
**APPLICATION OF FMECA AND FUZZY TOPSIS METHODS FOR
OCCUPATIONAL SAFETY AND HEALTH RISK ANALYSIS IN THE
PRODUCTION PROCESS OF STEEL FABRICATION**

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Abstract

Every activity in the steel fabrication workshop has potential risks that can cause losses. During 19 months, PT SW recorded 48 workplace accidents. This study aims to identify, evaluate, and analyze occupational safety and health risks, as well as determine alternative solutions to mitigate these risks. Based on the identification results, 88 risks were identified in the steel fabrication workshop. The FMECA method found five main risks: exposure to metal particles, exposure as fast cutting, exposure to sparks, exposure to cutting rays, and noise exposure. Conducted risk cause analysis through fishbone diagrams, resulting in several alternative solutions. The solutions were then prioritized using the fuzzy-TOPSIS method to determine the most effective solution.

Keywords: FMECA, Fuzzy-TOPSIS, Occupational Safety and Health, Risk Management

INTRODUCTION

The manufacturing industry in Indonesia continues to show growth, as can be seen from the increase in the number of companies to 10,988 in the 2021 to 2022 period (BPS, 2021 & 2022). This industry processes raw materials into semi-finished products or finished goods (Sasongko, 2023). However, activities in this sector carry significant occupational safety and health risks, and every worker has the potential to experience risk exposure. Even though the manufacturing industry greatly contributes to economic growth, this sector also records a relatively high number of work accidents. In 2023, the total number of work accident cases in various industrial sectors in Indonesia will reach 370,747 (Satudata kemnaker, 2024). Therefore, implementing a good occupational safety and health system is an urgent need to reduce the number of accidents.

PT SW is a company that operates in the manufacturing sector, especially in the steel fabrication process. Production stages in a steel fabrication workshop include marking, machining, fit-up, welding, finishing, coating, and packing. With the various processes carried out, this company faces high occupational safety and health risks for its workers. Based on the initial study result, in the last 19 months, there were 48 cases of work accidents recorded in production workshops. The fastest handling of this accident took two hours, with the total handling time for 48 cases reaching 96 hours. This condition causes a loss of working hours, which impacts company productivity because work targets must still be achieved even though working time is reduced.

Although various efforts have been made to improve occupational safety and health, traditional approaches are often less effective in dealing with dynamic risks in the steel fabrication sector. This research uses the Failure Modes Effect and Criticality Analysis (FMECA) method to identify risks and the Fuzzy Technique for Order Performance by Similarity to Ideal Solution (F-TOPSIS) to prioritize optimal risk mitigation solutions.

REVIEW OF LITERATURE

Occupational Safety and Health

According to (Warwick in Saputra et al., 2022), occupational health is a condition where workers are protected from physical, mental, emotional, or pain disorders caused by the work environment. Meanwhile, work safety refers to conditions safe from the risk of accidents or dangers in the workplace, including the condition of buildings, machines, safety equipment, and workers themselves (Simanjuntak, in Saputra et al., 2022). Three main reasons form the basis for the importance of occupational safety and health, namely humanitarian, legal, and financial (Brauer, 2022). In the steel fabrication industry, effective management of occupational safety and health is necessary to prevent accidents.

Work Accidents

Work accidents are unplanned and unwanted events involving the movement of workers, objects, or materials, resulting in injury, damage, death or loss to property or individuals (Putri et al., 2023). In the manufacturing sector, especially the steel fabrication industry, work accidents often occur, such as exposure to sparks, falls, or being hit by materials and work tools. Based on the 1970 OSHA standards, injuries resulting from work accidents can be grouped into six categories: minor treatment, medical treatment, lost work days, death, moderate injury, and permanent disability (Irzal, 2016).

Risk Management

Implementing risk management is an important step to prevent work incidents from occurring. Risk management is a set of policies and procedures designed to identify, manage, monitor, and control risks. The main goal is to reduce or eliminate adverse risks, including work accidents. This process includes hazard identification, potential hazard analysis, risk assessment, risk control, monitoring, and evaluation (Arta et al., 2021). Although occupational safety and health provide a basis for understanding risks in the workplace, the high number of accidents highlights the need for a more integrated risk management approach. This research develops this process through a systematic evaluation of failure modes and criticality levels using the FMECA method; in contrast, the Fuzzy TOPSIS approach is used to prioritize risk mitigation solutions more effectively.

