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A fuzzy inference system for predicting relief goods demand in the different scenarios of occurrence earthquake

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Abstract

Earthquake is one of the natural disasters that, depending on the scale, location, preventive measures, etc, can have financial and human effects to a large extent. Natural disasters have an uncertain nature. In other words, regarding the statistics related to such events, it is not possible to comment with high accuracy, which reveals the need to predict and estimate the dimensions of the possible effects of natural disasters. It should be noted that predicting the demand for relief goods and estimating the number of injured and displaced people as a result of these disasters can increase the efficiency of rescue operations and reduce the duration of this process, resulting in more services and reducing casualties costs. According to the mentioned cases and the necessity of conducting effective research from different aspects and in different fields, especially in the field of predicting and management of relief and disasters, this research was carried out. For this purpose, factors such as population ratios such as population density, texture erosion in different areas, earthquake time, and earthquake intensity based on the Richter scale, taking into consideration the opinions of experts in the field of geology and relief rescue, were used as inputs to the fuzzy inference system and the output of this system is determined by items such as the demand for biological, food, pharmaceutical goods, as well as the number of displaced and injured people.

Keywords: Earthquake, Prediction relief goods, Expert system, Fuzzy inference system (FIS)
2020 MSC: 03E72, 62A86

1 Introduction

The increase in the number of natural disasters such as earthquakes, floods, hurricanes, droughts, etc., and the expansion of their destructive range on the one hand and population growth in different parts of the world, on the other hand, have increased material damage and human casualties in such accidents. Despite technological advances, the suffering caused by these incidents has always been the main obstacle to the sustainable development of countries. Although the damage caused by these incidents cannot be compensated in various ways, especially financially and emotionally, by managing the crisis properly and responding in a timely and proper manner, the dimensions of the damage can be reduced. Yearly, almost 14 million people are being made houseless on average due to unexpected

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catastrophes like overflows and typhoons according to the study results of the United Nations Office for Disaster Risk Reduction (UNDRR) [51]. Recently, some countries in the world experienced hardest hit by natural disasters and catastrophes, such as an undersea earthquake with a magnitude of 9.3 Richter scale in the Indian Ocean, an earthquake with a magnitude of 8.0 Richter scale in Wenchuan, an earthquake with a magnitude of 7.3 Richter scale in Haiti, an earthquake with a magnitude of 9.0 Richter scale in the Pacific coast of Tōhoku region and an earthquake with a magnitude of 8.1 Richter scale in Nepal in 2015, Harvey in 2017, Indian Ocean Tsunami in 2004, Maria in 2017, Cyclone Nargis in 2008, and Hurricane Katrina in 2005. Also, the 2017 earthquake in Kermanshah / Iran killed 620 people and injured 9,388, leaving $ 5,600 million in damage. The Bam earthquake in Iran in 2003 also killed 26,271 people and injured 30,000. Perhaps, in handling any condition, the official immediate measure's ineffective welfare activities were its most worrying and critiqued dimension, which did not provide in due time the necessary goods demanded at the time of catastrophe [25]. Necessary goods' delay is intolerable following a catastrophe that may lead to loss of lives or further destruction. Catastrophe welfare activities' principal aim is delivering goods to the region of catastrophe without delay and reducing the victims' hurt. These activities include organizing public donations and collecting international donations. Also, the next stage is how to allocate relief goods to the affected areas and provide transportation. Finally, the strategy of distributing relief goods is adopted. The lack of goods due to the demand predictions is based on a comparison of the deficiencies related to other operational actions. The goods' redundancy is due to oversupply or non-supply decisively and partially related to the problems of a management system that may lead to public doubt of state corruptness. In Wenchuan Earthquake (China), some amassed and decayed foodstuffs lead us to this evidence [36, 27]. Federal Emergency Management Agency, like Hurricane Maria, has been extensively criticized due to undervaluing demand in the operational response and largesse' amassing and even rotting [9, 46]. Illogical demand predicting or non-forecasting brings huge trouble to the performance of operational actions. Due to Ref, demand predicting, on the contrary, can cause more than 7 percent savings on expenses of annual operating [52, 38].

The management of crises caused by natural disasters is very complex and widespread for various reasons and requires taking special measures. Crisis management is also a part of Disaster management. When any disaster either man-made or natural strikes the business operations paralyzing the normal operations, threatening the business, involving the destruction of property, resources, lives, etc, the Organization is faced with a crisis. Six steps to creating a crisis management plan:

1. Identify the crisis leadership team:

   Put the team together so everyone knows the ins and outs of your crisis strategy.

