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APPLICATION OF FAILURE MODE AND EFFECT ANALYSIS AND FAULT TREE ANALYSIS IN DETERMINING PREVENTION EFFORTS FAILURE OF THE FIRE EXTINGUISHING PROCESS

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ABSTRACT

Banyumas is one of the regencies that still experiences frequent fires. The fire caused physical or material losses. To minimize fire losses, many efforts can be made to prevent the occurrence of these potential causes, which are the cause of the failure of the firefighting process. This study aims to implement the Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) methods in determining efforts to prevent fire suppression failures. The result of the FMEA is Risk Priority Number (RPN) values to assess critical potential causes that need to be analyzed using FTA. In this research, there are ten important causes of potential, namely burned assets, difficult assets to save, victims panicking, witnesses/owners were not present, officers slipping, water sources being far from the location, victims being rescued too late, victims being trapped, officers being hit by debris, and officers inhaled excess smoke (congested). The result FTA obtained eleven minimum cut sets, which can fail the firefighting process in the Banyumas Regency, namely lack of awareness from related agencies, the protection system is not up to the firefighting standard and lack of maintenance of the fire protection system, lack of knowledge about how to evacuate yourself, the water source is far from the location, the owner does not live in the place (location), the victim has responsibility for the assets saved, high-priority asset value, a witness has not reported because the incident is considered to be handled by the residents, fire smoke is thick and firefighters not using self-contained breathing apparatus (SCBA).

Keywords: Fire, FMEA, FTA, Boolean Algebra

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PRELIMINARY

Banyumas is one of the regencies that still experiences frequent fires. Based on annual report data obtained from the Banyumas Regency Satpol PP Fire Service Unit, the average number of fires that occurred reached 104.6 cases over the last five years. The fire resulted in physical and material losses. Sometimes losses not only impact the owner but also the surrounding environment. Therefore, firefighters have carried out various socialisations in schools, agencies, and so on. The socialization is carried out based on requests from related parties. The socialization aims to provide a simulation of knowledge about fire so that victims can do it themselves and the firefighting process can run smoothly to minimize the losses experienced. However, some failures may occur in the firefighting process. Therefore, it is necessary to make various efforts to prevent failure in the firefighting process. Mathematical methods that can be used to determine these efforts are Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA).

FMEA is a method that can prioritize repairs from each failure mode that occurs to facilitate repair steps (Lestari & Mahbubah, 2021). In general, FMEA is a method that can identify opportunities for potential failure modes of a process or system (Occurance), the effects or impacts of these failures (Severity), and the controls carried out on a failure that occurs (Detection) (Ciani et al., 2019).

FTA is a method that can analyze system failures (Wulandari et al., 2022). The logic relations in fault tree models can be equivalently represented in Boolean algebra formulas (Yang & Jung, 2017). FTA is a 'top-down' Boolean logic tool commonly used to identify possible causes for potential operating hazards or undesired events (Shafiee et al., 2019). FTA produces a minimum cut set and path set to determine efforts to prevent the failure of the firefighting process. In this study, it is discussed that failure can occur in implementing the system caused to several components. Minimizing failure can be done by finding the cause of the failure, which will later be constructed into a fault tree.

Much research used FMEA and FTA to identify the defect and analyze them to improve the quality of the product (Pratama & Suhartini, 2019), (Febriana & Hasbullah, 2021) to improve the safety level of control software (CSW) by managing the CSW's design information and safety analysis results (Takahashi et al., 2021), to analyze the ring spinning yarn production process in the textile industry (Mutlu & Altuntaş, 2020), to identify the factors causing failure and reliability analysis of electric arc furnace (Banjarnahor, 2021). Moreover, FMEA can be used to determine the risk causing work accidents (Fithri et al., 2020), to analyze the floating offshore wind turbine failure causes(Li et al., 2021), to identify risk analysis of safety-critical systems (Shafiee et al., 2019). Based on these studies, the authors are interested in applying the FMEA and FTA methods in determining efforts to prevent the failure of the firefighting process in the Banyumas Regency.

