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Human Reliability Assessment (HRA) of Fire and Explosion Cases at Fuel Filling Stations (SPBU)

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Abstract

Filling Stations are public facilities provided by fuel distributors for the fuel needs of the broader community that have serious potential risks, such as fires and explosions that human actions or systems can cause. This research aims to identify the causes of these errors, evaluate their likelihood, and provide recommendations to reduce them. This paper incorporated Fault Tree Analysis (FTA) and the Success Likelihood Index Method (SLIM). Data analysis identifies 16 basic events from 3 aspects: human, technical, and management, focusing on FTA. Notably, SLIM highlights error mode 3 (0.0392 probability) as the most critical, while error mode 4 is the least significant (0.000234). These methods provide recommendations to minimize human error, including training, Application of SOPs, incident report submission system, supporting technology, supervision, regular inspections, and audits.

Keywords:
Fuel Filling Station, Fire and Explosion, Human Error, Fault Tree Analysis, Success Likelihood Index Method.

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INTRODUCTION

An event that may be undesirable and sometimes uncontrollable is fire and explosion. In an industry, fires and explosions are undesirable forms of process failure. The leading suspected causes of such failures are lack of equipment maintenance and negligence in performing duties [1]. One of the accidents that occur in the industrial world is at oil and gas processing facilities [2].

According to statistics presented by the Ministry of Energy and Mineral Resources, from 2016 to 2019, there was an increase in the number of accidents at Public Fuel Filling Stations (SPBU). In 2016 and 2017, there were nine accidents, while in 2018, there were 18 accidents, and in 2019 there were 16 accidents. Accidents involving activities at gas stations also include various types. In this case, 85% of accidents occurred during refueling, 9% during maintenance activities, and 6% during stockpiling. Other factors also play a role in accidents, including external factors. Using non-standard jerry cans caused 56% of accidents, while improper vehicle modifications, such as open spark plugs, burnt exhaust, and oversized fuel tanks, contributed to 29%. In addition, internal factors at gas stations also play a role, with the accident rate reaching 15% [3]. The concentration level of employees working at gas stations is also often decreased due to the high activity in the area. This phenomenon is also one of the triggers for fires due to human error [4]. The hazards that arise can harm some companies and society, such as material losses and casualties. Therefore, safety is vital for managers, consumers, and society [5].

Human error, which refers to actions or behaviors that do not produce the desired results in their tasks, significantly impacts system safety at all stages, from planning to maintenance. This phenomenon often leads to accidents in various industrial sectors. However, we can improve safety by managing these risks from human error. Therefore, in-depth analysis of accidents is important to identify crucial failure points and operational stages. This analysis suggests preventive measures can be designed to improve overall safety [6].

Fault Tree Analysis (FTA) is a method for evaluating safety and reliability by employing a visual representation to depict the sequence of factors contributing to a system malfunction. FTA also presents an organized tree structure, allowing a general understanding of the system without requiring an analysis that is too detailed. In addition, this method can accurately detect threat scenarios [7]. Fadli et al. (2021) incorporated the Fault Tree Analysis (FTA) and Failure Modes and Effects Analysis (FMEA) methods. From their research, the results of the analysis of two boilers are obtained. Boiler 1 has a reliability of 99.78%, while Boiler 2 is 99.96%. In the MTBH analysis, it is known that boiler 1 often experiences damage to the electric pump component and fails seven times, so the maintenance schedule is 19 working days. Boiler 2 is found in the electric pump component with an MTB of 216 with 14 failures; the maintenance schedule is nine working days [8].

Then, a study conducted by Marsudi (2021) explained the components of the Steam Soot Blowing System and Boiler Blowdown System in the boiler failed using the FTA method. The main causes of Steam Soot Blowing System failure are dirt that impedes the flow of cooling water, poor fuel, corroded pipes, and irregular thickness checks. Meanwhile, the Boiler Blowdown System components failed due to irregular drain valve cleaning, and excessive boiler fill water acidity, improper hydrazine and phosphate addition, worn out water level indicator, poor quality of the level indicator, and heavy contamination of the boiler fill water line. This FTA method can help identify such system component malfunctions [9],[14].

The Success Likelihood Index Method (SLIM) is a very useful tool in assessing human reliability as it can estimate an individual's error when a failure or mistake occurs in a particular task [10]. SLIM is a highly adaptive method commonly applied in assessment by experts. In the SLIM approach, experts identify important Performance Shaping Factors (PSFs) associated with a specific task. Then, the contribution of each PSF to human error is assessed and assigned a relative weight [11]. Research conducted by Ayundha Novianti et al. (2019) regarding human error analysis in grinding work used the Human Error Assessment and Reduction Technique (HEART) and Success Likelihood Index Method (SLIM) methods to reduce human error. The evaluation results show the highest value of HEART is 0.672, indicating maintenance at least once a month.

