Risk Assessment and Mitigation in Workplace Safety at Energy Distribution Company PT XYZ

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Submitted:
09 NOVEMBER 2024

Accepted:
16 DECEMBER 2024

ABSTRACT

PT XYZ has attempted to protect its employees from work accidents through Occupational Safety and Health (OSH) risk assessments, safety transformation, and the digitalization of safety management. However, the company has not achieved zero accidents due to factors such as the large area, many workers, diverse types of work, an unsafe work culture, and budget constraints. Therefore, risk mitigation is crucial for effective safety management. This study uses a combined method of Analytic Hierarchy Process (AHP)- Failure Mode and Effect Analysis (FMEA)- Bow Tie Analysis (BTA)- Similarity to Ideal Solution (TOPSIS) to select the appropriate risk mitigation strategies. The results showed that disruption handling work carries the highest risk, with 14 risks identified, including 7 high risks, 4 medium risks, and 3 low risks. A total of 79 mitigations have been effective, while 127 mitigations need to be implemented as a priority. The highest priority mitigations to reduce the risk of work accidents include the use of volt detectors, routine vehicle inspections, installation of warning signs, SCADA integration, checking climbing ladders, installing grounding, and using personal protective equipment. With the right mitigation steps, PT XYZ is expected to achieve optimal work safety and zero accidents.

***Keywords**: Occupational Safety, Risk Assessment, Risk Mitigation, Safety Management, Zero Accident*

ABSTRAK

PT XYZ telah berusaha melindungi karyawannya dari kecelakaan kerja melalui kajian risiko Keselamatan dan Kesehatan Kerja (K3L), transformasi keselamatan, dan digitalisasi manajemen keselamatan. Namun, perusahaan ini belum mencapai zero accident akibat faktor seperti wilayah yang luas, banyaknya pekerja, jenis pekerjaan beragam, budaya kerja yang tidak aman, dan keterbatasan anggaran. Oleh karena itu, mitigasi risiko menjadi penting untuk efektifitas keselamatan. Penelitian ini menggunakan metode gabungan Analytic Hierarchy Process (AHP)- Failure Mode and Effect Analysis (FMEA)- Bow Tie Analysis (BTA)- Similarity to Ideal Solution (TOPSIS) untuk memilih mitigasi risiko yang tepat. Hasil penelitian menunjukkan bahwa pekerjaan disruption handling memiliki risiko tertinggi, dengan 14 risiko yang terdiri dari 7 risiko tinggi, 4 sedang, dan 3 rendah. Sebanyak 79 mitigasi yang sudah efektif dan 127 mitigasi yang perlu dilaksanakan sebagai prioritas. Prioritas mitigasi tertinggi untuk mengurangi risiko kecelakaan kerja meliputi penggunaan volt detector, pemeriksaan rutin kendaraan, pemasangan rambu peringatan, integrasi SCADA, pengecekan tangga panjat, pemasangan grounding, dan penggunaan alat pelindung diri. Dengan langkah-langkah mitigasi yang tepat, PT XYZ diharapkan dapat mencapai keselamatan kerja yang optimal dan zero accident.

***Kata kunci**: Keselamatan Kerja, Penilaian Risiko, Mitigasi Risiko, Manajemen Keselamatan, Kecelakaan Nihil*

JIMKES

Jurnal Ilmiah Manajemen Kesatuan
Vol. 13 No. 1, 2025
pp. 209-220
IBI Kesatuan
ISSN 2337 – 7860
E-ISSN 2721 – 169X
DOI: 10.37641/jimkes.v13i1.3067

INTRODUCTION

In running its energy business, PT XYZ manages approximately 788 employees (both male and female) and 2,445 outsourced workers who work in both administration and engineering. These employees and outsourced workers are exposed to dangerous locations and situations, as the site is at a height and operates with a voltage range of 220 to 20,000 volts, making it prone to work-related accidents. PT XYZ has made various efforts to achieve zero accidents in its work environment. One such effort is the preparation of a risk study (Delvika & Mustafa, 2019). In the field of Occupational Safety and Health (OSH), the company adheres to several regulations, including the Board of Directors Regulation Number 0071.P / DIR / 2021, concerning General Guidelines for Integrated Risk Management at PT XYZ, and the General Manager Regulation Number 0004.P / GM / 2021, concerning General Guidelines for Integrated Risk Management at PT XYZ. However, despite these efforts, work accidents continue to occur, involving both PT XYZ personnel and the surrounding community.

