



## HSE Quality System Integration by Identifying and Prioritizing Risks Using Fuzzy FMEA Technique and FAHP (Case Study: Bandar Abbas Oil Refinery, Bandar Abbas, Iran)

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### Abstract

Quality management system offers a significant share of industrial processes, environmental effects, and health and safety risks. Quality systems help the operational managers of key processes including production management, environment management, and health and safety management of operators. HSE systems in safety process management have always tried to maintain environmental and health principles and properly deal with the risks. Risk is considered the extent of hazard of unpredictable events. Risk exists in all human activities. Risk management is a continuous process, known as the basis of HSE management.

Gas and oil industries are known as critical ones due to raw material quality and quantity, intermediate and final products, high complexity, low flexibility, and high vulnerability from the perspective of HSE. An accident can become catastrophe.

This article aimed to identify HSE risks in Bandar Abbas Oil Refinery using fuzzy Failure Modes and Effects Analysis (FMEA) and FAHP. The likelihood of severity, occurrence and detection was weighted using FAHP. Then, the risks were prioritized using fuzzy FMEA and Risk Priority Number (RPN).

According to the results, working at height, skin contact with toxins and chemicals, and lack of pond capacity in the path were found to be most hazardous risks.

**Keyword:** HSE, FMEA, FAHP, Risk.

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### INTRODUCTION

Quality systems investigate how to increase the potential benefits by preventing repetition and ensure the integration of objectives. HSE are based on these goals; for this reason, it is essential to integrate them. HSE is a set of organizational structures, responsibilities, solutions, methods, processes, and resources for managing occupational health, safety and environment. Today, HSE is of great importance due to the changes in strategies of countries and organizations toward environmental affairs, occupational health, and safety people (Mir Ghader, Mohammad Lou, Shaker, 2010). In today's world where industries mainly work in a competitive environment, changes are required as a continuous and strategic process for improving and progressing organizational goals in order to reach economic success. A process model appropriate for management can be pointed as a key element of HSE

management systems. This guarantees the continuation of HSE management systems (Jafarian, 2009).

Maintaining the health and safety of workers and environment plays a key role in industrial factory management. Therefore, a multi-criteria performance of safety and environment is required in industrial factories (Campagno et al., 2015). HSE systems are always engaged with safety processes in working environment and deal with hazards with respect to health and environmental principles. There are unavoidable risks in daily activities of personnel. Risk is considered the extent of hazard of unpredictable events. Risk exists in all human activities. Risk management is a continuous process, known as the basis of HSE management (Jafarian, 2009). The study by Campagno et al. (2015) was used in this research in order to identify the risks in Bandar Abbas Oil Refinery using FMEA. Then, AHP was used to prioritize the risks used for the quality system integration. An innovation in this study is the adoption of fuzzy logic to collect the data. Fuzzy FMEA and Fuzzy AHP were also employed to

identify the risks and prioritize them. Using this approach in petrochemical and refineries was a novel aspect of this article.

**RESEARCH METHOD**

This is an applied study because it aimed to investigate the effect of industrial safety quality system integration on oil refinery safety. It is also a descriptive study. A desk study was performed in related books and documents to get familiar with HSE quality systems. The statistical population consisted of 30 experts working in Bandar Abbas Oil Refinery, Iran. A purposive sampling was performed through interviews with the experts. A questionnaire was used to collect the data. Opinions of experts were employed for pairwise comparison.

First, we extracted the risks in refineries. They were reviewed by the experts working in Bandar Abbas Oil Refinery. Risk assessment was done using fuzzy FMEA. Finally, FAHP was employed to prioritize them.

**Fuzzy Failure Modes and Effects Analysis (FMEA)**

Fuzzy logic process is as follows:

1. Defining linguistic variables
2. Forming fuzzy membership functions
3. Forming fuzzy if/then database
4. Changing a real scalar value into a fuzzy value using fuzzy membership functions (Fuzzification)
5. Evaluating rules in fuzzy database (Fuzzy Inference System (FIS))
6. Combining the results from each rule
7. Changing output data into non-fuzzy values (Defuzzification)

**Proposed Model**

The opinions of experts were employed to identify the risks in Bandar Abbas Oil Refinery, Iran. They were classified using fuzzy AHP. Then, they were ranked using fuzzy FMEA. The proposed model consists of two stages: Calculating the weight of risk index using fuzzy AHP and Ranking risk factors in Bandar Abbas Oil Refinery, Iran.

AHP-FMEA is, in fact, a mixture of fuzzy FMEA and fuzzy AHP. In this new configuration, fuzzy AHP steps are added to the risk priority score to determine the weight of parameters after identifying the failure modes, forming the steps. In general, a 10-step procedure was developed to combine the advantages and avoid shortcomings as follows:

**Step I: Process/Product Information Collection:**

First, it is essential to know the process and service/product. The information in this step is considered the prerequisite for the next steps. This information covers different parts of process, product/service, and their communication and interaction. In AHP-FMEA method, a group of experts are employed to collect the data and evaluations. In other words, an expert team is formed for the investigation of process and

product/service. The group gains a basic idea using product engineering maps or work-flow diagrams of product/service.