2. Assess risk: Have a brainstorming session to assess various risks

3. Determine the impact: Each risk can cause different outcomes, so it's important to analyze them separately.

4. Plan the response: Determine what actions your team would need to take to respond.

5. Solidify the plan: Need to collaborate with key stakeholders so that everyone understands what to do and when.

6. Review and update: Revisit your crisis management plan and update it.

The number of casualties due to natural disasters in the world between 1965 and 1992 amounted to 3 million 610 thousand people, of which 88% were from countries that do not have a crisis management system or the existing crisis management system lacks the required preparedness and flexibility. The Swedish Red Cross also estimated the average number of casualties from natural disasters at 500 for rich nations and 30,000 for poor nations. Therefore, in areas that are always and potentially at risk of natural disasters, it is necessary to include the necessary planning for disaster prevention and coping in the macro strategies of that area, and the main goal of these plans is to predict, prevent, maintain preparedness and deal with the crisis, compensate for the destruction, seize opportunities and, finally, return to normalcy with the least cost and shortest time based on the priorities set.

Much attention has been paid to humanistic assistance or humanistic relief of supply-chain operation [44]. The crisis relief supply chain includes the movement and storage of raw materials, and final relief goods, as well as the ordering and distribution of relief goods from distribution centers to affected areas. Preparing the preconditions before the occurrence of the catastrophe is just one way to face urgent situations. Social expenses should be regarded in humanistic decision-making protecting models, and also, they should consider the deprivation and logical expenses to gain the desirable social output. These approaches can affect the short-term and long-term decisions of the organization. How to implement these approaches in organizations depends on the management of the organization. As there is not any alert or forewarning for us about catastrophes, particularly earthquakes, this attention is critical. Almost 500000 people were killed in the 2004 and 2010 tsunami earthquakes in Haiti [15, 16]. Efficient reactions to unexpected catastrophes and emergency conditions immediately are seriously challenging and require a coherent and unified decision procedure [41, 45]. Preparing the preconditions before the occurrence of the catastrophe is just one way to face urgent situations. Social expenses should be regarded in humanistic decision-making protecting models, and also, they should consider the deprivation and logical expenses to gain the desirable social output [22, 26]. Almost 300 million people from 1990 are affected by different catastrophes of those years and the annual ruin increased to 0.17 percent of GDP [24, 8]. By improving the humanistic relief logistics (HRL), proper methods of catastrophe actions management can decrease the catastrophes' effects on human lives [21, 29]. Death and ruins of earthquakes are including the structures' fire, tsunami, fall of stones, and earth fall.

Therefore, the principal reason for people's died in the world is structural failures and collapses, which show near 68.36 percent of death [10, 11] including 13.04% adobes, 6.80% stone wall, stonework, 2.72% timber, 24.80% earthen or rubble masonry 7.42% ferroconcrete, 13.76% modern brick, and 0.02% structures of steel [12]. During the last decade, catastrophes' repetition, impact, and intensity increased, due to the diverse elements that include national growth and changes in the ecosystem [17].

The world yearly mortality average for earthquakes, cyclones, tsunamis, and flood is 314 billion dollars according to United Nations Office for Disaster Risk Reduction [29, 50]. Additionally, almost nineteen hundred deaths and fatalities in Europe led to more than twenty-nine billion euros due to the earthquakes that happened between 1998 until 2009 [18]. The significance of applying systematic procedures for improving humanistic actions during the last decade is broadly considered in Operation Research Management Science (OR/ MS) [54].

Iran is one of the five countries in the world in the field of natural disasters. Therefore, due to the constant exposure to emergencies caused by natural disasters, especially earthquakes and floods, relief has a special place in Iran. The occurrence of these incidents has often been associated with damage to human life and property. For example, the Rudbar-Manjil earthquake in 1990, caused extensive damage in areas within a radius of 100 km from the epicenter near Rasht and 200 km northwest of Tehran. The cities of Rudbar, Manjil, and Lushan, and about 700 villages were destroyed and 300 villages were affected. The Bam earthquake was also a large earthquake that affected the city of Bam and the vicinity of Kerman in 2003 (Day in 1383 in the Persian calendar). According to official figures, the quake killed at least 26,000 people, injured 30,000, and left more than 100,000 homeless. As statistics show, natural disasters in Iran have been associated with very high human and financial losses, most of which have been due to a lack of proper crisis management. The challenges due to crisis management in Iran are as follows [4, 40].

