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A Hybrid Approach Based on AHP and FMEA Approaches for Risk Assessment of Refinery Construction Projects

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ABSTRACT

Through risk assessment, very valuable data was provided for decision making about risk reduction, improvement of the surrounding environment of hazardous installations, planning for emergency conditions, acceptable risk level, inspection and maintenance policies in industrial installations, and other cases. The gas and petrochemical industries have always been considered by the safety and environment experts and professionals, because of their numerous and widespread hazards. The purpose of this research was to assess the risk ratio of the phases of 17 and 18 refineries of Asaluyeh. The research method used in this research was descriptive-analytical, and multi-criteria models (hierarchy analysis) and FMEA risk assessment model were used. The results of this research indicated that the risk of oil and gas installations infrastructure in the phases of 17 and 18 refinery, for a hard and special threat meant that the occurrence probability of air and missile attacks and cyber attacks and bombing in such installations were located at the primary degree of threats.

Keywords: Threat, Risk Assessment, Hierarchy Analysis, Construction Project.

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1. INTRODUCTION

During the recent several decades, the occurrence of horrific events such as Bhopal in India, Chernobyl in Ukraine, Flixborough in England, and Suso in Italy have attracted the public's attention to the chemical industries and various risks existing in them and, consequently, have increased the necessity of a systematic analysis of the safety of various processes in the chemical industries (Eskandari, M, et al., 2015: 19).

Considering that oil, gas and petrochemical storing reservoirs are regarded as important and basic infrastructures, this industry has always been considered by the safety and environment experts and professionals (Bashiri Nasab, 2009: 1-11). In gas refineries, operational units deal with high temperature and pressure, and consequently, there is a probability of occurring events (Josie A, et al., 2013: 1-13). In the case of war occurrence and bombardment in cities, in a very short time, the functional system of infrastructural installations gets damaged (Hakim Panah, 2009: 103). These installations are created and exploited at a high cost that damaging them causes the pause of production and delivering services to the citizens, and the economic and social losses (JICA, 2000: 63). More than two thirds of threats are nowadays focusing on infrastructures and vital arteries, and the important role of vital arteries in the comprehensive management of urban crisis and the close link between these networks with each other on the one hand, and their economic value on the other hand makes us pay special attention to them (Lee et al., 2007: 29). Therefore, defending the vital infrastructures of every community is one of the determinant presuppositions for the survival of that community. Nonpassive defense in vital arteries is a set of measures that protect such centers against deliberate man-made threats. Assessing the vulnerability and risk of vital arteries, and observing the non-passive defense principles is the only guarantee for their salvation against threats.

Risk assessment is a logical method to investigate risks that identifies the hazards and their potential consequences on individuals, materials, equipment and environment. In fact, in this way, very valuable data is provided for decision making about risk reduction, improvement of the surrounding environment of hazardous installations, planning for emergency conditions, acceptable risk level, inspection and maintenance policies in industrial installations, and other cases (Nivolianitou, 2002). Risk assessment can be done by two qualitative and quantitative methods. A quantitative assessment focuses on risk factors and taking preventive measures, and is performed to control, eliminate or prevent hazards. In this regard, a scientific approach for decision making is required for the justification of costs, prevention and reduction of risk, and the necessity of rapid risk control programs. Accordingly, the purpose of this research was to evaluate the refineries construction projects based on the passive defense perspective, and the question that the researcher analyzed and investigated was how the risk

assessment of the South Pars phases 17 and 18 assets is on the basis of human-made threats.

2. RESEARCH HISTORY

Nouri et al. (2010) investigated the gas stations in order to assess the fire occurrence risk, and eventually, by combining the William Fine and FMEA methods, determined fire intensity at the stations (Nouri J, et al. 2010, 143-152).

Ebrahimzadeh et al. (2011) concluded in a research that the highest level of RPN score in the activities of transporting and replacing objects and the section of scraping external surfaces preceded and followed by corrective measures were (200, and 210), (72, and 84); respectively, while the priority score of risk in the welding and external drilling activities before and after the corrective measures was the RPN score of (144 and 120) and (24 and 36); respectively. In a research, Adl et al. (2013) concluded that the implementation of preventive repairs of a unit, the preparation and accurate implementation of these repairs can be the most important suggestion that can lead to the risk reduction by decreasing the probability of occurrence.

