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Risk Assessment from a Passive Defense Perspective- a Case Study at Shams Abad Industrial Estate, Iran

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ABSTRACT
With the increasing development of knowledge and the emergence of new technologies in different industrial and production sectors, especially the growth of chemical industries and, of course, ascending trend in the chemical accidents incidence, it is necessary to implement risk management principles and increase safety to prevent accidents is of particular importance. This study was conducted to assess the risks in chemical storage tanks in order to achieve a risk management, improve safety, and reduce vulnerability from the perspective of passive defense in the industrial estate. In this descriptive-analytical study, the FMEA and William-Fine methods were used to identify and prioritize risk based on the risk type and cost control in industrial town with a passive defense perspective in chemical production and maintenance unit at Shams Abad industrial estate. Based on the study's findings, 57 risks were identified, the first priority in the FMEA method was related to the chemicals tank temperature increase due to the lack of control and monitoring system, and tracking and warning devices with the calculated risk score of 720 and the last priority was related to liquid spills. The cause of natural factors was determined by a risk score of 90. A number of risks had the same risk scores. According to the William-Fine risk assessment method, immediate corrective actions also were needed and activities with these risks should be stopped until control measures were implemented. It was recommended that 9 risks should to be investigated as soon as possible. According to the priorities set and risks observed from the passive defense point of view, in order to control the identified risks, anticipation and provision of equipment and facilities were suggested to improve for controlling chemical accidents in industrial estates, development of maintenance instructions, installation and launching monitoring, tracking, announcing and controlling systems, establishing an automatic fire extinguishing system, providing and using appropriate personal protective equipment, observing the principles of passive defense in the correct location for the establishment of industrial estates according to the factors affecting passive defense, establishing a center for accident information in the country, strengthening inter-sectoral coordination in accident management, developing accident prevention and management programs, training employers, employees and educating locals, anticipating alternative routes for ambulance traffic and maneuvering in industrial estates.

KEYWORDS: *Risk Assessment, Passive Defense, FMEA, William-Fine, Vulnerability, Resilience*

INTRODUCTION

An overview on chemical incidents in the United States [1] and around the world clarified that the frequency and severity of chemical-related accidents are relatively prevalent. Based on the statistics, work-related accidents or lack of safety are the third leading causes of death worldwide including developed communities [2]. A study conducted by Bentley et al. [3] tried to identify the hierarchy of factors that may influence slip, trip, and fall accidents happening within a large organization. The results of their study proved the supervisor's significant role in workplace safety. A valid and appropriate model remained to assess the efficiency and environmental performance related to the health, safety, and environmental management system principles. In order to develop the previous efforts in this regard, Abbas Pour et al. proposed a model in which 12 oil and gas general contractors using Data Envelopment Analysis (DEA) ranked high-performing companies from weak ones. Accordingly, the results showed relative efficiency, inefficiency sources, and the rank of contractors [4].

Nivolianitou et al. [5] evaluated the dimensions of risk analysis and management and found that risk assessment should be along with risks and benefits balances, valuable data for risk reduction decision-making, improving the environment and hazardous facilities, planning for emergencies, and determining levels. In order to create such mentioned balance, some kind of short-term tradeoff between productivity and safety is necessary. Although, sometimes operations are interrupted including scheduled maintenance, maintenance on demand, response to warnings, subsystem failure, or a catastrophic accident. Michelle et al. [6] applied probabilistic risk assessment (PRA) and Markov models to track the changes in the system and its components through different performance phases. They found that the timing and extent of scheduled maintenance may decrease the probabilities of both production interruptions and catastrophic failures.

The project risks identifications is of particular and have a positive and negative impact on its surrounding. Therefore, in various studies such as Yazdani et al. was aimed to develop a model to investigate and detect unknown parts and dangers in systems to avoid accidents. In their study, they used risk assessment and FMEA methodology to determine the effect of special importance and the consequences of these events directly in time, cost, and quality [7]. Similarly, the process hazards and the component's failures of major equipment in a gas condensate storage tanks at Persian Gas Refining Company using HAZOP and FMEA methods were assessed by Ghahramani et al. [8]. They found 68 hazards and related risks as well as the highest and lowest risks. According to the acceptance level of risk in their study which was 200, all of the identified hazards risks had no need for any risk reduction measures. However, the protective maintenance (PM) and precise PM was proposed to reduce the probability of risk happening.

The objective of Hekmat Panah et al. [9] studies was to investigate variables affecting the crucial structure of the G industrial estate located in Isfahan province from a passive defense approach in order to strengthen stability, defensive power, and inhibition factors of the estate. Therefore, in their study, using the SWOT method various factors implementation was assessed such as proper location based on upstream documents, adequate coverage of electricity water, gas, and telecommunications facilities, and enough educational and cultural programs. Ultimately, they found incorrect or misconducting in the mentioned factors.