Environmental challenges

- Uncertainty of demand in terms of timing, location, type, and size)
- Sanctions against Iran for cooperation with other humanitarian organizations

Aid workers challenges

- Burn-out and turnover of rescuers and humanitarian volunteers, and shortage of skillful people
- Insufficient training for rescuers

Resources challenges

- Poor usage of technology for example GPS
- Insufficient transportation facilities (e.g. helicopters and trucks)
- Inappropriate aid products

Managerial challenges

- Insufficient management commitment to improve coordination
- Lack of governance principles and familiarity of top managers with management knowledge

Inter-organizational challenges

- Lack of trust among humanitarian organizations

- Differences in operational procedures among involved organizations (e.g., standards and techniques)

Affected people challenges

- Insufficient knowledge for affected people in post-disaster relief
- Unethical issues (e.g. theft)

Communication challenges

- information sharing limitations, competition to visibility and media coverage
- Communication barriers (e.g. different languages and cultures)

Organizational challenges

- Facility location problems including distribution center problem
- Insufficient cost management systems
- Weak monitoring on humanitarian rescue

1.1 Context of study

Iran is located on the Alpine-Himalayan seismic belt, which is one of the two seismic belts in the world, and the presence of multiple faults increases the probability of an earthquake on the Iranian plateau. The reason for the importance of this belt is that includes an array of mountain ranges extending for more than 15,000 kilometers (9,300 mi) along the southern margin of Eurasia through the mountains of Iran. It includes, from west to east, the major ranges of the Atlas Mountains and the Himalayas. Iran is one of the ten countries that are prone to disasters the most in the world and is the sixth most earthquake-prone country in the world. It should be noted that the earthquake belt covers 90% of Iran and earthquakes cause the most human casualties.

Table 1: List of earthquakes in Iran in the first 6 months of the year 1400 (Persian calendar)

Month	Total number of earthquakes	Number of earthquakes larger than 4 Richter	Magnitude of the largest earthquake (Richter)
Farvardin	825	15	5.9
Ordibehesht	960	11	5.5
KHordad	850	14	5.2
Tir	680	16	5.6
Mordad	645	10	4.9
SHahrivar	770	10	5.2

Figure 1 shows the list of earthquakes recorded in the first 6 months of 1400 (Persian calendar) in Iran. As it is known, in the first to the sixth month, it is equal to 825, 960, 850, 680, 645 and 770, respectively. From the mentioned number in the first to the sixth month, 15, 11, 14, 16, 10 and 10 earthquakes above 4 Richter were respectively.

According to the extensive research conducted in the field of geology and documented statistics and information on the occurrence of earthquakes with high intensity and destructive power in the current geographical location of Tehran city in previous periods and years, the need for full preparation and creation of contexts and appropriate infrastructure expresses different approaches to dealing with this event.

The existence of dangerous faults such as the North Tehran fault, which covers the area from Karaj to Lavasanat, the South Tehran fault, which is known as the North Ray fault, and the South Ray fault, has the possibility of an

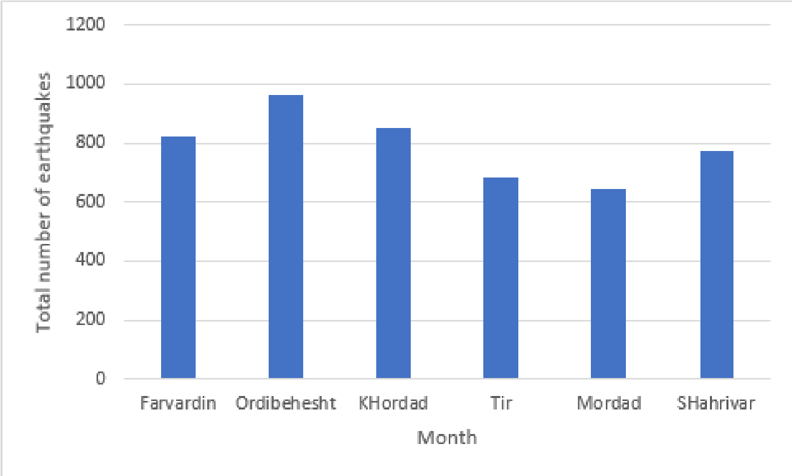

Figure 1: List of earthquakes in Iran in the first 6 months

earthquake with a magnitude of 7 to 7.6 Richter. The next fault is known as the Mosha-Fasham fault, which extends from Firoozkooh and Damavand to the Kandovan area and the length of this fault is more than 200 to 300 km. Mosha-Fasham fault is located between Alborz and Tehran plains. Also, this fault is adjacent to the peak of Tochal with a height of 3933 meters. The study of this fault indicates that there is an alluvial flow below it and the thickness of the earth's crust in this fault is about 40 to 43 km. Due to the proximity of this fault with the Ray fault and the reasons mentioned, it can be said that this fault has the potential for earthquakes of more than 7 Richter. Meanwhile, the fault north of Tehran in Lavasanat and Lashkarak branched from this fault and during the last ten thousand years, this fault has been active many times.

