Research Paper

Risk Assessment of Household Gas Heaters in Tehran During an Earthquake Crisis by Using the Fuzzy FMEA Model

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ABSTRACT

Background: A variety of gas heaters are used in residential, administrative, and commercial buildings in Iran. Home packages (HP) and central heating boiler rooms (CHBRs) are among the most common types of heating systems that can be damaged during earthquakes and, thus, harm the building and the residents.

Methods: By doing a survey and an interview in 50 residential buildings in District 16 of Tehran, the risks of these facilities were assessed during earthquakes from the viewpoint of the residents. To do the risk assessment, the failure mode and effects analysis (FMEA) model in the fuzzy space were applied. To analyze the risk priority number (RPN), defuzzification and the center of gravity method were used. Based on the results, 11 indicators were identified and evaluated for each system.

Results: The mean RPNs obtained for both systems were almost equal (the difference was about 2%). Thus, no definitive superiority can be presumed for HP or CHBR when earthquakes happen. The major difference in the risk of each system can be separately evaluated based on the conditions of each building, confidence about the quality of installation, connections, pipe materials, electric wire corrosion, etc.

Conclusion: It is suggested that the risks of CHBR and HP during earthquakes are the same, and some issues such as design, economy, and technical issues play a greater role in contractors' selection of the system.

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1. Introduction

Natural gas is a widely consumed source of energy whose application is rapidly growing. It is also a major source of urban energy. Natural gas supplies the energy required for heating and cooking in buildings. Therefore, the wide-ranging, expansive, and highly dispersed consumption of this energy source at the urban level is an environmental pollution challenge that has so far been neglected. Natural gas often comprises methane and small amounts of heavier hydrocarbons such as ethane, propane, butane, pentane, and C_6 [1]. In some states, natural gas contains small amounts of hydrogen, CO_2, nitrogen, oxygen, sulfur compounds, and water. The thermal value of natural gas depends on the percentage of hydrocarbons and inert gases in it, and lies in the 800-1200 BTU/SCF range based on its quality. The quality of natural gas differs based on its constituents' composition percentage [2, 3].

The quality and composition of fuels directly affect many combustion properties, the most important of which are the released heat rate, burning speed, excellent energy conservation tendency, and adiabatic flame temperature. The major contaminant sources of natural gas are heavy gases, hydrogen sulfide, hydrogen, CO, and CO_2. Due to the combustion of natural gas, different pollutants are released depending on the quality and composition percentage of its constituents. The most important pollutant is NOx; the quality and composition percentage of fuel constituents significantly affect the emission of pollutants, especially NOx and SOx [4].

The consumption of natural gas in a metropolitan such as Tehran is considerable due to the density of buildings and large residing population. In 2018, the average daily consumption of gas in Tehran Province was 77 million m^3, which is equivalent to the daily production of three phases of the South Pars/North Dome Gas-Condensate field. Between November and December 2018, a record of 122 million m^3 gas consumption was recorded in Tehran Province, which equals to the daily production of five phases of said field. Based on the data of the Gas Company in Tehran province, 50% of the gas sales belong to six million residential units in cities and villages; 25% (7 billion m^3) to power plants; 10% (2.5 billion m^3) to industries, and 15% to other sectors [5, 6]. Based on the available reports, the National Iranian Oil Refining and Distribution Company consumed 3.6 billion L of liquid fuel last year, apart from transportation; of this, 4.7 (165 million L of liquid fuel) was consumed in different residential sectors, factories, etc. It should be mentioned that ,except for transportation, 60 million L of the of liquid fuel belongs to the consumption of 400 casting workshops Tehran Province [7, 8].

Qualitative risk assessment is a reasonable method to determination of the quantity and quality of hazards as well as examination of the potential outcomes related to individuals, materials, equipment, and the environment. In fact, through risk assessment, the efficiency of existing control methods is specified, and valuable data are provided for decision-making on risk and hazard reduction, control system optimization, and responding plans [9].

Risk assessment is a major activity for many processes, including urban gas distribution networks for consumers [10]. In other words, the distribution network in the urban region forms a complex and sensitive network, and the accurate identification of the risks of this network is utmost importance. Awareness of these hazards as well as their risk assessment from the viewpoint of citizens provides an insight into urban residents' degree of comfort with regard to this distribution network and gas consumption.

Pipelines are among the most practical and safe methods to transfer the hazardous substances such as natural gas, though, this transfer method has always been exposed to different risk and hazards over time. Natural gas pipelines are often designed, built, used, and managed in an open environment. They are, therefore, exposed to various threats and unknown situations. These lines finally are connected to buildings for different purposes. In buildings, gas is mainly consumed for heating and cooking, for which different facilities are used in buildings. The major consumption of gas is heating the building. Currently, based on the technologies available in Iran, one or multiple systems (e.g. home packages (HP), central heating boiler room (CHBR), water heaters, and gas heaters) are used to supply water and air heating in the building.