RESEARCH METHOD

This research was carried out in a steel fabrication workshop through three stages of data collection using questionnaires. In the first stage, a questionnaire was used to identify occupational safety and health risks, which were distributed to 30 steel fabrication workshop workers. The second stage aims to assess and analyze the risks that have been identified. Meanwhile, in the third stage, a questionnaire is used to evaluate the best alternative solutions for risk mitigation. In the second and third stages, questionnaires are given to experts who are competent in the field of safety and health in the work environment.

Failure Modes Effect and Criticality Analysis (FMECA)

According to (Putra in Rahman & Fahma, 2021), FMECA is a method that integrates FMEA with critical point analysis using a critical matrix. (Catelani et al., 2021) explains that FMECA is used to carry out systematic risk ranking. Applying this method requires the contribution of a team of experts who assess the values required in calculating the RPN (Risk Priority Number). In this research, experts in the field of occupational safety and health applied the FMECA method in a steel fabrication workshop.

$$\text{RPN} = \text{Severity} \times \text{Occurrence} \times \text{Detection}$$

(1)

Table 1
Severity Parameter

Duration of Effect	Severity Criteria	Value
>8 hours	Very Dangerous	8
7 hours	Dangerous	7
6 hours	Very Serious	6
5 hours	Seriously	5
4 hours	Medium	4
3 hours	Important	3
2 hours	Minor	2
1 hour	Very Minor	1
30 minutes	Small	0,6
<30 minutes	Very Small	0,2

Source: Ilmi et al., (2024)

Table 2
 Occurrence Parameter

Probability of Occurrence Rate	Occurrence Criteria	Value
Once Every 12 Years	Failures Approaching Zero or None	1
Once Every 10 Years	Very Low, Rare	2
Once Every 8 Years	Low, Occasional	3
Once Every 6 Years		4
Once Every 4 Years		5
Once Every 2 Years	Average, Occasional	6
Once Every 1 Years	High, Frequent	7
Once Every 6 Months		8
Once Every 1 Month		9
Once Every 1 week	Very High	10

Source: Ilmi et al., (2024)

Table 3
 Detection Parameter

Detection	Detectability Criteria	Value
Not Detected	Not Possible	10
	Very Difficult	9
Hard to Detect	Very Late	8
	Not Sure	7
	Occasionally	6
Sometimes Detected	Low	5
	Too Late	4
Detectable	Easy	3
	Very Easy	2
Proficient at Detecting	Easy Corrective Action	1
Detectable at Any Time		

Source: Ilmi et al., (2024)

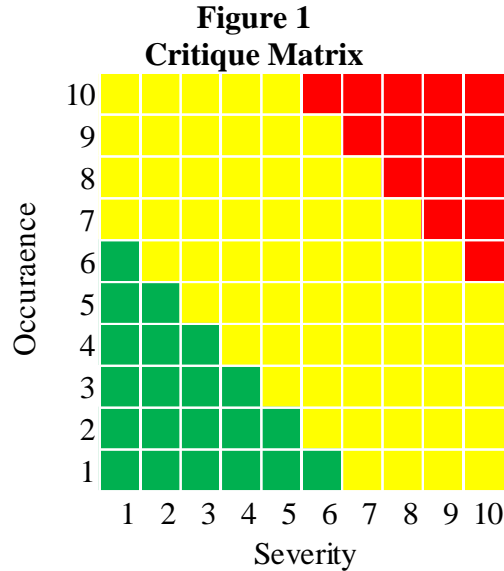
Criticality analysis is carried out using the risk priority number (RPN) method, whose assessment refers to the criticality parameters as listed in Table 4.