Information about the time and severity of earthquakes in Tehran indicates that approximately every 158 years an earthquake occurs in the city of Tehran; the last significant case is related to 1830 AD with a magnitude of 7.2 Richter. According to the experts of the International Institute of Seismology and Earthquake Engineering of Iran, based on the available seismic and historical statistics, it is expected that an earthquake of 7 Richter occurs every 200 years in a circle with Tehran in the center with a radius of 100 km, an earthquake of 6 Richter every 20 years, an earthquake of 5 Richter every 2 years, and an earthquake of 4 Richter every 6 months.

Table 2: List of Iran's earthquakes on a scale of about 7 Richter in the area around Tehran

Date (AD)	Division	Fault	Intensity (Richter)	Intensity of destruction (Mercalli)
Three hundred years BC	Rey	Parchin, Rey	7.6	X
743	Darvaze Khazar	Garmsar	7.2	VIII+
855	Rey	Kahrizak	7.1	VIII+
958	Taleghan	Mosha	7.7	X
1117	Karaj	Tehran	7.2	VIII+
1665	Damavand	Mosha	6.5	VIII+
1815	Damavand	Mosha	unknown	V+
1830	Damavand	Mosha	7.2	VIII+

The data used in this research have been extracted from the country's crisis management database, the Institute of Geophysics, the University of Tehran, and the Municipality of Greater Tehran. This data is used to estimate the number of displaced and injured people and also the demand for relief goods in 22 districts of Tehran using a fuzzy inference system, which results in improving the level of preparedness and accelerating and improving the service proving process for injured people. Relief goods in this study are divided into three categories, each of which is a package that includes a set of items of the same family. The first category is biological goods, which are essential items for the displaced, which include: blankets, tents, carpets, etc., the second category is food items, which include: canned food, packaged bread, drinking water, etc., and the third category is pharmaceutical goods that include: all kinds of drugs, dressing supplies, disinfectants, etc. Also, different plots will change using the opinions of experts and based on the intensity of the earthquake (Richter scale), the type of texture, population density, and the time of the earthquake (day or night). It should be noted that these plots are fuzzy and are entered into the system based on fuzzy numbers.

Therefore, the contributions of the paper are as follows:

- Estimating the amount of relief goods required using the fuzzy inference system
- Considering different scenarios for estimating relief goods such as earthquake

severity, time of occurrence, texture type and population density

- Considering a case study for a potential earthquake in Tehran
- Considering packages of relief goods in three types: biological, food and pharmaceutical

2 Literature Review

2.1 Predicting the relief Goods

In diverse countries, emergency goods have diverse definitions and categories. According to the National Development and Reform Commission of China in the Classified catalog of key supplies for emergency protection, relief goods have 3 classifications, 16 types, 65 subcategories, and more than 500 parts [37]. Equipment is divided into 21 classifications, 67 subclasses, and more than 700 individual equipment parts by Authorized Equipment List (AEL) issued by FEMA for readiness [20]. Resources are classified as 17 resource classifications, and 188 parts [19] according to National Incident Management System (NIMS). Documents of criteria assist individuals to understand the kind of goods that may be required. diverse catastrophes will be needed diverse goods requirements. For instance, there are no life rings, life jackets, search and rescue boats, and also, other goods in earthquake catastrophes, but in the flood catastrophes' emergency goods list. After a catastrophe like an earthquake, there will be needed to do some acts related to emergency goods; such as rescue mission, life-saving and life-supporting, transport and tactics, emergency health care, emergency technical assistance for lifesaving and life-supporting helps, and other things. The main challenge is predicting goods demand, such as kind and quantity of goods because of incertitude, complication, insufficient data, and sudden changes. Appropriate emergency demand predicting is an assumption by which the catastrophe's emergency actions' efficiency and reductions of loss can be guaranteed. emergency demand's inappropriate forecast furthers ineffectiveness of emergency activities and ineffectiveness of the decision process on topics like distributing and transporting. A decision-maker's own assessment leads to bad emergency management like issues distributing scant emergency goods immediately after a catastrophe, and goods' loss and stock in the response and recovery last phases that reduce the care to victims. The next research can be more effective on issues of catastrophe emergency activities, and reinforce the optimum distribution of relief sources.

So, considering a procedure dealing with unsure data for estimating the kind and amount of emergency goods is important. A great procedure for unsure data predicting is perceptional unclear case-reasoning. This procedure is on the basis of historical case data that background information usually presents wisdom as facing high incertitude, and an optimum same resolution clears when the main principle is entering, such as the earthquake magnitude.