**Step II: Identifying Potential Failure Modes**

After knowing the phenomenon under study, a brainstorming was carried out among the team members on potential failure modes threatening the industrial process or the quality of service/product. Failure is the lack of achievement of a certain component of phenomenon under investigation.

**Step III: Determining the Effects of Failure Modes:**

After listing the failure modes, the members reviewed and updated the effects. Inconsistent result of failure mode might be more than one.

**Step IV: Detecting the Reasons of Failure:**

After identifying the potential failure modes and their effects, a team meeting is performed to find the reason of the failure. These are the lists of potential possibilities of each failure.

**Step V: Determining the Degree of Parameters for each Potential Failure:**

Fuzzy AHP is employed in this step. Linguistic terms are used for pairwise comparison [Table 1].

**Table 1: Fuzzy Spectrum and Corresponding Linguistic Terms**

Code	Linguistic Term	Fuzzy Value
1	Equally Preferred	(1, 1, 1)
2	Low Preference	(1, 3, 5)
3	Strongly Preferred	(3, 5, 7)
4	Very Strongly Preferred	(5, 7, 9)
5	Extremely Preferred	(7, 9, 9)

**Step VI: Modification Measures**

Modification measures are taken into account to eliminate or reduce potential failure modes eligible for high risks. Systematic ways of solving problems were used to achieve the goal. Reduced failure is the best optimization method because inspection methods are not required, too.

**Step VII: Model Development**

The model is developed at two levels. The first level aims to determine the priority weight of severity, occurrence and detection. The second level is known as failure clusters. Since every failure potential forms a failure cluster, there are a total of 6 failure clusters: Intervention Risk of Tertiary Factors, Erosion Risks, Design Risks, Incorrect Operational Risks, Product Hazard Risk, Ecological Sensitivity Risk. The following [Table 2] shows the elements in each cluster.

**Table 2: Failure Elements**

Failure Cluster	Element	Failure Cluster	Element
Leakage from connections	Environmental Damage	Heat Exhaustion	Muscle Cramp
Line Erosion	Financial Loss		Urticaria
Lack of Pond Capacity in the Track	Financial Loss	Fall from Height	Physical Injuries
Proximity to Furnaces	Death	Flammable Materials	Fire
Blocking fences above vacuum suction	Death		Explosion
No Circuit to Ground	Financial Loss		Burn
	Environmental Damage		Physical Injury
Mechanical Seal Leakage	Death		Welding Passage
	Financial Loss	Welding Capsule	Periodic Inspection and Painting of Welding Capsules
	Fire	Fall of Tools	Financial Loss
Gas Leakage during Sampling	Toxification	Fall of Installations	Financial Loss
	Death	Crash with Installations	Physical Injury
Two-piece Platform	Maim	Overturning	Death
Fall from Height	Fracture	Car Accidents	Physical Injuries
	Financial Loss	X-Radiography	Chromosomal Changes
	Death	Fall of Height (Worker)	Physical Injuries
Scaffolding Overturning	Financial Loss	Radiography Source	Biological Changes
	Death	Crash of X-Radiography with Radiologist	Death
Electrocution	Financial Loss	Loss of Tower's Normal Conditions	Explosion
	Electric Shock	Manual Control of Pressure of H.P. Steam	Chain Valves on P
	Injury	Explosion	Fire
	Death	Chemical Inhale	Toxification
Fall	Injury	Chemical Dust	Death
Sharp Objects	Scratch	Oil Leakage	Financial Loss
	Surface cut		Environmental Damage

Skin Contact with Chemicals	Death	Container's High Pressure and Disrupted Trays	Financial Loss
	Toxification	Noise Pollution	Hearing Loss
	Skin Complications	Thermal Stress	Neurological Problems
Cuts and Lacerations of Organs	Scratch	Pollution from Nearby Factories	Chemical Inhale
	Surface cut		Chemical Dust
Loss of Tower's Normal Conditions	Explosion	Fall	Main
	Physical Injuries		Fracture
Device Out-of-Service	Explosion		
	Fire		
	Toxification		
	Death		
	Electrocution		
	Environmental Damage		
	Skin Damage		
Work at Height and Different Floors	Death		
	Physical Injuries		
Carbon Monoxide Poisoning	Injuries		
Slipping	Physical Injuries		
Fire	Suffocation		
Crash with Installations	Fracture		
Explosion	Death		

Failure clusters shows the damages.