Table 4
 Criticality Parameter

Criticality Level	RPN Value	Risk
Minor	0-30	Acceptable
Medium	31-60	Tolerable
High	61-180	
Very High	181-252	Unacceptable
Critical	253-324	
Very Critical	>324	

Source: Ilmi et al. (2024)

After conducting a criticality analysis using previously determined parameters, risks with Unacceptable status will be further explained using a criticality matrix. According to (Dofantara et al., 2023), the criticality matrix is used when there are the same Risk Priority Number (RPN) values, so it is necessary to determine priorities by considering the Severity (S) and Occurrence (O) values.



Source: Handoyo et al. (2023)

Fuzzy Technique for Order Performance by Similarity to Ideal Solution (F-TOPSIS)

One of the most effective decision-making methods is an order selection technique based on closeness to the ideal solution, known as TOPSIS. The main objective of TOPSIS is to rank various options (Sagnak et al., 2021). The criteria for this research are determined using the benefit, cost, opportunity, and risk (BCOR) technique.

Table 5
 Alternative Assessment for BCOR Criteria

Criteria	Tiers	Rating	Criteria	Tiers	Rating
Benefit (C1)	Very Good	5	Opportunity (C3)	Very Ready	5
	Good	4		Ready	4
	Simply	3		Ready Enough	3
	Bad	2		Not Ready	2
Cost (C2)	Very Bad	1	Risk (C4)	Very Unprepared	1
	Very Cheap	5		Very Small	5
	Cheap	4		Small	4
	Medium	3		Medium	3
	Expensive	2		Great	2
	Very Expensive	1		Very Large	1

Source: Fathimahhyati et al. (2021)

Fuzzy set theory is a mathematical framework for explaining uncertainty, imprecision, lack of information, and partial truth (Ainaya & Gustian, 2022).

Table 6

Fuzzy Parameter		
Fuzzy Set Name	Score	Range
Low	0,2	1
Less	0,4	2
Good Enough	0,6	3
Good	0,8	4
Very Good	1	5

Source: Rofiah et al. (2023)

Table 7

Importance Rating	
Name of Interest	Score
Very Important (VI)	1
Important (I)	0,75
Moderately Important (MI)	0,5
Not Important (NI)	0,25
Very Unimportant (VU)	0

Source: Rofiah et al. (2023)

The stages of applying fuzzy-TOPSIS are based on research (Krisnaningsih et al., 2023).

1. Make pairwise matrix nominations, based on the results of filling out the questionnaire
2. Perform defuzzification by converting the initial value into a fuzzy number
3. Perform matrix normalization with equation 2

$$\tilde{r}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m \tilde{x}_{ij}^2}} \quad (2)$$

4. Create a weighted normalized matrix with equation 3

$$y_{ij} = \tilde{r}_{ij} \times w_j \quad (3)$$

5. Perform calculations to obtain positive ideal solution values and negative ideal solutions with equations 4 and 5

$$A^+ = (y_1^+, y_2^+, y_3^+, \dots, y_n^+) \quad (4)$$

$$A^- = (y_1^-, y_2^-, y_3^-, \dots, y_n^-) \quad (5)$$

6. Calculate the distance of each alternative to the positive ideal solution and negative ideal solution with equations 6 and 7

$$D_i^+ = \sqrt{\sum_{j=1}^n (y_j^+ - y_{ij})^2} \quad (6)$$

$$D_i^- = \sqrt{\sum_{j=1}^n (y_{ij} - y_j^-)^2} \quad (7)$$

7. Ranking with the highest value of closeness coefficient (CCi) using equation 8

$$V_i = \frac{D_i^-}{D_i^- + D_i^+}$$

RESULTS AND DISCUSSION

Validity Test and Reliability Test

This study conducts data validation by comparing the calculated r-value with the table r-value, where the data is considered valid if the calculated r-value is greater than the table r-value and invalid if the calculated r-value is less than the table r-value (Sutrisno et al., 2022). The larger the sample size, the better its representation of the population, with a minimum sample size of 30 (Cohen in Sutrisno et al., 2022). To test validity, a comparison is made between the r-table (0.361 for $df = n-2$) and the r-count at a significance level of 5%. Variables that are deemed invalid will be removed to ensure data reliability. After that, the validity test is repeated on other variables, followed by the reliability test. The reliability test is used to measure the consistency of the questionnaire against indicators or variables (Sutrisno et al., 2022). A variable is considered reliable if the Cronbach Alpha value is more significant than 0.60, with higher values indicating better data reliability (Pambudi et al., 2023).

