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RESEARCH PAPER

Emission Risk Assessment of Toxic Gases of Floating Roof Storage Tanks

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Abstract
Events such as the emission of toxic gases are possible on floating roof storage tanks. Since gasoline is a high-consumption and volatile product stored in adjacent oil depots or large cities, it is necessary to assess their emission risk. Given that the multi-criteria methods allow the identification of and assessment of the indicators well and allow the participation of expert experts, so the FAHP method has been used to identify and assess the risk before the emission of toxic gases. The results showed the importance of 7 factors among 36 factors, 3 of which were related to equipment error. The DOW'S CEI method was used to assess the emission risk if the event occurred. This method provides safe boundaries based on Emergency Response Planning Guidelines (ERPGs), where the results indicate the settlement placement around the oil repository in the range of the predicted concentration at all three levels of ERPG.

Keywords: Floating roof tanks, risk assessment, FAHP, DOW'S CEI, Chemical exposure

INTRODUCTION

Storage tanks for petroleum products are among the most important and basic infrastructures in the oil industry that store large volumes of harmful and toxic substances (Guo et al., 2020). Accidents in oil repositories will have destructive effects (Kang et al., 2014). Oil and its products have a position due to high consumption (Karbasi et al., 2009). In 2019, the largest share of total energy supply in the world was related to oil with 30.9 percent, although this amount has decreased compared to 1973, including 46.2 percent share of oil in energy supply, but still has the largest share in energy supply in the world (energy Agency, 2021).

Atmospheric storage tanks are chosen according to the flash-point of the liquid. These tanks include two main types of a fixed roof and a floating roof. Floating roof tanks are also divided into external and internal tanks. They are used to store large amounts of highly volatile products such as crude oil or gasoline exposed to catastrophic events. The roof floats on the surface of the stored liquid and can float up or down depending on the liquid level in the tank. This type of reservoir eliminates oxygen and greatly reduces evaporation (Pouyakian et al., 2021). There is a gas emission risk from floating roofs tanks (Bouafia et al., 2020; Chang & Lin, 2006). Gases emitted into the atmosphere cause environmental pollution and even serious harm to humans (Gai et al., 2018; Huang et al., 2020; Wang et al., 2020). Gases contain compounds such as volatile organic compounds (VOCs), ozone, methane, dioxide, etc., which are toxic and dangerous

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substances for human health; regular exposure to these toxins, even at low concentrations, can affect worker health (Alhamdani et al., 2018). Air pollution is a major challenge in the oil industry (Karbasi et al., 2018).

Risk assessment plays an important role in preventing and reducing adverse risks in the chemical industry (Guan et al., 2022; Xin et al., 2016) The word risk is the cornerstone of decision making and means the possibility of an unfortunate event occurring in the severity of the risk (consequences of the event) (Shahriar et al., 2012). The risk assessment approach involves identifying risk-taking events and risks, derived from the magnitude of the effects of risk and estimating the probability of events (Topuz et al., 2011). Significant risks have to be controlled and minimized (Bouafia et al., 2020).

The application of reliable methods for potential risk analysis is critical for a flexible system and will effectively develop failure prevention and mitigation programs (Chen et al., 2020; Papadopoulou & Antoniou, 2014). A structured approach to risk identification reduces the chances of a risk being overlooked (Marhavilas et al., 2020). In the risk assessment and management process, it is necessary to prioritize the identified risks based on specific criteria. The reason for this is the high frequency of identified risks, their degree of importance and criticality, and especially the limited resources needed to control them (Yu et al., 2012).

The analytic hierarchy process is one of the multi-criteria methods with various applications (Saaty, 1988). This method is an efficient method to estimate the importance level of risks in risk assessment studies (Kokangül et al., 2017). In the current literature, AHP is the most common method used to determine the weight of indicators. This method, developed by Saaty, breaks down a decision problem into a system of hierarchical elements. Compare the importance of each element with a nominal scale. Then, a comparison matrix is created using quantitative comparison, and then the specific vector of the matrix is obtained to show the comparison weight between the elements of a given grading. Finally, the compatibility of the matrix is evaluated (Chen et al., 2020). AHP is a flexible and easily understood method for complex analysis of challenges and issues that allows objective and subjective factors to be considered in the goal and enables active participation (Dey, 2012).

Nowadays, it is valuable to combine different tools in risk management. After identifying and prioritizing the hazards leading to the emission of toxic gases, the adverse event assessment creates an effective complementary method, and an integrated system is formed. The Dow Chemical Exposure Index (CEI) examines the impact of health hazards on individuals due to exposure to toxic substances from possible events of chemical emission (AIChE, 1998).

Numerous studies have been conducted for emission risk assessment of chemical gases from storage tanks. Cheraghi et al. (2021) using the CEI and PHAST methods, determined the distance of the risk of emission of toxic chemicals from a gas refinery; based on both models, the most dangerous unit identified was the same. Zinke et al. (2020) have evaluated the quantitative emission risk of internal floating roof tanks using the Bayesian network method. In this study, events leading to critical increase or emission of volatile organic compounds from floating roof tanks containing naphtha and gasoline have been investigated. Kang et al. (2014) have done the risk zone of oil repositories by classifying hazards into two groups of inherent hazards and controllable hazards. In this study, the methods of error tree analysis, hierarchical analysis, and risk matrix have been used. Shi et al. (2014) have evaluated the occurrence of fire accidents and explosions of oil storage tanks using the error tree method and the hierarchical analysis method and evaluated the fuzzy set theory. Argyropoulos et al. (2012) by taking advantage of the checklist, techniques have tried to identify the causes of accidents in liquid hydrocarbon fuel storage tanks. Topuz et al. (2011) also have evaluated the environmental risk and human health in industries that use hazardous substances using three categories of factors. In this research, AHP and fuzzy logic have been used to rank risk sources.