**Step VIII: Ranking Risk Factors using Fuzzy FMEA**

$$RPN' = \frac{L + M + U}{3}$$

FMEA is a risk assessment method, used for the first time in early 1960s in aviation industry. It aims to identify and ranks potential failures. There are three factors in FMEA which determine the risk factor priority. The first factor is Severity Rating, showing the seriousness of destruction. The second factor is Occurrence Rating. The third is Detection Rating. In Fuzzy FMEA, triangular fuzzy numbers are used. Risk is calculated by multiplying these three factors (S\*O\*D), giving the fuzzy risk number. Finally the fuzzy number changes into a definite number followed by risk factor ranking. Greater risk shows higher importance and needs to be taken into account.

**Table 3: Abbreviations used in FMEA**

Triangular Fuzzy Scale	Linguistic Term	Fuzzy Value
(0, 1.5, 3)	Equally Preferred	Slight
(2, 3.5, 5)	Relatively Preferred	Low
(4, 6, 8)	Strongly Preferred	Medium
(7, 8.5, 10)	Very Strongly Preferred	High
(9, 10, 10)	Extremely Preferred	Very High

**Table 4: Severity, Occurrence, and Detection Rating using Linguistic Terms**

Failure Mode	Effect	Detection Rating			Occurrence Rating			Severity Rating		
Leakage from connections	Environmental Damage	10	8.5	7	5	3.5	2	5	5.3	2
Line Erosion	Financial Loss	8	6	4	8	6	4	5	3.5	2
Lack of Pond Capacity in the Track	Financial Loss 1	10	10	9	5	3.5	2	5	3.5	2
Proximity to Furnaces	Death	10	10	9	5	3.5	2	10	8.5	7
Blocking fences above vacuum suction	Death 2	10	10	9	8	6	4	10	8.5	7
No Circuit to Ground	Financial Loss 2	10	10	9	5	3.5	2	5	3.5	2
	Environmental Damage 2	10	8.5	7	5	3.5	2	3	1.5	0
Mechanical Seal Leakage	Death 3	10	8.5	7	8	6	4	10	8.5	7
	Financial Loss 3	10	10	9	8	6	4	3	1.5	0
	Fire	10	10	9	8	6	4	3	1.5	0
Gas Leakage during Sampling	Toxification	10	10	9	5	3.5	2	3	1.5	0
	Death 4	10	10	9	3	1.5	0	8	6	4
Two-piece Platform	Maim	10	8.5	7	5	3.5	2	10	8.5	7
Fall from Height	Fracture	10	10	9	5	3.5	2	8	6	4
	Financial Loss	10	8.5	7	5	3.5	2	5	3.5	2
	Death 5	10	8.5	7	3	1.5	0	10	8.5	7
Scaffolding Overturning	Financial Loss	10	10	9	5	3.5	2	5	3.5	2
	Death 6	10	8.5	7	5	3.5	2	5	3.5	2
Electrocution	Financial Loss	10	10	9	5	3.5	2	5	3.5	2
	Electric Shock	10	8.5	7	5	3.5	2	10	8.5	7
	Injury	10	10	9	3	1.5	0	10	8.5	7
	Death 7	10	8.5	7	5	3.5	2	5	3.5	2
Fall	Injury	10	8.5	7	5	3.5	2	5	3.5	2
Sharp Objects	Scratch	10	8.5	7	8	6	4	10	8.5	7
	Surface cut	10	8.5	7	8	6	4	5	3.5	2
	Death 8	10	8.5	7	8	6	4	3	1.5	0

Skin Contact with Chemicals	Toxification	10	10	9	8	6	4	10	10	9
	Skin Complications	10	10	9	8	6	4	3	1.5	0
Cuts and Lacerations of Organs	Scratch	10	8.5	7	8	6	4	10	8.5	7
	Surface cut	10	8.5	7	8	6	4	5	3.5	2
Loss of Tower's Normal Conditions	Explosion	10	8.5	7	5	3.5	2	5	3.5	2
Device Out-of-Service	Physical Injuries	10	10	9	5	3.5	2	10	10	9
	Explosion	10	10	9	3	1.5	0	3	1.5	0
	Fire	10	10	9	5	3.5	2	8	6	4
	Burn	10	8.5	7	5	3.5	2	3	1.5	0
	Toxification	10	8.5	7	5	3.5	2	5	3.5	2
	Death	10	8.5	7	5	3.5	2	5	3.5	2
	Electrocution	10	10	9	5	3.5	2	10	8.5	7
	Environmental Damage	10	10	9	5	3.5	2	3	1.5	0
Work at Height and Different Floors	Skin Damage	10	10	9	5	3.5	2	3	1.5	0
	Death	10	10	9	5	3.5	2	3	1.5	0
	Physical Injuries	10	10	9	5	3.5	2	10	8.5	7
Carbon Monoxide Poisoning	Injuries	10	10	9	8	6	4	3	1.5	0
Slipping	Physical Injuries	10	8.5	7	8	6	4	10	8.5	7
Fire	Suffocation	10	8.5	7	8	6	4	5	3.5	2
Crash with Installations	Fracture	10	8.5	7	8	6	4	10	8.5	7
Explosion	Death	10	8.5	7	5	3.5	2	8	6	4
Heat Exhaustion	Heat Exhaustion	10	10	9	8	6	4	10	10	9
	Reduced Alertness	10	8.5	7	10	10	9	3	1.5	0
	Muscle Cramp	10	10	9	10	10	9	3	1.5	0
	Urticaria	10	8.5	7	10	8.5	7	3	1.5	0
Fall from Height	Physical Injuries	10	10	9	10	10	9	3	1.5	0
Flammable Materials	Fire	10	10	9	5	3.5	2	10	8.5	7
	Explosion	10	8.5	7	5	3.5	2	10	8.5	7
	Burn	10	8.5	7	5	3.5	2	8	6	4
	Physical Injury	10	8.5	7	5	3.5	2	3	1.5	0

