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Original Research

Environmental Risk Assessment of a Gas Power Plant Exploitation Unit Using Integrated TOP-EFMEA Method

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Abstract

Our study focuses on environmental risk assessment of a gas power plant in southern Iran. In this research, after investigating the different activities and processes of the power plant, potential harmful factors were initially identified. Afterwards, the identified risk factors were assessed and classified regarding the severity and probability of occurrence, possibility of recycling, and dispersion of pollution into the environment. The EFMEA method was applied to assess the risks. In order to improve the EFMEA technique, the integrated EFMEA and TOPSIS method was used. The method was suggested to remove the uncertainty arising from EFMEA and perform a consistent and logical analysis. Accordingly, using TOPSIS, the weights of the risks were multiplied to a risk priority number (RPN) of environmental aspects. The results obtained from comparing the calculated risk numbers showed that the risk of explosion and gas leakage caused by commissioning the unit with gas-fuel (with RPN equal to 163.014) assigns itself the first priority amongst other risks. The proposed technique has high potential impact on managerial policy within environmental decisions. Considering the application of expert opinion, the suggested TOP-EFMEA method is more flexible than EFMEA.

Keywords: hazard, risk assessment, environment, gas power plant, EFMEA method, TOPSIS method, TOP-EFMEA technique

Introduction

Kerzner knows risk as measuring the amount and probability of failure to achieve predefined goals. In general, he considers "risk" equal to a lack of knowledge of a future event [1]. The failure of large engineering projects can reveal the importance of risk management, especially in activities like defense, construction, and industry due to the serious risks that may be imposed [2]. Managerial strategies such as environmental risk assessment can be properly used as a tool in order to achieve the concept of sustainable development [3]. Owing to the fact that environmental risk assessment, including identification of the affected environment, spatial-time modeling, dispersion and leakage, and assessment of important ecological components are accompanied by considering environmental sensitivities and quantitative risk estimation [4]. Considering the ever-increasing trend of the environmental risks caused by population growth, agriculture and industry, risk analyses require new methods that consider the uncertainty and com-

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plexity of problems in decision making and management policies. In recent years, many researchers have been focused on risk identification, risk analysis, and risk prioritization [5]. Regarding these issues, appropriate selection of environmental risk assessment techniques is considered an undeniable necessity [6]. In this respect, nowadays, hundreds of different methods have been introduced and developed, most of which cannot be able to assess environmental risks alone. They are often supplementary to each other [7].

The theory of the Integrated TOPSIS-EFMEA method is considered a suitable tool for modeling uncertainties in parameters applied for assessing the qualitative situation of environmental systems. The main purpose of the study ahead is the introduction and application of the integrated TOPSIS-EFMEA method in risk assessment of environmental aspects for exploitation unit of the gas power plant in Iran. Different strategies have been raised by Cahyani for risk management through the AHP method [8].

Rashad et al. [9] compared the risk consequences between different systems of energy generation. Finally, they suggested findings as well as emphasizing the role of nuclear energy in the global environment. Amiri et al. [10] carried out research regarding risk assessment in foreign transaction markets. In this study, analyses and prioritization of the risks were performed using integrated eigenvector, data envelopment analysis (DEA) and TOPSIS method. In 2008, Ton and Chia-Jen [11] conducted research titled "a systematic methodology for the creation of Six Sigma projects: A case study of a semiconductor foundry." In this study, by means of analytical hierarchy process (AHP), the benefits of each project were prioritized initially. Besides, FMEA was developed to evaluate the risks of each project. Finally, using two criteria, benefit and risk, the projects were classified as green belt, black belt, or other types of projects. Etiati et al. [12] performed research regarding the capabilities of flexibility, acceptability, maintenance, and support to improve the efficiency of the Afam thermal power plant. They used failure mode and effect analysis (FMEA) and critical analysis to reduce frequencies of failure as well as maintenance and repair costs of the power plant. Another study, "risk evaluation of green components to hazardous substances using FMEA and fuzzy AHP," was conducted by Hu et al. [13]. In a case study about electronic manufacturing in Taiwan, the weight of each index was calculated using fuzzy AHP and then each green RPN compound obtained from the FMEA method was integrated with the relative weight of risk indices. Ultimately, the final RPN for each component was determined [13]. Based on electrical studies and planning of Power Ministry of Iran, in 2001 in order to supply required electrical energy and provide the electricity of the city as well as to prevent voltage drops in southern Iran, four gaseous units in an area of approximately 100 ha with a capacity of 123.4 MW were installed. Considering the four installed units, the nominal capacity of the power plant was converted to 493.6 MW.

Technical specifications of the four 123.4 MW gas units in ISO conditions are as follow:

1) Turbine manufactured by Alstom Gas Turbine Factory in France
2) Model of turbine: Frame 9 E
3) Speed of turbine: 3000 RPM
4) A 140 MVA generator manufactured by Alstom Gas Turbine
5) Model of generator: T 240-370 three-phase generator – indoor cooling system
6) The output voltage of generator: 15 KV
7) Power coefficient: 0.8
8) Main transformer with power of 96/128/160 MVA manufactured by Iran Transformer
9) Conversion ratio of main transformer 230/15 KV
10) Turbine control system: Speed Tronicmark 5
11) Units at the power plant as indoor

In this research, exploitation unit of the power plant was considered a study unit and its environmental hazards were investigated.