In some studies, determining the importance levels of hazards has been studied by various methods, including AHP, but the classification of hazards has not been done in the AHP method. In this study, for the first time, the capability of this method in risk classification has been used in a new way. Since the sum of rankings is one, the importance of each cause was calculated in equal importance and is the basis for ranking. So, this method has been used to determine risk levels.

Most studies have either identified risks or evaluated a critical event. The present study has filled this gap, and after identifying and ranking the risk factors, the critical event is evaluated. Generally, the present study provides the possibility of identification, analysis, response, and control.

MATERIALS AND METHODS

In this study, by reviewing scientific sources, related events and applying expert opinions and with the help of hierarchical analysis tree drawing, the root causes of risk were identified, and risk assessment was done in the pre-risk stage. This method can show the causes of risk in a hierarchical and categorized way. So, it is a good way to manage risk. The studied material is gasoline because more volume than kerosene and diesel is stored in the desired oil storage and also, according to the MSDS form, has more risks. Figure 1 shows the risk assessment process for toxic gases emission from the gasoline floating roof storage tank in this study.Identifying the causes of risk: In the hazard identification step, events that occurred in oil repositories or similar areas were first identified. At the same time, the study site and its records were reviewed. In addition, authoritative scientific references were also studied. Finally, by applying expert opinions, the causes of the risk were identified.

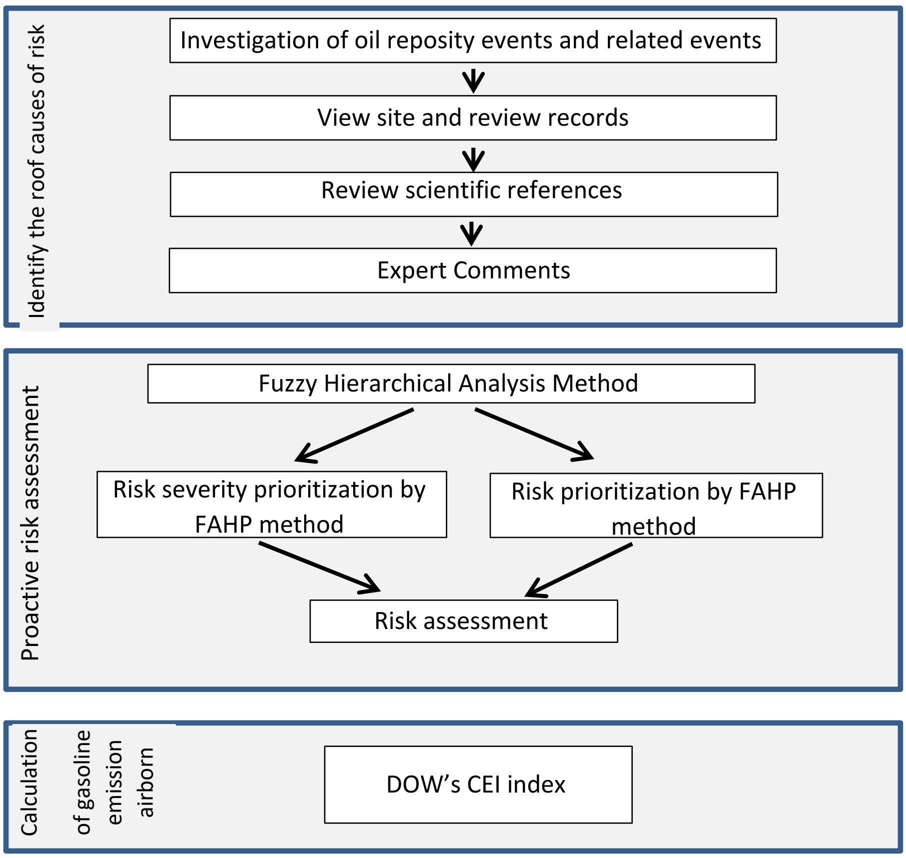

Fig. 1. The risk assessment process for toxic gases emission from the gasoline floating roof storage tank

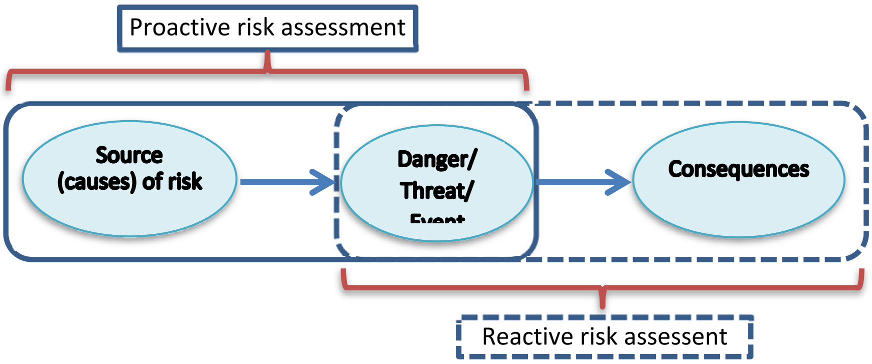

Fig. 2. Risk assessment according to the stage of occurrence

The studied site is an oil repository on the northwestern outskirts of the city. This repository contains storage tanks for petroleum products with a nominal capacity of 21 million liters each, but their practical and usable capacity is half the volume of each tank. On average, 5,800,000 liters of products are exchanged daily in this area. Most exchanges are related to gasoline, with a volume of approximately 5 million liters. So far, no event has been reported from this oil repository.