Lots of efforts put on the cities' security improvement. Different planners have various strategies to reach an ideal level of security. New spatial logics and related policies around the world in urban spatial development plans are undermined exclusively. Tousi et al. [10] evaluated Tehran metropolis spatial logic effective principles and policies from a passive defense perspective to propose an appropriate framework of spatial development policy making for vulnerability reduction. Consequently, they found that the militarization of the urban area is not an appropriate option for security establishment and a balance between costs and benefits for security and revelation strategic spaces should be noted.

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One of the most frequent threats for employees is exposure to hazardous materials. In order to minimize the related risks, it is necessary to establish effective assessment exposure procedures. Considering the FMEA successful experiment for risks assessment and firefighting guidelines in petrochemical industries, it can be used to detect the dangerous situation. Furthermore, the William-fine method is able to provide an acceptable insight into the hazard risk rate in such industries. Heidari et al. [11] combined AHP and William-fine methods to attain a model for chemicals exposure risk assessment in oil and gas industry. Hence, they found that the chemical exposure risk frequency were highly important from an economical point of view such that William-fine method were able to detect chemical exposure by combination of effect severity, exposure probability and detriment rate, and also minimization of personal judgments during the assessment.

In order to examine the strengths and weaknesses of the region and the industrial town from the perspective of passive defense, it is necessary to inspect and observe events' documents and records as well as the region's condition. Hosseini et al. [12] therefore, investigated industrial estates' predesign passive defense consideration to decrease damages on facilities, equipment, and workforces. So they used a comparative matrix to find effective factors for industrial estate location and proposed that this measure should be noted before establishing an industrial estate.

The chemical unit's location at Shams Abad industrial town has been presented in Figure 1.

Fig 1. Map and the location of the chemical unit in Shams Abad industrial town

MATERIALS AND METHODS

In this study, performing steps using an algorithm has been shown in Figure [1]. As shown in this diagram, in the first step, a high-risk chemical unit in the industrial town initially was identified and selected. The Shamsabad Industrial estate has more than 4,000 active industrial units, of which 655 are active in the field of chemicals (nearly 16%). A chemical production and maintenance unit including hydrocarbons (especially aromatic, Benzene, Toluene and Xylene) which are reserved in 900 thousand liters and 750 thousand liters tanks consist of 15 tanks of 32 thousand liters and 2 tanks of 12 thousand liters in the southeast of the town with 10 employees was selected as a case study to assess the risks. This unit had no accident management and safety documentation.

In the second step, the risks' existence in this industrial unit were identified and finalized.

In the third step, appropriate risk assessment methods were selected to examine the determined factors based on the FMEA and William-Fine methods, whereas the probability of occurrence, severity of impact and detection was examined by FMEA and severity of impact, rate of occurrence and probability of occurrence was assessed by William-Fine method. Ultimately, these methods provided a structure to score all risks, prioritize all identification, and present all possible risks.

The fourth step was to determine control strategies to reduce each risk and calculate the costs of implementing it in order to rank the risks based on William-Fine method.

In the fifth step, the strengths and weaknesses of the region and the town were examined from the perspective of passive defense, also in order to reduce the vulnerability caused by these shortcomings, the proposed solutions to increase preparedness for threats and crises were presented as follow:

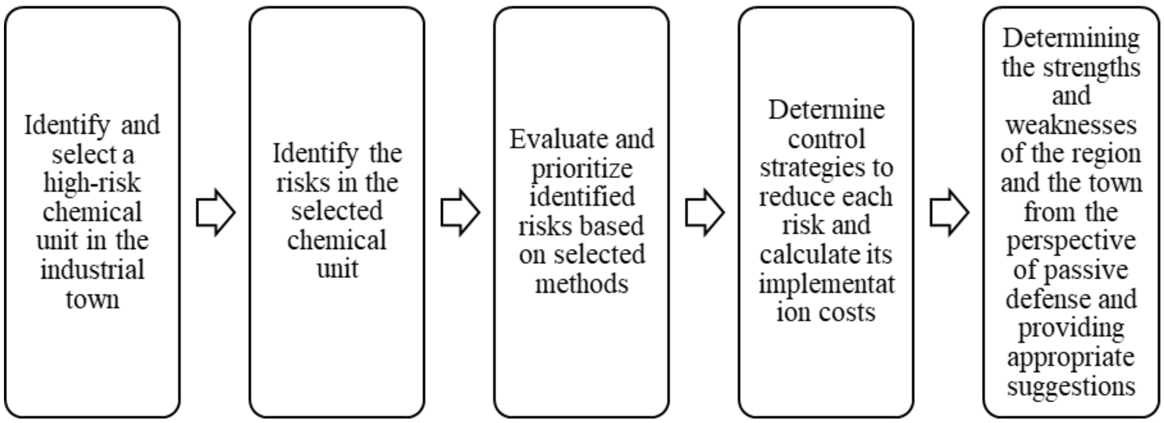

Fig 1. The diagram of study's work flow

What are the risks in similar chemical industries?