	Welding Passage	10	10	9	8	6	4	3	1.5	0
	Welding Radiation	10	10	9	8	6	4	3	1.5	0
Welding Capsule	Periodic Inspection and Painting of Welding Capsules	10	8.5	7	8	6	4	3	1.5	0
Fall of Tools	Financial Loss 4	10	10	9	5	3.5	2	5	3.5	2
Fall of Installations	Financial Loss 5	10	10	9	5	3.5	2	5	3.5	2
Crash with Installations	Physical Injury	10	8.5	7	5	3.5	2	10	8.5	7
Overturning	Death 9	10	10	9	5	3.5	2	10	8.5	7
Car Accidents	Physical Injuries	10	10	9	5	3.5	2	10	8.5	7
X-Radiography	Chromosomal Changes	10	8.5	7	5	3.5	2	5	3.5	2
Fall of Height (Worker)	Physical Injuries	10	10	9	5	3.5	2	5	3.5	2
Radiography Source	Biological Changes	10	10	9	5	3.5	2	5	3.5	2
Crash of X-Radiography with Radiologist	Death 10	10	10	9	5	3.5	2	10	8.5	7
Loss of Tower's Normal Conditions	Explosion	10	10	9	5	3.5	2	10	8.5	7
Manual Control of Pressure of H.P. Steam	Chain Valves on P	10	10	9	10	8.5	7	10	10	9
Explosion	Fire	10	8.5	7	5	3.5	2	8	6	4
Chemical Inhale	Toxification	10	8.5	7	5	3.5	2	8	6	4
Chemical Dust	Death 11	10	10	9	5	3.5	2	5	3.5	2
Oil Leakage	Financial Loss 6	10	10	9	8	6	4	10	8.5	7
	Environmental Damage	10	8.5	7	8	6	4	10	8.5	7
Container's High Pressure and Disrupted Trays	Financial Loss 7	10	8.5	7	5	3.5	2	8	6	4
Noise Pollution	Hearing Loss	10	10	9	5	3.5	2	5	3.5	2
Thermal Stress	Neurological Problems	10	10	9	5	3.5	2	10	8.5	7
Pollution from Nearby Factories	Chemical Inhale	10	8.5	7	5	3.5	2	10	8.5	7
	Chemical Dust	10	10	9	8	6	4	8	6	4
Fall	Main	10	8.5	7	8	6	4	10	8.5	7
	Fracture	10	8.5	7	5	3.5	2	10	8.5	7

In [Table 4], the first row of leakage from connections and environmental damage shows that the detection rating was reported 7, 8.5, and 10, meaning that, according to [Table 3], the IX: RPN Calculation

detection rating is high; however, occurrence and severity ratings were 2, 3.5, and 5, showing that they are low [Table 5].