Risk assessment before the occurrence:Identifying risks in the pre-occurrence stage is very important because by doing this step correctly, it will be possible to prevent the risk occurrence and its consequences. So, in this phase, methods that have a proactive approach and identify the causes of risk are used. These methods focus on risk prevention. Figure 2 shows the risk assessment according to the stage of risk occurrence, and the position of pre-occurrence and post-occurrence risk assessment is specified.

In this study, the root causes of risk were identified and set up hierarchically in a hierarchical analysis tree to assess the risk on the pre-risk occurrence stage. This method can show the causes of risk occurrence in a hierarchical and categorized way. So, it is a good way to manage risk. The material under consideration is gasoline because more of it is stored in the desired oil repository than kerosene and diesel, and it also has more risks, according to the MSDS form.

Fuzzy hierarchical analysis method: In the risk assessment and management process, it is necessary to prioritize the identified risks based on specific criteria. The reason for this is the high frequency of identified risks, their degree of importance and criticality, and especially the limited resources needed to control them. The hierarchical analysis process is recognized as an efficient method in estimating the importance level of risks in risk assessment studies (Kokangül et al., 2017). The fuzzy hierarchical analysis method is used as a tool to solve complex environmental problems and uncertainties. When the proposed approach is implemented, risk factors are ranked and prioritized according to their weight (Topuz et al., 2011). In the AHP method, subjective judgments in the formation of the pairwise comparison matrix may be accompanied by uncertainty. Fuzzy theory confronts the uncertainties caused by ambiguity and subjectivity (Ferdous et al., 2011; Ghaleh et al., 2019; Khashei-siuki & Sharifan, 2020; Naikan, 2019). Combining the AHP method with fuzzy logic leads to superior results.

The fuzzy AHP method used in this research is derived from Buckley geometric mean method. This method is known as improved fuzzy AHP (Buckley, 1985). Applying the Chang development analysis method is not responsive in most issues due to its limitations such as zero and negative weight, so the improved fuzzy AHP method has been used. The method description is as follows: Let, $\tilde{P}_{ij}$ is a set of decision makers' preferences about one indicator than another. The pairwise comparison matrix is formed as follows:

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{P}_{12} & \tilde{P}_{1n} \\ \tilde{P}_{21} & 1 & \tilde{P}_{2n} \\ \tilde{P}_{n1} & \tilde{P}_{n2} & 1 \end{bmatrix}$$ Equation 1.

Where n is the number of related elements in each row, the fuzzy weights of each index of the pairwise comparison matrix are obtained by the Buckley geometric mean method. The geometric mean value of the fuzzy comparisons of index i to each index is obtained from Equation 2.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{P}_{ij} \right)^{1/n} \qquad i = 1, 2, 3, \ldots, n$$ Equation 2.

Then the fuzzy weight of ith index is represented by a triangular fuzzy number.

$$w_i = r_i \otimes (r_1 \oplus r_2 \oplus \ldots \oplus r_m)^{-1}$$ Equation 3.

After calculating the fuzzy weight factors, we defuzzify the weights by the following formula and then normalize.

$$w_{crisp} = \frac{l + 2m + u}{4}$$ Equation 4.

As shown in Table 1 verbal expressions and fuzzy triangular numbers are used to calculate the weight in pairwise comparisons. In this research, fuzzy numbers of triangular sets have been used, which shows from low to high levels with membership numbers (Ferdous et al., 2011; Lu et al., 2015).

Prioritization of probability and severity of risk by FAHP method: First, pairwise comparisons of criteria in two categories of probability assessment and risk severity are created and provided to experts. After answering the pairwise comparisons, the rate of incompatibility of the tables was calculated, which was less than 0.1, and shows the stability and reliability of the pairwise comparisons to an acceptable level. Then the answers were integrated using the geometric mean method and in the form of pairwise comparisons, which are present below. The weights of pairwise comparisons have been calculated using the Buckley geometric mean method.

Table 1. Verbal expressions and fuzzy numbers for criteria weighting

Fuzzy equivalent of priorities			**priorities**	**code**
(u) upper limit	(m) Mean limit	(L) Low limit		
1	1	1	Equal importance	**1**
3	2	1	The same to relatively important	**2**
4	3	2	Relatively more important	**3**
5	4	3	Relatively more important than very important	**4**
6	5	4	Very important	**5**
7	6	5	high important to very important	**6**
8	7	6	Very important	**7**
9	8	7	Very important to absolutely important	**8**
10	9	8	Absolutely more important	**9**

0.028<	0.028≥	Severity / Probability
		0.028≥
		0.028<

Guide:

Level 3	Level 2	level 1

Table 2. Risk ranking matrix

Risk assessment: In order to assess the risk of toxic gases emission, the importance integration that the probability and severity of the risk have due to the causes examined by the FAHP method has been applied. Through the FAHP method, the sum of the rankings is one, so using the following formula, the importance of each cause in the case of equal importance is calculated as follows:

$$s = \frac{1}{N} \quad \text{Equation 5.}$$

S = importance of each cause in equal condition

N = sum of causes

Since 36 causes have been investigated in this study, the importance of each cause in the case of equal importance is 0.028. In order to rank the risks, the probability and intensity numbers are divided into two levels higher and equal and lower than 0.028. Risk rankings are determined according to Table 2 Risks are divided into three categories 1, 2, and 3.

Calculation of gasoline emission airborne: The CEI Chemical Exposure Index, along with the DOW Fire and Explosion Index, is provided by DOW Chemical Company and is used to the relative ranking of the health risks potential for the population around process units where chemicals are likely to be released (AIChE, 1998). The steps of implementing the chemical exposure index are presented in Figure 3.1.

RESULTS AND DISCUSSIONS

Figure 4 shows the hierarchy analysis tree for pre-occurrence risk assessment of floating roof oil tanks and specifically floating roof tanks for gasoline storage in an oil repository.