What are the first priorities for risk control in similar chemical industries?

What are the most important threats to the chemical industry in industrial estates?

What control methods are in place to reduce and eliminate risk in the chemical industry?

Are there any economic justifications for reducing risk and reducing vulnerability in these industries?

In this study, to determine this unit's risks first a face-to-face inspection was carried out and a review on the results of occupational health inspections was performed. Thereafter, the existing risks were determined using Table 1. The FMEA and William-Fine methods then were applied to score each risk according to the relevant scoring table. Accordingly, based on the scores obtained for each risk, prioritization was performed (Tables 1 and 2). The value for each factor related to the FMEA risk assessment method has been shown in 3, 4, and 5 Tables, respectively.

Calculation of risk score based on the FMEA method:

$D * O * S = RN$

Indicators used:

RN: Risk score

S: Deterioration or severity of the accident

O: Probability of occurrence

D: Probability of risk detection

The value for each factor related to the William-Fine method has been presented in 6, 7, 8, 9, 10, 11, 12 and 13 Tables, respectively.

Calculating the risk score based on William-Fine method:

$P * E * C = RN$

Indicators used:

C = Consequence intensity

E = Exposure rate

P = Probability of occurrence

$RN / (DC * CF) = J$

J = Acceptable cost

RN: Risk rate
CF: Cost Factor
DC: Correction degree

It should be noted that the Dollar exchange rate to Iranian Rial at the calculations related to the cost control time was 1 to 117,000 Rials. Therefore, to determine which risk control was economically justified; calculations were performed based on the number J and control the risks above 10 which were economically acceptable.

RESULTS

The related score for each risk using FMEA and William-Fine was identified and determined. The results of risk priority based on each method then determined and the final prioritization was obtained.

The first priority in the FMEA method was to "increase the temperature of the chemicals in the tank to a high temperature due to the lack of control, monitoring and tracking system" with the calculated risk score of 720 and the last priority was to "overflow liquids due to natural factors" with the calculated risk score of 90.

The results of the FMEA prioritization score have been illustrated in Figure 2.

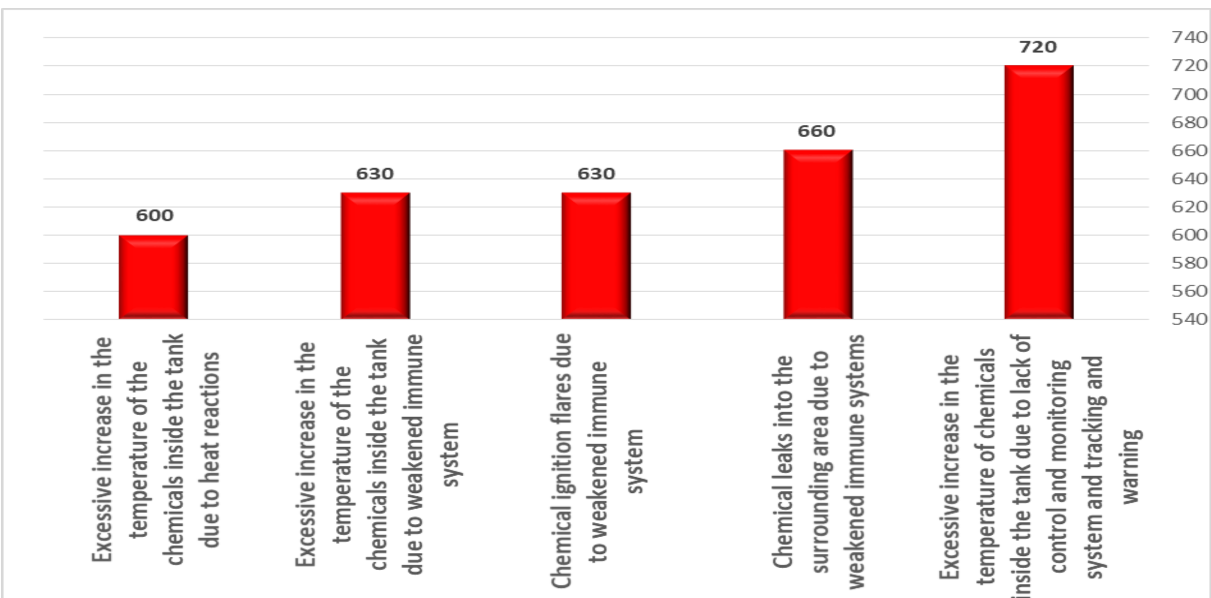

Fig 2. FMEA prioritization score

The priorities were different in the William-Fine method considering the cost of control measures. The first priority was related to "explosion and fire due to defective equipment" with a risk score of 350 and the lowest priority was related to "leakage of pipelines and connections due to a natural factor" with a risk score of 3. The first 5 priorities of the identified risks were identified in the William-Fine method (Figure 3).