METHODS

This study uses a quantitative descriptive approach based on case studies at the Banyumas Regency Satpol PP Fire Service Unit. Data collection techniques in this study used interviews and questionnaires. Respondents in this study were employees of the

Banyumas Regency Satpol PP Fire Service Unit, with a total of 22 respondents. The research phase begins with collecting historical data in the form of the number of fire cases and the process of extinguishing the fire. The second stage is the distribution of questionnaires to research respondents to determine the value of Occurrence (O), Severity (S), and Detection (D) using a ranking weight of 1 – 5, as shown in Table 1.

Table 1. Occurrence, Severity, and Detection Values

Probability of Failure (O)	Strength of failure impact (S)	Possibility of diagnosing the failure mode (D)	Ranking
Very Low	Very Low Impact	Very Low	1
Low	Low Impact	Low	2
Moderate	Moderate	Moderate	3
High	High Impact	High	4
Very High	Very High Impact	Very High	5

After the results of the questionnaire were obtained from the respondents, the next step was using the FMEA method, namely determining the RPN value obtained by multiplying the Occurrence, Severity, and Detection values, or RPN = O · S · D. The next stage after the RPN value is obtained is to determine the failure priority that will be repaired or further handled using the Pareto Diagram. The Pareto diagram is a diagram that is used to select a priority category of events so that the most dominant value can be determined by looking at the cumulative value (Saputra & Santoso, 2021). After obtaining the failure priority to be repaired, the next step is to find the root cause of the failure using the FTA method.

The FTA method is effective in finding the core of the problem because the FTA method ensures that an unwanted event or loss does not originate at a single point of failure. FTA identifies the relationship between causal factors and is displayed as a fault tree involving simple logic gates, namely AND gates and OR gates. Each failure can be described as a failure analysis tree by transferring or moving the failure components into symbols (Logic Transfer Components) and Fault Tree Analysis (Ponidi & P, 2020). In addition, FTAs have special symbols (Krisnaningsih et al., 2021) (Mutlu & Altuntaş, 2020), as a basic event, conditioning event, undeveloped event, and intermediate event.

The author uses TopEvent FTA software to create a fault tree and determine the minimum cut set. The author also uses Boolean algebra to determine the minimum cut set in FTA. In Boolean algebra, the symbol (.) is used for operations on the AND gate, while the sign (+) is used for operations on the OR gate (Ghurabi et al., 2022).

The following is a research flow in determining proposed efforts to minimize fire losses in Banyumas Regency using FMEA and FTA.

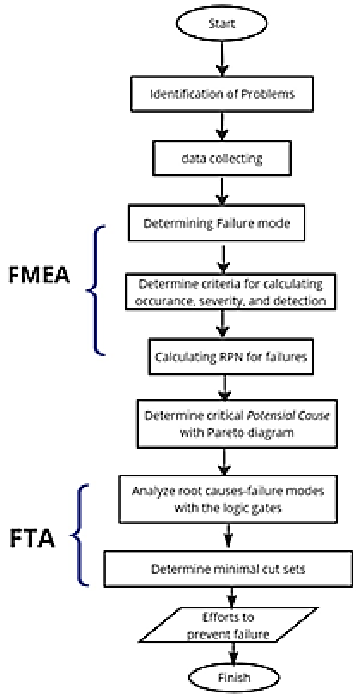

Figure 1. FMEA and FTA integration framework

RESULT AND DISCUSSION

The identification of the fire suppression process was obtained from the results of interviews with Banyumas Regency Satpol PP Fire Service Unit employees. There are five fire suppression processes: fire reporting, fire suppression, victim rescue, asset recovery, and incident data collection. Then from each process, the failure event and the consequences of the failure event are described. Table 2 presents data on the process of extinguishing fires, potential failure modes, and potential effects of failure.

Table 2. Fire Fighting Process

Process	*Potential Failure Mode*	*Potential Effect of Failure*
Fire reporting	Failed report	The incident late/failed to handle
Fire fighting	Failed fire fighting	Injured/dead victim, failed asset rescue
Victim rescue	Firefighter fell	Injured/died officer
	Injured/dead victim	Become a firefighter evaluation material
Asset rescue	Failed asset rescue	Victim suffers loss
Incident Data	The witness/owner does not know the chronology	Firefighters cannot evaluate due to the lack of reports

The RPN value is a value that states the priority scale of quality risk, which is used as a guide in planning. In addition, the RPN value is used to determine the potential cause, which will be analyzed using a fault tree. From the results of the questionnaires distributed in the Banyumas Regency Satpol PP Fire Service Unit**,** the average occurrence values (O), severity (S), and detection (D) were obtained, which are presented in Table 3.