Eskandari et al. (2015), in a research by introducing water and electricity arteries and by using two models of graph theory and the Leontief model, counted 240 scenarios to assess the vulnerability and risk of these arteries, and among the singlevariable scenarios, the explosion scenario in the purification unit, and among the combination scenarios, two purification units and an electricity station had the highest probability of occurrence (Eskandari et al., 2015: 19).

Mohammad Ataee (2014) in a research, evaluated airport key assets, airport threats, and airport vulnerability (Ataee, 2014: 22). Wang et al. (2013) in a research showed that the use of insulating layer in the interior and exterior walls of the design of reservoirs reduced their potential vulnerability during the earthquake (Wang D et al., 2013, 110).

Chang & Chang (2011) studied the incident in the industrial installations storing reservoirs in the last 40 years. Their results showed that 74 percent of the incidents occurred in oil refineries, oil terminals and their storage (Chang & Chang, 2011: 51). Millazzo and Maschio conducted a study in Italy in 2008 that considered most of the transportation systems of hazardous materials (Millazzo and Maschio, 2008: 37). Catalina and Cioaca (2013) in a research investigated the event probability of threats in the airport, especially passenger terminals, and offered solutions to neutralize or reduce the effects of terrorist threat on terminals (Cioaca, 2013: 82)

3. RESEARCH METHOD

This research has been of analytical-evaluation type. To investigate the research question, the Vulnerability Assessment Model and the Federal Risk Management of Emergency Management Agency (FMEA¹) and also in the section of valuating and weighing the research criteria, L. Saaty Network Analysis Model were used. In order to validate the results, in the first step, assets, threats, and vulnerability indicators were weighed. In order to weigh the indicators after setting the questionnaire, they were distributed, and their

results were extracted by using the Analytical Hierarchy Process (AHP) technique in Expert Choice software. After weighing the assets of the phases of 17 and 18 refineries of South Pars Site One, in the next step, based on the FMEA risk assessment model, the researchers obtained the weights of each asset that were extracted in the previous stage among the threats that endangered the equipment of the region. In the following part, the table of threats has been represented.

Table 1: Probability of Threat Occurrence ((Research	Findings
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No.	Threat type	Туре	Implemented Threat Method	Occurrence Probability		
1	Tool Hard		Hard Tool oriented Air and missile attacks Chemical, microbial, nuclear attacks			
		Method oriented	Marine attacks, regular ground attacks			
2	Sem	i-hard	Attacks by electromagnetic, graphite, sound bombs			
	Soft threat Non- security		Spy and human influence and so on			
3			Soft threat Unsafe demonstration, chaos			
			Economic sanction, cultural invasion, psychological operation and so on			
		Modern	Cyber terrorism and so on			
		terrorist	Bioterrorism			
	Special		Threat to bombing and its implementation			
4			Suicide attacks and remote control explosive shipments and so on			
	urreats	threats Classical terrorism	Urban punitive attacks and so on			
			Hostage taking , kidnapping and so on			
			Murder, assassination and so on			

Having prioritized the threats of the equipment of the region, in the next step, the vulnerability assessment of the region's assets against potential threats based on the confrontation weakness, defensive and protective weakness, access possibility, and the possibility to discover and identify were determined.

Hence, for each asset, a risk matrix was formed. In the risk matrix, having the numbers of assets, threat and vulnerability obtained from the previous sections, the final number of risk was obtained. In the assets, risk matrix of the region, in one dimension of matrix, the numbers related to risk components and in another dimension, the screened threats were located, so that ultimately the risk ratio of each asset against each threat was clearly specified. The obtained risk numbers carried useful conceptual outcomes, but it must have been specified what is the meaning of highness or lowness of risk numbers, that here, there was a need for the existence of a scale for the interpretation of the numbers, as have been shown in the table below (Table 2).

¹ Failure Mode and Effects Analysis

Table 2.	Einel	Coolo	of Diele	Degree	(Ialali	2012.07	`
Table 2:	гша	Scale	OI KISK	Degree	Ualall,	2013.07)

Scale	Score	Commentary	Grouping	
Too high	600-1000	The asset is severely		
U		prone to risk	Group 1	
High	250-600	The asset is highly prone		
	100 000	to risk		
Medium and	200-250	The asset is very prone to		
upward	200 250	risk		
Medium	150-200	The asset is relatively		
Medium	150-200	prone to risk	Group 2	
Medium	100-150	The asset is a little prone		
downward	100 150	to risk		
Low	50-100	The asset is very little		
LOW	50 100	prone to risk		
		The asset is rarely prone	Group 3	
Very low	1-50	to risk and is not worth to		
		be invaded		

4. RESEARCH FINDINGS

For risk assessment of the infrastructure of the phases 17 and 18 of refinery, the indicators of this section of the macro objectives of the project were used. On this basis, the following indicators have been considered for this step of studies (Table 3).