In contrast, the SLIM method, related to ground control, produced the highest HEP value of 0.96207. To reduce human error, management control should be implemented through training, procedures, work instructions, and technical guidance, including equipment storage and task recommendations [12]. Ratriwardhani & Ayu (2021) used the Success Likelihood Index Method (SLIM) to estimate the probability of human errors. This research obtained four human error factors: unsafe conditions, unsafe actions, personality, and work factors. The work process with the highest Human Error Probability (HEP) value is the disposal work process, which has a value of 0.00693. Several aspects need to be considered to reduce human error, such as detailed SOPs, strict supervision, rest periods, regular training, and assessing the abilities of the workforce [13].

In addition, this aspect of human error is an aspect that has not been widely discussed in fire and explosion cases at gas stations. Therefore, a human reliability assessment was conducted to identify the causes, evaluate the Human Error Probability (HEP) value, and provide recommendations to reduce human error. This paper aims to combine FTA and SLIM to identify the causes of accidents at gas stations, evaluate the Human Error Probability value, and evaluate recommendations to reduce human error.

Fault Tree Analysis (FTA)

Fault Tree Analysis (FTA) is a bottom-up deductive process that describes the causes of an event. A visual model of how equipment failure, human error, and external factors contribute to an accident or incident is created in FTA. Using logic gates and small events, FTA depicts the different steps in an accident, forming a fault tree for the event. Fault Tree Analysis has two approaches that can be applied: qualitative and quantitative. In the qualitative approach, the Fault Tree is used to identify possible causes and pathways to high-risk events. On the other hand, the quantitative approach allows the calculation of the probability of an unexpected event occurring by considering the probability of each known cause-effect event.

Figure 1 shows an example of an FTA on the failure of a smoke detector in a fire alarm system.

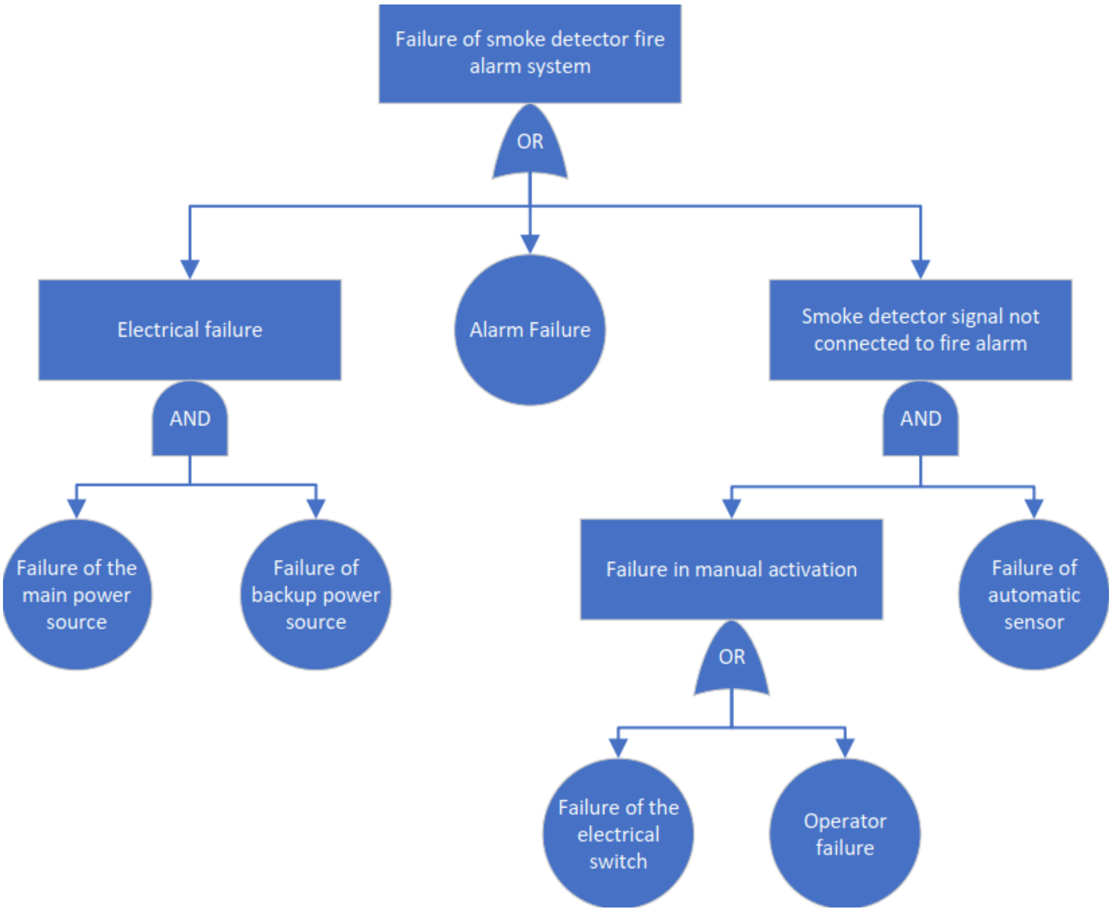

Figure 1. FTA Failure Fire Alarm System Smoke Detector [15]

From Figure 1 FTA has two types of marks: events and logic gates. The event mark is used to indicate the nature of each event. Logic gates are used to indicate the relationship between events.