A work accident is an unwanted event that occurs in the workplace or is related to work, which can cause harm to humans, property, or work processes (Ge et al., 2022). The impact can manifest as work-related diseases, injuries, or even death. According to Permenaker No. 5 of 2021, work accidents include incidents occurring in the work relationship, such as traveling to or from work, as well as diseases caused by the work environment. Work accidents can occur due to various factors, such as lack of supervision, non-compliance with safety standards, or unsafe work conditions (Wekoye et al., 2020; Polukarov et al., 2022). Therefore, the implementation of the Occupational Health and Safety Management System (OHSMS) is crucial for preventing work accidents. Prevention efforts include training, provision of personal protective equipment, and monitoring and evaluation of workplace risks. Awareness from all parties in maintaining work safety is an important step in creating a safe, productive, and healthy work environment (Pertiwi, 2023; Manutilaa et al., 2024).

Public accidents are unintentional incidents caused by various factors. Common factors contributing to accidents include the environment surrounding the equipment or installation (Adhakari et al., 2020). These accidents can result in physical damage, disability, or death to the general public (Putri & Lestari, 2023). In light of the ongoing work accidents at PT XYZ and to support the achievement of the KPI (Key Performance Index) aimed at realizing zero accidents (Zero Accident) at PT XYZ, the author attempts to analyze the risks of work accidents at PT XYZ. The urgency of this research is to assist PT XYZ in reducing the rate of work accidents. This is particularly important given that the national fatality rate remains high, with 12 incidents in 2023 and 7 incidents in 2024.

METHODS

This study begins by identifying problems, followed by a literature review to formulate the research objectives, limitations, and contributions (Adlini et al., 2022). Secondary data on workplace accidents in the PT XYZ area are collected, along with primary data from surveys on the impact and likelihood of risk events in engineering and field activities. The data are processed by combining survey results with brainstorming sessions, focusing on the causes of risks and the effectiveness of existing controls. The PT XYZ expert team, consisting of nine members, identifies the main causes and ineffective controls, which are then addressed with risk mitigation strategies. The study employs various analytical methods to assess risks. First, the Analytic Hierarchy Process (AHP) is used to determine which activities pose the highest risk and require immediate attention. The Failure Mode and Effect Analysis (FMEA) method is then applied to identify the risks associated with these activities, helping to determine the most critical risks. Next, a Bow Tie Analysis (BTA) is employed to identify the causes, preventive measures, and controls of these risks. Finally, risk mitigation is prioritized using the Root Cause Analysis (RCA) method, which identifies ineffective controls. To handle multiple risk mitigation activities, the study uses the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to establish a priority scale for implementation. The aim is to create an effective risk solution to reduce workplace accidents at PT XYZ.

RESULTS

AHP Analysis Results

There are two types of work carried out by PT XYZ: engineering and administrative work. Engineering work can be grouped into three types: maintenance, handling disturbances, and operations. From these three types of work, one activity is selected that is most at risk using the following AHP structure.