Most studies on risk assessment of gas distribution networks and transfer pipelines have been conducted in urban areas. Based on the degree of importance, the large number of the studies can be justified. Some of these studies are reviewed below:

Moradi et al. assessed the risk of urban gas distribution network using analytic hierarchy process (AHP) in Sanandaj, Iran [11]. In the assessment, due to the lack of access to all the information and their weighting criteria, the AHP technique was used in order to do the risk management of urban gas distribution network. The results showed that the interference of real persons (i.e., the sub-category of causal indicators) and substance hazard (i.e., the sub-category of outcome indicator) had the maximum weight, while the pipeline pressure indicator had the minimum weight.

Ghandehari et al. identified and quantitatively assessed the risk of urban gas lines and determined the sensitive regions by proposing an integrated model [12]. They segmented the region's line network using appropriate indicators and possible incident scenarios about gas leakage using failure mode and effects analysis (FMEA) and event tree analysis (ETA) techniques. They estimated the final outcomes and probabilities of these scenarios by different human, financial, and social dimensions. In the study, the optimality functions of the outcomes were extracted using the concepts of optimality theory, as well. Accordingly, the risks of sections pertaining by each scenario were estimated using the functions and the calculated probabilities as well as equal units. Eventually, different parts of the region were ranked in terms of risk.

Few studies have been conducted on risk assessment of thermal and heating facilities in buildings. For instance, Karimi Asl assessed the risk of these facilities in religious buildings using FMEA [13]. This study tried to identify the hazards and assess the risks using FMEA in the mentioned buildings to enhance the individual and visitors' satisfaction and comfort.

Omidvari et al. assessed the risk of medical and treatment facilities in several hospital buildings resulting from flammable facilities [3]. In the study, a combination of fuzzy theory, multiple-criteria and decision-making models, and FMEA risk assessment method were used. Based on the results, some recommendations were made to promote the staff's safety, confidence, and comfort resulting from the hazards of CHBR and heating facilities.

Nouri et al. examined the accidents in academic buildings in Iran. One of the factors which was considered in the study was the gas heating facilities in the studied buildings [14]. In the study, the FMEA method was adopted, in which a set of general indicators related to the environmental, safety, and health domains of these buildings was examined based on the status quo of the visited samples. The findings, however, do not enable us to do the precise and detailed evaluation of the heating and gas facilities in the examined buildings.

To date, diverse methods have been applied for risk assessment. Based on the reviewed literature, the FMEA method is among the most widely-used risk assessment method. The FMEA model can be combined with various theories and models such as the fuzzy theory to enhance flexibility, improve uncertainty, and approach reality [15]. To date, various studies have been combined the methods, and their results showed that there is more precision compared to the classic FMEA model [9, 16-18].

The present study aimed to assess the risk of safety and environmental incidents resulting from building heating facilities during earthquakes from the viewpoints of the residents of district 9 in Tehran. This examination provides an insight into the sustainable development of heating and thermal facilities, including HP and CHBR in the buildings in Tehran. It also provides some information about the citizens' trust of the natural gas-related facilities, especially after earthquakes.

2. Materials and Methods

The FMEA model along with fuzzy theory was adopted in order to do the risk assessment and comparison. Fifty buildings were selected for field visits and completing FMEA questionnaires. The information collected by the questionnaires and interviews with the residents were used in this study. The buildings were randomly selected from district 9 in Tehran. It should be mentioned that because some buildings used different heating systems such as gas heaters and water heaters, they were excluded. Finally, 50 buildings with CHBR or HP were chosen. The FMEA method and fuzzy theory adopted in this study. They have been explained below:

Failure mode and effects analysis (FMEA)

FMEA is one of the most well-known methods of risk identification. The FMEA technique is a preventive and systematic method mainly aiming to determine the points and paths in which the performance of a system can be disrupted under specific and pre-defined conditions, thereby disrupting the efficiency of the entire system. In this technique, after finding these points, the reasons for these damages are examined, and eventually, their prevention is studied. In fact, this technique is used to maintain the system's health and safety [19].

FMEA is a systematic tool based on the working group employed for defining, evaluating, preventing, removing, or controlling the states, reasons, and effects of potential errors in a system, process, design, or service [20].

The Risk priority number (RPN) is composed of three values named severity (S), occurrence (O), and discovery probability (D) [21, 22] which is estimated using the Equation 1.