**Table 5: Determining Risk Priority and Identified Failure Modes**

Failure Cluster	Factors	Detection Rating	Occurrence Rating	Severity Rating	RPN
Leakage from connections	Environmental Damage	0.728333333	0.3216667	1.7098333	0.4005807
Line Erosion	Financial Loss	1.475333333	1.4753333	2.1945	4.7765672
Lack of Pond Capacity in the Track	Financial Loss 1	7.051666667	2.9301667	1.42	29.340833
Proximity to Furnaces	Death	2.334333333	1.0025	7.3855	17.283319
Blocking fences above vacuum suction	Death 2	1.006333333	0.698	7.3433333	5.1581091
No Circuit to Ground	Financial Loss 2	1.217666667	0.5153333	3.3417667	2.1003612
	Environmental Damage 2	1.133666667	0.5153333	1.7585	1.0273442
Mechanical Seal Leakage	Death 3	0.726666667	0.5386667	7.0985	2.7785737
	Financial Loss 3	0.727333333	0.4913333	1.418	0.5067409
	Fire	1.433333333	1.014	1.8245	2.6517283
Gas Leakage during Sampling	Toxification	1.006233333	0.4211667	1.713	0.7260277
	Death 4	3.066666667	0.597	4.2653333	7.8089723
Two-piece Platform	Maim	0.826	0.271	7.3855	2.2632569
	Fracture	0.645333333	0.256	4.9406667	0.8162245
Fall from Height	Financial Loss	2.1825	1.0025	3.3105	7.2432292
	Death 5	1.762833333	0.4165	6.913	5.0756634
Scaffolding Overturning	Financial Loss	2.101	0.89483333	3.1235	5.87232
	Death 6	1.007833333	0.4311667	3.301	1.4344302
Electrocution	Financial Loss	0.894	0.371	3.3105	1.0980068
	Electric Shock	0.74283333	0.3311667	7.0985	1.7462426
	Injury	0.645333333	0.124	6.6535	0.5324219
	Death 7	0.979333333	0.4426667	3.3216667	1.440003
Fall	Injury	2.777166667	1.2488333	2.9685	10.295406
Sharp Objects	Scratch	0.826	0.616	7.3855	3.7578606
	Surface cut	0.778166667	0.5753333	2.8878333	1.2928981
Skin Contact with Chemicals	Death 8	0.728333333	0.5373333	0.8925	0.3492868
	Toxification	2.535333333	1.7206667	7.0786667	30.880425

	Skin Complications	0.592	0.39	1.3825	0.3191916
Cuts and Lacerations of Organs	Scratch	0.484333333	0.3506667	6.3698333	1.0818497
	Surface cut	0.778166667	0.5753333	1.615333	0.723417
Loss of Tower's Normal Conditions	Explosion	0.894	0.399	1.989	0.7094882
Device Out-of-Service	Physical Injuries	0.727333333	0.2941667	7.6666667	1.6403387
	Explosion	2.329	0.5245	1.5395	1.8805924
	Fire	2.334333333	1.0025	5.5006667	12.872491
	Burn	2.323833333	1.0321667	1.2925	3.1001689
	Toxification	2.530166667	1.1668333	3.3216667	9.8064994
	Death	2.7771	1.2488333	2.9685	10.295406
	Electrocution	3.009	1.248833	6.6535	25.00212
	Environmental Damage	3.009	1.248833	1.4945	5.6159417
	Skin Damage	3.009	1.248833	1.4945	5.6159417
Work at Height and Different Floors	Death	0.645333333	0.256	1.4945	0.2468994
	Physical Injuries	4.411666667	1.8745	6.15	50.858465
Carbon Monoxide Poisoning	Injuries	1.897666667	1.3346667	1.418	3.5645341
Slipping	Physical Injuries	0.484333333	0.3506667	6.3698333	1.0818497
Fire	Suffocation	1.341833333	1.014	3.3918333	4.6149929
Crash with Installations	Fracture	0.894	0.664	6.15	3.6507384
Explosion	Death	0.484333333	0.2076667	4.6246667	0.4651485
Heat Exhaustion	Heat Exhaustion	1.055666667	0.7333333	7.926	6.1359569
	Reduced Alertness	0.484333333	0.5386667	1.2925	0.3372058
	Muscle Cramp	2.535333333	2.535333333	1.2925	8.3080803
	Urticaria	0.778166667	0.7781667	0.8365	0.506537
Fall from Height	Physical Injuries	0.972	0.972	1.509	1.4256791
Flammable Materials	Fire	0.849666667	0.3448333	3.5621667	1.0442773
	Explosion	1.233666667	0.5153333	7.3188333	4.2757812
	Burn	0.522333333	0.2256667	4.754	0.5603693
	Physical Injury	0.665833333	0.2941667	1.418	0.2777397
	Welding Passage	0.578666667	0.38	1.3825	0.3040025

