FTA diagram of the potential hazard of hot ash exposure burns
(Source: processed data, 2023)

A : Human Aspect
B : Equipment Aspect
C : Environmental Aspect
1 : Workers are tired and sleepy
2 : Not complying with Standard Operating Procedures
3 : Electromotor not working properly
4: Hot environment
5: The distance is too close to combustion

Based on the laws of boolean algebra, figure 3 obtains the minimum cut set as follows:
T = A + B + C
A = 1 + 2
B = 3
C = (4.5)

So obtained:
T = A + B + C
T = (1 + 2) + 3 + (4.5)
T = 1 + 2 + 3 + (4.5)
The minimum cut set obtained is
{1}, {2}, {3}, {4,5}

The basic event probability in Figure 3 is obtained from interviews with representatives of boiler station workers. Probability calculations are carried out using the results of the comparison of interests at each basic event with the Analytical Hierarchy Process (AHP) calculation step.

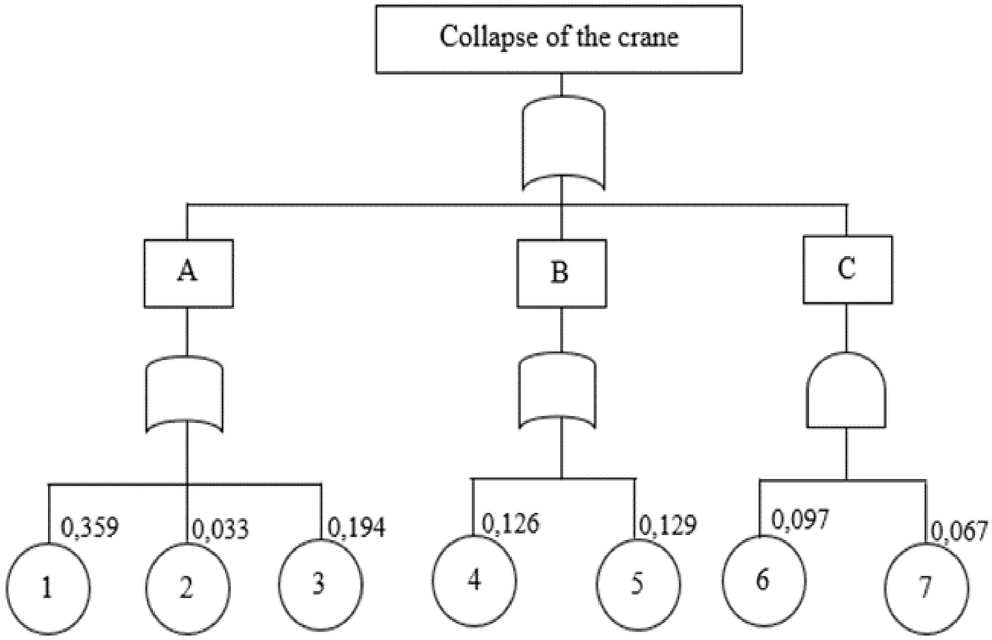


Fig. 4. FTA diagram of the potential hazard of collapse of the crane
(Source: processed data, 2023)

A : Human Aspect
B : Equipment Aspect
C : Environmental Aspect
1 : Negligent crane operator
2 : Tired workers
3 : Not complying with Standard Operating Procedures
4 : Old age of cranes
5 : Load capacity exceeded
6 : Air humidity has the potential for corrosion
7 : Oxidation process of iron

Based on the laws of boolean algebra, figure 3 obtains the minimum cut set as follows:
T = A + B + C
A = 1 + 2 + 3
B = 4 + 5
C = (6.7)

So obtained:
T = A + B + C
T = (1 + 2 + 3) + (4 + 5) + (6.7)
T = 1 + 2 + 3 + 4 + 5 + (6.7)
The minimum cut set obtained is
{1}, {2}, {3}, {4}, {5},{6,7}

The basic event probability in Figure 4 is obtained from interviews with representatives of milling station workers. Probability calculations are carried out using the results of the comparison of interests at each basic event with the Analytical Hierarchy Process (AHP) calculation step.