From Figure 2, a basic event is a symbol that indicates the cause of a hazard or risk. An intermediate event is a symbol for an event that still needs to be analyzed further, usually, this symbol is followed by a logic gate to describe the next event. An undeveloped event is a symbol that indicates that the event cannot be analyzed further due to a lack of data or information. The transfer symbol is a symbol for an event that requires further analysis in addition to the most important risk event of the analysis performed.

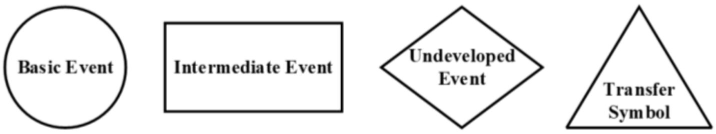

Figure 2. Basic Signs of Events [15]

From Figure 3, an AND gate is a symbol where a risk event can occur if all the input events below it are realized. An OR gate is a symbol where a risk event can occur if one or more of the underlying input events are realized. A Vote gate is a symbol where an event can occur if the number of events meets the necessary conditions.

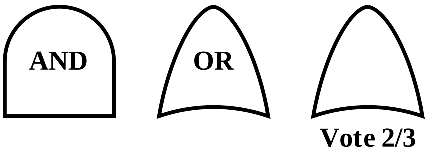

Figure 3. Basic Sign of Logic Gate [15]

Success Likelihood Index Method (SLIM)

The Success Likelihood Index Method, also called SLIM, is a tool for assessing the likelihood of human error when carrying out particular tasks. In this context, the subsequent stages outline the procedure for employing the SLIM method.

1. Determine the error modes.

Determining error modes can be done by conducting a comprehensive analysis of the assessed task to identify failure modes. In this process, various possible ways in which errors or omissions might occur can be considered. Common human errors associated with an incident will be analyzed to identify potential Performance Shaping Factors (PSFs) and possible occurrences of related incidents. As a result, a fault mode will be established in the context of an accident.

2. Identifying, weighting and normalizing Performance Shaping Factors (PSFs).

Performance Shaping Factor (PSF) plays the most important role in influencing the success of the task being evaluated. Experts are responsible for determining the relative importance of the Performance Shaping Factors (PSFs) and assessing which PSFs have the most significant influence on enhancing the likelihood of success. The PSF, regarded as the most influential, receives the top score of 100. PSFs with lesser but impactful effects on success are identified and assigned weights about the most significant PSF. For example, if the impact of the second PSF on success is only half that of the first PSF, then it is given a weight of 50. This procedure is then repeated for all PSFs. To achieve weight normalization, the weight of each PSF is divided by the total sum of all weights. This ensures that the normalized weights collectively add up to 1, signifying the proportional significance of each PSF in determining the probability of success.

3. Ranking PSF.

The ratings describe the extent to which the FSPs contribute to the probability of success in relative terms and have no dependence on each other. These ratings reflect the experts' view of the actual situation in the analyzed task in the event of an accident. Each PSF's rating remains independent and is not affected by the ratings of other PSFs.

4. Calculating the Success Likelihood Index (SLI) value.

The calculation process for each SLI involves multiplying the rank value by the normalized weight of each PSF. After that, the results of this multiplication are summed up. The SLI value will vary from 0 to 100. A value of 0 indicates a low probability of task step success, while a value of 100 indicates a high probability of success.

5. Convert SLI values into Human Error Probability (HEP) values.

The initial step involves standardizing the SLI values to transform SLI into HEP. This standardization process is accomplished by applying Equation 1 as outlined.

$$Log\ (POS_i) = a(SLI_i) + b \quad (1)$$

Equation 1 is a formula relating to the Log of the Probability of Success (POS), with a and b constants obtained through scientific methods. In this situation, the absolute probability estimation method is used for the endpoint, as in many circumstances, particularly in rare events, frequency data for estimation may not be available. This approach relies on the expertise of professionals to establish definite probabilities under both the best-case and the worst-case scenarios in the situation under assessment.

Then, the value of POS can be calculated using Equation 2, and the value of Human Error Probability (HEP) can be calculated using Equation 3.

$$POS = 10^{Log(POS)} \quad (2)$$

Equation 2 is an equation regarding the probability of success of the identified task, then the value of Log (POS) is obtained from the calculation results using Equation 1.

$$HEP = 1 - POS \quad (3)$$

Equation 3 is an equation regarding calculating the probability of human error. The HEP value is obtained by reducing the failure rate (1) by the value of the probability of success obtained using Equation 2.