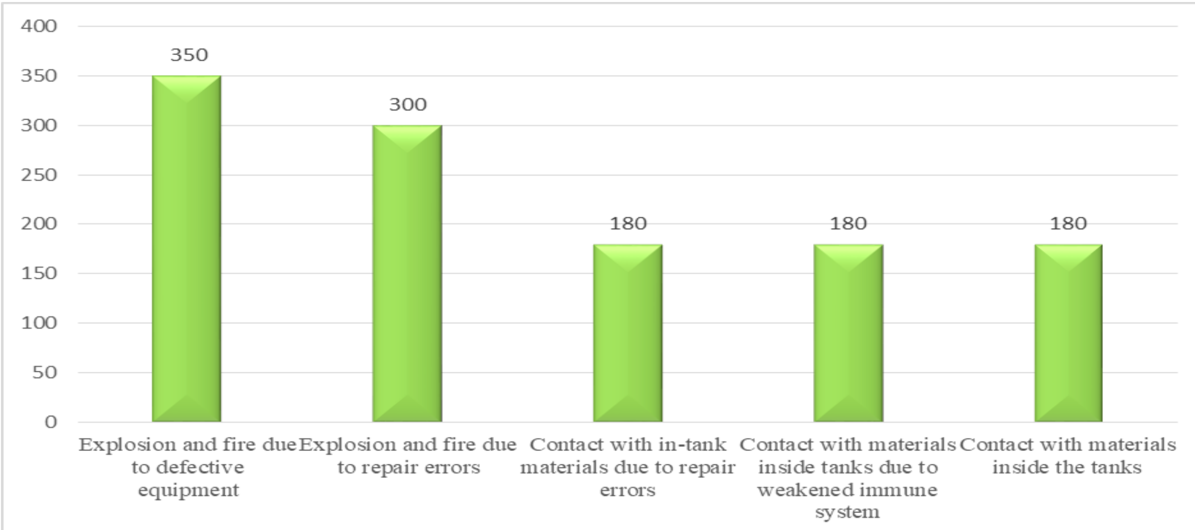

Fig 3. William-Fine prioritization score

According to William-Fine's risk rating, the first two identified risks included "explosion and fire due to defective equipment and explosion and fire due to repair errors" and require immediate corrective action. These risks must be stopped until control measures are taken (Table 2). Additionally, 9 risks should be controlled as soon as possible (abnormal risk) but for other 46 identified risks, although they needed to be eliminated but their situation was not an emergency (natural risk) (Figure 4).

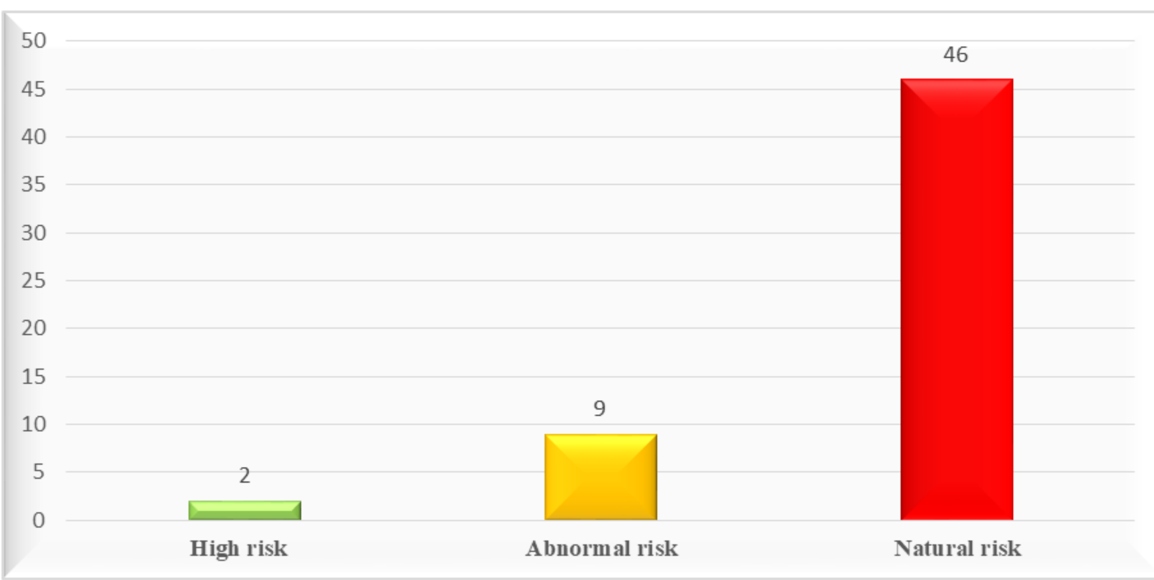

Fig 4. A comparison among identified risks by risk rating in William-Fine method

The control methods had 22 economically justified risks and 35 risk-free justifications, from an economic and cost point of view. The amount of acceptable risks and unacceptable risks were divided based on the ppercentages of risk control by performing control at 100%, 75-75%, 25-25% and below 25%, respectively (Table 2).