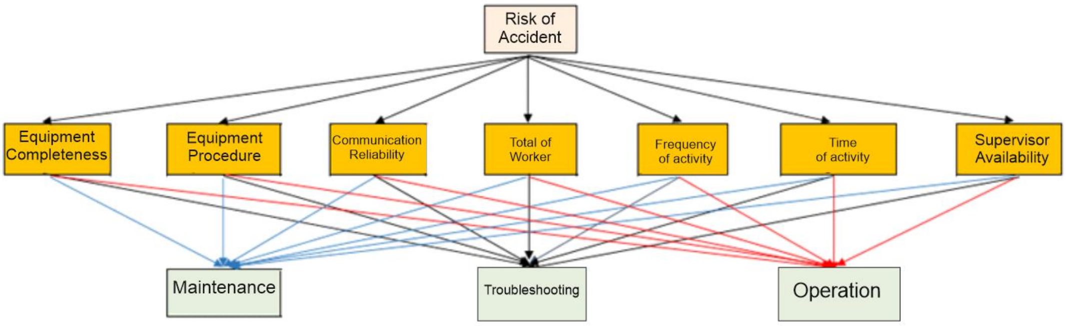

Figure 1. AHP Hierarchical Structure for Selecting Activity Types

Based on Figure 1, it shows that the most risky activities are selected according to the criteria of equipment completeness, procedure completeness, communication reliability, number of workers, activity frequency, activity duration, and supervisor availability. Furthermore, the completion of the questionnaire by the PT XYZ expert team resulted in the following matrix.

Table 1. Pairwise Comparison - activity criteria and results of multiplying criteria and activities

		Completeness of tools	**Completeness of procedures**	**Reliability of communication**	**Total of workers**	**Frequency activities**	**Activity time**	**Supervisor availability**	**Total**	**Rank**
Pairwise Comparison-activity criteria	Criteria	Cl	C2	C3	C4	C5	C6	C7	-	-
	Cl	1	1.05	174	1.03	199	0 96	1.34	-	-
	C2	095	1	186	055	182	116	141	-	-
	C3	0.57	0.54	1	0.73	190	1 56	0.77	-	-
	C4	097	181	137	1	311	248	093	-	-
	C5	0.50	0.55	0 53	032	1	0 45	0.46	-	-
	C6	104	086	064	040	223	1	054	-	-
	C7	0.74	0.71	130	1.08	2 16	1 85	1	-	-
	Total	578	652	844	512	142	946	646	-	-
Result of multiplying criteria and activities	Maintenance	0.046	0.035	0.033	0.059	0.019	0.025	0.049	0.267	2
	Trouble shooting	0.095	0.084	0.075	0.109	0.045	0.068	0.118	0.625	1
	Operation	0.029	0.039	0.023	0.034	0.012	0.019	0.021	0.178	3

Based on Table 1, the comparison between the criteria used to select the most risky types of activities within PT XYZ is shown. The comparison values are obtained from the results of the questionnaire filled out by experts, which range from 1 to 9. After normalization, the weights for each criterion are obtained as shown below. Table 1 indicates that the most risky activity at PT XYZ is the fault handling activity, followed by maintenance activities, with operating activities in the last place. However, fault handling is actually the final activity performed, after the operation and maintenance activities.

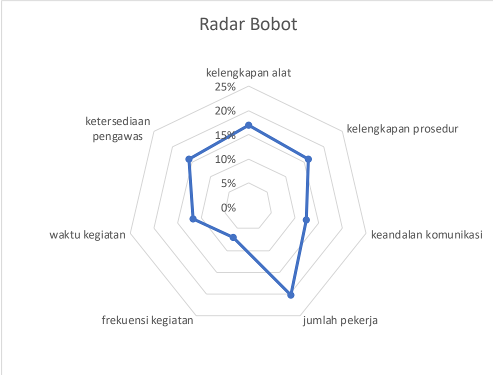

Figure 2. Radar of activity criteria values

Based on Figure 2, the weight of the criteria in determining the riskiest activities is as follows: the number of workers, with a value of 20.4%, followed by the completeness of tools (17.1%), completeness of procedures (15.9%), availability of supervisors (15.8%), reliability of communication (12.3%), activity time (11.6%), and the lowest is the frequency of activities, with a weight of 6.9%.

FMEA Analysis Results

FMEA (Failure Mode and Effects Analysis) of the flow of disruption handling activities at PT XYZ aims to identify potential risks that could disrupt the smooth operation of the company. In this process, high-risk critical steps have been mapped to ensure that disruption handling is carried out correctly. The results of this analysis are expected to serve as the basis for better decision-making in risk mitigation. Thus, it is hoped that PT XYZ's operations can run more safely and efficiently. The process/work sequence in disruption handling activities begins with the reporting/indication of a disruption sent to control, followed by network maneuvering, assignment of work orders to the technical team, preparation of work requirements, travel to the disruption location, preparation for implementation, localization of the disruption location, voltage testing, installation of grounding, disruption handling, final check, reporting of completed work, network normalization, and return to base/post. There are 14 activities in the disruption handling process, and each activity can experience failure or failure modes. The failure is then analyzed based on its impact, severity, probability, and control level using the specified parameters and questionnaires. Failure modes that occur in each activity of the disruption handling work will cause risks.