Experimental

Tests Carried Out in the Environmental Section of the Exploitation Unit of the Gas Power Plant in Iran

Iran gas power plant consumes gas and gas oil as fuel. Pollutants produced through the stacks of the power plant are dispersed into the air. During this research, a gas analyzer (a Testo 350 XL made in England) equipped with sensors to measure different parameters of air was used, and the tests were performed using the topical method. In addition, suspended particles and other standard parameters of clean air were measured. It is noteworthy that regarding the environmental standard, air pollutants were sampled from a height of 2.3 m of the stacks. The location and type of the pollutants discharged from the exploitation unit presented in Table 1. To analyze the results obtained from assessment of pollutants in the power plant, descriptive statistical indices (min, max, mean, variance, deviation mean) and statistical mean hypothesis testing (one-sample t-test) were used to compare with output standards of stack emissions in industrial centers, as well as the health standard of the community (quality of air) in Iran.

In order to measure environmental noise pollution of Iran gas power plant, a sound level meter device (cell 440 made by Casllacell in England) was applied at four stations alongside IEC651.1979 standard. Noise pollution was assessed using statistical mean hypothesis testing (one-sample t-test) and SPSS15 Software.

To identify solid and hazardous wastes of the power plant, all the understudied units were visited to determine the sources and qualities of the produced solid wastes. Analysis was followed by determining hazardous and non-hazardous wastes based on the "UNEP" list.

Table 1. Sampling stations and the type and rate of pollutants for analysis of outputted pollutant output from stacks of Iran gas power plant.

No.	Station	Type of fuel	μgr/m^3							C^o		%	
			CO_2	NO_x	NO	NO_2	SO_2	CO	H_2S	T-Gas	T-Amb	O_2	C_xH_y
1	unit No. 1	gas	3.44	179.5	179.5	0	6.2	4.5	0	530	40	10.8	538.8
2	unit No. 2	gas	3.48	179.9	176.6	0	4.5	0.0	0	533	39	13.5	549.4
3	unit No. 3	gas	3.51	175.4	175.4	0	4.3	1.7	0	540	38	13.1	514.9
4	unit No. 4	gas	3.36	164.0	164.0	0	4.8	68.0	0	527	39	13.5	414.5
5	unit No. 1	Gas oil	5.2	205.3	205.3	0	16.1	14.4	0	541	21	15.1	0.18
6	unit No. 2	Gas oil	Unit 2 was not in the production line										
7	unit No. 3	Gas oil	5.47	231.6	231.6	0	117.3	0	0	4.27	21	14.5	0.51
8	unit No. 4	Gas oil	5.38	191.3	191.3	0	99.2	0	0	563	23	14.6	0.67

Identification and Analysis of Exploitation Unit Environmental Risks for Iran Gas Power Plant

There are several methods for risk assessment, including Willian Fine, HAZAN, and FMEA, each of which has advantages and disadvantages. Therefore, no method can be confidently confirmed or rejected. How efficient a method is in an industry depends on several factors, such as design, structure, the type of the industrial activity, environmental conditions of the study area, etc. Given the lack of an overall and comprehensive approach to environmental risk assessment, TOP-EFMEA model was presented with the aim of using experts' opinions and experiences through the project. In this way, in order to obtain more accuracy in prioritization of the risks, the authors were able to apply the relative importance of risk-generating activities in each risk score using the TOPSIS method. Thereby, much better results were achieved from the perspective of spending time and costs as well as presenting control measures. Finally, the uncertainty could be reduced more precisely.

The advantages of TOPSIS method in this study are as follows:

1. Usage of some tools for increasing the accuracy and quality of risk prioritization.
2. Achieving more realistic and objective results in risk analysis and ranking.
3. By prioritizing, the possibility of simultaneous evaluation of the risks is provided. It is considered the best advantage of this method compared to other methods applied in risk assessment.
4. In order to increase the selection precision of the final risk among the existing risks specified by the EFMEA method, the TOPSIS multi-attribute decision-making method was applied to prioritize risks. In this way, more efficient results were obtained in terms of cost and effectiveness compared to other methods available for risk response planning.
5. In conditions where evaluators have to choose one risk management solution, the EFMEA model offers the same selection value for various options, while in the proposed model the suitable option could be selected using the TOPSIS method.
6. EFMEA can be "fuzzified" using the TOPSIS method.

EFMEA Method

After initial studies in the case of the considered subject, the activities of Exploitation Unit were identified using field studies.

In the next stage, EFMEA was used for the final identification of the activities and environmental aspects as well as the consequences of each activity.

Table 2. Severity of environmental degradation [14].