The most important weaknesses from the passive defense point of view included: the lack of proper location of the industrial town due to the weather conditions in the area, proximity to sensitive and important areas and residential areas, long distance to relief and fire centers, lack of incident management and prevention program, lack of information. Moreover, there was no exact data regarding chemicals materials used in industry, the lack of proper management of chemicals in industrial estates, and the lack of proper culture-building in relation to accidents.

Table 1. The level of risk control in comparison to the implementation of control methods and the number of acceptable risks

Natural risk	**Abnormal risk**	**High risk**	
They need to be removed, but they are not in an emergency	Requires review and attention as soon as possible	Immediate corrective action is needed, and activities with these risks must be stopped until control measures are taken.	Necessary actions

Table 2. *The level of risk control in comparison to the implementation of control methods and the number of acceptable risks*

	Percentage of risk control by performing control measures			
	100%	75%	50 -75 %	25-50% and below 25%
Number of acceptable risks	22	12	5	3
Number of unacceptable risks	35	45	52	54

DISCUSSION:

In the current study, experts who had more than 5 years' work experience in occupational health and chemical engineering in chemical industries were selected to determine exactly the risks and risk score calculations in both methods. Based on the FMEA method, 57 storage tanks' risk were identified in which "increased the temperature of the chemicals inside the tank due to lack of control and monitoring system and tracking and warning" with the calculated risk score of 720 and the final priority was determined to be "fluid overflow due to natural factors" with a risk score of 90. The results of the William-Fine method also showed that two risks of fire and explosion due to defective equipment and repair error were the most important identified risks (high risk) and leakage of pipelines and joints dislocation due to natural factors was the lowest priority. Therefore, it was suggested to perform immediate action and control measures in accordance with these risks type. These measures, as stated in the study of Nasiri et al. [13] can be determined based on the type of risk. Given the numerical average of the factors influencing the risk score in the FMEA method, the "probability of tracking" had the greatest impact on the risk score calculation in most identified risks. In addition, there was malfunction or problem in equipment, identification system, risk alarms, and controls in this industrial unit.

The highest impact on the calculated risk score based on the William-Fine method was related to the most probable outcome of a potential accident called "severity" and related to the risks of explosion and fire which happened due to defective equipment and repair error. It can be concluded that these risks lead to major losses in the chemical industry, especially flammable liquids such as toluene, benzene, and xylene. Kandahari et al. in the study found that a variety of risk assessment methods at chemical industries can be used including William-Fine, HAZOP, FMEA regarding advantages and disadvantages factors, design, structure, type of activity, and the environmental conditions [14].

Oil storage tanks and petroleum products common and the most important risk are fire and explosion which affected by three factors: human error, equipment failure, and other factors (natural and intentional acts of terrorism). In the study conducted by Amant Yazdi et al. [15] on environmental risk management in oil storage tanks at Yazd Oil Company, identified that the equipment failures with 41.67% were the most important cause of environmental risk and human error with 33.33% as the second factor was identified. Human error and equipment failures were identified as the main factor. This finding was consistent with the results of the present study. Similarly, Wang et al. [16] investigated crude oil tanks fire and explosion types using a hybrid technique of fault tree analysis and fuzzy set theory.

In order to reduce, control, and determine the hazardous consequences, deterministic and probabilistic risk assessment approaches were applied in various industries. These approaches were evaluated in the study by Ghasemi et al. [17] and concluded that the probabilistic approach was more reliable than deterministic approach.

Events initiative and its probable consequences are those important criteria to reduce risk cost. Having considered these factors, Ouache et al. [18] used the Bow-tie analysis based on fault tree analysis and event tree analysis method to solve weakness of assessment problem in Petroleum Company.

Furthermore, Mirzaei et al. [19] investigated gas storage reservoirs in processing industries using the Papion method and; ultimately they found the overflow of reservoirs as one of the most important risks.

Shaluf et al. [20] in their study proved that fire was the most important risk for oil storage tanks which was in line with the present study.

Oil tanks environmental risk such as wastewater, hazardous waste, dangerous steam and gas emission is extremely critical. In a study, Josi et al. [21] showed that the incorrect ground connection had the highest risk priority value while pipeline corrosion had the lowest risk priority. Besides, Rezaian et al. [22] tried to determine and prioritize hazards and risks in refineries and industrial companies to ultimately reduce accidents. So, the results of their study showed that the toxic gas inhalation was the main risk which was determined a low risk in the current study.

