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Analysis of occupational hazards and lateral environmental pollution in the construction phase of Yadavaran oil field

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A B S T R A C T

Occupational hazards in the petroleum industry have always been among the major problems in the various phases of construction and installation, which sometimes cause environmental damage. The present study aims to evaluate the risk of occupational accidents in the petroleum industry in the construction phase (2010-2015) in one of the largest oil fields in Iran, namely the Yadavaran Oil Field in Khuzestan Province, and also discuss the lateral environmental damage. The environmental damage such as air, soil, and water pollution caused by occupational accidents were identified, and the distribution and type of activity were analyzed. For this purpose, the Failure Mode and Effects Analysis (FMEA) model was applied to evaluate the risk of occupational accidents. A total of 47 occupational accidents were identified during the 6-year construction phase of this oil field. The data was collected and underwent statistical analysis and risk assessment based on the location and hazards clustering, which is the main novelty of the article. According to the results, the average number of risk priorities for the observed occupational accidents was 212. Also, the occupational accidents were categorized by the type of accidents, and several corrective measures suitable for each type of accident were suggested. Based on these suggestions, the corrective Risk Priority Number (RPN) was expected to be about 133.2. As a result of these corrections, the risk reduction was expected to be 37% of the initial value. The changes introduced were low-cost, continuous, and periodic measures with positive effects on this oil field.

1. Introduction

The petroleum industry in developing countries has been associated with more occupational accidents than many developed countries [1]. Therefore, the continuous improvement of safety practices in this industry should be emphasized. In all industries, the employer has a responsibility to the employees to ensure a safe workplace. Given the wide range of activities and a large number of employees with various levels of experience and education, the oil and gas industry has always been associated with many occupational accidents. The loss of skilled and experienced manpower has resulted in huge losses for the oil industry. Therefore, oil companies have tried to reduce the number of occupational accidents. The statistical analysis of accident indices in Iran, especially those leading to death in the petroleum industry, has been one of the important indices in evaluating the Health, Safety, and Environment (HSE) performance of a company, such that these indices are constantly updated and controlled by gathering relevant statistics and data [2]. In 2015, a full analytical report was prepared on the trend of petroleum industry accident indices in a 10-year period. It also included the sustainability report of the Ministry of Petroleum. In this report, the accident indices were evaluated and analyzed based on different indices and segments. The middle and

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root causes and factors in the occurrence of accidents were identified, with attention paid to the frequency of each factor, and corrective measures were proposed. Also, a report presented at the third meeting of the Central Council indicated that the number of accidents leading to death in the first seven months of 2016 declined by more than 40% compared to the same period in 2015. Accident analysis shows that the major causes of accidents are failure to implement the operational procedures and lack of effective supervision in the direct supervision layers [3]. In general, the studies carried out on safety in the petroleum industry can be divided into three categories.

1. Studies on the evaluation of safety, risk, and occupational accidents in oil and gas industries
2. Providing general strategies for management, monitoring, intelligence for preventing occupational accidents
3. Analysis of common and frequent occupational accidents in the oil and gas industry

In the following, some related studies are discussed.

Jozi and Saffarian (2011) identified and prioritized the risks and effects of the Abadan Gas Power Plant [4]. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method was applied to prioritize the risks. The results indicated the following environmental risks as the most important at the Abadan Gas Power Plant: a gas-fueled weight unit, fuel tanks, fuel delivery, gas fuel delivery in the operation unit, working on a liquid fuel clutch, and gas filter exchange in the mechanics unit [4].