Severity	Description of severity	Score
Severe / catastrophic	very harmful or potentially destructive / very high loss or severe consumption of resources	5
Serious	harmful, but not potentially destructive / high loss or consumption of resources	4
Medium	relatively harmful / moderate loss or consumption of resources	3
Low	low potential for harm / low loss or consumption of resources	2
Slight	harm is slight and can be negligible / slight loss or consumption of resources	1

Subsequently, by providing a standardized questionnaire and interviewing personnel as well as direct observation of the location, risk-generating activities and resources were detected.

Afterward, the RPN rate for environmental aspects and consequences of each activity (including pollution dispersion, recycling possibility, occurrence probability and occurrence severity) were calculated using the following equation and tables.

$$\text{Environmental degradation coefficient} = \text{dispersion of pollution} \times \text{severity} \times \text{probability of occurrence} \quad (1)$$

Severity: the rate of importance and seriousness of an environmental consequence caused by the aspect and rate of degradation. Table 2 is related to the severity of environmental degradation.

Probability of occurrence, refers to frequency of outbreak of environmental aspects and consequences resulting from its occurrence. Table 3 shows the probability of environmental consequences.

Dispersion of pollution refers to the spread of pollutants. Table 4 is related to the dispersion of pollution.

$$\text{Environmental degradation coefficient} = \text{severity} \times \text{probability of occurrence} \times \text{possibility of recycling} \quad (2)$$

Possibility of recycling refers to the recycling possibility of the materials or consumed energy resources. Table 5 is related to the possibility of recycling.

After assessment of the environmental aspects, Table 6 was used to classify the significant aspects and perform necessary control measures.

TOPSIS Method

Reasons for choosing TOPSIS over other methods of multiple criteria decision making can be summarized as follows:

1. Unlike AHP, in which criteria are compared in pairs, in TOPSIS the criteria are evaluated individually.
2. The most important advantage of TOPSIS compared to other methods of multi-criteria decision-making is that the selected option (criterion) has the least distance from the positive ideal solution (the best possible state) and the furthest distance from the negative ideal solution (the worst possible case).
3. The advantage of TOPSIS compared with ELECTRE is that TOPSIS leads to ranking and prioritizing the options. ELECTRE does not necessarily lead to ranking the options and may even eliminate some of them, while we needed a method that prioritizes the options (criteria).
4. TOPSIS in comparison with SAW is more accurate and advanced. TOPSIS is selected for the least distance from the positive ideal solution (the best possible state), while SAW, using sum-weighted dimensionless values (n_{ij}, w_j), is higher than the other options. Regarding the exact identification and prioritization of risks in the industry, it provides the possibility of planning and designing an appropriate program for risk response and has an important effect on industry success. In this paper, a new approach was presented to assess and rank possible risks in the exploitation unit of a gas power plant located in southern Iran.

Table 3. Occurrence probability of environmental consequences [14].

Probability of occurrence	Score
Very high and inevitable occurrence (it can possibly happen every day)	5
Common occurrence (it can possibly happen during a week)	4
Possible and moderate occurrence (it can possibly happen during a month)	3
Trace occurrence (it can possibly happen once a year)	2
Impossible and unlikely occurrence (it can possibly happen once every 10 years)	1

Table 4. Dispersion of pollution [14].

Range of pollution	Score
At regional level	5
At project level	4
At workshop level	3
At unit level	2
At workstation level	1

Table 5. Possibility of recycling [14].

Possibility of recycling	Score
Consumption of non-recyclable resources	5
Waste of non-recyclable resources	4
Waste of resources having hard recyclability and improvement	3
Waste of resources having easy recyclability and improvement	2
Consumption of recyclable resources	1

As has already been mentioned, the relative importance of each activity was obtained using TOPSIS [15]. The TOPSIS standardized questionnaire was completed by personnel of the exploitation unit. Then TOPSIS questionnaires were quantified using a bipolar distance scale and finally the decision matrix was formed. Afterward, the six-fold stages of TOPSIS were performed to determine the weight of each activity as follows:

Table 6. Ranking of risk level [14].

Consequence level	Coefficient of degradation	Description of performance and control operations
The aspect is not significant	1-25	Low
Situation is not suitable and needs revision in the next priority	50-26	Medium
The aspect is significant and should be improved as the first priority	125-51	High

1) Calculating the normalized decision matrix: The normalized value r_{ij} is calculated as follows (Eq. 3):

$$\mathrm{r_{ij}} = \frac{\mathrm{r_{ij}}}{\left(\sum_{i=1}^{m} \mathrm{r_{ij}^2}\right)^{\frac{1}{2}}} \quad , \quad (\mathrm{j}=1,\dots,\mathrm{n}) \tag{3}$$

2) Calculating the weighted normalized decision matrix. The weighted normalized value V is calculated as below (Eq. 4):

$$\mathrm{V} = \mathrm{N_D} * \mathrm{W_{n*n}} \tag{4}$$

...where V is the weighted normalized matrix and W is a diameter matrix of the obtained weights for criteria. In this research, values for W were calculated by Entropy Technique [16-18].