Table 3. Determining RPN Value

Process	*Potential Failure Mode*	*Potential Cause*	*Prevention*	O	S	D	RPN
Fire reporting	Failed report	The incident finder does not know where to report	Socialization of firefighters' phone numbers	1,55	4	2,09	12,96
		Fireworks office phone damaged/trouble	Contacting Telkom and making sure the handset is plugged in correctly	1,55	4	1,82	11,28
		The whistleblower does not know the address of the nearest fire station	Socialization of the address of the nearest Fire Post office	1,55	4	2,14	13,27
Fire fighting	Failed fire fighting	Not enough water in the tank	Checking after the tank is used	1,45	4	2,50	14,50
		Expired APAR	Conduct regular fire extinguisher (APAR) checks	1,45	4	2,18	12,64
		The water source is far from the location	Ensuring all the water in the tank is sufficient	1,45	4	3,41	19,78
Victim rescue	Firefighter fell	Firefighter crushed by debris	Wear full Personal Protective Equipment (PPE)	2,23	3,45	2,5	19,23
		Excessive smoke inhalation (shortness of breath)	Equip yourself with SCBA (*self-contained breathing apparatus*)	2,23	3,45	2,27	17,46
		Firefighter slip	Wear full PPE	2,23	3,45	2,64	20,31
	Injured/dead victim	Late victim saved	Respond as quickly as possible	2,09	3,55	2,64	19,59
		Panic victim	Socialization of fire rescue flow	2,09	3,55	3,18	23,59
		Trapped victim	Socialization of fire rescue flow	2,09	3,55	2,64	19,59
Asset rescue	Failed asset rescue	Assets on fire	Fire simulation	3	3,95	2,77	32,82
		Assets are hard to save	Fire simulation	3	3,95	2,64	31,28
Incident Data	The witness/owner does not know the chronology	The witness/owner was not at the location	Firefighters help find the closest CCTV point to the location	2,32	3,64	2,50	21,11
				Total RPN			**289,40**

A Pareto diagram is used to compare various events according to their size. The events are arranged from the largest on the left to the smallest on the right. This arrangement can help determine the priority of events to be (investigated further. The Pareto diagram has an 80/20 concept, which means that 80% of the effect is caused by 20% of the causes Saputra & Santoso, 2021). The formula can obtain the percentage of each potential cause $\frac{RPN\ Value}{Total\ RPN\ Value} \times 100\%$. Table 4 presents the percentages for each potential cause sorted from the largest to determine the cumulative percentage.

Table 4. Cumulative Percentage for Potential Cause

No.	*Potential Cause*	RPN	Percentage	Cumulative Percentage
1	Assets on fire	32,82	11,34%	11,34%
2	Assets are hard to save	31,28	10,81%	22,15%
3	Panic victim	23,59	8,15%	30,3%
4	The witness/owner was not at the location	21,11	7,29%	37,59%
5	Firefighter slip	20,31	7,02%	44,61%
6	The water source is far from the location	19,78	6,83%	51,44%
7	Late victim saved	19,59	6,77%	58,21%
8	Trapped victim	19,59	6,77%	64,98%
9	Firefighter crushed by debris	19,23	6,65%	71,63%
10	Excessive smoke inhalation (shortness of breath)	17,46	6,03%	77,66%
11	Not enough water in the tank	14,50	5,01%	82,67%
12	The whistleblower does not know the address of the nearest fire station	13,27	4,58%	87,26%
13	The incident finder does not know where to report	12,96	4,48%	91,73%
14	Expired APAR	12,64	4,37%	96,10%
15	Fireworks office phone damaged/trouble	11,28	3,90%	100%
Total		289,41		

Based on Table 4, the cumulative percentage that causes failure up to 80% is in potential causes no. 1 to 10. Furthermore, potential causes with critical RPN and in the cumulative percentage area of 80% will be further analyzed using the FTA method, which aims to determine efforts to prevent failures in the firefighting process by avoiding these potential causes. A potential cause is an event that can cause a failure mode. The failure mode is the top event (T) in the fault tree. From each potential cause, the root cause of the incident is searched. Table 5 contains event symbols and root causes of events used in making a fault tree analysis.