Based on the considerations of National Iranian Oil Company passive defense guideline [23], the most important identified threats, including non-compliance with the principles of passive defense in the correct location for the establishment of industrial estates were determined as the highest priority. However, there were identified some weaknesses from the passive defense prospective also according to existing guidelines in the industrial town including lack of information on chemicals and chemical accidents in the country, weakness in inter-sectoral coordination in accident management, lack of accident prevention and management programs, insufficient training of employers, employees and training of locals, weakness in forecasting and providing necessary equipment and facilities to control chemical accidents in industrial estates, failure to anticipate alternative routes, non-compliance with the principles of passive defense during the construction and operation of industrial estates, incomplete implementation of health attachments within industrial estates, lack of emergency helicopter landing runways, alternative routes for ambulances, shelter and safe places to use at the time of the accident, lack of a chemical database in industrial estates, lack of special telephone number for chemical accidents, lack of maneuvers in industrial estates, lack of monitoring of waste disposal and industrial effluents. After identifying, quantifying, and prioritizing risks, a risk response program was needed to outlines the risk management strategies before the occurrence. Among the corrective proposals to reduce effects and the occurrence of risk can be: strengthening engineering controls and safety equipment, using safety signs in high-risk areas, developing and implementing accident management programs, compiling and implementing inspection protocol, development and implementation of repair programs, storage of tanks and equipment, installation of monitoring systems, tracking, announcing and controlling the temperature of tanks, establishment of appropriate automatic fire extinguishing system, establishment of emergency chemical evacuation system at the time of accident, labeling of chemicals, provision of chemical safety sheets in access to staff training and the use of fire alarm and extinguishing systems, the use of thermal, smoke and flame sensors in tanks to alert personnel in the event of an increase in temperature or accident, the use of passive defense criteria to counter deliberate and terrorist actions based on principles of camouflage, concealment, cover-up, deception, retroactive and news reporting. American Petroleum Institute (API) recommended practices about oil tanks, refineries, pipeline, and similar facilities containing Class I or Class II petroleum liquids. These practices suggest an emergency shout down, high-level detection devices, independent and automatic high-level detection system to prevent overfilling of tanks [24].

Similarly, Mohamad Fam et al. [25] suggested to install a system on the bottom of the tank to direct possible leakage to the network created inside the site and avoid wasting. It is also recommended also to check sealing connections and leaks, regular and accurate preventive maintenance program to avoid any leakage of liquids or vapors resulting from it (such as calibration and annual testing of safety valves). Appropriate personal protective equipment (PPEs) use in accordance with the standards (appropriate gloves and masks) also, one of the main measures of the officials to examine the aspects of passive defense in establishing and operating industrial towns and the obligation of chemical industries to evaluate the existing risks and implement a to prevent, control, and continuous inspections of the program during the industrial process [26].

It is suggested for similar studies to be conducted in all industrial estates with a passive defense point of view in order to determine the vulnerability of industrial estates as well as authorities to focus on reducing threats and dealing with chemical incidents vulnerabilities in the whole country using the appropriate policies and future planning.

In the present study, the FMEA and William-Fine binoculars were used to assess oil tanks' risk. In future research, it is suggested to practice other methods such as HAZOP, AHP, and improved William-Fine.

CONCLUSION

In the current study, according to the study unit, the advantages of FMEA and William-Fine techniques were used to identify and evaluate the safety and health risks of aromatic hydrocarbon storage tanks. The strengths and weaknesses of the region from the perspective of passive defense also were assessed by examining the parameters affecting security and reducing vulnerability. In this study, a qualitative evaluation was done from the perspective of passive defense, so it is recommended to determine the quantitative criteria for evaluating the security indicators and reduce vulnerability in industrial estates.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest in this study.