	Welding Radiation	0.634333333	0.4186667	1.37	0.3638367
Welding Capsule	Periodic Inspection and Painting of Welding Capsules	0.728333333	0.5373333	1.4985	0.5864496
Fall of Tools	Financial Loss 4	1.055666667	0.4426667	3.3216667	1.5522429
Fall of Installations	Financial Loss 5	0.849666667	0.3448333	2.8878333	0.8461161
Crash with Installations	Physical Injury	0.836	0.371	7.3855	2.2632569
Overturning	Death 9	0.634333333	0.249	6.3003333	0.9951313
Car Accidents	Physical Injuries	3.585666667	1.4493333	3.7208333	19.336524
X-Radiography	Chromosomal Changes	0.726666667	0.3233333	3.1235	0.7338837
Fall of Height (Worker)	Physical Injuries	0.578666667	0.2256667	2.8378333	0.3705807
Radiography Source	Biological Changes	0.538666667	0.2076667	2.7431667	0.3068592
Crash of X-Radiography with Radiologist	Death 10	1.762833333	0.8011667	6.913	9.763391
Loss of Tower's Normal Conditions	Explosion	0.727333333	0.2941667	6.913	1.4790863
Manual Control of Pressure of H.P. Steam	Chain Valves on P	1.217666667	1.1336667	7.8446667	10.828998
Explosion	Fire	0.574	0.349	4.644	0.6637483
Chemical Inhale	Toxification	0.728333333	0.3216667	4.754	1.1137698
Chemical Dust	Death 11	0.790666667	0.3233333	3.1235	0.7985193
Oil Leakage	Financial Loss 6	0.645333333	0.4293333	6.6535	1.8434394
	Environmental Damage	0.522333333	0.38	6.4761667	1.2854327
Container's High Pressure and Disrupted Trays	Financial Loss 7	0.665833333	0.2941667	5.0306667	0.9853364
Noise Pollution	Hearing Loss	0.700333333	0.2773333	2.7003333	0.5244743
Thermal Stress	Neurological Problems	0.797	0.3216667	6.3215	1.6206324
Pollution from Nearby Factories	Chemical Inhale	0.537	0.232	5.443	0.6781107
	Chemical Dust	0.797	0.5373333	4.754	2.0359227
Fall	Maim	0.932833333	0.697	7.3433333	4.7813741
	Fracture	0.647166667	0.2838333	6.5118333	1.1961422

**X= Prioritizing Criteria**

In order to gain detection, occurrence, and severity ratings, averaging method, defuzzification, was used. RPN is calculated

by multiplying detection rating by occurrence rating, and severity rating.

[Table 6]

**Table 6: Prioritizing Criteria**

	Failure Mode	Effects	RPN
1	Work at Height and Different Floors	Physical Injuries	50.858465
2	Skin Contact with Chemicals	Toxification	30.880425
3	Lack of Pond Capacity in the Track	Financial Loss 1	29.340833
4	Device Out-of-Service	Electrocution	25.00212
5	Car Accidents	Physical Injuries	19.336524
6	Proximity to Furnaces	Death	17.283319
7	Device Out-of-Service	Fire	12.872491
8	Manual Control of Pressure of H.P. Steam	Chain Valves on P	10.828998
9	Fall	Injury	10.295406
10	Device Out-of-Service	Death	10.295406
11	Device Out-of-Service	Toxification	9.8064994
12	Crash of X-Radiography with Radiologist	Death 10	9.763391
13	Heat Exhaustion	Muscle Cramp	8.3080803
14	Gas Leakage during Sampling	Death 4	7.8089723
15	Fall from Height	Financial Loss	7.2432292
16	Heat Exhaustion	Heat Exhaustion	6.1359569
17	Scaffolding Overturning	Financial Loss	5.87232
18	Device Out-of-Service	Environmental Damage	5.6159417
19	Device Out-of-Service	Skin Damage	5.6159417
20	Blocking fences above vacuum suction	Death 2	5.1581091
21	Fall from Height	Death 5	5.0756634
22	Fall	Maim	4.7813741
23	Line Erosion	Financial Loss	4.7765672
24	Fire	Suffocation	4.6149929
25	Flammable Materials	Explosion	4.2757812
26	Sharp Objects	Scratch	3.7578606
27	Crash with Installations	Physical Injury	3.6507384
28	Carbon Monoxide Poisoning	Injuries	3.5645341

29	Device Out-of-Service	Burn	3.1001689
30	Mechanical Seal Leakage	Death 3	2.7785737
31	Mechanical Seal Leakage	Fire	2.6517283
32	Two-piece Platform	Maim	2.2632569
33	Crash with Installations	Physical Injury	2.2632569
34	No Circuit to Ground	Financial Loss 2	2.1003612
35	Pollution from Nearby Factories	Chemical Dust	2.0359227
36	Device Out-of-Service	Explosion	1.8805924
37	Oil Leakage	Financial Loss 6	1.8434394
38	Electrocution	Electric Shock	1.7462426
39	Device Out-of-Service	Physical Injuries	1.6403387
40	Thermal Stress	Neurological Problems	1.6206324
41	Fall of Tools	Financial Loss 4	1.5522429
42	Loss of Tower's Normal Conditions	Explosion	1.4970863
43	Electrocution	Death 7	1.440003
44	Scaffolding Overturning	Death 6	1.4344302
45	Fall from Height	Physical Injuries	1.4256791
46	Sharp Objects	Surface cut	1.2928981
47	Oil Leakage	Environmental Damage	1.2854327
48	Fall	Fracture	1.1961422
49	Chemical Inhale	Toxification	1.1137698
50	Electrocution	Financial Loss	1.980068
51	Cuts and Lacerations of Organs	Scratch	1.0818497
52	Slipping	Physical Injuries	1.0818497
53	Flammable Materials	Fire	1.0442773
54	No Circuit to Ground	Environmental Damage 2	1.0273442
55	Overturning	Death 9	0.9951313
56	Container's High Pressure and Disrupted Trays	Financial Loss 7	0.9853364