Table 3: Infrastructures of the Phase 17 band 18 of Refinery

	Installations and assets					
Administrative-	Administrative buildings					
service installations	Firefighting unit					
Oil and gas installations	Clotting					
	Desulphurization and					
	Dehumidification unit					
	Bhutan Reservoirs					
	Liquid gas reservoirs					

Unit of injecting Methane to the
main line
Methane, Ethan, Propane and
Bhutan separation unit and making
them cool
Cooling Tower unit

In the second stage, after recognizing and forming the tree structure of hierarchical analysis model, two components of administrative-service installations, and oil and gas installations were entered into the Expert Choice software for the formation of paired matrix, which its stages have been addressed below. In the first step of the hierarchical analysis model, the formation of hierarchical structure related to the subject has been addressed (Table 4).

Table 4	Infrastructures	of the	Phase 17	and 18 o	of Refinery
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	Installations and assets			
Administrative-	Administrative buildings			
service installations	Firefighting unit			
	Clotting			
	Desulphurization and Dehumidification			
	unit			
Oil and gas	Bhutan Reservoirs			
installations	Liquid gas reservoirs			
Instanations	Unit of injecting Methane to the main line			
	Methane, Ethan, Propane and Bhutan			
	separation unit and making them cool			
	Cooling Tower unit			

At this stage of the hierarchical analysis model, the formation of a paired matrix between the criteria was addressed. According to the extracted results, it was specified that the criterion of oil and gas installations with the weight equal to 0.667 value has allocated the highest score ratio to itself, and in the second rank, the criterion of administrative-service installations was located with the weight equal to 0.33. The importance coefficient of the criteria has been shown in the diagram below.



Diagram 1: Determining the Importance Coefficient of the Criteria

In this stage of the model, the importance coefficient (weight) of the sub-criteria was determined, and the sub-criteria of each of the criteria were compared in pair. The results showed that the sub-criterion of "administrative buildings" with the weigh equal to 0.66 value has allocated the highest weight, and the sub-criterion of "firefighting unit" with the weight equal to 0.33 has allocated the second rank to itself.



Diagram 2: Determining the Importance Coefficient of the Sub-Criteria of Administrative-Service Infrastructure

The results extracted from the determination of the importance coefficient of the sub-criteria of oil and gas installations indicated that the "liquid gas reservoirs" sub-criterion with the weight of 0.24 values has allocated the

highest weight to itself. Also, the sub-criterion of "Bhutan reservoirs" with the weight equal to 0.22 has allocated the second rank to itself.





After determining the importance coefficient of the criteria and sub-criteria, the importance coefficient of the options has been determined. The results extracted from the hierarchical analysis model showed that the functional value with the score equal to 0.525 has allocated the first rank among the options to itself. In the second rank, the replacement value with the score equal to 0.27 and, finally, the economic value with the score equal to 0.2 was located. The diagram below shows the final score matrix of assets value indicators.



Diagram 4: Determining the Importance Coefficient of the Options

In the following, in order to accurately investigate the results of asset value, threat and vulnerability in the first step, the assets, threats and vulnerability assessment indicators that were weighted in the previous stage should be implemented in the assets of the phases of 17 and 18 of refinery.

Table 5: Assets Value of the Infrastructure of the Phase of 17 and 18 of Refinery by Implementing the Weight of Indicato
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Assets values indicators	Economic value	Functional value	Replacement value	Total scores	Assets priority and importance
Key assets	0.2	0.525	0.257	Total scores	degree
Administrative-service	8	6	7	21	Second
installations	1.6	3.15	1.925	6.675	Second
Oil and gas installations	10	9	8	27	First
On and gas instantions	2	4.725	2.2	8.925	FIISt

The results obtained from the table indicated the dependence ratio of the activity of the phases of 17 and 18 of refinery in Asaluyeh region on the assets listed in the table above, in a way that asset dependency had a direct relationship with the obtained scores.