Incertitude analyses in relation to the catastrophes' happening to create proper preparation methods are essential when facing the catastrophes [7]. Batara et al. concentrated on relief situations preset to prepare for the earthquakes [5]. According to them, a new procedure was represented for calculating the possible earthquakes and people who may suffer. Their procedure is on the basis of the foreseen procedures of earthquake engineering history by applying possible plots for displaying the incertitude in relation to the prevention of earthquakes. They regarded the suggested procedure by applying the earthquake background data in Turkey, where the earthquake possibility is significant. Also, they represented case research that displayed that their procedure function is resolving the category distribution issue of the Turkish Red Crescent [5]. Abdalzaher and Elsayed, by focusing their attention on the catastrophes like earthquakes for achieving higher security while evacuating, by applying data communication networks (DCNs), represented road network traffic (RNT). Five models of DCN are suggested for displaying the cross-sectional control, meandrous cross-check, and cracked round about, of the similar RNT cases, in other words, rapid stream relations, left turn impact four-way traffic analogy. According to the 5 models, DN resolutions can be applied to resolve RN issues by applying the road network (RN) for DN. Their semblances output showed there is much close intensity of traffic in DCN and RNT outlines. The suggested landscape is stressed by applying t-test and ANOVA analyses. Consequently, DCNs can be applied in managing the more secure destruction in the event of a natural catastrophe [1].

Humanistic relief logistics (HRL) has always been an important factor in relief operations, and logistical efforts account for about 80% of disaster relief. This formal logistical strategy is adapted from the military operations used in World War II. Therefore, in general, it can be said that in order to achieve the goals of crisis management, humanistic relief logistics is an area that can make a lot of improvements.

Figure 1 illustrates the main mapping notion between the data communication networks (DCNs) and road network traffic (RNT) by using the main parameters of both. The road lanes are matched to transmission media and cross-sections are performed by switches to obtain the mapping theory (See figure 2).

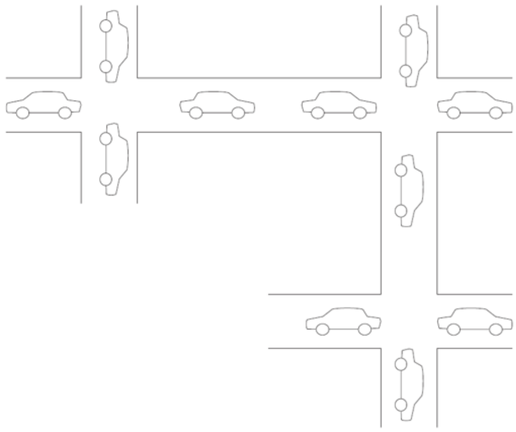

Figure 2: Data communication networks (DCNs) and road network traffic (RNT)

Ghasemi et al. represented a mathematical pattern to manage a catastrophe emergency before and after the catastrophe. The suggested multi-period pattern controls the distribution sites' allotment and localization decisions. Foodstuffs and drugs were regarded as emergency goods in their research. By two meta-heuristic methods, the suggested pattern was resolved at last [23].