Table 2. Risks arising from disturbance handling activities

Code	Activity	Failure Mode	Risk Effect	Average
1	Reporting/transmitting disturbance indication to the control center	Failure to report disturbance indication	Difficulty in locating disturbances	131
2	Network maneuvering	Failure in network maneuvering	Prolonged outage duration	160
3	Assigning work orders to technical teams	Failure to transmit work orders	Customer complaints	96
4	Preparation of work requirements	Incomplete work requirements	Human error	113
5	Traveling to the disturbance location	Traffic accident with another vehicle	Vehicle collision	189
6	Work preparation	Inadequate work preparation	Falling from heights	156
7	Isolating the disturbance location	Disturbance location vulnerability	Struck by a vehicle due to work location	138
8	Voltage testing	Hazardous parts still present	Electric shock	214
9	Grounding installation	Imperfect grounding	Explosion due to short circuit spark	161
10	Disturbance handling	Unresolved disturbances	Repeated outages	118
11	Final check	Neglecting the final check	Tripping/slipping/falling	117

12	Reporting job completion	Errors in disturbance resolution reporting	Decline in work performance	129
13	Network normalization	Network maneuvering errors	Explosion due to open spark	146
14	Returning to the base	Single traffic accident	Impact/cutting/crushing injuries	142

Based on Table 2, it shows that there are 14 (fourteen) risks that will be assessed for their impact level (severity), likelihood level (occurrence), and control level (detection) through a questionnaire distributed to the entire expert team. The results of the questionnaire are processed to produce a Risk Priority Number (RPN), which indicates the average RPN value. The risks are then grouped into three categories: 50% fall into the top category, including electric shock, vehicle collision, explosion due to short circuit fire, long duration of blackout, falling from a height, explosion due to open fire, and hit/trapped/cut. Risks in the medium category, comprising 30%, include hit by a vehicle due to work location, difficulty finding the location of the disturbance, decreased work performance, and blackout. Risks in the low category, making up 20%, include stumbling/slipping/falling, human error, and customer complaints.

BTA Analysis Results

The Bow Tie Analysis (BTA) method in this study was used to evaluate the main causes of work accident risks and identify mitigation measures for the most risky activities, namely handling disruptions at PT XYZ. This analysis revealed that customer complaints were one of the significant risks, with the main causes including long outage durations, lack of prior notification, slow officer response, and poor electricity quality. Additionally, other risks such as human error, incomplete work preparation, and equipment or system failure were also of concern. To address these risks, this study identified 10 risk mitigation measures related to customer complaints. Of these, 4 mitigations were considered very effective, such as periodic network maintenance and regulation of electricity voltage and frequency. However, the other 6 mitigations required improvement, including accelerating the maneuver process, increasing communication reliability, and delivering disruption information automatically. The priority mitigation recommendations compiled included accelerating the maneuver process, increasing communication reliability, sending disruption information automatically, and dispatching officers efficiently. The results of this analysis underscore the importance of prioritizing mitigation strategies to address the most significant risks by optimizing resources, thereby supporting PT XYZ's efforts to achieve its zero-accident target.