Table 6: Threats Values of the Infrastructure of Phases 17 and 18 of Refinery by Implementing the Weight of Indicators

Threat type	Туре	Threat instances	Severity of damage	Enemy's ability	Target attractiveness	Total	Prioritizing	
		Indicators weight	0.591	0.146	0.263	500105		
Hard	Tool oriented	Missile and air attacks	9	10	8	27	First	
rooroneneu			5.319	1.46	2.104	8.883	i ii St	

		Chemical, microbial, and	10	9	8	27	Second	
		nuclear attacks	5.91	1.314	2.104	9.328	Second	
	Method oriented	Marine attacks, regular	9	9	3	21	Fifth	
	Method offented	ground attacks	5.319	1.314	0.789	7.422	I'IIUI	
	Semi hard	Attacks with electromagnetic,	5	9	8	22		
		graphite, sound bombs and so on	2.955	1.314	2.104	6.373	Eighth	
		Spy and human influence and	2	8	5	15	Twolfth	
		so on	1.182	1.168	1.315	3.665	iweirth	
	Security	Unsafe demonstration,	4	2	1	7	Eleventh	
Soft		turbulence and chaos and so on	2.364	0.292	0.263	2.919		
uneaus	Non-security	Technical sabotage	5	4	3	12	Tenth	
		Technical Sabotage	2.955	0.584	0.789	4.328	Tentin	
		Economic sanction,	6	9	9	24	Seventh	
		psychological operation	3.546	1.314	2.367	7.227	beventin	
		Cuber Terroriem		8	7	23	Sixth	
	Modorn torrorism	Gyber rentonisin	4.728	1.168	1.841	7.737	JIXII	
	Modelin terrorism	Biological threats	9	8	8	25	Third	
Special threats		Diorogical till cato	5.319	1.168	2.104	8.591		
		Threat to bombing and	7	8	8	23	Fourth	
	Classic	implementing it	4.137	1.168	2.104	7.409		
		Suicide attacks and remote	6	6	5	17	Ninth	
		control explosive shipments	3.546	0.876	1.315	5,737		

As can be observed in the table above, threats like air and missile attacks, biological threats and bombing, chemical and

microbial threats in the phases 17 and 18 of the refinery had the highest scores.

Table 7: Vulnerability Assessment of the Oil and Gas Installations of the Phases 17	and 18 of Refinery against Probable Threats
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Threat type	Threat instances	Confrontation weakness	Defensive and protective weakness	Access possibility	Possibility to discover and identify	scores	tizing
	Oil and gas installations threats	0.242	0.092	0.63	0.036	Total :	Priori
Hard	Missile and air attacks	9	8	7	8	32	Second
maru	MISSINE and an attacks	2.178	0.736	4.41	0.288	7.612	Second
Semi hard	Electromagnetic bombs	2	1	1	3	7	Fourth
		0. 484	0.092	0.63	0.108	1.314	
	Spy and human influence,	3	2	2	4	11	
Soft	technical sabotage and economic sanction	0.726	0.184	1.26	0.144	2.314	Third
	Threat to bombing and	9	10	8	8	35	
Special	implementing it, suicide attacks and explosive shipments	2.178	0.92	5.04	0.288	8.426	First

As it can be observed in Table (7), the infrastructure of oil and gas installations primarily, had the highest ratio of vulnerability against bombing threat and implementing it, suicide attacks and explosive shipments, and then missile attacks.

Threat type	Threat instances	Confrontation weakness	Defensive and protective weakness	Access possibility	Possibility to discover and identify	rotal cores	ioritizi ng
	Oil and gas installations threats	0.242	0.092	0.63	0.036	τ N	Pr
Hard	Missile and air attacks	8	8	6	7	29	Second
Haru	MISSILE allu all attacks	1.936	0.736	3.78	0.252	6.704	Second
Semi	Electromagnetic and graphite	8	7	3	5	23	Third
hard	bombs	1.936	0.644	1.89	0.18	4 .65	Third
	Spy and human influence, technical	5	4	4	5	18	
Soft	sabotage and/or economic sanction	1.21	0.368	2. 52	0.18	4.278	Fourth
Special	Cyber terrorism, biological threats,	10	6	8	8	32	First
opeciai	bombing and implementing it	2.42	0.552	5.04	0.288	8.3	1.1.50

rabie of famerability against frobable fine and the fine and to of footblot footblot fine against frobable fine and the fi	Table 8: Vulnerabilit	y Assessment of Administrative	Service Installations of the Phases o	f 17 and 18 of Refinery against Probable Threats
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As can be observed in Table (8), the infrastructure of the administrative service installations primarily had the highest ratio of vulnerability against the cyber terrorism threat, biological threats, bombing and implementing it, then the air and missiles attacks threat. The threat of electromagnetic, graffiti bombs was located in the third place, and spying and human influence, technical sabotage and/or economic sanctions were located in the fourth place.