Ebrahimzadeh et al. (2011) evaluated the potential risks of the Shiraz Oil Refining Company via analysis of risk states and their effects [5]. The milling, welding, and transportation of objects in the Shiraz Refinery were assessed by assigning a RPN for each of the above activities. The results showed that the highest RPN score belonged to the transportation of objects and scraping the exterior surfaces before and after corrective measures, which were 200 and 210 and 72 and 84, respectively. Meanwhile, the RPN score before and after corrective measures for welding and exterior drilling were 144 and 120 and 36 and 24, respectively. However, the findings showed that the activities with a low RPN score had a higher priority than those with a higher score in terms of the severity of injury [6]. Mirzaei Siroui et al. (2017) conducted the behavioral immune system deployment analysis on accident reduction in the Persian Gulf Star Oil Company. First, the workers were observed for unsafe behaviors, and these actions were recorded using the checklist of safe behaviors. In the next step, the educational and psychological interventions were performed, and then observations were once again made and recorded. The data were analyzed by SPSS software and the dependent t-test [7]. In another study published by Ata'ollah Ramezani Amiri et al. (2017), human occupational accidents were analyzed by Tripod Beta in one of the South Pars refineries. All the information regarding the occupational accidents were collected, of which those leading to death and four types of accidents with the highest frequency were selected. All the factors involved in the sequence of events leading to the accident were identified through examinations and interviews. Next, the routes for each accident were plotted using Tripod-Beta, and the cause of the accident was analyzed; the underlying factors involved in the accidents were identified [8]. Mete (2019) studied the FMEA based on the analytic hierarchy process (AHP) and Multi-Objective Optimization on the basis of Ratio Analysis plus full multiplicative form (MULTIMOORA) integrated approach under fuzzy sets to evaluate the occupational risks in a natural gas pipeline construction project. A comparative study, correlation analysis, and sensitivity analysis were presented to assess the new risk approach. An integrated approach showed acceptable results for evaluating occupational risks in a pipeline construction project using fuzzy sets, indicating the uncertainty in a more appropriate approach [9]. Asad et al. (2019) reviewed the occupational accidents in the upstream petroleum industry at various oil drilling sites in the world during 2000-2018 [1]. Different accidents in this study were collected, analyzed, and categorized by site location. The statistical population is presented. The results and casualties caused by occupational accidents investigated in this study are strong proof of the importance of the need for controlling and reducing occupational accidents in the petroleum industry in the Middle East and East Asia. In some studies, the safety perspectives and occupational accidents were considered from the early stages of selecting a contractor. Gharedaghi and Omidvari (2019) suggested the contractor selection model for the oil and gas industry in the safety approach using Analytic network process (ANP) -Decision making trial and evaluation laboratory (DEMATEL) in the gray environment [10]. Some studies have focused on measuring and increasing awareness, safety attitude, and occupational health among corporate workers to reduce occupational accidents [11]. According to Mukhtar et al. (2020), every worker must have sufficient information on health status and knowledge of occupational safety to be safe from any accidents and injuries. Their results showed that continuous and intelligent education is an important and effective factor in this regard [11]. Some studies have also focused on specific common accidents in the industry. For example, Shokouhi et al. (2019) predicted the probability of falling using a Bayesian network model in the Iranian petroleum industry [12]. According to their prediction, more than half of the occupational accidents involving falling in the study population could be reduced by equipping and developing falling protection devices and establishing a safe work platform. One of the questions in accident risk management in oil fields is whether the location of the accident is related to the type of accident [13,14]. If the two issues are linked, more efficient and effective management can be created in similar oil fields. At present, the oilfields in Iran generally apply occupational accident risk management to regions, which in many cases can focus and control risk management more accurately and effectively based on the location and type of operation of the unit [15,16]. This saves more time and money for the area. Also, with a more accurate view of the region regarding occupational accidents, we will eventually see fewer accidents and less loss of life, property, and time. Generally, the importance of occupational accidents in the petroleum industry and the measures taken to control and reduce these accidents are evident [17,18]. Since the average occupational accidents in Iran are relatively high, the precise identification of their roots is necessary [19,20]. In the present study, an accident risk assessment was performed by examining and analyzing the occupational accidents that occurred during the 6-year construction phase of the Yadavaran Oil Field. The novelty of this article was its focus on the gathering of comprehensive data that was statically analyzed based on location and clustering.

2. Materials and methods

In this research, the FMEA technique was applied to investigate occupational risks in the construction industry during the construction and operation phases of civil projects [21,22]. First, occupational accidents in the construction phase of the Yadavaran oil field were identified and categorized. Then, these accidents were separately evaluated using the FMEA risk assessment technique for each phase. The HSE databases [23,24], questionnaires, face-to-face interviews, and statistics and data of the Yadavaran oil field were used to identify occupational accidents. In the next step, the accidents related to each other by the nature of the risk and at least affect one of the Severity, Occurrence and Detection (SOD) parameters were categorized and prioritized. Then, based on the importance of each of the common and effective occupational accidents in the activity of phases, the corrective measures specified to resolve the impressionability of the phases from each other were proposed. In the following, the methods and techniques used in this study are explained and introduced.

2.1. Study area

The Yadavaran field is an Iranian oil field located in Khuzestan province (Figure 1). This field is located about 70 km southwest of Ahvaz, north of Khorramshahr, in the geographical area of Kushk and Hosseinieh, and is among the common fields with Iraq. The length of the field is about 45 km, and its width is 15 km. It extends from the north to the south along the border with Iraq. Based on the most recent studies and the results of examining the observation wells and reservoir dynamics models, the amount of oil at the field site based on the most probable state is estimated to be over 34 billion barrels. This project put a great deal of effort to use domestic forces, especially the indigenous forces of the region. In this respect, a considerable share of the 3,680 people working in this project were indigenous forces of the region, creating employment in the operational area. Currently, 1,500 people are working on the project. To date, about 64 million man-hours have been worked since the beginning of the project. Hence, maintaining the specialized manpower is essential in this project.