METHODOLOGY

This section explains the relationship between the research's input, process and output variables, as seen in Figure 4. From the conceptual model in Figure 4, in the case of fires and explosions, data is obtained based on the results of interviews, available information (news), and gas station safety books. Incident data are obtained from the results of interviews that have been conducted with sources who have the position/division of supervisor at SPBU XYZ (due to limited permissions and data confidentiality) and from the SPBU safety book, as well as information about fires and explosions that occurred at SPBU XYZ obtained from the news. Two methods are used from the data obtained: FTA and SLIM. In the FTA method, a fault tree is made to identify the overall causal factors/causes of the gas station fire and explosion case. In the SLIM method, a scenario is obtained from the FT results that have been made, and then the determination of the PSF following the case is carried out to give weight and rank the PSF to get the SLI value for each failure mode. Then, the SLI value is calibrated to get the error probability value (HEP). After obtaining the HEP value and using both methods, it can provide recommendations to reduce accidents caused by human error in the gas station area.

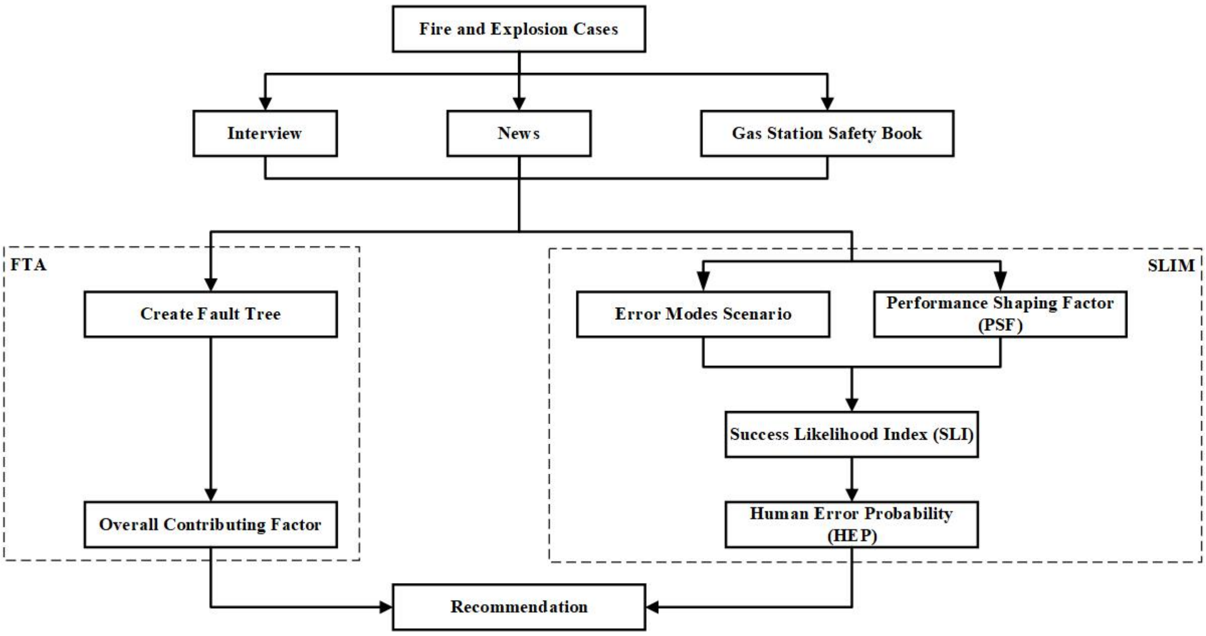

Figure 4. Conceptual Model

RESULT AND DISCUSSION

This assessment of human reliability in the case of fires and explosions at gas stations has an output in the form of human error probabilities and several recommendations as a means of information to reduce human error.

Result

The first step is to collect data, which is the initial stage to obtain the information needed to achieve the research objectives. Data regarding the causes of the accident were obtained through sources such as the Gas Station Safety Handbook, as well as from interviews with related parties and information related to the accident that occurred at SPBU XYZ.

Table 1 displays several fault modes that occur during fires and explosions at SPBU XYZ. Based on the collected data, the accident was evaluated by categorizing the causes of failure based on human, technical, and management aspects. The basic steps of Fault Tree analysis were then carried out, followed by the creation of a Fault Tree model specific to the case of fires and explosions at filling stations.

Table 1. Data on the causes of gas station fire and explosion cases

No	Causes of Gas Station Fire and Explosion
1	Officer allowed a leak in the coupling
2	Officer opens manhole cover
3	Officer did not install the fuel truck grounding
4	Officers do not properly understand the fuel unloading procedure
5	Inadequate layout
6	Signage is not explosion proof
7	Lack of safety awareness
8	Lack of supervision during fuel unloading

In Figure 5, the type of Fault Tree (FT) shown only classifies some types of failures. There are 16 basic events divided into three aspects, namely human, technical, and management aspects. The human aspect includes six basic events, the technical aspect includes seven basic events, and the management aspect includes three basic events. These results make it easier to determine the fault modes used in the SLIM method.