Table 3. Analysis of causes and evaluation of customer complaint risk mitigation

Risk ID	Description	Couses	No	Risk Mitigation	Value	Effectiveness
3	Customer Complaints	Frequent power outages	1	Perform maintenance	3	Very effective
			2	Reduce the source of interference	3	Very effective
		Long outage duration	3	Speed up the maneuvering process	7	Not effective
			4	Accelerate fault repair	4	Effective
		Poor electricity quality	5	Perform voltage regulation	4	Effective
			6	Perform frequency regulation	4	Effective
		No advance notice of outage	7	Send outage plan info	3	Very Effective
			8	Sending outage info due to disturbance automatically	8	Not effective
			9	Dispatch officers	6	Less effective
			10	disturbance handling	5	Partially effective

Based on Table 3, the risks associated with customer complaints due to power outages are illustrated, along with the various causes and mitigation measures implemented. The identified causes include frequent power outages, long outage durations, poor power quality, and lack of advance notice of outages. Some of the mitigation measures implemented include routine maintenance, reduction of disturbances at the source, prompt repair of disturbances, and voltage and frequency regulation. Evaluation of the effectiveness of these mitigation measures shows that some, such as notification of planned outages and voltage regulation, are very effective, while others, such as automatic outage handling and information delivery, are less effective. Overall, these approaches demonstrate differences in effectiveness in addressing customer electricity-related concerns.

TOPSIS Analysis Results

The first stage in the risk mitigation priority analysis is to determine the weight of the risk mitigation assessment criteria, which is carried out using the AHP method. Once the weight of each criterion is known, it is then used in the TOPSIS analysis. The risk mitigation to be selected using TOPSIS must first determine the criteria and their respective weights, so the weighting of the criteria is analyzed first using the AHP method.

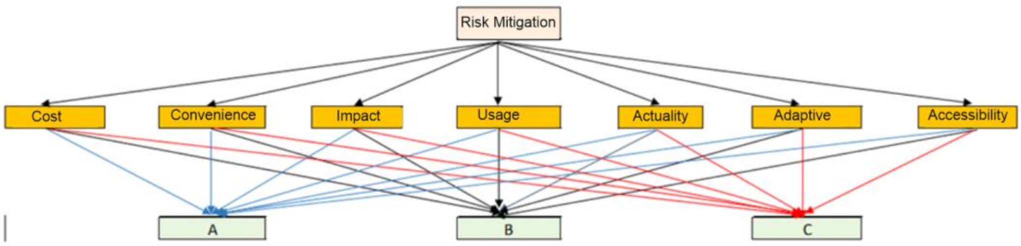

Figure 3. AHP Hierarchical Structure for Selecting Risk Mitigation

Based on Figure 3, it shows that the most prioritized mitigation is selected based on the criteria of cost, ease, impact, use, actuality, adaptiveness, and accessibility. The meaning of each mitigation criterion and its assessment can be seen in Table 4.

Table 4. Definition of risk mitigation criteria

Criteria	Definition	Value	Attribute
Cost	Costs required	The cheaper the better	Cost
Ease	Ease of implementation	The easier it is to use	Benefit
Impact	Benefits felt	The bigger the more it is chosen	Benefit
Use	Can be used in all conditions	The more it can be used in all conditions the more it is chosen	Benefit
Relevance	Following the times	The more up to date the better	Benefit
Adaptive	Can adjust to circumstances	The more it suits the situation the more it is prioritized	Benefit
Accessibility	Supports all types of activities	The more it can be used for all types of activities the more it is chosen	Benefit

Based on Table 4, the criteria for assessing risk mitigation focus on costs, benefits, and flexibility. Criteria such as cost indicate that cheaper products are preferred, while ease and impact prioritize ease of implementation and perceived benefits. Usability assesses the flexibility of the product in various conditions, and topicality reflects the importance of staying current. Adaptability measures the product's ability to adapt to change, while accessibility evaluates support for various types of activities. All of these criteria have the Benefit attribute, indicating that benefits and flexibility are the top priorities in risk mitigation. Furthermore, the completion of the questionnaire by the PT XYZ expert team produced the following matrix.