Table 5. Symbol and description of FTA

No.	Symbol	Information
1	T(Top Event)	The failure mode for a critical potential cause
2	G_1	Assets on fire/hard to save
3	G_2	Panic victim
4	G_3	Witness/owner not at the location
5	G_4	Late victim saved
6	G_5	Trapped victim
7	G_6	Firefighter inhaled excess smoke (shortness of breath)
8	G_7	No fire protection system
9	G_8	The fire protection system is not working
10	G_9	Late report
11	G_{10}	Victim prioritizes asset safety
12	B_1	The water source is far from the location
13	B_2	Lack of knowledge about how to evacuate yourself

No.	Symbol	Information
14	B_3	The owner does not live in the place (location)
15	B_4	Lack of knowledge about how to evacuate yourself
16	B_5	Lack of knowledge about how to evacuate yourself
17	B_6	Fire smoke is thick
18	B_7	Firefighters not using SCBA
19	B_8	Lack of awareness from related agencies
20	B_9	The protection system is not up to the firefighting standard
21	B_{10}	Lack of maintenance of the fire protection system
22	B_{11}	A witness has not reported because the incident is considered to be handled by the residents
23	B_{12}	The victim has responsibility for the assets saved
24	B_{13}	High-priority asset value
25	U_1	Firefighter slipped
26	U_2	Firefighter crushed by debris
27	U_3	The fire incident is quite large
28	U_4	Psychological factors of the victim
29	U_5	Witness only helps report the incident
30	U_6	Insufficient funds from relevant agencies
31	U_7	Access fire location is difficult for officers to reach

For potential causes of assets on fire or assets hard to save, symbolized by G_1, this can occur due to the absence of a fire protection system (G_7) or a malfunction of the fire protection system (G_8). These two things are not basic events because they still need to be developed again. In addition, large fire incidents (undeveloped events) can also result in assets on fire/hard-to-save assets. The logic gate used is an OR gate because assets will burn/be hard to save if one of the events occurs; namely, the fire protection system is not available, it is not functioning, or a large fire incident occurs. Faulty tree analysis for assets on fire/hard-to-save assets is illustrated in Figure 2.

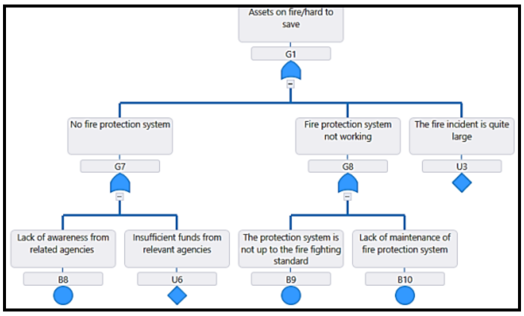

Figure 2. Fault Tree G_1

Based on Figure 2, when written in Boolean algebra with the "top-down" method as follows:

$G_1 = G_7 + G_8 + U_3$

with $G_7 = B_8 + U_6$ and $G_8 = B_9 + B_{10}$.

Substitution so that we get $G_1 = (B_8 + U_6) + (B_9 + B_{10}) + U_3$.

Furthermore, in the same way, the incident's root cause is searched for other potential causes. Figure 3 shows the Fault tree for the root cause of all potential causes.