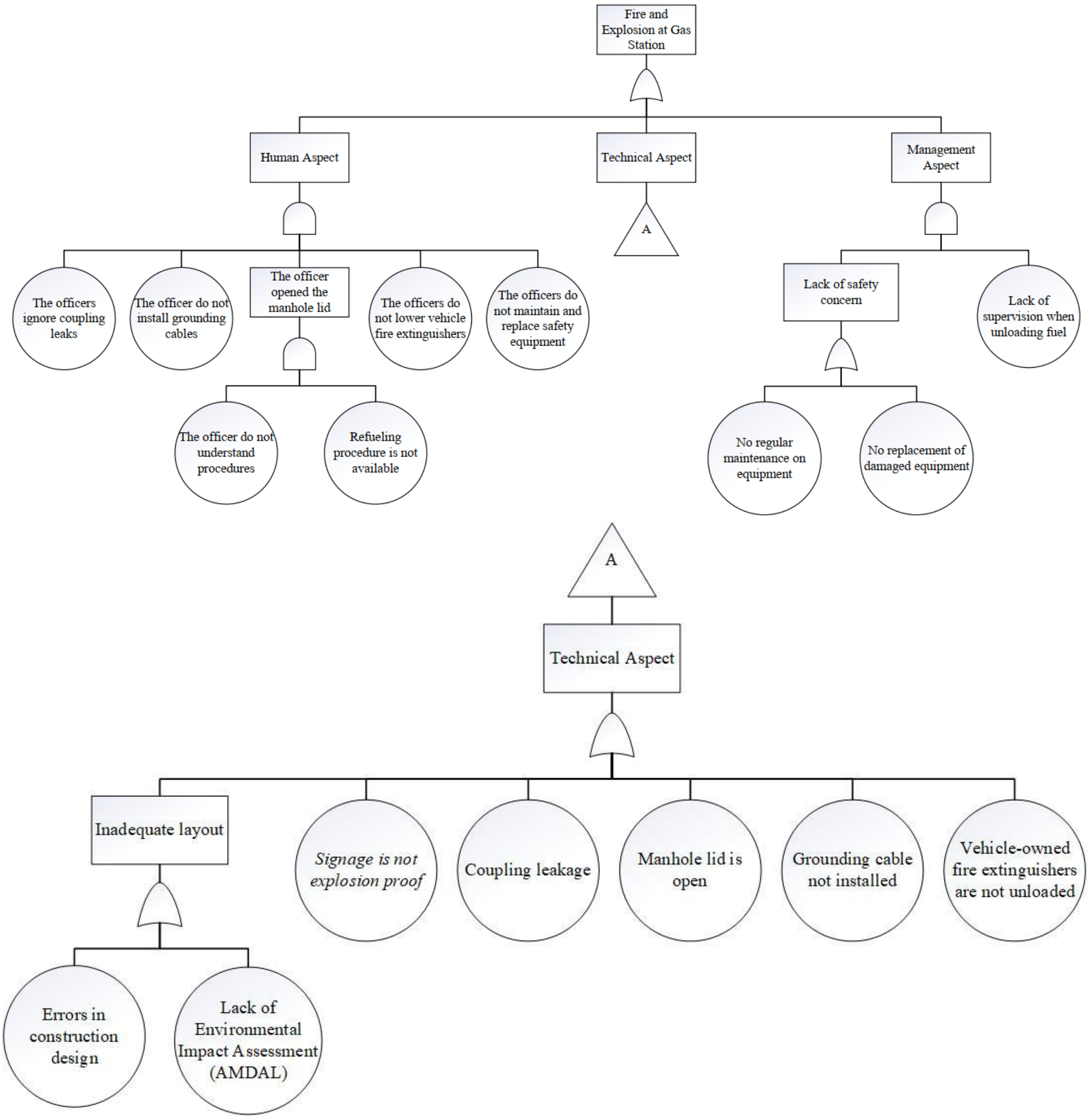

Figure 5. Fault Tree fire and explosion of SPBU XYZ

Table 2 and Table 3 show several fault modes associated with the accident and some performance-shaping factors (PSF). This information was derived from data in the Gas Station Safety Handbook [3], through the results of the realized interviews. Additional support was provided through thorough cause identification using the Fault Tree.