Based on the initial analysis of the 88 identified occupational safety and health risk variables, six invalid variables were found, with the calculated r-value smaller than the table r-value, namely the variables with codes R2, R8, R9, R10, R31, and R78. The six variables were then removed, and the validity test was conducted again. The results of the data processing show that the calculated R-values of all variables are greater than the table R-values. Thus, all variables are declared valid and can proceed to the reliability test stage. The reliability test result shows a Cronbach's Alpha value of 0.962, indicating that all variables are reliable.

Failure Modes Effect and Criticality Analysis (FMECA)

The FMECA process is carried out first by calculating the risk priority number (RPN) moreover, conducting a criticality analysis based on the parameter.

Table 11
 Criticism Level

Activities	Process	Code	Risk	RPN	Criticality Level
Marking	Making marks on materials	R1	Slashed material	80	Tolerable
		R3	Exposure to metal particles	648	Unacceptable
Machining	Material cutting	R4	Exposure to cutting fumes	224	Unacceptable
		R5	Exposure to sparks	224	Unacceptable
		R6	Exposure to cutting rays	192	Unacceptable
		R7	Exposure to noise	192	Unacceptable
		R11	Limbs exposed to cutting machines	90	Tolerable
		R12	Broken cutting blade	90	Tolerable
		R13	Exposed to electricity	252	Unacceptable
		R14	LPG hose leak	180	Tolerable
		R15	Fire	126	Tolerable

		R16	Exposure to metal from turning	252	Unacceptable
		R17	Exposure to noise	168	Tolerable
		R18	Exposure to lubricating oil odour	54	Tolerable
	Turning	R19	Slipped on spilled lubricating oil	54	Tolerable
		R20	Slashed material	36	Tolerable
		R21	Body parts exposed to turning machines	36	Tolerable
		R22	Broken machine tool	27	Acceptable
		R23	Exposed to electricity	120	Tolerable
		R24	Fire	84	Tolerable
			R25	Limbs exposed to work tools	36
	Material Corner Formation	R26	Limbs hit by the workpiece	36	Tolerable
		R27	Material fall	48	Tolerable
		R28	Slipped on spilled lubricating oil	48	Tolerable
		R29	Exposed to electricity	84	Tolerable
		R30	Fire	84	Tolerable
		R32	Slipped on spilled lubricating oil	36	Tolerable
	Making holes in the material	R33	Exposure to metal particles	60	Tolerable
		R34	Limbs crushed	36	Tolerable
		R35	Material fall	36	Tolerable
		R36	Exposed to electricity	63	Tolerable
		R37	Fire	63	Tolerable
Fit Up	Compilation of material components	R38	Workpiece fall	63	Tolerable
		R39	Limbs crushed	63	Tolerable
		R40	Skashed material	54	Tolerable
		R41	Falling from a height	42	Tolerable
Welding	Material splicing	R42	Slashed material	60	Tolerable
		R43	Slipping material	45	Tolerable
		R44	Engine cable slips	80	Tolerable
		R45	Lack of air/oxygen	60	Tolerable
		R46	Exposure to welding spatter	120	Tolerable