Table 5. Pairwise Comparison – mitigation criteria

Criteria		Cost	Ease	Impact	Use	Relevance	Adaptive	Accessibility	Distance and Solution
		Cl	C2	C3	C4	cs	C6	C7	
Pairwise Comparison - mitigation criteria	Cl	1	52	14	15	16	22	21	-
	C2	194	1	19	37	54	60	47	-
	C3	704	522	1	156	298	183	109	-

	C4	647	269	64	1	85	87	40	-
	C5	637	184	34	117	1	57	31	-
	C6	460	168	55	115	174	1	16	-
	C7	479	214	92	251	327	612	1	-
	Total	32.2 1	1.508	378	792	1.054	1.121	363	-
Customer complaint risk mitigation assessment results	Atribute	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	-
	Weight	0.031	0.065	0.253	0.135	0.113	0.120	0.283	-
	Speed up the maneuvering process	21	3	42	39	38	35	39	-
	Send info on disturbance automatically	26	31	9	39	39	37	38	-
	Dispatch yantek officers	2	28	36	35	36	34	32	-
	Improve communication reliability								-
	Atribute	35	33	42	39	39	38	37	-
Positive and negative ideal solution matrix	A+	cost	benefit	benefit	benefit	benefit	benefit	benefit	-
		Min(yij)	Max(yij)	Max(yij)	Max(yij)	Max(yij)	Max(yij)	Max(yij)	-
	A-	0.012	0.035	0.133	0.069	0.058	0.064	0.151	-
		Max(yij)	Min(yij)	Min(yij)	Min(yij)	Min(yij)	Min(yij)	Min(yij)	-
	Yi+	0.020	0.030	0.114	0.062	0.053	0.057	0.124	-
Distance between mitigation alternatives and positive ideal solution	Yi	0.012	0.035	0.133	0.069	0.058	0.064	0.151	-
	Speed up the maneuvering process	YI	Y2	Y3	Y4	Y5	Y6	Y7	-
	Send info on disturbance automatically	0.012	0.032	0.133	0.069	0.056	0.058	0.151	0.006
	Dispatch yantek officers	0.015	0.033	0.124	0.069	0.058	0.062	0.147	0.011
	Improve communication reliability	0.012	0.030	0.114	0.062	0.053	0.057	0.124	0.035
	Yi-	0.020	0.035	0.133	0.069	0.058	0.064	0.143	0.012
Distance between mitigation alternatives and negative ideal solution	Yi	0.002	0.030	0.114	0.062	0.053	0.057	0.124	
	Speed up the maneuvering process	YI	Y2	Y3	Y4	YS	Y6	Y7	
	Send info on disturbance automatically	0.012	0.032	0.133	0.069	0.056	0.058	0.151	0.035
	Dispatch yantek officers	0.015	0.033	0.124	0.069	0.058	0.062	0.147	0.028
	Improve communication reliability	0.012	0.030	0.114	0.062	0.053	0.057	0.124	0.009
	Atribute	0.020	0.035	0.133	0.069	0.058	0.064	0.143	0.030

Based on Table 5, the analysis of customer complaint risk mitigation using the Pairwise Comparison method is shown to assess the weight of criteria and alternative solutions. In the first part, a comparison is made between criteria, namely Cost (C1), Convenience (C2), Impact (C3), Usage (C4), Actuality (C5), Adaptability (C6), and Accessibility (C7). The values in the table reflect the relative priority between the criteria, where criteria such as Accessibility (C7) have a greater weight (0.283) than Cost (C1), which has a weight of 0.031. This weight is used to assess alternative mitigation solutions. The alternative solutions that are evaluated include accelerating the maneuver process, sending information automatically when a disruption occurs, dispatching Yantek officers, and increasing communication reliability. Each alternative is assessed based on criteria with the attributes Cost (the smaller, the better) and Benefit (the bigger, the better). The results of this evaluation are compared with the positive ideal solution (the best value for the Benefit criterion and the lowest for Cost) and the negative ideal solution (the worst value for Benefit and the highest for Cost). The distance between the alternatives and the ideal solution is calculated to determine how close each alternative is to the best solution. Based on the calculation results, the alternative "Accelerating the maneuver process" has the smallest distance to the positive ideal solution (Yi+ = 0.006), so it is considered the best solution. The alternative "Sending information on disturbances automatically" takes second place with a Yi+ distance of 0.011. This analysis shows that the selected solution is based on the priority of the previously determined criteria.