REFERENCES

1. Pipeline and Hazardous Materials Safety Administration's Yearly Incident Summary Report. United States Department of Transportation Pipeline and Hazardous Materials, Safety Administration Office of Hazardous Material Safety. 2019. Available at https://portal.phmsa.dot.gov/PDMPublicReport and accessed (06/06/2019).
2. Hollnagel E. Human reliability analysis: context and control. New York: Academic Press; 1993.
3. Bentley T, Haslam R. A comparison of safety practices used by managers of high and low accident rate postal delivery offices. *Safety Science*, 2001; 37 (1):19-37.
4. Abbas pour M, Hosseinzadeh Lotfi F, Karbassi AR, Roayaei E, Nikoomaram H. Development of a model to assess environmental performance, concerning HSE-MS principles. *Environmental Monitoring and Assessment*. 2010; 165: 517-528.
5. Nivolianitou Z. Risk Analysis and Risk Management: A European in sight. *Law, Prohability and Risk*. 2002; 1(2):161- 174.
6. Michelle M, Cowing M, Elisabeth P, Peter W. Dynamic modeling of the tradeoff between productivity and safety in critical engineering systems. *Reliability engineering and system safety*. 2004; 86: 269- 284.
7. Vazdani S, Sabzeghabaei Gh, Dashti S, Cheraghi M, Alizadeh R, Hemmati A. FMEA Techniques Used in Environmental Risk Assessment. *Environment & Ecosystem Science (EES).* 2017, 1(2), pp: 16-18
8. Ghahramani A, Adl J, Nasl S.J. Risk Assessment in Gas Sweeping Unit, Gas Refinery. *Journal of School of Public Health and Institute of Public Health Research*. 2005, Volume 3, Number 4(12); pp: 41-50.
9. Hekmatpanh M, Naseri M, Ghodoosi H.H, Amini H. Assessment of Isfahan's Industrial Estate on Passive Defense. *Geography Journal*. 2016; Vol.16, No.50, pp: 327-344.
10. Tousi N.S. Assessing Impacts of Passive Defense Policies Interventions on Spatial Logic of Tehran Metropolitan Area (TMA). *Proceeding REAL CORP* 2013. 2013.
11. Heydari M., Omidvari M, M Fam I. Presenting of a material exposure health risk assessment model in Oil and Gas Industries (case study: Pars Economic and Energy Region). *JHSW*. 2014, 3 (4), pp: 11-22.
12. Hosseini A.H, Eshgh A.F, Mahmoud K.M, Hosseini M. Evaluation of an industrial town from the perspective of passive defense, 11th Iranian Geographers Congress, Tehran, Iran Geographical Association, Shahid Beheshti University, 2011. [Persian]. https://www.civilica.com/Paper-IGAC11-IGAC11_183.html
13. Nasiri Gh, Nariman Nezhad A, Rafiee M, Javadi Moghadam M. Safety & Firefighting Procedures in Petrochemical Industries Handbook. Hagh publications. 2nd edition. Tehran. 2013. [Persian].
14. Kandahari, Mohammad, Motof Sh, Andalib A. Assessing the risks of industrial estates and managing them with the principles of passive defense, case study: Barakat Pharmaceutical Industrial Estate, 3rd National Conference on Metropolis Management with Safety, Health and Environment Approach, Tehran, Faraand Sazeh Company Installation buildings. 2017. https://www.civilica.com/Paper-MMCONF03 MMCONF03_043.html
15. Amanat Yazdi L, Moharamnejad N. Environmental Risk Management of Fire in Oil Warehouses and Storage Tanks - case Study: Central Storage of Yazd Oil Products Distribution Company. *Journal of Environment Science*. 2013; 2: 61-72. [Persian].
16. Wang D, Zhang P, Chen L. Fuzzy Fault Tree Analysis for Fire and Explosion of Crude Oil Tanks, *J of Loss Preven in the Proc Indus*. 2013, 26(6), pp: 1390- 98.
17. Ghasemi Sh, Yavari K, Mahmoudvand R, Sahabi B. Comparing two Different Views to the Application of FMEA Method for Risk Assessment: A Case Study of Iran's Gas Refinery. *QEER*. 2014; 10 (42), pp: 135-159.
18. Ouach R, A. J. Adham Ali. Reliability Quantitative Risk Assessment in Engineering System using Fuzzy Bow-Tie. *Int J Curr Eng Technol*. 2014; 4(2), pp: 117-23.
19. Mirzaei aliabadi M, Mohammad FAM I, Kalatpour O, Babayi mesdaraghi Y. Risk assessment of liquefied petroleum gas (LPG) storage tanks in the process industries using the Bowtie technique. *johe*. 2016; 3 (2), pp: 1-11.
20. Shaluf I, Abdullah S. Floating Roof Storage Tank Boilover. J of Preve in the Process Indus. 2011; 24(1), pp: 1-7.
21. Josie A, Karim Jozani M. Oil Storage Environmental Risk Assessment using AHP and EFMEA Integrated Approach- a case study, First National Conference on Environment, Energy and

Biolo Defense. 2013; 1: 1-10. [Persian]. https://www.civilica.com/Paper-ECONF01-ECONF01_103.html
22. Kabouli S.S, Jozi S.A, Zayeem Dar M. Evaluating Health Safety and Environmental Risks in an Oil Refineries Using AHP and FMEA methods, Published in 5th International Conference on Citizen HSE, 2017. [Persian]. https://www.civilica.com/Paper-SRBIAU05-SRBIAU05_013.html
23. National Iranian Oil Company's Health, Safety, and Environment (HSE) guideline, Available at https://hse.mop.ir/portal/file/?309357/Final-96.pdf, accessed in 06/10/2020.
24. API STD 2350. American Petroleum Institute (API). 3rd Edition, January 2005.
25. Mohammadfam I, Kianfar A. Application of Hazard and Operability Study (HAZOP) in Evaluation of Health, Safety and Environmental (HSE) Hazards (Case Study: Oil Storage of National Iranian Oil Products Distribution Company). *Journal of Environmental Science and Technology*, 2010; 12(1): 39-49.
26. Alizadeh A, Mehdi Gholami MH, Derafshi S. Risk assessment of chemical storage and storage tanks in a petrochemical company and its effects on adjacent residential and industrial areas. *Journal of Safety Message*. 2011; 8(29): 6-15. [Persian], Available at magiran.com/p864364