Probability and intensity calculations were also done by the fuzzy AHP method for the toxic gases emission and then the probability weight multiplied by the intensity to give RPN values which are shown in Table 3. Specific risks, seal defects, floating roof errors, vent performance, temperature changes, earthquakes, non-compliance with safety tips during repairs, hot work, and disregard for work permits are at the third level of risk.

In the present study, 36 risk factors were identified in 7 categories for the toxic gases emission from gasoline storage tanks and were measured in terms of risk incidence probability and severity of the risk. As Xie (2021) studies have shown, the proposed AHP method more accurately identifies weak links in the safety system and provides theoretical foundations for

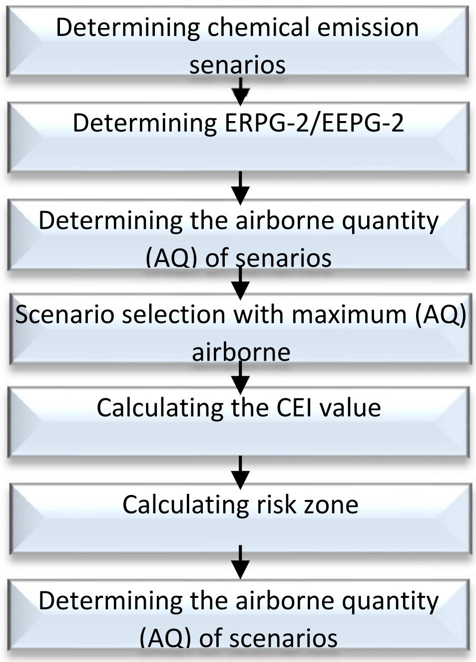

Fig. 3. Stages of implementation of the DOW Chemical Exposure Index (CEI) (Source: AIChE, 1998)

risk prevention and control. The ranks obtained from probability and severity were integrated to determine the risk number. The AHP method was used, where the sum of the ranks is one, and the mean ranks were extracted in equal conditions and used as a basis for measurement. The risk matrix was formed by defining three levels. High risk is related to the ranks where both the probability rank and the risk intensity rank are higher than the base number. The average risk is related to the factors where one of the ranks is more than the base number, and the low risk is related to the factors where both ranks are lower than the base number. 10 factors in the risk probability assessment were rated higher than the base number. 13 factors in the risk intensity measurement received a rank higher than the base number. 7 factors of both probability ranking and their intensity were more than the base number, which are the most important risks according to the risk matrix. These factors include specific risks, seal defects, vent performance, floating roof errors, air temperature changes, earthquakes, and non-compliance with safety tips during repairs. In the study by Zinke et al. (2020), the damage of the sealing system, as well as the increase of storage fluctuations and the role of temperature, have been identified as the reasons for the toxic gases emission from the floating roof storage tanks. Bouafia and et al. (2020) Studies have also shown that catastrophic release from gasoline storage tanks (toxic cloud dispersion) due to leakage is the worst case scenario. In the present study, the hazards leading to the release of vapors and the formation of toxic clouds have been identified.

So far, no event has been reported in the studied oil repository. Due to the importance of storing gasoline in the storage tanks of the studied oil repository, the rupture of the gasoline tank is considered equivalent to the thickest pipe connected to it, which has a diameter of 12 inches, and the risk range has been calculated for three emergency response modes (ERPG).

Since there is no sudden evaporation according to the DOW guidelines, all the released liquid enters the evaporation pool, where the area of the pool is calculated in the corresponding row.

The results obtained from the case study are shown in Table 7.

The results of CEI index calculations showed that the affected radius is 6125 m for ERPG-