In the risk matrix of the assets of the phases 17 and 18 of refinery, in one dimension of the matrix, the numbers related to the risk components, and in another dimension, the screened threats were located, so that eventually the risk ratio of each asset against each threat was clearly specified (FEMA A452, 2005, 208). The obtained risk numbers carried useful conceptual outcomes, but it must be specified what the

highness or lowness of the numbers of risk mean, that here, the existence of a scale for the interpretation of risk numbers was needed. This scale has been available in Document No. 452 related to Federal Emergency Conditions Management Agency of the United States of America, but the scale provided in that document, regarding the threats from the United States, could not naturally be an accurate and documentable scale for the threats of the domain of this research. Because the present research was carried out for the infrastructures of the phases of 17 and 18 of refinery in the Islamic Republic of Iran, that the nature of threats affecting them was different. So a native scale that is documentable results, the observable scale was compiled in the tables below, and was regarded as the analogy basis for the risk analysis of the phases of 17 and 18 of refinery.

Table 9: Final Scale of Risk Degree

Scale	Score	Commentary	Grouping
Too high	600-1000	The asset is severely prone to risk	Group 1
High	250-600	The asset is highly prone to risk	droup 1
Medium and upward	200-250	The asset is very prone to risk	
Medium	150-200	The asset is relatively prone to risk	Group 2
Medium downward	100-150	The asset is a little prone to risk	
Low	50-100	The asset is very little prone to risk	Group 3
Very low	low 1-50 The asset is rarely prone to risk and is not worth to be invade		droup 5

Table 10: Determining the	Assets Risk of the Infrastructure	of the Phases 17 and 18	of Refinery against Threats
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Assets of the		Hard threat	Semi- hard threat	Soft threat	Special threat
phases of 17 and		Air and missile	Electromagnetism	Sabataga canction	Cubor bombing
18 of refinery		attack	and graphite	Sabotage-Saliction	Cybei-boilibilig
	Threat number	8.88	6.37	4.32	8.59
Oil and gag	Asset number	8.92	8.92	8.92	8.92
installations	Vulnerability number	7 .62	1.314	2.31	8.42
	Risk number	603.5772	74.66201	89.01446	645.164
	Degree of risk	1	3	3	1
	Threat number	8.88	6.37	4.32	8.59
Administrative- service installations	Asset number	6 67	6.67	6.67	6.67
	Vulnerability number	6.7	4.65	4.27	8.3
	Risk number	396.8383	197.5687	123.0375	475.551
	Degree of risk	1	2	2	1

The risk of oil and gas installations infrastructure in the phases of 17 and 18 of refinery for hard and special threat meant that the probability of air and missile and cyber attacks and bombing in such installations has been located in the primary degree of threats.

5. CONCLUSION

Establishing infrastructure installations and projects at the regional and district levels without complying with and compiling their criteria and risk assessment have caused them to be exposed to natural and human threats. This meant that the main purpose of risk assessment management plans was to create and expand removing the barriers and weaknesses of equipment and assets, and to select the optimal location of resources in all regions and sectors of the country. The results of the risk assessment of the South Pars Phases 17 and 18 of Refinery showed that risk assessment for hard and special threats meant that the occurrence probability of air and missile and cyber attacks and bombing in such installations has been located in the primary degree of threats. In other words, if the enemy intends to destroy and destruct the oil and gas infrastructure, the most probable option is to use a hard and special threat. Semi-soft and soft threats, in spite of having third degree of risk, had low and very low probability. Also, the emergence probability of semi-hard threats, such as electromagnetic or graphite bombs, to destroy the oil and gas infrastructure was poor. In the risk of administrative - services infrastructure at the phases of 17 and 18 of refinery, for hard and special threat meant that the occurrence probability of air and missile and cyber attacks and bombing in such installations was located at the primary degree of threats. Also, semi-hard and soft threats, in spite of having a second degree of risk, had low and very low probability compared with the first degree of threats.

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