Few investigations have concentrated on emergency demand predicting. It is mostly supposed that the emergency demand is a familiar and determinist factor in most investigations [2], or according to some investigations, the emergency demand has been presented as hypothetical factor [13]. A significant way of research for reducing the time of reaction is a more appropriate evaluation of the emergency demand. Some investigations have described the emergency demand regarding the beneficiary population that survives and require emergency assistance [35, 32], and most investigations have foreseen emergency demand on the basis of the affected region's people by applying some methods [39]. exceptions of this involve Holguín-Veras and Jaller [25] that applied former emergency demand data sources at diverse phases after a catastrophe strikes for fixing demands [25]. Holguín-Veras et al. considered the source demands after Hurricane Katrina by applying mathematical patterns and took the result that nearly 150 diverse parts were requested, which is far fewer than the 350–500 previously estimated [25]. Emergency demand is stipulated or evaluated as a determinist demand for a plot, for numerous plots, or as a dynamical demand that changes during the time. Marcelin et al. [32] took the post-evacuation population as demand, and evaluated near 50 percent of the affected region people. Mete and Zabinsky [33] evaluated demand by applying the foreseen destruction and density of people for six plots, and showed arbitrariness by applying the plot method. Rawls and Rawls and Turnquist [42] defined demand and showed the catastrophe incertitude by applying the plots. Due to the computational complexity of the model formulation, a heuristic solution that considers the embedded network structures of the SMIP was devised by combining two methodologies: the L-shaped method and the Lagrangian relaxation. The results show that with increasing demand, service time increases sharply. Davis et al. [14] set an element of demand changing for each plot to show the demand amount's dynamical changes that vary in relation to the time and estimation of the storm. For presenting the dynamical demand, some studies have applied rates of consumption for every item [39, 43]. Rawls and Turnquist [43] regarded the people in the affected region (in emergency demand) as correlated to the evacuees' rate that follows the S-shaped curve. The model presented is a two-stage stochastic program that offers a basis for planning for the arrivals of evacuees at shelter locations. A case study using shelter locations in North Carolina and a set of hurricane threat scenarios is used to illustrate the application of the model and how it supports an emergency relief strategy. Sheu thought the emergency demands correlate extremely with the survivors' number and developed the time-dependent emergency demands foreseen pattern for 2 kinds of goods [47]. Sheu and Lu et al. foresaw dynamic emergency demands considering the number of people minus the victims' instant number in an affected region after the catastrophe and gathered the victims' number in every affected region by information combination processes from numerous sources applying an approach of the entropy-based weighting [48]. There are other procedures for predicting demands, like numerous linear retrogressions, case-based reasoning, time sequences, BP neural network, and pattern of gray system, besides consumption of demands, catastrophe plot similitude, and multi-source information combination. For predicting the demand for emergency goods, Sun et al. applied unclear-rough set pattern [49]. For improving the predicting goods demand time sequences' correctness, Mohammadi et al. suggested a genetical algorithm - adaptable particle swarm optimizing, on the basis of radial base function neural network pattern [34]. For predicting the fatalities of the earthquake, Xing et al. suggested a pattern of robust wavelet (RW) v-support vector machine (v-SVM) [55]. For conducting the demand forecasts of the quality, quantity, and emergency goods kind, Liu et al. analyzed the CBR patterns, and thus applied the case-based reasoning foreseen pattern related to the process of risk analysis [30]. Liu reviewed the elements that influence superhighway relief source demand, and thus applied the neural network pattern for predicting the expressway emergency goods demand that represents a logical guidance booklet for the emergency sources' systematic allotment [31]. Tang et al. suggested a pattern for predicting demand on the basis of the number of saved survivors after an earthquake, and a pattern of goods allocation regarding the gratification of demand and the expense of allocation, and thus applied the affinely adaptable potent optimizing method for resolving the incertitude to reduce the demand [3]. The study patterns are on the basis of the background information for predicting the demand. For protecting the decision-making process, technologies on the basis of the background information are significant patterns. Nevertheless, demand time-sequences studies that depend on the timely catastrophe prediction information's accuracy, is not used in our research. Our research concentrates on initial predicting of the general demand in the event of a natural catastrophe. Though, catastrophe plots can approximately show that the catastrophe incertitude, true incertitude, and the possible evaluation of occurrence in every plot are important. the pattern of relating unclear theory with CBR can lead us to details and processes of decision-making in comparison to the catastrophe plots and unclear rough sets that can just gain the pure demand's output. Wang et al. applied SVM retrogression for choosing feature elements to forecast the demand for foodstuff relief [53]. Wang et al. examined the effect of relief goods and suggested the dynamical classification's estimation process for emergency goods demand, and also, suggested a scalable unclear thorough estimation pattern on the basis of the matter-element model's correspondence function. The dynamical classification's estimation process for emergency goods demand is as Poisson-based probability distribution functions, and Markov or Semi-Markov chains. While Poisson models assume that earthquakes occur randomly in time, space and magnitude, Markov models describe subsequent earthquakes as energy release sequences. The research output resolved the constant categorization's issue of emergency goods demand with the dynamic changes of demands and goods [5]. Zheng et al. explored according to the assumption of limited goods, and, keeping the prediction's updating demands in mind, applying dynamical programming, suggested the optimum emergency goods' demand [6].

Therefore, the research gaps of the paper are as follows:

- Lack of estimating the amount of relief goods required using the fuzzy inference system
- Lack of considering different scenarios for estimating relief goods
- Lack of considering a case study for a potential earthquake in Tehran
- Lack of considering kinds of relief goods

3 Research method

Fuzzy rule-based networks are a well-known method family within soft computing. They are based on fuzzy concepts to address complex real-world problems. This network receives fuzzy information as input and then provides the required output to the decision-maker using fuzzy rules. A fuzzy inference system (FIS), or rule-based system, is a system that formulates an input-to-output mapping using fuzzy logic. These systems are made up of a number