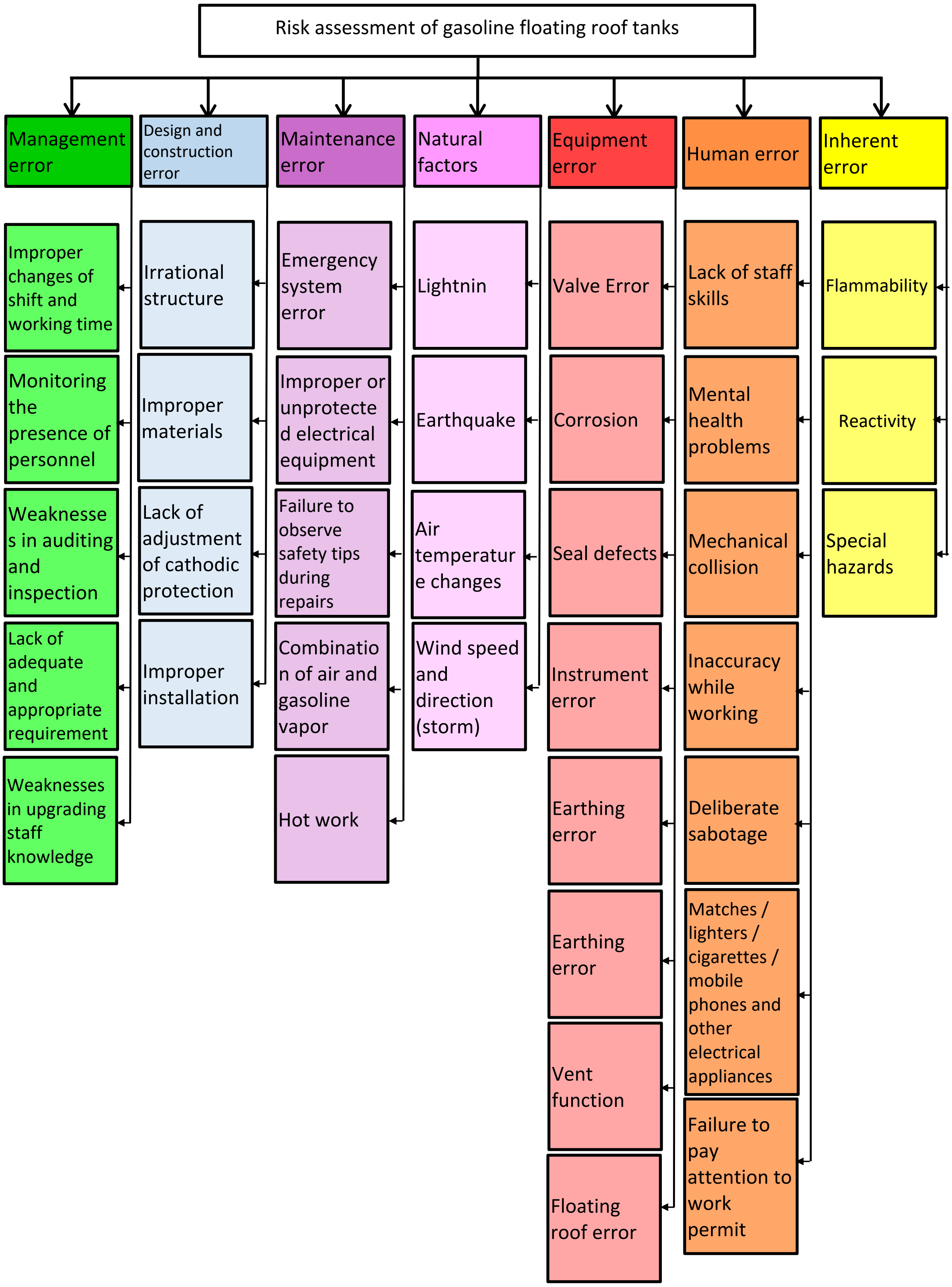

Fig. 4. Hierarchical Analysis Tree

Table 3. RPN values and risks level in the toxic gases emission

RPN	severity weight	probability weight	sub-criteria	Criteria
0.000795	0.03141	0.02531	Flammability	Inherent error
0.000431	0.01924	0.02239	Reactivity	
0.031721	0.18277	0.17356	Special hazards	
0.000385	0.01737	0.02667	Lack of staff skills	human error
0.000144	0.01279	0.01124	Mental health problems	
0.000454	0.02470	0.01839	Mechanical collision	
0.000303	0.01175	0.02580	Inaccuracy while working	
0.000215	0.03379	0.00635	Deliberate sabotage	
0.00002	0.00463	0.00454	Matches / lighters / cigarettes / mobile phones and other electrical appliances	
0.000893	0.02261	0.03949	Failure to pay attention to work permit	
0.000554	0.01982	0.02759	Valve Error	Equipment error
0.000222	0.00962	0.02312	Corrosion	
0.002881	0.04173	0.06903	Seal defects	
0.00019	0.01115	0.01704	Instrument error	
0.00003	0.00394	0.00743	Electrostatic phenomenon	
0.00002	0.00401	0.00579	Earthing error	
0.00195	0.02969	0.06568	Vent function	
0.002007	0.05083	0.03948	Floating roof error	
0.000365	0.01647	0.02216	Lightning	Natural factors
0.001895	0.03937	0.04115	Air temperature changes	
0.001848	0.04276	0.04312	Earthquake	
0.000293	0.01363	0.02146	Wind speed and direction (storm)	
0.000826	0.02465	0.0.0	Emergency system error	Maintenance error
0.000557	0.04069	0.01417	Improper or unprotected electrical equipment	
0.001317	0.03537	0.03725	Failure to observe safety tips during repairs	
0.00018	0.00973	0.01846	Combination of air and gasoline vapor	
0.001138	0.02585	0.04402	Hot work	
0.000391	0.02404	0.01625	Irrational structure	Design and construction error
0.00029	0.02483	0.01167	Improper materials	
0.000861	0.04578	0.01880	Lack of adjustment of cathodic protection	
0.000801	0.04148	0.01930	Improper installation	
0.00003	0.00811	0.00332	Improper changes of shift and working time	Management error
0.00005	0.00938	0.00546	Monitoring the presence of personnel	
0.000556	0.03315	0.01707	Weaknesses in auditing and inspection	
0.000204	0.02127	0.00958	Lack of adequate and appropriate requirements	
0.00010	0.01450	0.00681	Weaknesses in upgrading staff knowledge	

1 with a concentration of 200Ppm, 2739 m for ERPG-2 with a concentration of 1000 Ppm, and 1369 m for ERPG-3 with a concentration of 4000 Ppm. The concentration of 4000 Ppm is the maximum airborne concentration that everyone can be exposed to for one hour without causing any casualties. The concentration of 1000 Ppm is the maximum airborne concentration as defined in the ERPG, which is believed that at concentrations below it, almost everyone can be exposed for up to an hour, without experiencing irreversible effects and other serious health effects or symptoms that can damage a person's performance. Concentration 200 Ppm is the maximum airborne concentration which is believed that at concentrations below it, almost everyone can be exposed for up to an hour, with only mild, temporary adverse health or odor

Table 4. Information required to calculate CEI

references	English unit	SI Unit	info
DOW CEI Guide	0 psig	0 KPa	**Gauge pressure (Pg)**
Ministry of Petroleum	49.94 Ib/ft^3	710-800 kg/m^3	**Liquid density in the tank (ρ1)**
Ministry of Petroleum	22.96 ft	7 m	**Maximum height of liquid in the tank**
Study team (based on data received from the (Ministry of Petroleum	12 in	304.8 mm	**The diameter of the hole**
Ministry of Petroleum	68 F	20°C	**Temperature**
MSDS (based on data received from the (Ministry of Petroleum	8.99 Psig	62 KPa	**Liquid vapor pressure (PV)**
U.S. EPA 2009	108	108(MW)	**Molecular Weight**