57	Fall of Installations	Financial Loss 5	0.8461161
58	Two-piece Platform	Fracture	0.8162245
59	Chemical Dust	Death 11	0.7985193
60	X-Radiography	Chromosomal Changes	0.7338837
61	Gas Leakage during Sampling	Toxification	0.7260277
62	Cuts and Lacerations of Organs	Surface cut	0.723417
63	Loss of Tower's Normal Conditions	Explosion	0.7094882
64	Pollution from Nearby Factories	Chemical Inhale	0.6781107
65	Explosion	Fire	0.6637483
66	Welding Capsule	Periodic Inspection and Painting of Welding Capsules	0.5864496
67	Flammable Materials	Burn	0.5603693
68	Electrocution	Injury	0.5324219
69	Noise Pollution	Hearing Loss	0.5244743
70	Mechanical Seal Leakage	Financial Loss 3	0.5067409
71	Heat Exhaustion	Urticaria	0.506537
72	Explosion	Death	0.4651485
73	Leakage from connections	Environmental Damage	0.4005807
74	Fall of Height (Worker)	Physical Injuries	0.3705807
75	Flammable Materials	Welding Radiation	0.3638367
76	Skin Contact with Chemicals	Death 8	0.3492868
77	Heat Exhaustion	Reduced Alertness	0.3272058
78	Skin Contact with Chemicals	Skin Complications	0.3191916
79	Radiography Source	Biological Changes	0.3068592
80	Flammable Materials	Welding Passage	0.3040025
81	Flammable Materials	Physical Injury	0.2777397
82	Work at Height and Different Floors	Death	0.2468994

First, we identified the HSE quality risks in Bandar Abbas Oil Refinery. The risks were weighted using fuzzy AHP. Pairwise comparison measures the severity, occurrence, and detection

rating. Then, fuzzy FMEA was employed to rank the risks. [Table 2] shows the failure elements and the clusters. Next, we calculated RPN. [Table 1 to 3] shows the results.

**CONCLUSION**

Quality and quality seeking along with an acceptable working process have become important issues in recent years. Business progress and greater share of markets coupled with certain concepts such as customer satisfaction, and meeting the legal and international requirements are motive factors for organizations to move toward systematizing the activities. Various international occupational health, safety, and environment standards and quality have an undeniable role. The similarity of management systems and advantages of its implementations has raised MIS. Integrating HSE system and organization's management can facilitate the effective

implementation of HSEQ Management System, help the transparency of responsibilities, and avoid overlapping. Therefore, this article aimed to integrate HSE quality systems through identifying and prioritizing risks using fuzzy FMEA and fuzzy AHP. Finally, fuzzy FMEA was used to assess the risks in Bandar Abbas Oil Refinery.

A total of 84 effective criteria were extracted, as shown in [Table 5]. AHP was employed to prioritize the criteria and sub-criteria. To this end, pairwise comparison matrix was developed by the team of experts. Then, risk was assessed and RPN was calculated using fuzzy FMEA and AHP, as shown in [Table 7].

**Table 7: Risk Assessment and RPN using Fuzzy FMEA and Fuzzy AHP**

Failure Cluster	Factors	RPN-AHP	RPN- FMEA
Leakage from connections	Environmental Damage	0.4005807	104.125
Line Erosion	Financial Loss	4.7765672	126
Lack of Pond Capacity in the Track	Financial Loss 1	29.340833	118.4166667
Proximity to Furnaces	Death	17.283319	287.5833333
Blocking fences above vacuum suction	Death 2	5.1581091	493
No Circuit to Ground	Financial Loss 2	2.1003612	118.4166667
	Environmental Damage 2	1.0273442	44.625
Mechanical Seal Leakage	Death 3	2.7785737	433.5
	Financial Loss 3	0.5067409	87
	Fire	2.6517283	87
Gas Leakage during Sampling	Toxification	0.7260277	50.75
	Death 4	7.8089723	87
Two-piece Platform	Maim	2.2632569	252.875
	Fracture	0.8162245	203
Fall from Height	Financial Loss	7.2432292	104.125
	Death 5	5.0756634	108.375
Scaffolding Overturning	Financial Loss	5.87232	118.4166667
	Death 6	1.4344302	104.125
	Financial Loss	1.0980068	118.4166667
	Electric Shock	1.7462426	252.875