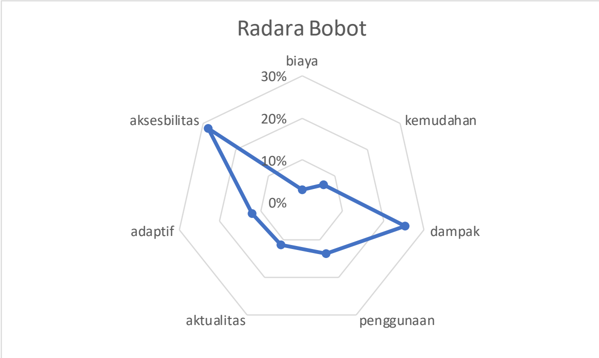

Figure 4. Mitigation criteria weight radar

Based on Figure 4, the highest priority criteria weight in determining mitigation is accessibility, with a value of 28.3%, followed by impact (25.3%), use (13.5%), adaptability (12.0%), actuality (11.3%), ease (6.5%), and the lowest is cost, with a weight of 3.1%.

Table 6. Customer complaint risk mitigation preference values

Mitigation	Preference value	Best	Worst	Ranking
Speed up the maneuver process	0.851	v		1
Send information on disturbances automatically	0.711			3
Dispatch technical officers	0.199		v	4
Improve communication reliability	0.717			2

Based on Table 6, the risk of customer complaints can be mitigated by prioritizing specific measures. The best option is accelerating the maneuver process, followed by improving communication reliability. Sending information about disruptions ranks third, while dispatching technical officers is the least preferred. These mitigation steps are applied to all 14 risks identified in disruption handling activities. Consequently, the risks are prioritized from highest to lowest based on the preference values.

DISCUSSION

Data were obtained to determine the weight of the selection criteria for risky activities using the Analytical Hierarchy Process (AHP) method. The risks that arise in selected activities were determined using the Failure Mode and Effects Analysis (FMEA) method. The causes of the risks were identified, and the effectiveness of mitigation measures was assessed using the Bow Tie Analysis (BTA) method. The sequence of risk mitigation actions to be taken was determined using the TOPSIS method. The stages in the AHP method begin with defining the problem, creating a hierarchical structure that starts with a general objective, followed by criteria and alternative choices, creating a pairwise comparison matrix, normalizing data, calculating eigenvector values, and testing their consistency. Eigenvectors from each pairwise comparison matrix are calculated, and the consistency of the hierarchy is tested. If the consistency ratio (CR) is not less than 0.100, the assessment must be repeated. This approach helps companies in management to support the achievement of organizational goals (Pertiwi, 2023; Nendi, 2024; Fauziah & Baskara, 2024).

The results obtained from this AHP analysis represent the priority of the riskiest activities at PT XYZ. These activities are then analyzed in more detail regarding the risks and their level of risk using the FMEA method. This method is a systematic approach used to track the flow of certain materials or resources in a system (Baars et al., 2022). Several steps in compiling an FMEA include identifying potential failures that could occur in each process, identifying the frequency of problems, identifying the control system, calculating the Risk Priority Number, and determining corrective actions. The results of the FMEA analysis indicate the types of risks that might occur and the severity of their levels (Bhattacharjee et al., 2020; Qin et al., 2022). The risk levels can be categorized into three: high, medium, and low. For each risk level, the causes and mitigations are then analyzed further using the BTA and RCA methods.

The results of the BTA and RCA analyses provide risk mitigation strategies that can be applied to high, medium, and low-risk categories. For each risk level, the mitigation priorities are analyzed using the TOPSIS method. The steps involved in the TOPSIS method include: the calculation of the normalization matrix, the calculation of the weighted normalization matrix, determining the positive and negative ideal solutions, calculating the distance between each alternative and the ideal solutions, and calculating the preference value for each alternative. The results of the TOPSIS method provide risk mitigation information that best aligns with the company's needs. This includes a structured, measurable, and solution-focused list of mitigations that effectively support the company's objectives (Ratih et al., 2024). As a result, the company can allocate resources more effectively to minimize risk impacts, maintain operational stability, and enhance strategic competitiveness (Nikmah et al., 2024; Sulistiyarso et al., 2024).