Table 5. CEI index calculations

No.		English unit	SI unit
1	Liquid discharge released	$L = 2.234D^2\rho_1\sqrt{\frac{144P_g}{\rho_1} + \Delta h} = 2.234 * 12^2 * 49.94\sqrt{\frac{144*0}{45.57} + 22.96} = 76980.395 Ib/min$	$\mathbf{L = 9.44 * 10^{-7}D^2\rho_1\sqrt{\frac{1000P_g}{\rho_1} + 9.8\Delta h} = 9.44 * 10^{-7} * 304.8^{\,2} * 800\sqrt{\frac{1000*0}{800} + 9.8 * 7} = 581.104 Kg/s}$
2	The total amount of fluid released	$W_T = 15L = 15 * 76048 = 1154705.939\ Ib$	$\boldsymbol{W_T = 900L = 900 * 580 = 522993.719 Kg}$
3	Evaporation * pond area	$A_P = 30.5\frac{W_P}{\rho_1} = \frac{1151896.22}{49.94} = 705216.883\ Ft^2$	$\mathbf{m^2}$ $\boldsymbol{A_P = 100\frac{W_P}{\rho_1} = 100\frac{522993.719}{800} = 65374.2}$
4	The amount of airborne evaporated from the pool surface	$AQ_P = 0.154(A_P^{0.95}) * \frac{(MW)(P_V)}{T + 459} = 0.154(703500.89^{0.95}) * \frac{(108)(8.99)}{68 + 459} = 102044.038\ Ib/min$	$\boldsymbol{AQ_P = 9 * 10^{-4}(A_P^{0.95}) * \frac{(MW)(P_V)}{T + 273} = 9 * 10^{-4}(65250^{0.95}) * \frac{(108)(62)}{20 + 273} = 772.3635\ kg/s}$
5	CEI value	$CEI = 281.8\sqrt{\frac{AQ}{ERPG-2*MW}} = 281.8\sqrt{\frac{102044.038}{1000*108}} = 273.919$	$\boldsymbol{CEI = 655.1\sqrt{\frac{AQ}{ERPG-2}} = 655.1\sqrt{\frac{772.3635}{4417.17}} = 273.93}$

symptoms that are clearly perceptible.

Since the studied oil repository is adjacent to residential areas and the nearest neighborhood is located at a distance of about 360m and according to the research results, the adjacent community is in an insecure area relative to the oil repository and is affected by the distribution radius of all three concentration levels in ERPG. Cheraghi et al. (2021) have presented similar results in their study.

In the present study, the hierarchical arrangement and its graphics (separate colors for each category of risks) have resulted in an understandable and practical schematic.

Table 6. Risk range calculation

ERPG	VALUE		English unit	SI unit
	ppm	Mg/m3		
ERPG-1	200	883.43	$HD = 9243\sqrt{\frac{AQ}{(ERPG-1)*(MW)}}$ $= 9243\sqrt{\frac{102044.038}{(200)*(108)}}$ $= 20089.99\,ft$	$HD = 6551\sqrt{\frac{AQ}{ERPG-1}}$ $= 6551\sqrt{\frac{772.3635}{883.43}}$ $= 6125.37m$
ERPG-2	1000	4417.17	$HD = 9243\sqrt{\frac{AQ}{(ERPG-2)*(MW)}}$ $= 9243\sqrt{\frac{102044.038}{(1000)*(108)}} = 8984.52$	$HD = 6551\sqrt{\frac{AQ}{ERPG-2}}$ $= 6551\sqrt{\frac{772.3635}{4417.17}}$ $= 2739.34$
ERPG-3	4000	17668.71	$HD = 9243\sqrt{\frac{AQ}{(ERPG-3)*(MW)}}$ $= 9243\sqrt{\frac{102044.038}{(4000)*(108)}} = 4492.26$	$HD = 6551\sqrt{\frac{AQ}{ERPG-3}}$ $= 6551\sqrt{\frac{772.3635}{17668.71}}$ $= 1369.67$

Table 7. CEI worksheets

Chemical Name: Gasoline			**Industrial unit: an oil repository**
The largest volume of a chemical in a process container, L10.5 million			**Total inventory of chemicals per unit L43,000,000**
The temperature of a process vessel containing a chemical ° 20C			**Container pressure is a process containing a chemical 750mm Hg**
Evaluated scenario			
The amount of airborne released according to the scenario (in kg/s): 160 / (in pounds per minute): 6164			
Chemical exposure index			
Danger zone	Density		
m	ppm	Mg / m3	
6125	200	588.96	**ERPG-1**
2739	1000	2944.79	**ERPG-2**
1369	4000	11779.14	**ERPG-3**
Ft	m		**distance**
1259 Ft	From the south: the first downstairs dining hall: 384 meters		**To adjacent non-industrial units**
787 Ft	From the east: 240 meters away from the municipal emergency department and heavy motor		
1197 Ft	From the east: 365 meters from the Hesarak neighborhood		**To the community adjacent to the site**
472 Ft	Archive 1: 144 meters		**to other facilities in the unit**
515 Ft	Archive 2: 157 meters		
597 Ft	Gym: 182 meters		

CONCLUSION

This study evaluates the risk of an oil repository. The strength of this study is that the risk assessment has been done systematically before the event and the event causes, and then the event risk has been done continuously. It is important to provide a schematic of the risk causes in such a way that the main risks and causes can be easily understood through a graphic examination. One of the main purposes of this identification tree is to have a useful and effective guide for identifying the dangers of oil repositories so that people working in different parts and positions of oil repositories with different management, science, and experience levels be able to receive appropriate information and have a positive role in the risk management process. The results show that this method has prominent advantages as follows:

- Comprehensiveness: This method is comprehensive for several reasons. There is no such classification in any of the reviewed references, while in this study, an attempt has been made to see the root causes of risk from all aspects and in appropriate classifications with a comprehensive view. It should be noted that in order to maintain the comprehensiveness of the research and review all important factors, the main criteria have been separated because increasing the number of sub-criteria in a category increases the evaluation error. For example, in the new HSE science, human error can be seen in the set of management errors, but these two criteria have been defined due to the wide range of causes leading to the accident in this category and the possibility of more accurate assessment.
- Most references have identified the risk causes, but due to the method structure, the complexity of the presentation, addressing all risk aspects (identification, evaluation, and analysis) in one format, the attitude of authors, and other factors, it is not possible to easily understand the root causes identified. Most methods, because they deal with different aspects of risk, create a large amount of information and weakly address the causes of risk while addressing the causes of risk is very important because it can prevent the risk occurrence.
- In the present research, it is important to be clear about the identified causes. Because the oil industry is important and risky, it is necessary to present the causes of risk without complexity, simple and understandable as it facilitates the speed of receiving information for both a senior manager and a trained worker.

While completing the study, the emission risk with the DOW'S CEI index showed that the adjacent neighborhoods are in an unsafe zone, which highlights the importance of applying this method and is an alarm for risk management of this oil repository, so pay close attention to safety, risk management, and crisis management issues are important.

GRANT SUPPORT DETAILS

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

REFERENCES

AIChE. (1998). *Dow's Chemical Exposure Index Guide: First Edition*. https://www.wiley.com/en-us/Dow%27s+Chemical+Exposure+Index+Guide-p-9780470935293#download-product-flyer

Alhamdani, Y. A., Hassim, M. H., Shaik, S. M. and Jalil, A. A. (2018). Hybrid tool for occupational health risk assessment and fugitive emissions control in chemical processes based on the source, path and receptor concept. *Process Safety and Environmental Protection*, *118*, 348–360. https://doi.org/10.1016/j.psep.2018.06.032

Argyropoulos, C. D., Christolis, M. N., Nivolianitou, Z. and Markatos, N. C. (2012). A hazards assessment methodology for large liquid hydrocarbon fuel tanks. *Journal of Loss Prevention in the Process Industries*, *25*(2), 329–335. https://doi.org/10.1016/j.jlp.2011.12.003

Bouafia, A., Bougofa, M., Rouainia, M. and Medjram, M. S. (2020). Safety Risk Analysis and Accidents Modeling of a Major Gasoline Release in Petrochemical Plant. *Journal of Failure Analysis and Prevention*, *20*(2), 358–369. https://doi.org/10.1007/s11668-020-00826-9

Buckley, J. J. (1985). Fuzzy hierarchical analysis. *Fuzzy Sets and Systems*, *17*(3), 233–247. https://doi.org/10.1016/0165-0114(85)90090-9

Chang, J. I. and Lin, C. C. (2006). A study of storage tank accidents. *Journal of Loss Prevention in the Process Industries*, *19*(1), 51–59. https://doi.org/10.1016/j.jlp.2005.05.015

Chen, X., Wu, Z., Chen, W., Kang, R. and He, X. (2020). Selection of key indicators for reputation loss in oil and gas pipeline failure event. *Engineering Failure Analysis*, *99*(March 2018), 69–84. https://doi.org/10.1016/j.engfailanal.2019.01.071

Cheraghi, M., Bagherian-Sahlavani, A., Noori, H. and Mohammad-Fam, I. (2021). Evaluation of hazard distances related to toxic releases in a gas refinery: comparison of chemical exposure index and consequence modeling approaches. *International Journal of Occupational Safety and Ergonomics*, *27*(3), 641–653. https://doi.org/10.1080/10803548.2019.1621023

Dey, P. K. (2012). Project risk management using multiple criteria decision-making technique and decision tree analysis: a case study of Indian oil refinery. *Http://Dx.Doi.Org/10.1080/09537287.2011.586379*, *23*(12), 903–921. https://doi.org/10.1080/09537287.2011.586379

energy Agency, I. (2021). *Statistics report Key World Energy Statistics 2021*.

Ferdous, R., Khan, F., Sadiq, R., Amyotte, P. and Veitch, B. (2011). Analyzing system safety and risks under uncertainty using a bow-tie diagram : An innovative approach. *Process Safety and Environmental Protection*, *91*(1–2), 1–18. https://doi.org/10.1016/j.psep.2011.08.010

Gai, W., Du, Y. and Deng, Y. (2018). Regional evacuation modeling for toxic-cloud releases and its application in strategy assessment of evacuation warning. *Safety Science*, *109*(March), 256–269. https://doi.org/10.1016/j.ssci.2018.06.007

Ghaleh, S., Omidvari, M., Nassiri, P. and Momeni, M. (2019). Pattern of safety risk assessment in road fl eet transportation of hazardous materials (oil materials). *Safety Science*, *116*(May 2018), 1–12. https://doi.org/10.1016/j.ssci.2019.02.039

Guan, W., Liu, Q. and Dong, C. (2022). Risk assessment method for industrial accident consequences and human vulnerability in urban areas. *Journal of Loss Prevention in the Process Industries*, 104745. https://doi.org/https://doi.org/10.1016/j.jlp.2022.104745

Guo, X., Ji, J., Khan, F. and Ding, L. (2020). Fuzzy bayesian network based on an improved similarity aggregation method for risk assessment of storage tank accident. *Process Safety and Environmental Protection*, *144*, 242–252. https://doi.org/10.1016/j.psep.2020.07.030