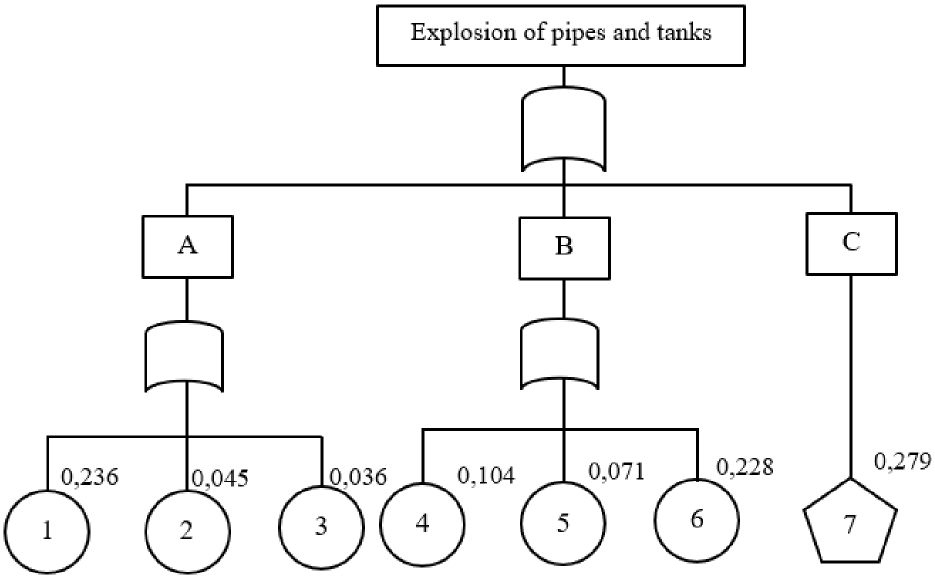


Fig. 5. FTA diagram of the potential hazard of collapse of the crane
(Source: processed data, 2023)

A : Human Aspect
B : Equipment Aspect
C : Environmental Aspect
1 : Negligent valve pipe operator
2 : Tired workers
3 : Not complying with Standard Operating Procedures
4 : Old age of pipe
5 : Corroded pipes are prone to corrosion
6 : Lack of pipe maintenance
7 : High temperature pressure

Based on the laws of boolean algebra, figure 3 obtains the minimum cut set as follows:
T = A + B + C
A = 1 + 2 + 3
B = 4 + 5 + 6
C = 7

So obtained:
T = A + B + C
T = (1 + 2 + 3) + (4 + 5 + 6) + 7
T = 1 + 2 + 3 + 4 + 5 + 6 + 7
The minimum cut set obtained is
{1}, {2}, {3}, {4}, {5},{6}, {7}

The basic event probability in Figure 5 is obtained from interviews with representatives of evaporation station workers. Probability calculations are carried out using the results of the comparison of interests at each basic event with the Analytical Hierarchy Process (AHP) calculation step.

After knowing the root causes of the 3 top events above, suggestions that can be given to companies in the hope of preventing or minimizing the occurrence of these potentials are providing training to employees according to their respective work fields, providing complete personal protective equipment for workers, scheduling routine machine maintenance. In addition, companies must also be more assertive by imposing sanctions on employees who do not comply with company rules.

5. CONCLUSION

Based on the identification results at 6 work stations, a total of 12 potential hazards were obtained, where each station was taken 2 potential hazards with high potential. Using the FMEA method, RPN calculations are carried out for all of these potential hazards. So that 3 potential hazards with the highest RPN value are taken, namely potential for exposed hot ashes at the boiler station with an RPN of 33,716. In second place is the potential collapse of the crane at the mill station with RPN 27,192. Then in third place is the potential Explosion of pipes and tanks at the evaporation station with an RPN value of 23.549. Of these 3 potentials will be used as the top event and the root causes are sought using the FTA method. To find out the cause, grouping the causal factors from humans, equipment, and the environment is carried out. It can be concluded that the cause of the human factor is workers who are tired, negligent, and do not comply with SOPs. From the equipment factor, the cause can be identified, namely from the old age of the equipment and lack of machine maintenance. And when viewed from environmental factors, namely high pressure and high temperature and humidity which can have an impact on corrosion of iron equipment. So that the suggestions that can be given to companies are imposing sanctions on employees who do not comply with the rules, providing job training according to their respective fields, and scheduling regular machine maintenance.

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