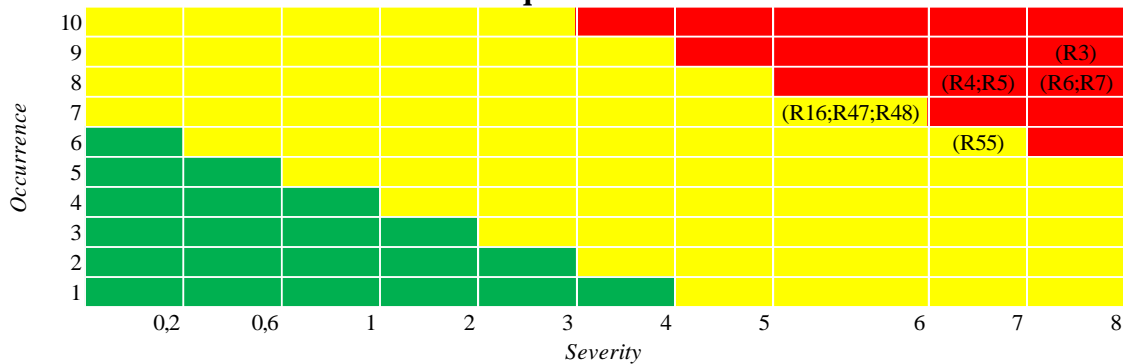
		R47	Exposure to welding beam radiation	336	Unacceptable	
		R48	Exposure to welding fumes	336	Unacceptable	
		R49	Exposed to electricity	160	Tolerable	
		R50	Fire	112	Tolerable	
		R51	Exposure to metal particles	96	Tolerable	
		R52	Slashed workpiece	36	Tolerable	
		R53	Slipping material	27	Acceptable	
	Workpiece surface smoothing	R54	Engine cable slips	36	Tolerable	
		R55	Exposure to noise	336	Unacceptable	
		R56	Limbs exposed to grinding stones	36	Tolerable	
		R57	Lack of air/oxygen	36	Tolerable	
		R58	Exposed to electricity	84	Tolerable	
		R59	Fire	63	Tolerable	
Finishing		R60	Slipping	48	Tolerable	
		R61	Falling from a height	72	Tolerable	
		R62	Slashed workpiece	48	Tolerable	
		R63	Limbs injured while using work tools	27	Acceptable	
		Welding Inspection	R64	Exposure to liquid penetrant/cleaner/developer	27	Acceptable
			R65	Exposure to magnetic liquids	36	Tolerable
			R66	Exposure to radiation radiographic testing	96	Tolerable
		R67	Fire	96	Tolerable	
		R68	Exposure to blasting sand	120	Tolerable	
		R69	Exposure to noise	168	Tolerable	
		R70	Engine hose slips	80	Tolerable	
	Sandblasting	R71	Exposed to high-pressure compressor wind	60	Tolerable	
		R72	Dirty environment	75	Tolerable	
		R73	Material fall	45	Tolerable	
		R74	Falling from a height	54	Tolerable	
		R75	Fire	112	Tolerable	
Coating		R76	Spilled paint liquid	60	Tolerable	
		Painting	R77	Exposure to paint liquid	60	Tolerable
			R79	Exposure to noise	126	Tolerable
			R80	Engine hose slips	60	Tolerable

		R81	Material fall	60	Tolerable
		R82	Falling from a height	126	Tolerable
		R83	Fire	144	Tolerable
		R84	Slipping packaging material	108	Tolerable
Packing	Packaging	R85	Slashed material	84	Tolerable
		R86	Limbs crushed	36	Tolerable
		R87	Lmbs was hit by hammer	27	Acceptable
		R88	Falling work tools	27	Acceptable

Source: Primary data processed by researchers (2025)

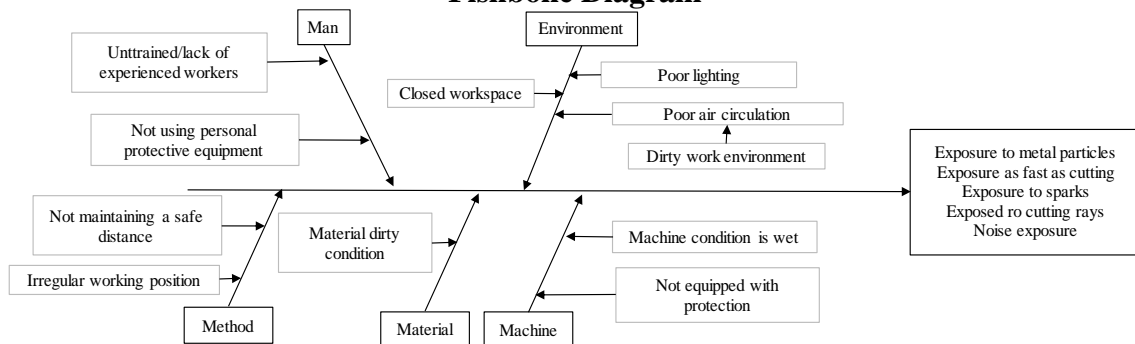
Risks that fall into the "unacceptable" category will be analyzed in more depth using a criticality matrix. These risks include codes R3, R4, R5, R6, R7, R16, R47, R48, and R55.