1. $RPN=S\times O\times D$

Table 1. Hazard severity

Rank	Magnitude of Effect	Details
10	Hazardous - without alarm	The severity is lamentable, e.g. risk of death and total destruction
9	Hazardous - with alarm	The severity is lamentable but comes with an alarm.
8	Very high	Severity is irreparable - impossibility of performing the main tasks and loss of a limb
7	High	Severity is high, e.g. burning of facilities and the body
6	Moderate	Severity is low, e.g. contusion and mild food toxicity
5	Low	Severity is very low, e.g. contusion and mild food toxicity
4	Very low	Severity is very low, but most people feel it, e.g. slight gas leakage
3	Minimal effects	Leaves minimal effects such as hand scratch during turning
2	Very minimal	It has a very minimal effect.
1	None	No effect

Hazard severity or the degree of novelty is the "potential hazard effect" on individuals. It is considered because of its "effect". Hazard severity can be reduced only through applying the changes in the process and performance of activities. To do so, there are some quantitative indicators ranging from 1 to 10. Table 1 presents the hazard severity [23].

The occurrence probability specifies the frequency with which the cause of a potentially hazardous mechanism can be defined (Table 2). The value of occurrence might be reduced only by eliminating or reducing the causes or mechanism of each hazard. The occurrence probability ranges from 1 to 10. The assessment of previous evidences is very useful. Assessment of control processes, standards, requirements, work regulations , and their application can greatly contribute to find the value [21].

Discovery probability is a type of capability assessment to identify a cause or a mechanism of hazard. In other words, the discovery probability is the ability to identify the hazard before its occurrence. Like previous probability, the examination of control processes, standards, requirements, work regulations, and their application can greatly contribute to find the value (Table 3) [21].

One of the problems of the FMEA method is to use of a crisp space for the scoring oriented from the type of human thinking system, the impossibility of error-free decision-making, and simplifying the interviews and questionnaires. Fuzzy theory is one of the most suitable methods for further flexibility of FMEA calculations and the uncertainty improvement of the questionnaires [24]. In this study, FMEA calculations were performed in the fuzzy space. The details have been provided below.

Table 2. Hazard occurrence probability

Hazard Occurrence Probability	Rank
Occurrence of an accident or defect is inevitable and highly probable.	10
	9
Probability of occurrence of an accident or defect is very high.	8
	7
Probability of occurrence of an accident or defect is moderate to low.	6
	5
	4
Probability of occurrence of an accident or defect is very rare or rare.	3
	2
Probability of occurrence of an accident or defect is improbable.	1

Table 3. Hazard discovery probability

Criteria	Discovery Capabilities	Rank
There is no control, or if there is control, it cannot discover the potential hazard.	None whatsoever	10
There is a very minimal probability that the hazard can be tracked and detected by using the existing controls.	Very minimal	9
There is a minimal probability that the hazard can be tracked and detected by using the existing controls.	Minimal	8
There is a very small probability that the hazard can be tracked and detected by using the existing controls.	Very low	7
There is a small probability that the hazard can be tracked and detected by using the existing controls.	Low	6
In half of the cases, it is probable that the potential hazard is tracked and detected by using the existing control.	Moderate	5
There is a relatively high probability that the potential hazard is tracked and detected by the exiting control.	Relatively high	4
There is a high probability that the potential hazard is tracked and detected by the exiting control.	High	3
There is a very high probability.	Very high	2
The potential hazard can be tracked and detected by using the existing controls almost certainly.	Almost certain	1

Fuzzy environment

According to Zadeh (1965, 1975), a fuzzy number $\tilde{x}$ is a fuzzy set (the membership function of $\tilde{x}$ is denoted by μ_x) which is of a universe of discourse (the real line R) which is defined as [25]:

Convex, that is, $\forall\, t_1, t_2 \in R$ and $a \in [0, 1]$, $\mu_x\,(at_1+(1-a)t_2) \geq \min\,(\mu_{\tilde{x}}(t)\ \mu_{\tilde{x}}\,(t_2)) \geq$;

Normalized, that is, $\sup\ \{\mu_{\tilde{x}}\,(t_1)\ /\ t \in R\}=1$

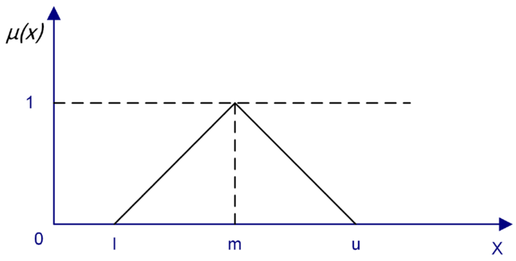
The triangular fuzzy number was adopted in which three real numbers (i.e., l, m, u) were used in its definition. The l, m, and u are the lower, mean and upper limits of the triangular fuzzy number, respectively. Figure 1 shows a typical triangular fuzzy number in which the three numbers were required.

Moreover, the fuzzy environment and equivalent fuzzy numbers of the crisps have been provided in Figure 2 and Table 4 [24].