Calculation of the second step of TOPSIS method requires computing weights (W). For this purpose, several methods are available, including a) Eigenvector b) Entropy c) Weighted Least Squares d) LINMAP and so on. Each of the noted methods has some constraints.

In this study, the Shannon Entropy Method was used for the two following reasons:

1. Calculation of the weight (W) based on the decision matrix:

Unlike the other methods, in Shannon Entropy Method, calculating the weight (W) of the indices is done based on the decision matrix.

2. Having the condition of ∑W=1:

In the current study, the Shannon Entropy Method was applied to be equal to 1 the sum of the weights.

To obtain the weights of the criteria by Entropy technique the following steps were followed [16].

Step 1: calculation of P_{ij} (Eq. 5):

$$P_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \quad ; \forall_{i,j} \tag{5}$$

Step 2: calculation of Entropy value E_j (Eq. 6):

$$E_j = -k \sum_{i=1}^{m} \left[p_{ij} \ln p_{ij} \right] \quad ; \quad \forall_j \tag{6}$$

Step 3: calculation of uncertainty value d_j (Eq. 7):

$$d_j = 1 - E_j \quad ; \quad \forall_j \tag{7}$$

Step 4: calculation of W_j weights (Eq. 8):

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad ; \quad \forall_j \tag{8}$$

3) Determination of the positive-ideal and negative-ideal solutions (Eqs. 9, 10):

Positive ideal solution =

$$A^+ = \left\{ (\max_i V_{ij} \,\middle|\, j \in J_1), \min_i V_{ij} \,\middle|\, j \in J_2 | i = 1,2,\dots,n \right\} \tag{9}$$

Negative ideal solution =

$$A^- = \left\{ (\min_i V_{ij} \,\middle|\, j \in J_1), \max_i V_{ij} \,\middle|\, j \in J_2 | i = 1,2,\dots,m \right\} \tag{10}$$

4) Calculation of separation measures using the n-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given as (Eq. 11):

$$d_i^+ = \left\{ \sum_{j=1}^{n} \left(V_{ij} - V_j^+ \right)^2 \right\}^{\frac{1}{2}} \quad (i=1,2,\dots,\mathrm{m}) \tag{11}$$

Similarly, the separation from the negative ideal solution is given as (Eq. 12):

$$d_i^- = \left\{ \sum_{j=1}^{n} \left(V_{ij} - V_j^- \right)^2 \right\}^{\frac{1}{2}} \quad (i=1,2,\dots,\mathrm{m}) \tag{12}$$

5) Relative closeness of the alternative C_i to ideal solution was calculated in the following way (Eq. 13):

$$C_i = \frac{d_i^-}{(d_i^- + d_i^+)} \quad (i=1,2,\dots,\mathrm{m}) \tag{13}$$

6) in this step, the alternatives were ranked and on basis of descending order of C_i the existing alternatives can be ranked by the most important degree [19-23].

TOP-EFMEA Proposed Method

According to the following formula, by integrating each activity weight with RPN of each aspects of the considered activity as well as their summary, the final RPN of risks and environmental aspects of the exploitation unit were calculated for representing the risk control strategies (Eq. 14).

$$RPN_{overall} = \sum_{i=1}^{n} w_i \times RPN_I \tag{14}$$

Where w_i is the weight of each activity and RPN_I is the risk priority number for each environmental aspect.

The proposed EFMEA-TOPSIS approach is a suitable and flexible way for environmental risk assessment.

Multi-criteria decision-making theory provides a framework for modeling complex systems. Using this method can overcome uncertainty and improved understanding of complex systems. Compared with EFMEA, in the proposed EFMEA and TOPSIS method the equal RPNs are replaced by different RPNs making management easier.

Result and Discussion

The Results of the Tests Performed in the Environmental Section of Gas Power Plant Exploitation Unit of Iran

Considering the results obtained from descriptive statistics and statistical mean hypothesis testing (One-sample t-test), the findings were compared with the standard offered by the Department of Environmental Protection of Iran, revealing that CO_2 mean is equal to 4.26 μgr/m^3. Its maximum and minimum values are 5.47 and 3.36, related to the stack of unit 4 with fuel of gas and the stack of unit 1 with fuel of gas oil in an operational state.

Carbon monoxide (CO): based on the assessment results, the mean of CO equals 2.65 μgr/m^3. The maximum and minimum values are 68 and 0 μgr/m^3, respectively related to the stack of unit 4 with fuel of gas and the stack of unit 4 with fuel of gas oil in operational states. The mean rate of monoxide carbon rising from output units 3, 2, 1, and 4 of the power plant is less than the standard value.

Nitrogen monoxide (NO): the findings of the tests show a mean of 189.1 μgr/m^3. The maximum and minimum values are 231 and 164 μgr/m^3 related to the exhaust stack of unit 4 with fuel of gas and the stack of unit 3 with fuel of gas oil.