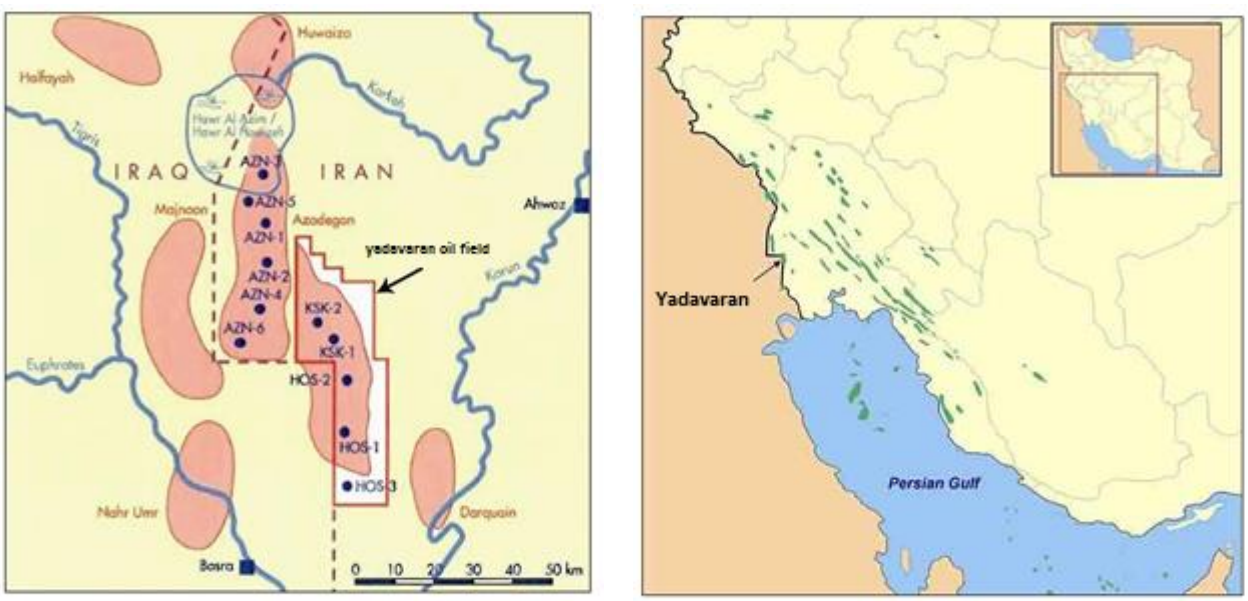

Fig. 1. Yadavaran Oil Field.

In total, four sites will be created in this region as follows:

- Site A1: Kushk manifold
- Site B2: Hosseinieh manifold
- Site C3: Oil and gas separation unit and filtration and refining unit
- Site D4: Water inlet area (transmission line)

The project is located in a semi-arid hot and dry climate with hot and dry summers from June to September, which usually turns into winter rapidly. Then, until February, the temperature is relatively mild with little rain such that the annual rainfall is 170 mm and the average temperature is 25^{o} C. The dominant wind direction in the region during the year is from the west and northwest. The project area has a flat and smooth landscape, and thus the wind direction is not affected by the local features. The north winds of the Mediterranean currents reaching Iran decrease the mid-day moisture and make the heat and sultry winds blowing from the southwest tolerable.

2.2. FMEA model

The FMEA technique or analysis of failed states and their effects is a systematic and preventative approach for identifying the points and routes where the process or design of a system could face a problem and disrupt its overall performance [25]. In this technique, after finding these points, the causes of these failures are discussed and their prevention is investigated so that the output of the FMEA analysis will be a reliable design. This technique is used to maintain the health safety of the system [26]. The FMEA steps in this study are shown in Figure 2.