Figure 2
Critique Matrix



The results of the criticality matrix analysis based on the Severity and Occurrence values show that some risks are at a high level. The next step is to identify the cause of the problem using a fishbone diagram. This diagram helps reveal the root of the problem so that alternative solutions can be formulated (Apriono et al., 2024).

Figure 3
Fishbone Diagram



Various studies have identified several key risk factors. On the human aspect, lack of training, lack of experience, and non-use of personal protective equipment are significant causes (Tamba et al., 2023; Dewi et al., 2021; Nurissa'adah et al., 2022; Putri et al., 2024; Poetri & Hartini, 2023). Regarding methods, risks are triggered by a lack of safety distance and inappropriate working positions (Tamba et al., 2023; Putri et al., 2024; Poetri & Hartini,

2023). Material factors also contribute, especially if the material is dirty. In terms of machinery, risks arise from wet or unprotected machinery (Aqsa et al., 2024; Putri et al., 2024). Meanwhile, environmental factors include dirty workspaces, poor air circulation, inadequate lighting, and closed workspaces.

Once the cause of the problem has been identified, the next step is to formulate alternative solutions to address it.

Table 12
 Alternative Solution

Code	Alternative Solution
A1	Provide training to employees
A2	Regular health and safety education
A3	Periodic worker health checks
A4	Placing workers according to their field of expertise
A5	Providing work aids
A6	Provide good quality work tools
A7	Scheduling regular maintenance of work tools
A8	Provide good quality materials
A9	Provide personal protective equipment specific to job requirements
A10	Provide SOP for each work activity
A11	Sanctioning regulations for non-compliance
A12	Conduct periodic supervision while working
A13	Provide sufficient work area lighting
A14	Perform regular cleaning of the work area

Source: Primary data processed by researchers (2025)

Fuzzy Technique for Order Performance by Similarity to Ideal Solution (F-TOPSIS)

Alternative solutions that have been identified are then assessed using the BCOR criteria. The BCOR value for each alternative solution is obtained as follows. The step is to defuzzify the matrix by converting the alternative solution values into fuzzy numbers.

Table 13
 Defuzzification

	C1	C2	C3	C4
A1	1	0,4	1	0,8
A2	0,8	1	0,8	0,6
A3	0,8	0,6	0,6	0,6
A4	0,8	0,8	0,8	0,8
A5	0,8	0,6	0,8	0,6
A6	0,8	0,6	0,8	0,8
A7	1	0,8	0,8	0,8
A8	0,6	0,6	0,6	0,6
A9	1	0,8	1	0,6
A10	0,8	1	0,8	0,6

A11	1	1	1	0,6
A12	1	1	0,8	0,8
A13	0,6	1	0,6	0,6
A14	0,8	1	0,8	0,6

Source: Primary data processed by researchers (2025)

After the values are converted to fuzzy, the next step is calculating the normalization matrix using equation 2.

Table 14
 Matrix Normalization

	C1	C2	C3	C4
A1	0,313	0,130	0,330	0,315
A2	0,250	0,324	0,264	0,236
A3	0,250	0,194	0,198	0,236
A4	0,250	0,259	0,264	0,315
A5	0,250	0,194	0,264	0,236
A6	0,250	0,194	0,264	0,315
A7	0,313	0,259	0,264	0,315
A8	0,188	0,194	0,198	0,236
A9	0,313	0,259	0,330	0,236
A10	0,250	0,324	0,264	0,236
A11	0,313	0,324	0,330	0,236
A12	0,313	0,324	0,264	0,315
A13	0,188	0,324	0,198	0,236
A14	0,250	0,324	0,264	0,236

Source: Primary data processed by researchers (2025)

After obtaining the normalized matrix value, the next step is calculating the weighted normalization. The weighted normalized assessment is carried out by multiplying the normalized matrix results by the weight of the importance of the criteria. The criteria importance weights are as follows.