Nitrogen oxides (NO_x): the mean of nitrogen oxides is 189.571 μg/m^3. The maximum and minimum values are 231 and 64 μgr/m^3, respectively, related to the exhaust stack of unit 4 with fuel of gas and stack of unit 3 with fuel of gas oil. The mean of Nitrogen oxides output from units 3, 2, 1, and 4 of the power plant is less than the standard value (test value).

Sulphur dioxide (SO_2): the obtained results showed that the average of SO_2 is equal to 48.983 μgr/m^3. Its minimum and maximum values are respectively equal to 4.30 μgr/m^3 and 117.30 μgr/m^3 related to unit No. 3 in two states; gas and gas oil fuels.

C_xH_y: the results showed a mean equal to 288.422%. The maximum and minimum values are 549.40% and 0.18%, respectively, related to the stack of unit No. 1 with fuel of gas oil and the stack of unit No. 2 with fuel of gas under production state. Total average of the output air temperature (T-gas) from the stack of unit No. 4 is 523ºC. Also, the maximum and minimum values are 427ºC and 563ºC (respectively related to units 3 and 4 with fuel of gas oil). It is noteworthy that the average of oxygen (O_2) is 13.585%. The minimum and maximum values are 10.8% and 15.10%, respectively. The maximum value belongs to unit No.1 with fuel of gas oil and the minimum value is related to unit 1 with fuel of gas.

NO_2 *and* H_2S: Total mean of NO_2 and H_2S is zero. The rates of NO_2 and H_2S are zero in all cases. Table (7) shows descriptive statistics of atmospheric pollutants in different stations of the Iranian gas power plant.

Table 8 shows comparison of the power plant pollutant with standard of pollutant CO.

Sound assessment results of the Iranian gas power plant environment at four stations and their comparison with noise pollution standards for industrial environments in Iran, which is equal to 75 dB, showed that it is a less than permissible range (criteria) in all the stations.

Data analysis on solid waste produced in the power stations reveals that ten out of twelve types of the applied materials were recognized as safe (hazardless), while two of them were found to be as hazardous. The dangerous of these materials was defined based on the UNEP or RCRA lists and/or one of the four specifications: toxicity, flammability, corrosion, and sever affinity.

Results of Analysis Using EFMEA

In order to risk assessment of the power plant exploitation unit, identification, analysis, and classification of the risks were carried out using EFMEA and TOPSIS. This study was carried out in order to reduce environmental hazards and also to keep pace with updated management systems. All activities and processes in the mentioned unit were investigated using the applied method. By using this method, all the hazards can be compared with each other. Therefore, using the results obtained from the risk assessment tables, the authorities will be able to identify strengths and weaknesses of the mentioned unit, follow their causes, and resolve and mitigate risk.

Table 9 gives a sample of the analysis results obtained using EFMEA that shows a ranking of hazards with high risk levels.

Weighing Activities Using TOPSIS

The relative importance of each activity was determined using TOPSIS. The TOPSIS standardized questionnaires were given to power plant personnel at. Then, TOPSIS ques-

Table 7. Descriptive statistics of atmospheric pollutants in different stations of the Iranian gas power plant.

Parameter	N	Minimum	Maximum	Mean	Standard Error of Mean	Standard Deviation
CO_2	7	3.36	5.47	4.262	0.385	1.21
NO_x	7	164	231.6	189.571	8.544	22.607
NO	7	164	231.6	189.1	8.64	22.87
SO_2	7	4.30	117.3	48.943	20.821	55.089
CO	7	0	68	12.657	9.427	24.943
T-Gas	7	427	563	523	16.614	43.958
T-Amb	7	21	40	31.571	3.517	9.306
O_2	7	10.8	15.1	13.585	0.538	1.424
C_xH_y	7	0.18	549.4	288.422	103.137	272.875

Table 8. Comparison of the power plant pollutant with standard of pollutant CO.

Variable	Test Value=350					
	t	df	sig	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
CO	-14.568	6	0	-137.34	-160.411	-114.27

df – degrees of freedom, sig – significance level

tionnaires were converted from qualitative to quantitative form using bipolar distance-scale, and finally the decision matrix was formed. Afterward, the six stages of TOPSIS were performed to determine the weight of each activity. Weighing results are shown in Table 10.

Results of Risk Analyzing and Ranking Performed Using Integrated EFMEA and TOPSIS

Table 11 illustrates the results of risk analysis and ranking carried out using integrated EFMEA and TOPSIS methods.

When the system is set up, the turbine is activated and input air is compressed. The compressed air flows from the compressor into the annular space of combustion chamber and while passing the line is mixed with fuel. Then an explosion occurs. Combustion of burning materials leads to an increase in temperature. By increasing the temperature, air volume also is raised. Thus, high-volume hot air with certain pressure is exhausted from the combustion chamber and conducted toward the turbine blades.

After being exhausted from the turbine, gases are released toward the output stack and then discharged from the outlet. Spin axis evolution at the end is applied to rotate

Table 9. Ranking of hazards with high risk level.