Huang, W., Huang, F., Fang, J. and Fu, L. (2020). Journal of Petroleum Science and Engineering A calculation method for the numerical simulation of oil products evaporation and vapor diffusion in an internal floating-roof tank under the unsteady operating state. *Journal of Petroleum Science and Engineering*, *188*(September 2019), 106867. https://doi.org/10.1016/j.petrol.2019.106867

Kang, J., Liang, W., Zhang, L., Lu, Z., Liu, D., Yin, W. and Zhang, G. (2014). A new risk evaluation method for oil storage tank zones based on the theory of two types of hazards. *Journal of Loss Prevention in the Process Industries*, *29*(1), 267–276. https://doi.org/10.1016/j.jlp.2014.03.007

KARBASI, A. A. R., NABI BIDHENDI, G. H. R., MOATAR, F. and MAHIN ABD ELAHZADEH, E. (2009). ROLE OF OIL STORAGE TANK STRUCTURE IN THE PREVENTION EMISSION OF HYDROCARBON POLLUTION. *JOURNAL OF ENVIRONMENTAL STUDIES*, *35*(50), 73–82. https://www.sid.ir/en/journal/ViewPaper.aspx?ID=159579

Karbasi, A., Khoramnezhadian, S., Zavareh, S. R. A. and Sani, G. P. (2018). Determination of the emission rate and modeling of benzene dispersion due to surface evaporation from an oil pit. *Journal of Air Pollution and Health*, *3*(3 SE-Original Research). https://japh.tums.ac.ir/index.php/japh/article/view/173

Khashei-siuki, A. and Sharifan, H. (2020). Groundwater for Sustainable Development Comparison of AHP and FAHP methods in determining suitable areas for drinking water harvesting in Birjand aquifer . Iran. *Groundwater for Sustainable Development*, *10*(December 2019), 100328. https://doi.org/10.1016/j.gsd.2019.100328

Kokangül, A., Polat, U. and Dağsuyu, C. (2017). A new approximation for risk assessment using the AHP and Fine Kinney methodologies. *Safety Science*, *91*, 24–32. https://doi.org/10.1016/j.ssci.2016.07.015

Lu, L., Liang, W., Zhang, L., Zhang, H., Lu, Z. and Shan, J. (2015). Journal of Natural Gas Science and Engineering A comprehensive risk evaluation method for natural gas pipelines by combining a risk matrix with a bow-tie model. *Journal of Natural Gas Science and Engineering*, *25*, 124–133. https://doi.org/10.1016/j.jngse.2015.04.029

Marhavilas, P. K., Filippidis, M., Koulinas, G. K. and Koulouriotis, D. E. (2020). An expanded HAZOP-study with fuzzy-AHP (XPA-HAZOP technique): Application in a sour crude-oil processing plant. *Safety Science*, *124*(December 2019), 104590. https://doi.org/10.1016/j.ssci.2019.104590

Naikan, V. N. A. (2019). Abstract : *Engineering Failure Analysis*, 104195. https://doi.org/10.1016/j.engfailanal.2019.104195

Papadopoulou, M. P. and Antoniou, C. (2014). Environmental impact assessment methodological framework for liquefied natural gas terminal and transport network planning. *Energy Policy*, *68*, 306–319. https://doi.org/10.1016/j.enpol.2014.01.044

Pouyakian, M., Jafari, M. J., Laal, F., Nourai, F. and Zarei, E. (2021). A comprehensive approach to analyze the risk of floating roof storage tanks. *Process Safety and Environmental Protection*, *146*, 811–836. https://doi.org/10.1016/j.psep.2020.11.051

Saaty, T. L. (1988). What is the analytic hierarchy process? In *Mathematical models for decision support* (pp. 109–121). Springer.

Shahriar, A., Sadiq, R. and Tesfamariam, S. (2012). Risk analysis for oil & gas pipelines: A sustainability assessment approach using fuzzy based bow-tie analysis. *Journal of Loss Prevention in the Process Industries*, *25*(3), 505–523. https://doi.org/10.1016/j.jlp.2011.12.007

Shi, L., Shuai, J. and Xu, K. (2014). Fuzzy fault tree assessment based on improved AHP for fire and explosion accidents for steel oil storage tanks. *Journal of Hazardous Materials*, *278*, 529–538. https://doi.org/10.1016/j.jhazmat.2014.06.034

Topuz, E., Talinli, I. and Aydin, E. (2011). Integration of environmental and human health risk assessment for industries using hazardous materials: A quantitative multi criteria approach for environmental decision makers. *Environment International*, *37*(2), 393–403. https://doi.org/10.1016/j.envint.2010.10.013

Wang, J., Yu, X. and Zong, R. (2020). Journal of Loss Prevention in the Process Industries A dynamic approach for evaluating the consequences of toxic gas dispersion in the chemical plants using CFD and evacuation modelling. *Journal of Loss Prevention in the Process Industries*, *65*(December 2019), 104156. https://doi.org/10.1016/j.jlp.2020.104156

Xin, P., Khan, F. and Ahmed, S. (2016). *Dynamic Hazard Identification and Scenario Mapping Using Bayesian Network*. https://doi.org/10.1016/j.psep.2016.11.003

Yu, W., Mingbang, T., Dongbo, W., Qiang, Z. and Shihui, S. (2012). *2012 International Symposium on Safety Science and Technology Study on the HSE management at construction site of oil and gas processing area*. *45*, 231–234. https://doi.org/10.1016/j.proeng.2012.08.149

Zinke, R., Melnychuk, J., Köhler, F. and Krause, U. (2020). Quantitative risk assessment of emissions from external floating roof tanks during normal operation and in case of damages using Bayesian Networks. *Reliability Engineering and System Safety*, *197*(November 2019), 106826. https://doi.org/10.1016/j.ress.2020.106826