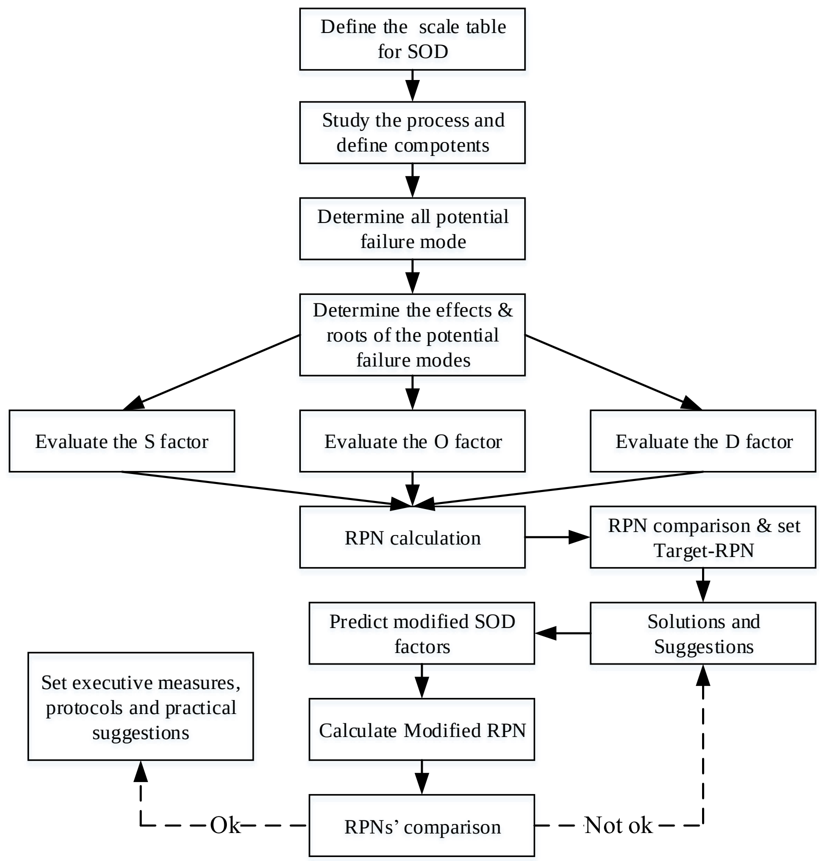

Fig. 2. FMEA steps in this study.

The risk severity or recentness is the "potential risk effect" on the individuals; the risk severity is concerned only about its "effect". The reduction in risk severity is only possible through changes in the process and activities. There are few indices for this risk severity, which are expressed on a scale of 1 to 10 [27]. The probability of occurrence determines at which frequency the cause of risk potential mechanism occurs. One can reduce the number of occurrences only by eliminating or reducing the causes or mechanisms of any risk. The probability of occurrence is measured on a scale of 1 to 10. The review of records is very useful in this regard. Investigating the control processes, standards, requirements, and rules of work, and their application is very useful to achieve this number [28]. The detection probability is applied to assess the ability to identify a cause/mechanism of risk; in other words, the detection probability is the ability to find the risk before the accident occurrence. Examining the control processes, standards, requirements, and rules of work and their applications is very useful to achieve this number [28]. The factors of severity (S), occurrence (O), and detection (D) in the FMEA method are scored through some tables. These factors are assigned a score of 1 to 10 according to the definitions provided. For further information about these tables, please see [27,29,30].

The risk priority number is the product of three numbers calculated from severity (S), occurrence (O), and detection (D) [28].

$$\text{Detection} \times \text{Occurrence} \times \text{Severity} = \text{RPN} \tag{1}$$

The risk priority number will be between 1 and 1000. For high-risk numbers, this number can be lowered through corrective items. The references of experts for data collection used in the FMEA model are given in Figure 3.

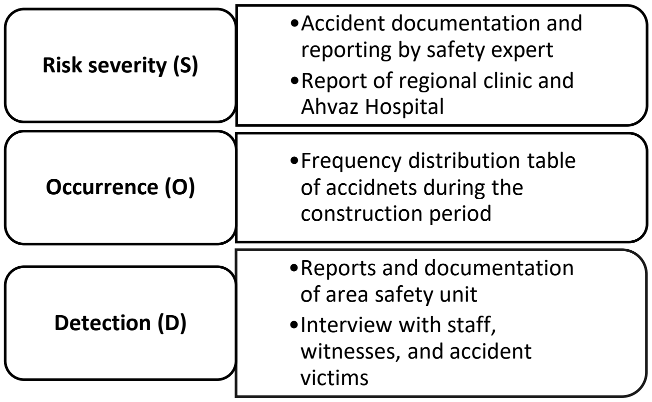

Fig. 3. Reference for data collection used in the FMEA model.

3. Results and discussion

In this section, the occupational accidents that occurred at the Yadavaran Oil Field during 2010-2015 have been investigated. For this purpose, the statistics and information available in the area were used. Moreover, some interviews were conducted with the managers and safety administrators of the site and then analyzed. The status of the risk priority number of occupational accidents in this oil field was investigated using the FMEA risk assessment technique. Occupational accidents are considerable in the petroleum industry, considering the extent and variety of services and operations in the construction phase. The construction phase of the Yadavaran oil field began in 2010 and was completed by 2015. During this period, significant accidents for equipment and environmental staff were incurred. However, this study only investigated the accidents related to the construction phase. As can be seen from Table 1, most of the occupational accidents resulted in direct losses for the staff. Moreover, in some cases, the equipment and environment losses are mainly associated with on-site traffic accidents. It is noteworthy that exploitation in the oil field is generally associated with many environmental pollutions. In the construction phase, the environmental damage is mainly due to civil activities and is caused indirectly with a very limited number due to the occupational safety accidents. In addition, the environmental damages caused by occupational accidents is very minor. The accidents that were similar to each other, such as finger cuts or bruises, were placed in the same categories. To start the analysis, the accidents that were similar in terms of the type of losses were categorized and presented together. Also, working at a height above 50 cm was considered as working at a height. A total of 47 occupational accidents occurred in this area during the construction phase. These cases were categorized based on the severity of the casualties by each of the accidents in terms of their type and type of losses, as well as the location and time of the accident. The information in this study can be used to create a list of occupational accidents of an oil field to determine the severity and probability of their occurrence and identify their detection probability based on the reports of safety experts and those witnessing these accidents.