3. Results and Discussion

In this section we compare and assess the risk of two conventional heating systems in Iran, namely HP and CHBR. These systems are commonly used in the majority of administrative and residential buildings. Although they have similar functions, they have some differences in safety at the time of earthquakes. Thus, using the examinations performed in this study, a better insight into the risks of each system can be provided.

During the visits of 50 residential buildings in Tehran, the status of CHBR and HP was examined; interviews with the residents were conducted to identify the criteria and effective factors on the risk of these facilities during earthquakes. In addition, the FMEA questionnaires were



$$\mu_{\tilde{A}}(x)=\begin{cases} \dfrac{x-l}{m-l}, & l \leq x \leq m \\ \dfrac{u-x}{u-x}, & l \leq x \leq u \\ 0, & \text{otherwise,} \end{cases}$$

Figure 1. Fuzzy triangular number

Table 4. Equivalent fuzzy numbers

Crisp No.	Equivalent Fuzzy Number (l, m, u)
1	(1, 1, 2)
2	(1, 2, 3)
3	(2, 3, 4)
4	(3, 4, 5)
5	(4, 5, 6)
6	(5, 6, 7)
7	(6, 7, 8)
8	(7, 8, 9)
9	(8, 9, 10)
10	(9, 10, 10)

completed. Eleven risks were identified for each studied facilities which were listed in the Tables 5 and 6.

After being transferred to the fuzzy space, the average results of 50 questionnaires and interviews after being transferred to the fuzzy space were presented for each system separately in Tables 4, 5, and 6. The RPN values in Tables 5 and 6 were calculated based on the multiplication operator in fuzzy equations.

During the visits, the residents expressed several concerns about the heating facilities of the buildings during earthquakes. Most cases can be attributed to gas and gas transfer pipes' leakage or explosion. Although the main gas transfer stations in Tehran are equipped with valve shutdown facilities during natural disasters such as earthquakes, urban residents are highly concern about gas leakage and explosion. Some others are concern about other equipment such as tanks and pumps. Earthquakes can cause numerous accidents related to gas equipment in residential buildings.

Secondary gas pipes' breakage in the building is a concern which is originated from two systems examined in this study. Of course, the path of secondary pipes is longer in buildings with HP than others which means that they run a higher risk of breakage in the buildings. It should be mentioned that the gas pipe junctions in the building are shorter in buildings with CHBR.

As HPs are usually installed at a high location and their connection is not robust against earthquakes, they may be separated from the wall and fall down. The distance between water or gas equipment and HPs are rarely long enough. Therefore, there is a risk of breakage or leakage, especially for gas. CHBRs do not have this problem, and the majority of burner and boiler facilities are installed on the ground, usually with strong and reliable connections.

The expansion tank is usually installed at a high location in CHBRs, which might be toppled down during earthquakes. In most of the visits, weak and unreliable connections were observed in the frameworks support-

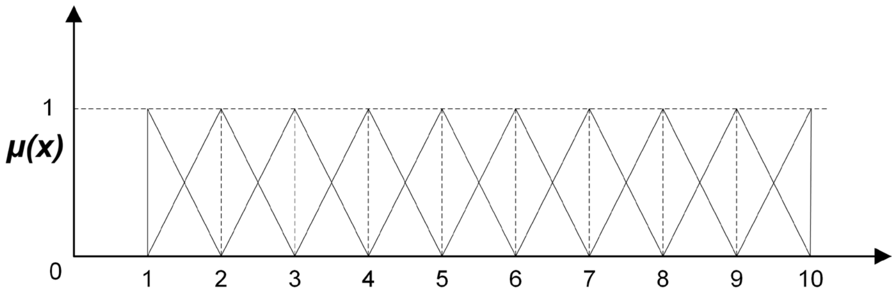


Figure 2. Fuzzy environment

Table 5. Estimated mean scores related to the risks of HP in the fuzzy space

	Risks	S			O			D			Fuzzy RPN		
		l	m	u	l	m	u	l	m	u	l	m	u
1	Fracture of the main inlet gas pipe to the building	5	6	7	7	8	9	2	3	4	70	144	252
2	Breakage of gas sub-pipes inside the building	7	8	9	7	8	9	4	5	6	196	320	486
3	The package falls from a height	6	7	8	5	6	7	2	3	4	60	126	224
4	Damage to the boiler	5	6	7	3	4	5	5	6	7	75	144	245
5	Damage to the burner	6	7	8	3	4	5	4	5	6	72	140	240
6	Damage to pumps	2	3	4	2	3	4	4	5	6	16	45	96
7	Damage to the hot water storage tank	3	4	5	3	4	5	3	4	5	27	64	125
8	Damage to radiators	1	2	3	5	6	7	2	3	4	10	36	84
9	Damage to the chimney outlet	2	3	4	4	5	6	3	4	5	24	60	120
10	Incomplete combustion and smoke leakage	5	6	7	3	4	5	6	7	8	90	168	280
11	Package noise and noise pollution	4	5	6	5	6	7	2	3	4	40	90	168
	Average	4.2	5.2	6.2	4.3	5.3	6.3	3.4	4.4	5.4	61.8	121.5	210.9