Table 2. Error mode of gas station fire and explosion case

No	Error Mode
1	Officer allowed a leak in the coupling and collected the leak using a bucket
2	Officer did not install the fuel truck grounding
3	Officers do not properly understand the fuel unloading procedure
4	Officer did not lower the fire extinguisher belonging to the vehicle (tank truck)
5	Officer did not perform maintenance or replacement on safety equipment

Table 3. Performance Shaping Factor (PSF)

No	PSF
1	Training
2	Equipment and Tool Condition
3	Procedur
4	Supervision

Table 4 gives weight and normalization to each PSF, where PSFs with higher significance than others PSFs will get a high weight.

Table 4. Weighting and normalizing PSF

No	PSF	*Assign Weight*	*Normalized Weight*
1	Training	100	0.32
2	Equipment and Tool Condition	85	0.27
3	Procedur	60	0.23
4	Supervision	55	0.18
	Total	300	1

Table 5 illustrates the ranking of the PSFs against all fault modes, i.e., how much impact the identified factors have on each fault mode.

Table 5. PSF rating on each error mode

Error Mode	PSF 1	PSF 2	PSF 3	PSF 4
1	80	50	85	90
2	85	10	80	95
3	90	10	85	70
4	80	60	95	80
5	70	80	85	75

Table 6 and Table 7 are the results of the calculation of the SLI value in each error mode, where the SLI value obtained in error 1 is 74.33, error mode 2 is 64.58, error mode 3 is 62.67, error mode 4 is 77.73, and error 5 is 76.75.

Table 6. SLI error mode 1, 2, and 3

PSF	*Normalized Weight*	*Error Mode 1*		*Error Mode 2*		*Error Mode 3*	
		PSF *Rating*	***Product 1***	**PSF *Rating***	***Product 2***	**PSF *Rating***	***Product 3***
1	0.32	80	26.67	85	28.33	90	30.00
2	0.27	50	14.17	10	2.83	10	2.83
3	0.23	85	17.00	80	16.00	85	17.00
4	0.18	90	16.50	95	17.42	70	12.83
Total	1	**SLI 1>>**	74.33	**SLI 2>>**	64.58	**SLI 3>>**	62.67

Table 7. SLI error mode 4 and 5

PSF	Normalized Weight	Error Mode 4		Error Mode 5	
		PSF Rating	Product 4	PSF Rating	Product 5
1	0.32	80	26.67	70	23.33
2	0.27	60	17.00	80	22.67
3	0.23	95	19.00	85	17.00
4	0.18	80	14.67	75	13.75
Total	1	**SLI 4>>**	77.33	**SLI 5>>**	76.75

Table 8 shows the results of the best and worst scenarios based on the reference from the International Association of Oil and Gas Producers (IOGP) [16], as well as the calculated a and b constants.

Table 8. Results of best-case and worst-case scenarios and constant values a and b

Error Modes	HEP *Best Case*	HEP *Worst Case*	*"a" Constant Value*	*"b" Constant Value*
1	10^{-3}	10^{-1}	0.000453	-0.04576
2	10^{-4}	10^{-1}	0.000457	-0.04576
3	10^{-3}	10^{-1}	0.000453	-0.04576
4	10^{-5}	10^{-3}	0.000004	-0.00043
5	10^{-5}	10^{-2}	0.000043	-0.00436

Table 9 is the result of the change from SLI value to HEP value, where the value indicates if the error rate is high if it is at 0.5 to 1 (failure) and medium if the error rate is at 0 to 0.49.

Table 9. The result of changing SLI to HEP value

Error Modes	SLI	LOG (POS)	POS	HEP	*Upper Bound*	*Category*
1	74.33	-0.0121	0.973	0.0274	4.7E-2	*Acceptable*
2	64.58	-0.0162	0.963	0.0367	7.5E-2	*Acceptable*
3	62.67	-0.0174	0.961	0.0392	2.0E-1	*Acceptable*
4	77.33	-0.0001	0.999	0.0002	8.6E-2	*Acceptable*
5	76.75	-0.0010	0.998	0.0023	3.6E-1	*Acceptable*

Table 10 is the result of recommendations drawn from the literature and validated by the gas station. In this table, there are 6 recommendations generated to reduce human error. While Table 11 is a recommendation that has been categorized based on the value of human error obtained previously.

Table 10. Recommendations to reduce human error

No	Recommendation
1	Training
2	Application of Standard Operating Procedure (SOP)
3	Incident Report Submission System
4	Supporting Technology
5	Supervision
6	Regular Inspections and Audit

Table 11. Recommendations based on human error value

Error Mode	HEP	Recommendation
Officers do not properly understand the fuel unloading procedure	0.0392	Training Application of SOP Supervision
Officer did not install the fuel truck grounding	0.0367	Safety Training Application of SOP Supervision
Officer allowed a leak in the coupling and collected the leak using a bucket	0.0274	Training Application of SOP Incident Report Submission System Supporting Technology Supervision Regular Inspections and Audit
Officer did not perform maintenance or replacement on safety equipment	0.0023	Training Application of SOP Supervision Regular Inspections and Audit
Officer did not lower the fire extinguisher belonging to the vehicle (tank truck)	0.0002	Training Application of SOP Supervision