	Activity	Aspect	Consequence	Severity	Occurrence of probability	Pollution dispersion or the possibility of recycling	RPN	Risk level (consequence)
1	Gas fuel filter replacement	Gas venting	Waste of resources	5	3	4	60	High
2	Testing and commissioning diesels	Noise resulting from operation of diesels	Noise pollution	5	3	4	60	High
		Smoke omitted from operation of diesel	Air pollution	5	3	4	60	High
3	Commissioning the unit to produce electricity	Out pollutants from the exhaust	Air pollution	5	5	4	100	High
4	Commissioning unit with gas fuel	Gas leakage	Waste of resources	5	3	4	60	High

Table 10. Results obtained from weighing activities using TOPSIS.

Unit	Criteria	Relative approximate to the ideal solution (Cl+)*	Weight (W)	Rank
Exploitation	Commissioning the unit with gas fuel	0.807	0.049	1
	Commissioning the unit to produce electricity	0.802	0.050	2
	Fuel tanks	0.798	0.047	3
	Delivery of gas fuel (gas station)	0.630	0.050	4
	Changing the gas fuel filter	0.530	0.052	5
	Lighting the transformers	0.519	0.050	6
	Cooling down unit	0.450	0.055	7
	Fuel change of the unit from gas to gas oil (fuel change)	0.380	0.051	8
	Commissioning the unit with liquid fuel	0.356	0.051	9
	Commissioning and testing the equipment of the liquid fuel system	0.349	0.048	10
	Commissioning and testing cooling system equipment	0.345	0.045	11
	Commissioning and testing lubrication system equipment	0.343	0.048	12
	Being dual fuel (Mix)	0.339	0.047	13
	Testing and commissioning diesels	0.317	0.050	14
	Transfer of gas oil to the unit and tanks	0.227	0.050	15
	Delivery of liquid fuel (fuel discharge)	0.185	0.051	16
	Bleeding the gas oil filters	0.098	0.045	17

* The relative closeness to the ideal solution

the generator rotor as well as generate electric power. Unit commissioning with gas is followed by leakage and explosion risk, whose consequence is the contamination of water, air, and soil as well as a waste of resources. Thus, as can be seen in Table 11, unit commissioning with gas fuel scored 163.014 and is placed in the first priority. Also, commissioning the unit to produce electricity and fuel tanks with scores of 133.96 and 97.356 after commissioning the gas unit has the highest levels of risk, respectively. While the traditional EFMEA is simultaneously assigned high priority (RPN equal to 60) to activities like changing the gas fuel filter, testing, and commissioning diesels and commissioning the unit with gas fuel.

Conclusions

The current study was carried out with the aim of analyzing the environmental risks of a gas power plant located in southern Iran using the proposed TOPSIS-EFMEA method. Since precise identification and prioritization of risks provides the possibility of planning a suitable program for responding to the identified risks, this paper, presents a new approach to measure and rank the risks that may be imminent at the exploitation unit. The integrated method of TOPSIS and EFMEA (TOP-EFMEA) is a suitable tool for modeling uncertainty of parameters applied to assess the qualitative situation of the environmental systems. The proposed integrated method uses the expert knowledge. Therefore, it doesn't have any restrictions regarding the availability of a strong expert team.

In general, the integrated TOPSIS-EFMEA method has the following advantages compared with EFMEA.

In this model, the assessment of the environmental risks and their prioritization is obtained by the expert's knowledge, experience, and opinion. This method can be found on the nature of the current activities (interference of relative importance of existing activities). EFMEA can be "fuzzified" using integrated TOPSIS-EFMEA.

In comparison with EFMEA, the integrated method used in the current study doesn't have the mentioned problems that can result from using TOPSIS. Sharma in his article points out that in EFMEA, RPN has the same diagnosis for different numbers of severity and probability [24]. Tay also notes that each of the input factors have equal importance in this method, while it is not true in reality [25]. Sachdeva, in order to resolve the objection against EFMEA, applied TOPSIS to calculate the weight of the risk indices of a paper factory located in India [26].

In this study in order to overcome existing problems as well as arrive at a qualitative manner of risk assessment like very high, high, medium, low, and so on, [27] the calculation theory of the relative importance of each activity was considered to prioritize the risks. Alongside, the weight of

Table 11. Results of risk analysis and ranking using integrated EFMEA and TOPSIS.