Table 6. Estimated mean scores related to the risks of CHBR in the fuzzy space

	Risks	S			O			D			Fuzzy RPN		
		l	m	u	l	M	u	l	m	u	l	m	u
1	Fracture of the main inlet gas pipe to the building	7	8	9	6	7	8	2	3	4	84	168	288
2	Damage to the expansion tank	3	4	5	3	4	5	2	3	4	18	48	100
3	Damage to the boiler	6	7	8	3	4	5	5	6	7	90	168	280
4	Damage to the burner	6	7	8	3	4	5	4	5	6	72	140	240
5	Damage to pumps	3	4	5	2	3	4	4	5	6	24	60	120
6	Damage to hot water storage tanks	3	4	5	3	4	5	3	4	5	27	64	125
7	Damage to radiators	1	2	3	5	6	7	2	3	4	10	36	84
8	Damage to the boiler connection to the chimney	4	5	6	6	7	8	5	6	7	120	210	336
9	Damage to the chimney outlet	3	4	5	5	6	7	7	8	9	105	192	315
10	Incomplete combustion and smoke leakage	6	7	8	3	4	5	5	6	7	90	168	280
11	Engine room noise and noise pollution	2	3	4	5	6	7	2	3	4	20	54	112
	Average	4.0	5.0	6.0	4.0	5.0	6.0	3.7	4.7	5.7	60.0	118.9	207.3

ing these reservoirs. The volume of the expansion tank in HPs is much lower than that in CHBRs; as a result, it has a lower risk and causes less concern for the residents.

Risk of damage to the boiler during an earthquake was among the most important concern of the residents. Gas leakage and smoke are very common in case of boiler damage. Risk of damage to the burner during earthquakes is another important concern. Gas leakage from the connections in one hand and the existence of a flame in the other hand can lead to explosion. This can be observed in both studied systems. To ensure the quality of gas pipe-to-burner connections and lack of corrosion of electric wires and equipment can prevent the boiler and burner-related accidents.

Hot water tank, radiator, and water pumps exist in both systems and can be damaged during earthquakes. Destruction and malfunction of these pumps can disrupt the function of the heating system. Moreover, breakage and leakage of inlet and outlet connected to the pump, water tank, and radiators can lead to water leakage in the building. Damage to the boiler-to-chimney connection and the chimney's outlet path can lead to gas toxicity, boiler and burner malfunction, and gas leakage in the building. It is usually difficult to identify a disruption in the path of chimneys and their connection. So, these problems are not likely to be discovered.

Another damage in heating equipment such as boiler or pump caused by earthquakes, is loud noise and noise pollution. This problem is easily identified and has no casualty, though, it can cause undesirable situations during and after earthquakes.

An important point was the large number of HPs compared to CHBRs in two buildings with a similar number of residential units. For instance, there was one CHBF in a five-story building with 2 residential units on each floor, but a similar building had 10 HPs. Overall, the probability of accidents is higher in buildings with HPs due to the larger number of the facilities. In the other hand, due to the larger volume and size of CHBRs, the extension of accidents can be larger. However, we are not able to claim which system causes more damage. The equipment and facilities status are different across buildings, and many different possibilities exist during earthquakes.

Finally, the mean values of each column have been provided in Tables 7 and 8. For the final comparison, the fuzzy RPN values were defuzzified using the center of gravity method. The final values have been presented in Tables 7 and 8. Moreover, the values as well as mean value have been plotted in Figures 3 and 4.

Based on Figure 3, the risk of damage to radiators and pumps is lower than the other facilities. In addition, they have the minimum RPN value. HPs exist in each

Table 7. Defuzzified RPN values for the risk of HPs

	Risks	x1	x2	x3	Defuzzified RPN
1	Fracture of the main inlet gas pipe to the building	70	144	252	155.33
2	Breakage of gas sub-pipes inside the building	196	320	486	334.00
3	The package falls from a height	60	126	224	136.67
4	Damage to the boiler	75	144	245	154.67
5	Damage to the burner	72	140	240	150.67
6	Damage to pumps	16	45	96	52.33
7	Damage to the hot water storage tank	27	64	125	72.00
8	Damage to radiators	10	36	84	43.33
9	Damage to the chimney outlet	24	60	120	68.00
10	Incomplete combustion and smoke leakage	90	168	280	179.33
11	Package noise and noise pollution	40	90	168	99.33
	Average	61.82	121.5	210.9	131.42

Figure 3 . Defuzzified RPN values for the risk of HPs

apartment unit which increase the length of gas junction pipes in the buildings. Based on the interviews and questionnaires, they had the highest risk value with a RPN of 334. Other items had less risk values (i.e., close to the mean value) (131.42).