From the results of the analysis conducted on the selection of work accident risk mitigation using the AHP, FMEA, BTA, and TOPSIS methods, the following conclusions can be drawn: The type of activity most at risk at PT XYZ is disturbance handling work. There are 14 (fourteen) risks associated with disturbance handling work. These risks are grouped into three categories: high risk, medium risk, and low risk. High risks in disturbance handling include electric shock, vehicle collisions, explosions caused by short-circuit fires, prolonged blackout durations, falls from heights, explosions due to open flames, and injuries from being hit, pinched, or cut. Medium risks include being hit by a vehicle due to the work location, difficulty in locating the source of the disturbance, decreased performance achievement, and repeated blackouts. Low risks involve tripping, slipping, or falling; human error; and customer complaints. The results of this analysis assist PT XYZ's management in managing work accident risks in a more structured, data-based, and focused manner, concentrating on the most vulnerable areas. This approach enables the management to perform various functions effectively and efficiently, helping the organization achieve its goals with optimal results (Hopkin, 2018; Mascia et al., 2020; Hendarwan et al., 2023).

The total risk mitigation resulting from the analysis is 206, consisting of 79 mitigations that have been running effectively and 127 mitigations that have not been effective. The ineffective risk mitigations in the high-risk category include electric shock (27 mitigations), vehicle collisions (11 mitigations), explosions due to short-circuit fires (10 mitigations), extended blackout durations (7 mitigations), falls from heights (17 mitigations), explosions caused by open fires (3 mitigations), and incidents of being hit, pinched, or cut (6 mitigations). In the medium-risk category, ineffective risk mitigations include being hit by a vehicle due to the work location (5 mitigations), difficulties in locating disturbances (11 mitigations), decreased performance (7 mitigations), and repeated blackouts (10 mitigations). For the low-risk category, ineffective mitigations include tripping, slipping, or falling (3 mitigations), human error (9 mitigations), and customer complaints (4 mitigations). By identifying both effective and ineffective risk mitigations, organizations can take the necessary corrective actions to enhance safety and operational performance (Radiansyah et al., 2023; Fauzan, 2024).

The top-priority mitigation for high-risk types includes using a volt detector (to prevent electric shock), conducting routine vehicle inspections (to mitigate vehicle collisions), installing warning signs (to address explosions caused by short circuit fires), integrating key points with Supervisory Control and Data Acquisition (SCADA) (to reduce long blackout durations), checking ladders before use (to prevent falls from heights), installing grounding systems (to mitigate explosions due to open fires), and using specialized PPE for confined spaces (to prevent injuries such as being struck, pinched, or cut). For medium-risk types, the most critical mitigations are conducting safety briefings (to prevent accidents caused by vehicles at the work location), adding fault indicators and integrating SCADA (to quickly locate disturbances), repairing offline SCADA systems (to address decreased performance), and improving reliability while expanding the communication network (to reduce repeated blackouts). For low-risk types, priority mitigations include repairing roof leaks (to prevent tripping, slipping, or falling), conducting optimal supervision (to minimize human error), and speeding up the maneuver process (to address customer complaints). Risk mitigation is crucial in managing occupational safety, equipment maintenance, and system reliability within an organization or company (Bhattacharjee et al., 2020; Smith, 2021; Zebua et al., 2024).

CONCLUSION

PT XYZ is an energy distribution company facing complex operational challenges, including high-voltage work and tasks performed at height. This study employed the AHP, FMEA, BTA, and TOPSIS methods to identify and analyze risks and determine mitigation priorities. Disturbance handling was identified as the riskiest activity, with significant hazards such as electric shock, vehicle collisions, and explosions caused by short circuits. The AHP method was utilized to assess risks based on operational criteria, while FMEA provided a Risk Priority Number (RPN) for each identified risk. BTA was used to evaluate the causes and the effectiveness of existing controls, and TOPSIS prioritized mitigation measures based on cost, impact, and ease of implementation. Mitigation recommendations for high-risk activities included the use of voltage detectors and routine vehicle inspections. This study supports PT XYZ in efficiently allocating resources, enhancing operational stability, and achieving its zero-accident target by emphasizing the importance of consistent implementation of mitigation strategies.

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