Discussion

In Figure 5, a Fault Tree was created to determine the overall cause of the SPBU XYZ fire and explosion case. There are 16 basic events from 3 aspects: human, technical, and management. The human aspect causes six basic events (officers ignore coupling leaks, officers do not install grounding cables, officers lack understanding of procedures, fuel filling procedures are not available, officers do not lower fire extinguishers owned by vehicles, and officers do not perform routine maintenance or replacement of safety equipment). The technical aspect was caused by seven basic events (errors in construction design, lack of environmental impact assessment (AMDAL), explosion-proof signage, coupling leakage, a manhole cover was open, and grounding cable was not installed. The vehicle's fire extinguisher was not lowered). Then, the management aspect is caused by three basic events (no routine maintenance on equipment, no replacement of damaged equipment, and lack of supervision during fuel unloading). Then, the fault modes are selected based on the human aspect because this research focuses on human reliability. Thus, several fault modes can be identified according to the created FT structure, as seen in Table 2.

The selection of FSPs and the assignment of weights in this case were obtained through interviews and discussions with resource persons who had direct experience of the incident at the gas station. For example, training was identified as the most significant factor that greatly influenced the whole, giving it a weight of 100. Furthermore, equipment and equipment condition also had great significance. It was given a weight of 85, which exceeded the weight of the other FSPs, as equipment quality and condition, such as pipeline safety and potential leaks, had a potentially harmful impact on the gas station. Therefore, it is important to keep equipment and installations in optimal condition.

Then, the PSFs are ranked in each error mode. For example, in error mode 2, a value of 85 is given to PSF 1 because training plays a vital role in minimizing the occurrence of such errors. This is especially risky if grounding cables are not installed, which can result in the accumulation of electrical charges. PSF 2 was given a score of 10 because this PSF has a limited impact on reducing errors, not in the context of grounding but more related to the actions of personnel who are negligent in installing grounding. PSF 3 was given a score of 80 because error mode 2 can be overcome by following existing procedures, so the probability of a fault occurring will be low. PSF 4 was given a score of 95 because the error could have been avoided through good supervision.

In Table 6 and Table 7 the SLI calculation is carried out according to the step to find out how big the probability of success index is. The largest SLI value is obtained in error mode 1 (74.33), where the value indicates that the probability of success of the task step is high. The SLI with the smallest value is in error mode 3 (62.67), which indicates that the probability of success of the task step is the lowest among other error modes.

In Table 8, the human error probabilities of the best and worst cases in the case of gas station fire and explosion are estimated, where both scenarios are given a value of 0 for the worst and 100 for the best. The limits are entered as SLI values, then the best- and worst-case HEPs are entered as Probability Of Success (POS) values into Equation 1 to perform a general calibration of the SLIM method and obtain the constants a and b.

Then, convert the SLI value obtained to determine the HEP value. Using the existing equation and the value of each error mode, the highest HEP value is obtained in error mode 3 (Officers do not properly understand the fuel unloading procedure) with a value of 0.0392. This value shows that the error level is medium because it is almost close to the failure rate of 1 but still below 0.5. So, these errors are likely to cause fires and explosions at gas stations and are followed by error mode 2 (Officer did not install the fuel truck grounding) with a HEP value of 0.0367, error mode 1 (Officer allowed a leak in the coupling and collected the leak using a bucket) with a HEP value of 0.0274, error mode 5 (Officer did not perform maintenance or replacement on safety equipment) with a HEP value of 0.0023, and the smallest HEP value is in error mode 4 (Officer did not lower the fire extinguisher belonging to the vehicle (tank truck)) with a HEP value of 0.0002. So, it is necessary to make improvements to minimize these errors. Then, a comparison of the HEP value with the upper bound value to validate previous research. An acceptable category was obtained in all error modes because it is below the UB value [17].

After getting the value of HEP, the recommendations in Table 11 are obtained based on the literature and validation at the gas station, and six recommendations are obtained to reduce human error. Table 11 is a recommendation that is classified based on the value of human error obtained in the previous calculation. The recommendations are given to each error mode by considering the recommendations needed in each error mode. Error mode 1 requires safety training, implementation of SOPs, and close supervision so that officers are not negligent and better understand the procedures for the unloading of fuel.

CONCLUSIONS AND SUGGESTION

Based on the results of the identification of the overall cause of this gas station fire and explosion case, it can be concluded that this accident was caused by several basic events grouped into human, technical and management aspects. Basic events in human technical aspects are then used as error modes to evaluate the Human Error Probability (HEP) value. Using the Success Likelihood Index Method (SLIM), it was found that the probability of the largest accident was in error mode 3 of 0.0392. These errors can be caused by a lack of training, non-compliance with SOPs, and negligence in existing supervision at gas stations, so it is crucial to evaluate. Therefore, several recommendations are obtained that can be used to reduce human error in the gas station area so that unwanted things can be avoided.