ATTACHMENTS

Table 3. FMEA-identified risks rating

Risk score	Tracking score	Probability of tracking an accident	Intense score	The severity of the occurrence	Probability score	The probability of an accident	Existing risks	The cause of the risk

Table 4. Scoring table for identified risks by William-Fine method

Risk score	Probability score	The probability of an accident	Intense score	The severity of the consequences	Confrontation score	The amount of exposure	Existing risks	The cause of the risk

Table 5. FMEA quantification intensity table

Value	Descriptive phrase
10	Complete system failure / death / very severe injuries / very severe impact on the entire industrial settlement, region, environment
9	Damage to the system is severe / severe injuries / severe impact on the entire industrial settlement, region, environment
8	Damage to the system is very high / Relatively severe injuries / Relatively severe impact on the entire industrial settlement, region, environment
7	Damage to the system is high / Medium injuries / Medium impact on the entire industrial settlement, region, environment
6	Damage to the system is moderate / low injuries / low impact on the entire industrial settlement, region, environment
5	Damage to the system is low / Very little damage / Very little impact on the entire industrial settlement, region, environment
4	Damage to the system is very low / minor injuries / minor impact on the entire industrial settlement, region, environment
3	Damage to the system is very minor / Very minor injuries / Very minor impact on the entire industrial settlement, region, environment
2	Damage to the system is insignificant / Minor injuries / Slight impact on the entire industrial settlement, region, environment
1	Possible damage to the system and individuals and the environment can be ignored.

Table 6. FMEA quantification probability table

Value	Descriptive phrase
13	Accidents or defects are very, very likely (once a day or more)
12	Accidents or defects are very likely (every 3 to 4 days)
11	The probability of an accident or defect is very high (once a week)
10	The probability of an accident or defect is high (once a month)
9	There is a possibility of an accident or moderate defect (once every 3 months)
8	The probability of an accident or defect is low (every 6 months to once a year)
7	The probability of an accident or defect is very low (once a year)
6	Rare accident or defect (every 1 to 3 years)
5	It is very unlikely that an accident or defect will occur (every 3 to 5 years).
4	The probability of an accident occurs every 5 to 10 years
3	The probability of an accident is once every 10 to 20 years
2	Incidents occur every 20 to 30 years
1	Incidents occur every 30 to 50 years

Table 7. FMEA probability tracking quantification table

value	Descriptive phrase
10	Lack of any tracking system and no operator
9	Objective and random tracking
8	Random tracking of measuring instruments
7	Objective and periodic tracking
6	Tracking with measuring instruments periodically
5	Tracking with measuring instruments permanently
4	Automatic tracking with visual or auditory alarms
3	Automatic tracking with visual and auditory alarms
2	Automatic tracking with alarm and control system
1	Automatic tracking with alarm and simultaneous control with the controller system and operator

Table 8. The severity of the consequence (C) by William-Fine method

Rate	Classification
100	Numerous deaths - long cessation of activity - catastrophic
50	Several deaths - between $ 40,000 and $ 100,000 in damages
25	Mortality, damage between $ 100,000 and $ 400,000
15	Severe injuries (amputation - permanent disability) Damage between $ 1,000 and $ 100,000
5	Moderate injuries - damages up to $ 1,000
1	Injuries and minor injuries

Table 9 William-Fine (E) exposure rate

Rate	Classification
10	Constantly (a few with a day)
6	Repeatedly (once a day)
3	Occasionally (once a week or month)
4	Once a year
1	Rare (may occur during system life)
0.5	It is very unlikely to happen

Table 10. Possibility of occurrence (P) by William-Fine method

Rate	Classification
10	In the event of an accident, the risk is quite expected
5	It is quite possible - the chance of its occurrence is 50%
3	It will be an accident and an unusual case
0/5	After several years of exposure, it does not occur, but sometimes it may occur
0/1	An unintended consequence (not happening at all)

Table 11. Risk score and control measures by William-Fine method

Rate	Necessary activities
200-1500	Immediate corrective action - stop the process until the risk is reduced
90-199	It needs to be reviewed and considered as soon as possible
0-89	The risk must be eliminated without delay, but it is not an emergency

Table 12.Estimated cost for corrective activities (CF)

Rate	Classification
10	More than $ 50,000
6	$ 50000-25000
4	$ 25,000-10000
3	10000-1000 dollars
2	$ 1000-100
1	$ 25-100
0/5	Under $ 25

Table 13 Degree of correction (the amount of risk reduced) DC

Rate	Classification
1	100% risk is eliminated
2	At least 75% of the risk is eliminated
3	75-50% risk is eliminated
4	50-25% risk is eliminated
6	Less than 25% of the risk is eliminated