Table 1. Summary of occupational accidents in the construction phase of Yadavaran Oil Field during 2011-2015.

Number	Activity	Type of accident	Severity of			Date	Site
			Human	Equipment	Environment		
1	Pipe coating operation	Hand crushing and finger cuts	2			2010	F2 well site
2	Getting caught in the equipment while working	Ankle sprain	1			2010	FATH-28 RIG SITE
3	-	Snakebite	1			2010	F7 WELL SITE
4	Transportation	Vehicle deviation from the road and overturn	1	1	1	2010	T2 ROAD
5	Equipment cleaning	Hand crush	3			2010	F5 WELL SITE
6	Working with lift	hand crushing and breaking	2			2011	F8 WELL SITE
7	Collision with sharp surfaces when working	Ankle twist	1			2011	F8 WELL SITE
8	Equipment repair	Hand crushes and finger cuts	1			2011	PILING UNIT
9	Trench visit	Falling	2			2011	CTEP
10	Getting caught in the equipment at work	Hand crushing and breaking	2			2011	APP-1
11	Collision with sharp surfaces when working	Hand-cut	4			2011	F15 WELL SITE
12	Chemical explosion	Burn	3			2011	PERMANENT CAMP

Number	Activity	Type of accident	Severity of: Human	Equipment	Environment	Date	Site
13	Working with equipment	Hand-cut	2			2011	HOSEINIEH MANIFOLD
14	Working with equipment	Hand crush	1			2012	S1 WELL SITE
15	Pipe coating operation	Hand-cut	2			2012	SITE PIPE YARD
16	Working with equipment at height	Falling	1			2012	CAMP
17	Equipment cleaning	Burn	2			2012	RIG 210 SIPC
18	Working with equipment	Hand crushes and finger cuts	1			2012	CTEP
19	Loading/unloading	Hand crushes and fingers breaking	2	1		2012	SIPC WAREHOUSE
20	Working with equipment at height	Falling	1			2012	F17 WELL SITE
21	Pipe coating operation	Falling	1			2012	FATH-28 WELL S1
22	Transportation	Vehicle deviation and overturn	2	1		2012	EKTESHAF ROAD
23	Working with equipment at height	Falling	3			2012	S2 WELL SITE
24	Working with equipment at height	Falling	1			2012	S21 WELL SITE
25	Working with equipment	Hand crush	1			2012	F10 WELL SITE
26	Working with equipment	Hand crush	2			2013	WELDING SHOP
27	Getting caught in the equipment at work	Foot crush and cuts	2			2013	S25 WELL SITE
28	Working with equipment	Hand crush	2			2013	CTEP
29	Working with equipment	Collision with objects	3	1		2013	VEHICLES MAINTENANCE SHOP
30	Transportation	Vehicle deviation and overturn	2	1		2013	T2 ROAD
31	Transportation	Vehicle deviation and overturn	1	1		2013	EKTESHAF ROAD
32	Working with equipment at height	Falling	2			2013	CTEP
33	Working with equipment at height	Falling	2			2013	CTEP
34	objects falling on people	Death	5			2013	CTEP
35	Working with equipment	Explosion	5			2013	CTEP
36	Working with equipment	Hand-cut	2			2013	CTEP
37	Working with equipment	Hand-cut	2			2013	CTEP
38	Collision with hot surfaces	Burn	3			2014	CTEP
39	objects Falling on people	Collision with objects/falling	2			2014	CTEP
40	Getting caught in the equipment at work	Ankle twist	2			2014	CTEP
41	Working with equipment at height	Broken hand and foot	4			2014	CTEP
42	Working with equipment	Hand-cut	2			2014	FPS CAMP
43	Working with equipment	Hit in the face	1			2014	F7 WELL SITE
44	Working with equipment at height	Falling	3			2015	CTEP
45	Working with equipment	Collision	1			2015	KUSHK MANIFOLD
46	Trench visit	Falling	1			2015	S15 WELL SITE
47	Transportation	Vehicle deviation and overturn	1	1		2015	AR1

In Table 1 and Figure 4, the frequency analysis of the occupational accidents based on the location of occurrence shows that about 32% of these accidents occurred around the oil wells. Also, 30% of the occupational accidents happened at the main operating and processing site of the Yadavaran oil field, known as the CTEP. These two areas account for more than 60% of the accidents. Also, about 11% of accidents occurred due to transportation at on-site operating routes, which could be reduced to an acceptable level with further safety measures. Nevertheless, the number of accidents per year is acceptable due to the heavy traffic of construction machinery. Occupational accidents are sometimes associated with environmental pollution.