Based on the results obtained in this study, the authors suggest that what can be given as input or evaluation for further research is to identify through a quantitative approach to FTA, which aims to compare probability results with the SLIM method—involving experts experienced in FTA who can provide validation of the Fault Tree that has been compiled. In addition, it is essential to consider technical and management aspects as error modes in the Fault Tree that has been compiled.

REFERENCES

[1] D. Aulia, S. Ermal, H. D. Ariesyady, and F. Lestari, "Identifikasi ledakan dan kebakaran PT . X Siak dengan metode Lean- FMEA , RCA , dan kuantifikasi menggunakan diagram pareto," vol. 23, pp. 10–18, 2023.

[2] M. Dadashzadeh, F. Khan, K. Hawboldt, and P. Amyotte, "An integrated approach for fire and explosion consequence modelling," *Fire Saf. J.*, vol. 61, pp. 324–337, 2013.

[3] Kementrian ESDM RI, "Keselamatan SPBU Pedoman Teknis dan Pembelajaran dari Kejadian," *Direktorat Jendral Miny. dan Gas Bumi*, pp. 1–123, 2020.

[4] B. Shafawardahni, V. K. Bakti, H. Z. Ilmadina, and C. Vision, "Sistem informasi deteksi dini kebakaran pada area spbu secara realtime," 2020.

[5] Kementrian ESDM RI, "Tekan Kecelakaan di SPBU, Ditjen Migas Siapkan Rencana Aksi," 2020.

[6] P. Kumar, S. Gupta, and Y. R. Gunda, "Estimation of human error rate in underground coal mines through retrospective analysis of mining accident reports and some error reduction strategies," *Saf. Sci.*, vol. 123, no. September 2018, p. 104555, 2020.

[7] A. P. Henriques de Gusmão, M. Mendonça Silva, T. Poleto, L. Camara e Silva, and A. P. Cabral Seixas Costa, "Cybersecurity risk analysis model using fault tree analysis and fuzzy decision theory," *Int. J. Inf. Manage.*, vol. 43, no. August, pp. 248–260, 2018.

[8] R. Fadli, J. Jufrizel, and W. P. Hastuti, "Analisa Sistem Instrumentasi dan Keandalan Boiler dengan Metode Fault Tree ANALYSIS (FTA) dan Metode Failure Mode And Effect Analysis (FMEA)," *El Sains J. Elektro*, vol. 2, no. 2, 2021.

[9] S. Marsudi, "Analisa Resiko Kegagalan Sistem Boiler Dengan," *Sensiste*, no. November, pp. 38–41, 2021.

[10] D. E. Embrey, P. Humphreys, E. A. Rosa, B. Kirwan, and K. Rea, *SLIM-MAUD: An approach to assessing human error probabilities using structured expert judgement*. US Nuclear Regulatory Commission, Washington DC: NUREG/ CR-3518, 1984.

[11] R. Abbassi, F. Khan, V. Garaniya, S. Chai, C. Chin, and K. A. Hossain, "An integrated method for human error probability assessment during the maintenance of offshore facilities," *Process Saf. Environ. Prot.*, vol. 94, no. C, pp. 172–179, 2015.

[12] D. Ayundha Novianti, A. Maisarah Disrinama, and Haidar Natsir Amrullah, "Analisis Probabilitas Human Error Pada Pekerjaan Grinding dengan Metode HEART dan SLIM-ANP di Perusahaan Jasa Fabrikasi dan Konstruksi," *Proceeding 1st Conf. Saf. Eng. Its Appl.*, no. 2581, pp. 54–60, 2018.

[13] R. A. Ratriwardhani and F. Ayu, "Penilaian Probabilitas Human Error Di Industri Tambang Batubara," *Med. Technol. Public Heal. J.*, vol. 5, no. 1, pp. 66–74, 2021.

[14] A. M. Al Banna and A. R. Ramadhani, "High Blow-By Pressure Failure Quantification of Doosan Excavator DX300LCA Using Bayesian Network," *Motiv. J. Mech. Electr. Ind. Eng.*, vol. 5, no. 3, pp. 593–606, 2023, doi: 10.46574/motivection.v5i3.282.

[15] Winsky, "Analisis Pohon Kesalahan (Fault Tree Analysis)," *Irmapa.Org*, 2021.

[16] IOGP, "Human factors in QRA," *Europe*, no. 434, 2010.

[17] D. I. Gertman, H. S. Blackman, L. N. Haney, K. S. Seidler, C. Sullivan, and H. Hahn A., "INTENT: A Method For Estimating Human Error Probabilities for Errors of Intention," *Reliab. Eng. Syst. Saf.*, vol. 35, pp. 127–136, 1992.