Table 15
 Weight of Importance

Criteria	Code	Attribute	Weight
Benefit	C1	Benefit	1
Cost	C2	Cost	0,75
Opportunity	C3	Benefit	0,75
Risk	C4	Cost	1

Source: Primary data processed by researchers (2025)

Table 16
 Weighted Normalized Matrix

	C1	C2	C3	C4
A1	0,313	0,097	0,247	0,315
A2	0,250	0,243	0,198	0,236

A3	0,250	0,146	0,148	0,236
A4	0,250	0,194	0,198	0,315
A5	0,250	0,146	0,198	0,236
A6	0,250	0,146	0,198	0,315
A7	0,313	0,194	0,198	0,315
A8	0,188	0,146	0,148	0,236
A9	0,313	0,194	0,247	0,236
A10	0,250	0,243	0,198	0,236
A11	0,313	0,243	0,247	0,236
A12	0,313	0,243	0,198	0,315
A13	0,188	0,243	0,148	0,236
A14	0,250	0,243	0,198	0,236

Source: Primary data processed by researchers (2025)

After obtaining the weighted normalized value, the next step is determining the positive ideal solution (A+) and negative ideal solution (A-) using equations 4 and 5.

Table 17

Positive and Negative Ideal Solution				
	C1	C2	C3	C4
A+	0,313	0,097	0,247	0,236
A-	0,188	0,243	0,148	0,315

Source: Primary data processed by researchers (2025)

After determining the value of the positive ideal solution (A+) and the negative ideal solution (A-), the next step is calculating the distance to the positive ideal solution and the distance to the negative ideal solution using equations 6 and 7.

Table 18

Distance of Positive and Negative Ideal Solution

	D+	D-
A1	0,079	0,216
A2	0,166	0,112
A3	0,127	0,140
A4	0,148	0,093
A5	0,093	0,148
A6	0,122	0,126
A7	0,135	0,143
A8	0,167	0,125
A9	0,097	0,185
A10	0,166	0,112
A11	0,146	0,178
A12	0,173	0,135
A13	0,216	0,079
A14	0,166	0,112

Source: Primary data processed by researchers (2025)

The last stage is calculated to determine the preference value. The highest preference value indicates that the best alternative solution is determined through the TOPSIS method.

Table 19

Preference Result

Rank	Alternative Solution Code	Vi
1	A1	0,733
2	A9	0,655
3	A5	0,614
4	A11	0,550
5	A3	0,525
6	A7	0,515
7	A6	0,507
8	A12	0,438
9	A8	0,429
10	A2	0,403
11	A10	0,403
12	A14	0,403
13	A4	0,386
14	A13	0,267

Source: Primary data processed by researchers (2025)

Alternative solutions with codes A1, A9, A5, A11, and A3, include Providing training to employees, providing personal protective equipment specific to job requirements, providing work aids, sanctioning regulations for non-compliance, and periodic worker health checks, ranking the highest. The highest ranking indicates the most effective solution in addressing priority risks. However, other alternative solutions are also important to minimize occupational health and safety risks in the steel fabrication workshop.

CONCLUSION

82 occupational safety and health risks were identified, where based on processing using the FMECA method of 82 identified occupational safety and health risks, there are 5 risks categorized as high-level risks, namely risks with exposure to metal particles, exposure to cutting fumes, exposure to sparks, exposure to cutting rays, and noise exposure. The best alternative solutions obtained in dealing with priority risks are providing training to employees, providing specific personal protective equipment according to work needs, providing work aids, providing sanction regulations for non-compliance, periodic worker health checks, scheduling regular maintenance of work tools, providing good quality work tools, conducting supervision while working regularly, providing good quality materials, periodic safety and health education, providing SOPs for each work activity, cleaning the work area regularly, placing workers according to their fields of expertise, and providing sufficient work area lighting.

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