Depending on the type of accident, environmental damage can be classified along with occupational safety damage. Occupational accidents are sometimes associated with environmental pollution. Depending on the type of accident, environmental damage can be classified together with occupational safety damage. According to the observations made in the study area, when occupational accidents were accompanied by environmental accidents and as a result of environmental pollution, due to emergency activities for the injured, addressing environmental pollutants was not a priority. In some materials, environmental damage has been ignored, and the damage to manpower has generally covered up environmental issues. The frequency of occupational accidents based on the event location is shown in Figure 4. As can be seen, most occupational accidents were at well sites, whereas the traffic accidents accounted for the least number of accidents. The occupational accidents are presented in 12 categories in Table 2. Also, the number of accidents and the frequency percentage of all the accidents have been calculated and presented for the 6-year construction phase of the Yadavaran oil field. Falling and injuries to the hands and fingers were the most frequent accidents. Notably, during this period, an explosion and objects falling on people led to the death of two workers and caused substantial damage to this region in terms of worker health. Moreover, the frequency of occupational accidents by time of occurrence is given in Figure 5, which shows that 2012-2013 had the most incidence of occupational accidents.

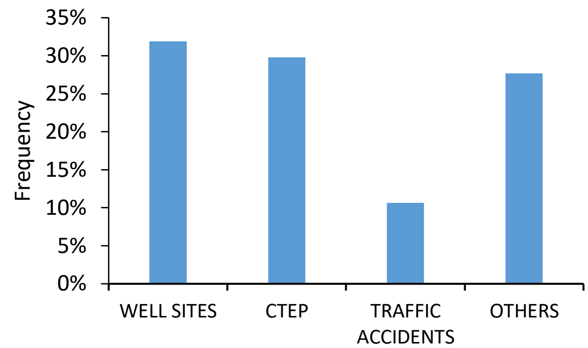

Fig. 4. Frequency of occupational accidents based on the event location.

The occupational accidents are presented in 12 categories in Table 2. Also, the number of accidents and the frequency percentage of all the accidents have been calculated and presented for the 6-year construction phase of the Yadavaran oil field. Falling and injuries to the hands and fingers were the most frequent accidents. Notably, during this period, an explosion and objects falling on people led to the death of two workers and caused substantial damage to this region in terms of worker health. Moreover, the frequency of occupational accidents by time of occurrence is given in Figure 5, which shows that 2012-2013 had the most incidence of occupational accidents.

Table 2. Frequency of occupational accidents by type of accident.

No	Type of accident	Number of occupational accidents	Frequency percentage (%)
1	Falling	10	21
2	Vehicle deviation and overturn	5	11
3	Explosion	1	2
4	Collision with objects	3	6
5	Hand-cut	6	13
6	Foot cut and crush	2	4
7	Ankle sprain	2	4
8	Burn	3	6
9	Hit in the face	1	2
10	Hand/finger crush and injury	11	23
11	Snakebite	1	2
12	objects Falling on people	2	4
	Total	47	100

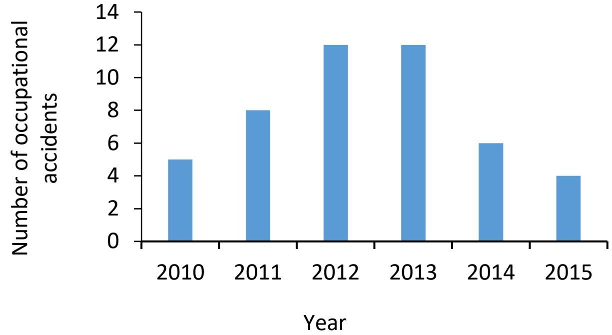

Fig. 5. Frequency of occupational accidents by time of occurrence.