No.	Activity	Aspect	Consequence	W*RPN	$RPN_{overall} = \sum_{i=1}^{n} w_i \times RPN_I$
1	Commissioning unit with gas fuel	Explosion	Soil pollution	40.35	163.014
			Air pollution	25.824	
			Water pollution	19.368	
		Gas leakage	Waste of resources	48.42	
			Soil pollution	29.025	
2	Commissioning of unit to produce electricity	Pollutants exit from the exhaust	Air pollution	58.5	133.96
		Hot air exited from exhaust	Thermal energy loss	26.325	
		Noise due to operation of turbo generator machines	Noise pollution	17.55	
		Oil spill	Waste of resources	21.06	
			Soil pollution	10.53	
3	Fuel tanks	Fire and explosion	Soil pollution	31.92	97.356
			Air pollution	39.9	
			Water pollution	25.536	
4	Testing and commissioning of diesels	Gasoline spill	Waste of resources	15.216	69.423
			Soil pollution	11.412	
		Noise resulting from operation of diesel	Noise pollution	19.02	
		Smoke resulting from operation of diesel	Air pollution	23.775	
5	Delivery of gas fuel (gas station)	Gas leakage	Waste of resources	31.5	63
			Air pollution	31.5	
6	Changing the gas fuel filter	Gas venting	Waste of resources	32.22	51.552
			Air pollution	19.332	
7	Commissioning and testing equipment of liquid fuel system	Gasoline spill	Waste of resources	16.752	29.316
			Soil pollution	12.564	
8	Lighting of transformers	Oil spill	Waste of resources	18.684	28.026
			Soil pollution	9.342	
9	Cooling down unit	Oil spill	Waste of resources	16.2	24.3
			Soil pollution	8.1	
10	Fuel change of unit from gas to gas oil (fuel Change)	Gasoline spill	Waste of resources	10.26	17.1
			Soil pollution	6.84	
11	Commissioning the unit with liquid fuel	Gasoline spill	Waste of resources	6.408	16.02
			Soil pollution	9.612	
12	Commissioning and testing lubrication system equipment	Oil spill	Waste of resources	6.174	15.552
			Soil pollution	12.348	
13	Dual fuel-making units	Gasoline spill	Waste of resources	9.153	15.255
			Soil pollution	6.102	
14	Delivery of liquid fuel (fuel discharge)	Gasoline overflowing and outflow	Waste of resources	8.92	10.36
			Soil pollution	4.44	
15	Transfer of gas oil fuel to the unit and tanks	Gasoline spill	Waste of resources	3.324	4.432
			Soil pollution	1.108	
16	Bleeding the gas oil fuel filters	Gas oil draining	Waste of resources	0.588	4.116
			Soil pollution	3.528	
17	Commissioning and testing cooling system equipment	Leakage of kumazor	Soil pollution	1.035	1.035

risk factor indices was calculated using integrated entropy and TOPSIS. TOPSIS calculations are an appropriate tool for modeling and measuring these activities (risks). Application of TOPSIS calculations in ranking the risks has the following advantages:

- Employing the specialists' mental inferences in model directly
- Compatibility of the weights assigned to the objective criteria in the final decisions
- Achieving more objective and realistic results in analyzing and ranking the risks.

Therefore, the calculated risks of the gas power plant using TOP-EFMEA method as well as examination of Table 11 indicate that the activities including "commissioning the unit with gas fuel", "commissioning the unit to produce electricity" and "fuel tanks" with scores of 163.014, 133.96, and 97.356 have the highest risks among the risks of the exploitation unit while "testing and commissioning the cooling system equipment" has the lowest risk score equal to 1.035. Regarding adverse impacts like pollution (especially air pollution), the forenamed risks were determined to be the most important factors generating risk in the power plant. Also, Athanasios knows non-radioactive outputs resulting from fuel combustion (unit commissioning with non-radioactive fuel) of power plants causing harm to human health and ecosystems [26]. The EPA considers the main pollutants produced in gas power plants as a result of fuel combustion (commissioning units with gas fuel) as well as fuel storage and transmission [28]. Besides, dangerous situations in Abadan gas power plant exploitation unit include the phases of production, transmission, and maintenance of fuel. Stefan introduces the fuel production and maintenance as the main cases of high-risks [29].

After identifying, quantifying, and prioritizing the risks by using the proposed method, the most important objectives of the management plans were specified to deal with the main risks of the gas power plant at the exploitation unit. The program covers risk elimination, risk reduction, risk transfer, and risk acceptance [30].