Figure 4 shows that the risk of damage to radiators and expansion tanks is lower than the other facilities, and they have the minimum RPN value. Due to the concentration of the entire building's heating system in one room as well as the larger size of the equipment compared to HPs, CHBRs can cause different and severe damages during earthquakes, such as damage to the boiler-chimney connection, damage to the chimney outlet, incomplete combustion, and smoke leakage, with a RPN of 222.00, 204.00, and 179.33, respectively. It should be mentioned that the mean RPN value was 128.73. We should also pay attention to the risk of the main gas pipe breakage which is connected to inside of the building and has a considerable risk value for both systems. By the interview method, the citizens mentioned two points which might have a large impact on the risk score.

Table 8. Defuzzified RPN values for the risk of CHBRs

	Risks	x1	x2	x3	Defuzzified RPN
1	Fracture of the main inlet gas pipe to the building	180.00	177.00	174.00	180.00
2	Damage to the expansion tank	55.33	53.50	51.67	55.33
3	Damage to the boiler	179.33	176.50	173.67	179.33
4	Damage to the burner	150.67	148.00	145.33	150.67
5	Damage to pumps	68.00	66.00	64.00	68.00
6	Damage to hot water storage tanks	72.00	70.00	68.00	72.00
7	Damage to radiators	43.33	41.50	39.67	43.33
8	Damage to the boiler connection to the chimney	222.00	219.00	216.00	222.00
9	Damage to the chimney outlet	204.00	201.00	198.00	204.00
10	Incomplete combustion and smoke leakage	179.33	176.50	173.67	179.33
11	Engine room noise and noise pollution	62.00	60.00	58.00	62.00
	Average	128.73	126.27	123.82	128.73

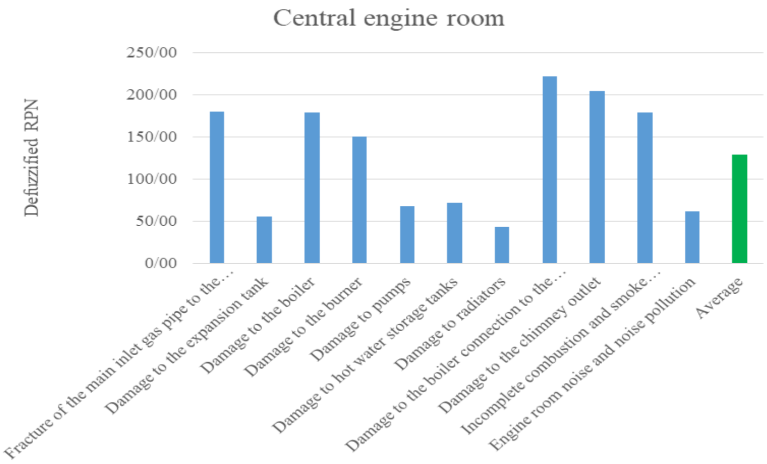


Figure 4. Defuzzified RPN values for the risk of CHBRs

The possibility of urban gas shutdown by automatic shutdown facilities after earthquakes is very high in urban areas, which can have a positive effect on this risk.

In case of accidents and gas leakage from the main pipe, a possible explosion may occur outside of the building. Finally, the RPN values of both systems were compared (Figure 5). Based on the questionnaires, the risk of HP system (mean RPN) was higher than that of the CHBR system (mean RPN of 131.42 vs 128.73).

The mean risk of HP was about 2% higher than the mean risk of CHBR. Overall, the small difference between the mean RPNs of the two systems can be neglected. As mentioned, based on the results of questionnaires and the fuzzy FMEA model, no definitive superiority can be presumed for HP or CHBR during earthquakes. The major difference in the risk of each system can be separately evaluated based on the conditions in each building, confidence about the quality of installation, connections, pipe materials, electric wire corrosion, etc. Thus, it is suggested that the risk of CHBR and HP during earthquakes is the same, and some issues such as design, economy, and technical issues play a greater role in selection of the system by the contractors. The important point is that citizens should ensure gas equipment risk reduction to decrease the hazards before and during crises such as earthquakes by regular checkup and ensuring the factors discussed in this paper.

It should be noted that the use of fuzzy space for FMEA calculations enhances the flexibility of computations and improves the uncertainty in model's estimations. In classic FMEA, the values are estimated by individuals' point of view as the scores in a crisp manner, thereby having some errors. The concepts of membership function in fuzzy theory and their combination with crisp calculations in the FMEA model approximates the results of reality and make more flexible, computational processes.