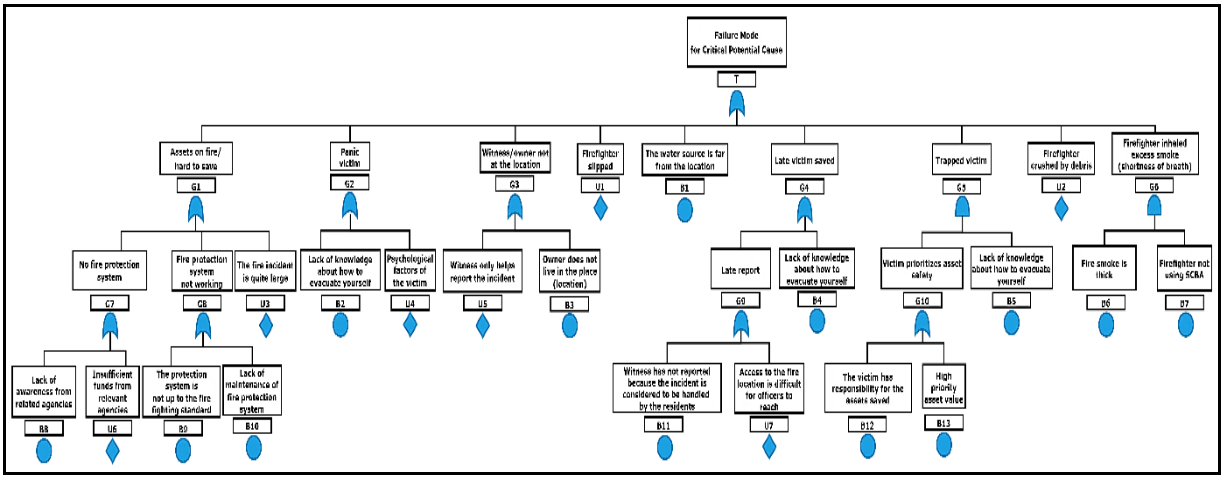

Figure 3. Fault Tree of Critical Potential Cause

The next step is to find the minimum cut set using Boolean algebra. From Figure 3, the Boolean equation is obtained as follows:

$$T \;= G_1 + G_2 + G_3 + U_1 + B_1 + G_4 + G_5 + U_2 + G_6$$

with

$G_1 = G_7 + G_8 + U_3$ $\quad$ $G_2 = B_2 + U_4$ $\quad$ $G_3 = B_3 + U_5$ $\quad$ $G_4 = G_9 + B_4$

$G_5 = G_{10} \cdot B_5$ $\quad$ $G_6 = B_6 \cdot B_7$ $\quad$ $G_7 = B_8 + U_6$ $\quad$ $G_8 = B_9 + B_{10}$

$G_9 = B_{11} + U_7$ $\quad$ $G_{10} = B_{12} + B_{13}$

By using the top-down approach and the properties of Boolean algebra, we get:

$$T = G_1 + G_2 + G_3 + U_1 + B_1 + G_4 + G_5 + U_2 + G_6$$

$$= B_8 + B_9 + B_{10} + B_2 + B_3 + B_1 + B_{11} + B_4 + B_5 \cdot B_{12} + B_5 \cdot B_{13} + B_6 \cdot B_7 + U_1 + U_2 + U_3$$
$$+ U_4 + U_5 + U_6 + U_7.$$

Because $U_1, U_2, U_3, U_4, U_5, U_6,$ and U_7 are not basic events, then algebraically, we get 11 minimum cut sets.

$M_1 = B_8$ $\quad$ $M_2 = B_9$ $\quad$ $M_3 = B_{10}$ $\quad$ $M_4 = B_2$

$M_5 = B_3$ $\quad$ $M_6 = B_1$ $\quad$ $M_7 = B_{11}$ $\quad$ $M_8 = B_4$

$M_9 = B_5 . B_{12}$ $\quad$ $M_{10} = B_5 . B_{13}$ $\quad$ $M_{11} = B_6 . B_7$

The minimum cut set obtained is the cause of 10 potential causes that cause failures of up to 80% of the fire suppression process. For example, a minimum cut set of M_1 or M_2, or M_3 is the cause of the failure of the fire suppression process on burnt assets/assets difficult to save, namely the lack of awareness from the relevant agencies, or the protection system does not meet fire extinguisher standards or lack of maintenance of the fire protection system.

Efforts to prevent potential critical causes in the firefighting process can be carried out by referring to the FTA results. Preventive measures include the fire department inspecting the fire protection system, socializing the dangers of fire to relevant agencies and the public, and expanding the scope of socialization such as on social media, and building owners should have a person in charge of the place if they don't live in the place, and bring spare trucks (at least two trucks leaving for one fire).

CONCLUSION

The FMEA method and the FTA method are implemented to determine failure prevention efforts in the fire suppression process. There are ten potential causes based on the highest RPN, namely burning assets, assets difficult to save, victims panicking, witnesses/owners not present, security officers, water sources far from the location, victims being rescued too late, victims trapped, officers being overwhelmed, and officers inhale as quickly as possible (shortness of breath). Efforts to prevent failures include fire protection inspections at agencies, expanding the scope of socialization, having responsibility for unoccupied places, officers using Self Contained Breathing Apparatus (SCBA), and bringing spare trucks.

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