Accidents such as being hit in the face are very random experiences that occur due to personal mistakes. In many accidents that occurred in this oil field in recent years, personal protective equipment has controlled and reduced the injury to employees. Accidents that involve snakebites are common due to the specific climatic conditions and the presence of reptiles. However, the workers have had the required training to deal with snakebites. Also, the warning signs and tutorials installed on the bulletin board and workshop area have had a significant impact on staff awareness. In most of the accidents that occurred in the area, the injured persons were quickly transported to the clinic and received immediate medical treatment, and if required, transferred to the hospital in Ahvaz. One of the flaws in the region's health and environmental safety system that can be seen in all national oil and gas industries is the lack of systematic, intelligent information technology systems. Such systems can speed up monitoring, training, the sharing of experiences, the measures related to different working groups, and following up corrective measures associated with different accidents. This can substantially reduce personal error and also prevent the random inefficiency of the system. In this section, the risk assessment is performed for this specific period based on the information obtained from the operating area and construction phase of the Yadavaran oil field and relying on the FMEA model. The three parameters of risk severity, risk occurrence, and risk detection probability are suggested as the most important factors in the order of their appearance. The risk severity was collected and proposed based on the reports of the health safety unit and the environment and clinic reports in this area. As noted, the greater the risk number, the more severe the injury to the individual. To estimate the risk occurrence parameter, the frequency percentages obtained during the 6-year construction phase were used. Therefore, it can be said that these two parameters are obtained based on real information experienced in the region and the full construction phase of an oil field. In the end, the risk detection parameter was obtained based on interviews with safety experts and victims. Finally, the risk priority number is obtained from multiplying the three above parameters. This is a number between 1 and 1000; the greater it is, the greater the risk. Therefore, it must be considered by authorities and managers to modify and predict preventive measures. According to Table 3, the average risk severity in the 47 accidents experienced in the Yadavaran oil field was 6.2, average accident occurrence was 5.3, average detection probability by people and staff was 6.5, and the average risk priority number was 212.

Table 3. FMEA model of occupational accidents in the construction phase of Yadavaran Oil Field.

Number	Location	Number of occupational accidents	Frequency percentage (%)	S	O	D	RPN
1	Falling	10	21	6	9	6	324
2	Vehicle deviation and	5	11	4	7	3	84
3	Explosion	1	2	9	4	8	288
4	Collision with objects	3	6	6	4	7	168
5	Hand cut	6	13	6	7	6	252
6	Foot cut and crushing	2	4	7	4	6	168
7	Ankle sprain	2	4	5	4	6	120
8	Burn	3	6	7	5	7	245
9	Hit in the face	1	2	4	3	8	96
10	Hand/finger crush and injury	11	23	6	9	7	378
11	Snakebite	1	2	5	4	5	100
12	objects Falling on people	2	4	9	4	9	324
	Total	47	100	6.	5.	6.	212.

In the following, the risk priority number for 12 accidents experienced have been obtained and presented. As known, the bitter experience of hand injuries received the highest value due to the frequency of the accident and considerable damage to those injured in this type of risk. However, falling led to death and caused severe accidents, but due to its lower frequency of occurrence received less risk than hand and finger injuries. Here, to evaluate the corrective measures and their effectiveness on RPN, the measures appropriate for each accident are suggested. As can be expected, with each of these corrective measures, at least one of the risk detection parameters was reduced, leading to a decrease in the final number. The numbers used in this section were obtained based on interviews and investigations of the proposed corrective measures after the occurrence of an accident by a safety group at the Yadavaran oil field. Finally, the results showed how much the efforts of this group reduced the accidents and probability of occupational accidents in the area. Table 4 presents the corrective measures of the risk assessment

model following the proposed parameters. According to the interviews and surveys of experts and specialists, their suggestions for improving the quality and number of personal protective equipment and increasing codified and intelligent training courses related to safety and the environment could improve the severity (S) by one unit and the possibility of risk detection (D) by two units, respectively. The average risk severity was 5.6, the risk occurrence parameter was 5.3, and the risk detection parameter was 4.5. Finally, the first number following the corrective measures was 133.2. According to the new corrective measures, the modified RPN was significantly reduced. Also, the results showed their considerable effect of the RPN on damage to hands, fingers, etc. The results after the corrective measures showed a 37% reduction. The changes were low-cost but continuous and periodic measures. So, the positive effect of the corrections can be seen in this oil field. The RPN fluctuation before and after corrective measures are illustrated in Figure 6, which shows a sharp decrease.

Table 4. Risk assessment of occupational accidents after corrective measures.