4. Conclusion

Gas systems have been always paid attention during earthquakes due to the potential gas leakage and explosion. Gas heating equipment are commonly used in all

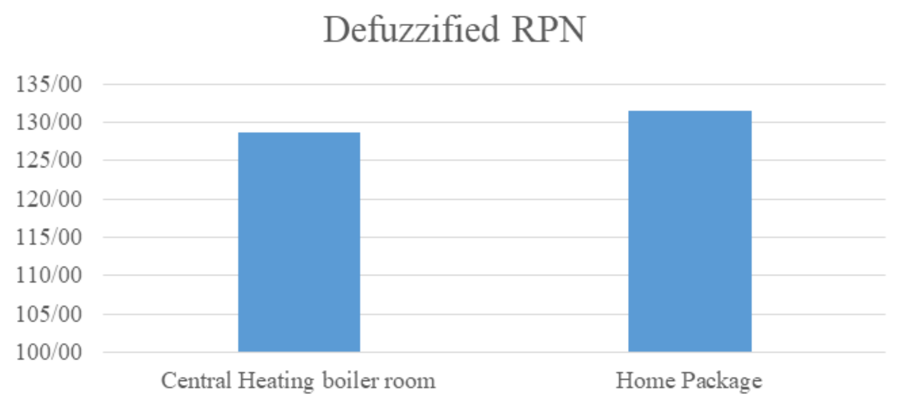


Figure 5. A comparison of the defuzzified mean RPN values for the two systems

residential buildings in Iran, and have a high potential risk during earthquakes. In this study, during the visits, we found that a considerable number of heating facilities, especially CHBRs, were old and worn out that need repairment. The issue can double the risk of accidents resulted from the damage to facilities during earthquakes.

On the other hand, HPs can cause numerous concerns for the residents during earthquakes. The large number of packages in the buildings, their installation at high level, and lack of regular visits were the most important concerns observed during visits and interviews.

Based on the results of FMEA model, three factors namely severity, occurrence rate, hazard discovery rate were evaluated in 50 residential buildings in Tehran (district 9). FMEA's estimations were performed in a fuzzy space to improve uncertainty and flexibility, which can confer better results compared to the classic FMEA model.

Finally, the RPN values of the two systems were compared. Based on the results, the RPN of the HP system was about 2% higher than that of the CHBR system (mean RPN value of 131.42 vs 128.73). Overall, the small difference between the mean RPNs of the two systems can be neglected and the risk of both systems can be deemed equal. As mentioned, based on the results of the questionnaires and the fuzzy FMEA model, no definitive superiority can be presumed for HP or CHBR during earthquakes. The major difference in the risk of each system can be separately evaluated based on the conditions in each building, confidence about the quality of installation, connections, pipe materials, electric wire corrosion, etc. Thus, it is suggested that the hazard rate of CHBR and HP during earthquakes is the same, and some issues such as design, economy, and technical issues play an important role in selection of the systems by contractors. The important point is that citizens should ensure the gas equipment risk reduction in order to decrease the hazards before and during the crises such as earthquakes. They can be sure of the risk reduction by regular visits, high confidence about the factors discussed in this paper, and installation of a frame for HPs.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declare no conflict of interest.

References

[1] Sahu AB, Mohamed AES, Panigrahy S, Bourque G, Curran H. Ignition studies of C1-C7 natural gas blends at gas-turbine-relevant conditions. J Eng Gas Turbine Power. 2021; 143(8):081022. [DOI:10.1115/1.4050063]

[2] Kargbo DM, Wilhelm RG, Campbell DJ. Natural gas plays in the Marcellus shale: Challenges and potential opportunities. Environ Sci Technol. 2010; 44(15):5679-84. [PMID]

[3] Omidvari F, Jahangiri M, Mehryar R, Alimohammadlou M, Kamalinia M. Fire risk assessment in healthcare settings: Application of FMEA combined with multi-criteria decision making methods. Math Probl Eng. 2020; 2020:8913497. [DOI:10.1155/2020/8913497]

[4] Garcia-Gonzales DA, Shamasunder B, Jerrett M. Distance decay gradients in hazardous air pollution concentrations around oil and natural gas facilities in the city of Los Angeles: A pilot study. Environ Res. 2019; 173:232-6. [PMID]

[5] Manesh MK, Rezazadeh A, Kabiri S. A feasibility study on the potential, economic, and environmental advantages of biogas production from poultry manure in Iran. Renew Energy. 2020; 159:87-106. [DOI:10.1016/j.renene.2020.05.173]

[6] Hafeznia H, Pourfayaz F, Maleki A. An assessment of Iran's natural gas potential for transition toward low-carbon economy. Renew Sust Energ Rev. 2017; 79:71-81. [DOI:10.1016/j.rser.2017.05.042]