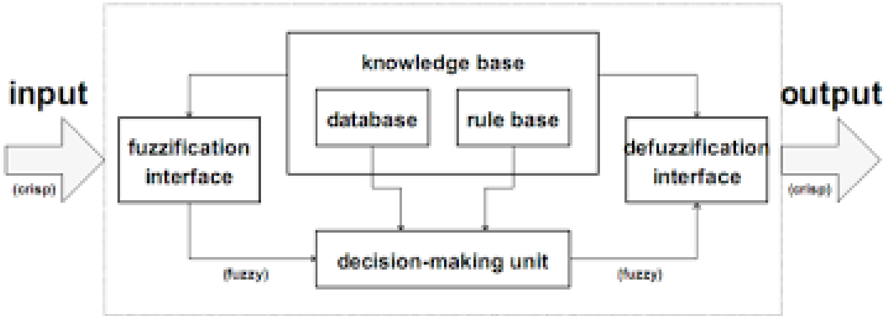

Figure 3: The main structure of the fuzzy inference system

of "if-then" statements. The main structure of the fuzzy inference system consists of five function blocks shown in Figure 3.

First, the criteria for determining the amount of demand are selected by experts and converted to a fuzzy number. Then, fuzzified criteria are entered into the fuzzy inference engine. In this process, linguistic membership functions are first defined, and then the desired operators are customized. In the next step, the rules set by the experts are evaluated and aggregated by the relevant operators. In the last step, the required amount of demand is estimated. In this research, we consider a membership function for each input variable to convert specific inputs into fuzzy numbers and enter them into the fuzzy inference system. Triangular fuzzy numbers are used for this purpose.

The FIS approach was applied to solve the problem in MATLAB R2020b v9.9.0.1495850 software. All tests were run on a computer with an Intel Core i5-8250U 1.60 GHz CPU and 8 GB RAM. The membership function µ always contains values of the range [0 and 1]. A fuzzy number is denoted by a range of real numbers, each with a membership degree between 0 and 1.

The fuzzy set $\bar{A}$ of the reference set U is represented as the following ordered pairs:

$$\bar{A} = \{(x, \mu\bar{A}(x)|x \in U\} \tag{1}$$

In the above equation, x is an element of the set $\bar{A}$ that has the property of this set to some extent. The limits or degree of membership are indicated by. The degree of membership $\mu\bar{A}(x)$ indicates to what extent the element x has the property of the set $\bar{A}$.

Triangular fuzzy number (TFN) is a type of fuzzy number that is represented by three real numbers as $F = (l, m, u)$. The upper bound, denoted by u, is the maximum value that the fuzzy number F can take. The lower bound denoted by l is the minimum value that the fuzzy number F can take. The value of m is the most probable value of a fuzzy number. The membership function of a triangular fuzzy number is as follows:

$$\mu_f(x) = f(x) = \begin{cases} \dfrac{x-l}{m-l} & l < x < m \\ \dfrac{u-x}{u-m} & m < x < u \\ 0 & Otherwise \end{cases} \tag{2}$$

Mamdani Inference System has been used as fuzzy operators. Therefore, the operator's min and multiplication are used to process each rule. Equations (3) and (4) show how these operators are used in this study.

$$R(U, V) = min[\mu_A(u), \mu_B(u)] \tag{3}$$
$$R(U, V) = \mu_A(u).\mu_B(u) \tag{4}$$

Also, the linguistic terms considered in this research include High (H), Medium (M), and Low (L). Figure 4 shows the fuzzy structure that has been considered in this study.

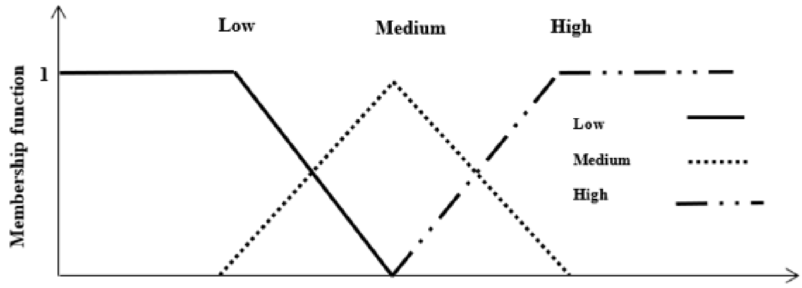

Figure 4: The triangular fuzzy membership function

4 Results and discussion

The fuzzy inference system approach will eventually lead to conclusions that are typically fuzzy. These fuzzy results are not easy to understand and interpret, so they must be converted to definite (Crisp) numbers. The process of converting fuzzy numbers to definite numbers is called defuzzification. The defuzzification method used in this research is the surface center method, which is calculated as follows:

$$DF_{ij} = \frac{l(u_{ij} - l_{ij}) + (m_{ij} - l_{ij})}{3} + l_{ij} \tag{5}$$

In order to convert the verbal variables in the first stage, the appropriate fuzzy interval is considered according to Table 3. In the next stage, the triangular membership function is selected due to the proper separation of quantitative numbers (three fuzzy intervals are considered).