Electrocution	Injury	0.5324219	123.25
	Death 7	1.440003	104.125
Fall	Injury	10.295406	104.125
Sharp Objects	Scratch	3.7578606	433.5
	Surface cut	1.2928981	178.5
Skin Contact with Chemicals	Death 8	0.3492868	76.5
	Toxification	30.880425	560.6666667
	Skin Complications	0.3191916	87
Cuts and Lacerations of Organs	Scratch	1.0818497	433.5
	Surface cut	0.723417	178.5
Loss of Tower's Normal Conditions	Explosion	0.7094882	104.125
Device Out-of-Service	Physical Injuries	1.6403387	327.555556
	Explosion	1.8805924	21.75
	Fire	12.872491	203
	Burn	3.1001689	44.625
	Toxification	9.8064994	104.125
	Death	10.295406	104.125
	Electrocution	25.00212	287.5833333
	Environmental Damage	5.6159417	50.75
	Skin Damage	5.6159417	50.75
Work at Height and Different Floors	Death	0.2468994	50.75
	Physical Injuries	50.858465	287.5800000
Carbon Monoxide Poisoning	Injuries	3.5645341	87
Slipping	Physical Injuries	1.0818497	433.5
Fire	Suffocation	4.6149929	178.5
Crash with Installations	Fracture	3.6507384	433.5
Explosion	Death	0.4651485	178.5
Heat Exhaustion	Heat Exhaustion	6.1359569	560.6666667
	Reduced Alertness	0.3372058	123.25
	Muscle Cramp	8.3080803	140.1666667

	Urticaria	0.506537	108.375
Fall from Height	Physical Injuries	1.4256791	140.1666667
Flammable Materials	Fire	1.0442773	287.5833333
	Explosion	4.2757812	252.875
	Burn	0.5603693	178.5
	Physical Injury	0.2777397	44.625
	Welding Passage	0.3040025	87
	Welding Radiation	0.3638367	87
Welding Capsule	Periodic Inspection and Painting of Welding Capsules	0.5864496	76.5
Fall of Tools	Financial Loss 4	1.5522429	118.4166667
Fall of Installations	Financial Loss 5	0.8461161	118.4166667
Crash with Installations	Physical Injury	2.2632569	252.875
Overturning	Death 9	0.9951313	287.5833333
Car Accidents	Physical Injuries	19.336524	287.5800000
X-Radiography	Chromosomal Changes	0.7338837	104.125
Fall of Height (Worker)	Physical Injuries	0.3705807	118.4166667
Radiography Source	Biological Changes	0.3068592	118.4166667
Crash of X-Radiography with Radiologist	Death 10	9.763391	252.875
Loss of Tower's Normal Conditions	Explosion	1.4790863	287.5833333
Manual Control of Pressure of H.P. Steam	Chain Valves on P	10.828998	794.2777778
Explosion	Fire	0.6637483	178.5
Chemical Inhale	Toxification	1.1137698	178.5
Chemical Dust	Death 11	0.7985193	118.4166667
Oil Leakage	Financial Loss 6	1.8434394	493
	Environmental Damage	1.2854327	433.5
Container's High Pressure and Disrupted Trays	Financial Loss 7	0.9853364	178.5
Noise Pollution	Hearing Loss	0.5244743	118.4166667
Thermal Stress	Neurological Problems	1.6206324	287.5833333
Pollution from Nearby Factories	Chemical Inhale	0.6781107	252.875

	Chemical Dust	2.0359227	348
Fall	Maim	4.7813741	433.5
	Fracture	1.1961422	252.875

**DISCUSSION**

In this study, we initially selected 82 criteria for failure modes provided by the experts. Then, fuzzy FMEA and FAHP were combined to prioritize the risks. According to the results, the most important risks are Work at Height and Different Floors, Skin Contact with Chemicals, and Lack of Pond Capacity in the Track. The results were consistent with those of the study by Behbahani et al. (2013) on risk assessment of drilling operation using FMEA of North Drilling Company. The results were also consistent with those of Campagno et al. (2014) who investigated the HSE quality system integration and prioritized the risks using AHP. AHP is capable of prioritizing environmental risks in different units. This ranking determined the prioritized resource allocation for the maintenance. The results of the study by Li et al. (2014) on investigation of HSE system performance using weighting and fuzzy assessment were consistent with ours because both studies employed the opinions of the experts to design a framework for identifying and prioritizing oil industry-related risks. The results were also consistent with those of Kongsvik et al. (2015) who investigated the HSE culture in oil industry. This study and ours showed that organizational learning analysis is essential for the safety and benefits. On the other hand, the results were consistent with the studies by Carvalho et al. (2015) which investigated the advantages of HSE and quality system integration and Santos et al. (2014) which studied the integration of safety, environment, and quality systems. All three studies worked on individual systems and quality management system with ISO 9001, environment management system with ISO 14001, and occupational health and safety management systems with OHSAS 18001.

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