References

1. KERZNER H. Project management a systems approach to planning scheduling and controlling. John Will & Sons, New Jersey, **2003**.
2. LEE E., PARK Y., SHIN J. Large engineering projected risk management using a Bayesian belief network, Expert Syst. Appl., **36**, 5880, **2008**.
3. HARRALD R. H., SHAW G. L., RUBIN C. B., YELETAYSI S. Review of risk based priorization/decision making methodologies for dams, the Georg Washington University Institute for Crisis Disaster and Risk Management, 1776 gs4 nw suite110,Washington DC, USA, **2006**.
4. TORMS A. Environmental risk analysis, Norway, **2004**.
5. DATTA S., MUKERJEE S.K. Developing a Risk Management Matrix for Effective Project Planning – An Empirical Study, Project Manag. J., **32**, 45, **2000**.
6. AZADEH A., MOHAMMAD FAM I., GARAKANI M. M. A Total Ergonomic Design Approach to Enhance the Productivity in a Complicated Control System, Inf. Technol. J., **6**, 1036, **2007**.
7. AZADEH A., NOURI J., MOHAMMAD FAM I. he Impacts of Macroergonomics on Environmental Protection and Human Performance in Power Plants, Iran. J. Environ. Health Sci. Eng., **2**, 60, **2005**.
8. CAHYANI S. Risk Management Strategy of Power Generation of PT -Indonesia Power. ISAHP, **7**, 7, **2003**.
9. RASHAD S. M., HAMMAD F. H. Nuclear Power and the Environment: Comparative Assessment of Environment and Health Impact of Electricity-Generating Systems, Appl. Energ., **65**, 211, **2000**.
10. AMIRI M., ZANDIEH M., VAHDANI B., SOLTANI R., ROSHANAEI V. An integrated eigenvector-DEA-TOPSIS methodology for portfolio risk evaluation in the FOREX spot market, Expert Syst. Appl., **37**, 509, **2010**.
11. TON, S., CHIA-JEN CH. A systematic methodology for the creation of Six Sigma projects. A case study of semiconductor foundry, Expert Syst. Appl., **34**, 2693, **2008**.
12. ETIATI M. C., OGAJI S. O. T., PROBERT S. D. Integrating reliability, availability, maintainability and supportability with risk analysis for improved operation of the Afam thermal power-station, Appl. Energ., **84**, 202, **2007**.
13. HU, A. H., HSU CH. W., KUO T. CH., WU W. CH. Risk evaluation of green components to hazardous substance using FMEA and FAHP, Expert Syst. Appl., **36**, 7142, **2009**.
14. DANIELSSON M., GUNNARSSON S. A. Guideline for Implementation of Environment Failure Mode and Effect Analysis Method. Marmarit Publish. Sofia, Bulgaria. pp. 127, **2001**.
15. HWANG C. L., YOON K. S. Multiple Attribute Decision-Making: Methods and Applications, Springer, New York, **1981**.
16. CHANG HUNG C., HSUAN CHEN L. A Fuzzy TOPSIS Decision Making Model with Entropy Weight under Intuitionistic Fuzzy Environment. In: Proceedings of the International MultiConference of Engineers and Computer Scientists, I IMECS, March 18-20, Hong Kong, **2009**.
17. SACHDEVA A., KUMAR D., KUMAR P. Multi-factor failure mode critically analysis using TOPSIS, J. Ind. Eng. Int., **5**, 1, **2009**.
18. SRDJEVIC B., MEDEIROS Y., FARIA A. An Objective Multi-Criteria Evaluation of Water Management Scenarios. Water Resour. Manag., **18**, 35, **2004**.
19. DAG˘DEVIREN M., YAVUZ S., KILINÇ N. Weapon selection using the AHP and TOPSIS methods under fuzzy environment, Expert Syst. Appl., **36**, 8143, **2009**.
20. DODANGEH J., YUSUFF R., JASSBI J. Using Topsis Method with Goal Programming for Best selection of Strategic Plans in BSC Model, J. Amer. Sci., **6**, 136, **2010**.
21. MAHMOODZADEH S., SHAHRABI J., PARIAZAR M., ZAERI M. S. Project Selection by Using Fuzzy AHP and TOPSIS Technique, Int. J. Hum. Soc. Sci., **1**, 333, **2007**.
22. OPRICOVIC S., HSHIUNG TZENG G. Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS, Eur. J. Oper. Res., **156**, 445, **2004**.
23. ONUT S., SONER S. Transshipment site selection using the AHP and TOPSIS approaches under fuzzy environment, Waste Manage., **28**, 552, **2008**.
24. SHARMA R. K., KUMAR D., KUMAR P. Systematic failure mode effect analysis (FMEA) using fuzzy linguistic modeling, Int. J. Qual. Reliab. Manage., **22**, 986, **2005**.

25. TAY, K. M., LIM C. P. Fuzzy FMEA with a guided rules reduction system for prioritization offailures. Int. J. Qual. Reliab. Manage., **23**, 1047, **2006**.
26. ATHANASIOS I., PILAVACHI P. Objective and subjective evaluation of power plants and their non-radioactive emissions using the analytic hierarchy process, Energ. Policy, **35**, 4027, **2007**.
27. EPA. Profile of the Fossil Fuel Electric Power Generation Industry, EPA Office of Compliance Sector Notebook Project., Office of ComplianceOffice of Enforcement and Compliance Assurance U.S. Environmental Protection Agency401 M St., SW (MC 2223-A) Washington, DC 20460, **1997**.
28. XU K., TANG L. C. Fuzzy Assessment of FMEA for Engine Systems. Reliab. Eng. Syst. Safe., **75**, 17, **2002**.
29. HIRSCHBERG S., BURGHERR P., SPIEKERMAN G., DONES R. Severe accidents in the energy sector: comparative perspective, J. Hazard. Mater., **111**, 57, **2004**.
30. AZADEH A., MOHAMMAD FAM I. Integrated M HSEE Management Systems For Industry: A Case Study In Gas Refinary, J. Chin. Inst. Eng., **32**, 670, **2009**.