Number	Location	Suggested corrective measures	Modified S	O	Modified D	RPN
1	Falling	Training: personal safety equipment improvement	5	9	4	180
2	Vehicle deviation and overturn	Training: traffic sign improvement	4	7	1	28
3	Explosion	Training: periodic visit of explosives storage sites	9	4	6	216
4	Collision with objects	Training	6	4	5	120
5	Hand-cut	Training: personal safety equipment improvement	5	7	4	140
6	Foot cut and crush	Training: personal safety equipment improvement	6	4	4	96
7	Ankle sprain	Training: personal safety equipment improvement	4	4	4	64
8	Burn	Training	7	5	5	175
9	Hit in the face	Personal safety equipment improvement	3	3	6	54
10	Hand/finger injuries and crushing	Training: personal safety equipment improvement	5	9	5	225
11	Snakebite	Training: access to medicines in more sites	4	4	3	48
12	Objects fall on people	Training periodic visit of equipment such as cranes	9	4	7	252
	Total		5.6	5.3	4.5	133.2

Based on the proposed solutions, the RPN decreased significantly. There are other solutions and options to reduce the risks of occupational accidents. For example, in the process units, the probability of risks can be changed by changing the technology of the process, or the involvement of human resources can be reduced by developing automation. However, with the changes in the process and the development of automation, the overall risk does not necessarily decrease, and even new cases of job accidents can occur. Training scenarios and increasing the expertise of human resources in a project are efficient options because they do not change the overall work process of the complex and thus do not create unknown risks (Of course, if changing the process has a direct effect on reducing job risk, they must be carefully evaluated and changes made at the discretion). It should be noted that casualties or deaths in the workplace can be caused by many events and dangers. For example, in the oil region of the study mode, an explosion caused casualties, while with a slight change in the environmental conditions, the causes of the accident and the momentary behavior of people on the scene, the damage could have been different. Therefore, small and secondary factors, in other words, chance, can affect the conversion of an accident with casualties to injuries and vice versa. The major measures envisaged, such as the solutions proposed in this study, also aim to create the minimum conditions for reducing the severity of risk, incidence rate, and risk detection rate.

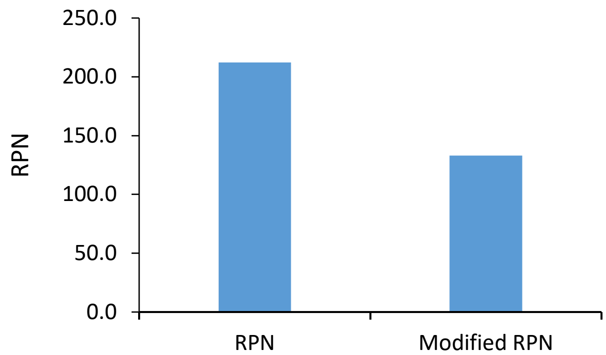

Fig. 6. RPN before and after corrective measures.

4. Conclusions

This study attempted to evaluate the risk of occupational accidents in the petroleum industry during the construction phase in one of the largest oil fields in Iran, namely the Yadavaran Oil Field in Khuzestan Province. The assessments were performed using the FMEA model, which is a well-known method of assessing the risk of occupational accidents. According to visits, interviews, and statistics, 47 occupational accidents were identified in the construction phase of this oil field, and its information was collected. Many occupational accidents cause direct damage to manpower and equipment, as well as to some materials due to the release of environmental pollution, where environmental damage occurs directly or indirectly at the scene of the accident. The type of accident, the type and amount of pollutants, the extent of its occurrence, and the local conditions of the region are of great importance in the severity of environmental damage associated with it. As a result, one of the measures that can prevent this type of environmental damage is to reduce the risk of occupational accidents, and thus, reduce the emission of environmental pollutants caused by their occurrence. Therefore, solutions that can reduce the risk of occupational accidents such as accidents, transportation, the overturning of trucks carrying chemicals, leakage of petroleum products from transmission pipes, and the explosion of fuel tanks can indirectly decrease the emission of environmental pollutants. According to the results, the average risk severity was 6.2 in the 47 accidents experienced in the Yadavaran Oil Field, the average risk occurrence of accidents was 5.3, the average risk detection by individuals and staff was 6.5, and the average risk priority number was 212. Also, based on the type of accidents categorized, several corrective measures were proposed. Overall, it was anticipated that based on these measures, the average risk severity, risk occurrence, and risk detection would be 5.6, 5.3, and 4.5, respectively. Finally, the first number after corrective measures would be 133.2. According to the results, after the corrective measures, the risk reduction would be by 37%. Although the changes were low cost, they are continuous and periodic measures and led to positive effects in this oil field. As discussed in the previous section, training and retraining in occupational accident management increase the employees' mental sensitivity to environmental conditions and the causes of accidents, which ultimately reduces the likelihood of accidents. It also creates better mental conditions for people to behave more appropriately in the moment of an accident, thus reducing the loss of life. The analysis of the classification of the type of accident and the type of damages caused by it based on the location of the incident can be considered as the most important achievement of this study. According to the results, there is a direct relationship between the location of the accident and the type of accident during the construction phase of a project. These results can be generalized for use in the construction phase of other similar oil fields, with more focus on location-related categorized events for risk management and control.

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