[7] Yousefi H, Roumi S, Tabasi S, Hamlehdar M. Economic and air pollution effects of city council legislations on renewable energy utilisation in Tehran. Int J Ambient Energy. 2018; 39(6):626-31. [DOI:10.1080/01430750.2017.1324819]

[8] TGASCO. Annual performance report of Tehran Gas Company [Internet]. 2020. Available from: http://tehrangasco.ir/

[9] Rezaee MJ, Yousefi S, Eshkevari M, Valipour M, Saberi M. Risk analysis of health, safety and environment in chemical industry integrating linguistic FMEA, fuzzy inference system and fuzzy DEA. In: Rezaee MJ, Yousefi S, Eshkevari M, Valipour M, Saberi M, editors. Stochastic Environmental Research and Risk Assessment. New York: Springers; 2020. pp. 201-18. [DOI:10.1007/s00477-019-01754-3]

[10] Padash A, Vahidi H, Fattahi R, Nematollahi H. Analyzing and evaluating industrial ecology development model in iran using FAHP-DPSIR. Int J Environ Res. 2021; 15:615-29. [DOI:10.1007/s41742-021-00335-z]

[11] Moradi A, Najafi Kani E, Parvini M. [Risk assessment of municipal natural gas pipeline networks using Analytic Hierarchy Process (AHP) for Sanandaj City (Persian)]. Iran Occup Health J. 2017; 14(4):1-12. [Link]

[12] Ghandehari M, Momeni M, Mehregan M. Quantitative risk assessment of urban gas pipelines and identify sensitive areas by providing comprehensive and integrated model. Mod Res Decis Making. 2019; 4(1):140-66. [Link]

[13] Karimi Asl M. FMEA risk assessment in religious places. the first national conference on the development of health, safety and environment in the field of recreational, sports, religious and cultural places of the city with the approach of citizen protection and the city 2016. Tehran, April 27, 2017. [Link]

[14] Nouri J, Abbaspour M, Fard MT, Fam IM. Advantages of integrated management system in educational centers. J Food Agric Environ. 2010; 8(3-4):1259-64. [Link]

[15] Davison S, van den Elshout S, Wester B. Integrated urban emission inventories, CiteAIRII, common information to European air, interreg IVC programme, 2011.

[16] Balaraju J, Raj MG, Murthy CS. Fuzzy-FMEA risk evaluation approach for LHD machine: A case study. J Sustain Min. 2019; 18(4):257-68. [DOI:10.1016/j.jsm.2019.08.002]

[17] Qin J, Xi Y, Pedrycz W. Failure Mode and Effects Analysis (FMEA) for risk assessment based on interval type-2 fuzzy evidential reasoning method. Appl Soft Comput. 2020; 89:106134. [DOI:10.1016/j.asoc.2020.106134]

[18] Li Z, Chen L. A novel evidential FMEA method by integrating fuzzy belief structure and grey relational projection method. Eng Appl Artif Intell. 2019; 77:136-47. [DOI:10.1016/j.engappai.2018.10.005]

[19] Cebi A. New Risk Assessment Approach for Occupational Health and Safety Applications. Paper presented at: International Conference on Intelligent and Fuzzy Systems. 21-23 July 2020; Istanbul, Turkey. [DOI:10.1007/978-3-030-51156-2_157]

[20] Kabir S, Papadopoulos Y. A review of applications of fuzzy sets to safety and reliability engineering. Int J Approx Reason. 2018; 100:29-55. [DOI:10.1016/j.ijar.2018.05.005]

[21] Chiozza ML, Ponzetti C. FMEA: A model for reducing medical errors. Clin Chim Acta. 2009; 404(1):75-8. [PMID]

[22] McDermott R, Mikulak RJ, Beauregard M. The basics of FMEA. Boca Raton: CRC Press; 2008. [Link]

[23] Fattahi R, Khalilzadeh M. Risk evaluation using a novel hybrid method based on FMEA, extended MULTIMOORA, and AHP methods under fuzzy environment. Saf Sci. 2018; 102:290-300. [DOI:10.1016/j.ssci.2017.10.018]

[24] Vahidi H, Ghazban F, Abdoli M, Kazemi V, Banaei SMA. Fuzzy analytical hierarchy process disposal method selection for an industrial state; case study Charmshahr. Arab J Sci Eng. 2014; 39(2):725-35. [DOI:10.1007/s13369-013-0691-1]

[25] Zadeh LA, Klir GJ, Yuan B. Fuzzy sets, fuzzy logic, and fuzzy systems. In: Zadeh LA, editors. Advances in Fuzzy Systems: Applications and Theory. Singapore, 1996. [DOI:10.1142/2895]