Table 3: Fuzzification of answers

Input variable	Verbal variables of the input variable	Output variable	Verbal variables of the output variable
Severity or strength of earthquake damage	No	Number of biological goods packages demanded	No
Building texture of the area	Weak	Number of food packages demanded	No
	Medium		
	High		
Population density	Weak	Number of pharmaceutical goods packages demanded and the injured	No
	Medium		
	High		
Earthquake time (night or day)	No	Number of the displaced	No

The population of the 22 districts of Tehran has been extracted from the statistical yearbook compiled in the database of the National Statistics Portal of Iran, which is shown in Table 4.

According to the above, another input variable to the fuzzy inference system is the texture type of the area. Table 5 shows the area and ratio of worn texture in Tehran by district.

Table 4: Population and number of households living in Tehran by district

District	Population	Number of households
1	531,274	188,523
2	749,022	257,870
3	369,502	127,179
4	990,146	325,274
5	928,738	315,901
6	278,947	92,783
7	336,550	120,395
8	479,005	164,137
9	207,624	62,346
10	342,223	125,605
11	333,127	113,688
12	256,601	80,629
13	265,796	82,570
14	538,073	170,416
15	706,844	219,733
16	289,077	86,018
17	309,230	99,767
18	445,429	140,511
19	282,598	82,583
20	395,088	124,499
21	196,874	67,401
22	191,934	68,261
Total	9423702	3,116,092

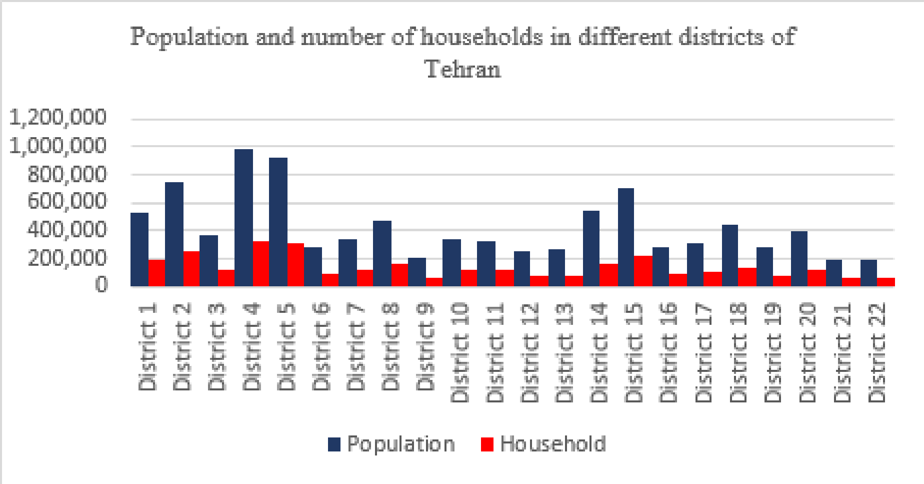

Figure 5: Graph of population and number of households living in Tehran by district

Table 5: Area and ratio of worn texture in Tehran by district

District	Total number of blocks	Number of blocks (worn texture)	Worn texture ratio	Area of texture blocks (hectares)	Area of worn texture blocks (hectares)	Area of zones (hectares)
1	2,004	90	4.49	53	2.36	65
2	2,556	28	1.10	26	0.29	24
3	1,300	42	3.23	17	0.56	25
4	2,718	5	0.18	4	0.01	7
5	2,157	8	0.37	6	0.02	7
6	1,242	5	0.40	3	0.01	5
7	1,163	263	22.61	185	41.84	238
8	1,144	178	15.56	108	16.85	144
9	654	290	44.34	105	46.37	146
10	1,075	619	57.58	320	184.08	428
11	901	307	34.07	270	92.07	355
12	1,389	541	38.95	479	186.43	593
13	921	147	15.96	53	8.39	73
14	1,870	532	28.45	190	53.93	258
15	2,324	560	24.10	187	45.00	246
16	1,358	331	24.37	108	26.31	152
17	1,035	409	39.52	166	65.57	236
18	1,379	182	13.20	76	10.07	103
19	895	39	4.36	16	0.69	21
20	1,799	261	14.51	100	14.52	137
21	840	5	0.60	5	0.03	7
22	684	3	0.44	1	0.00	1

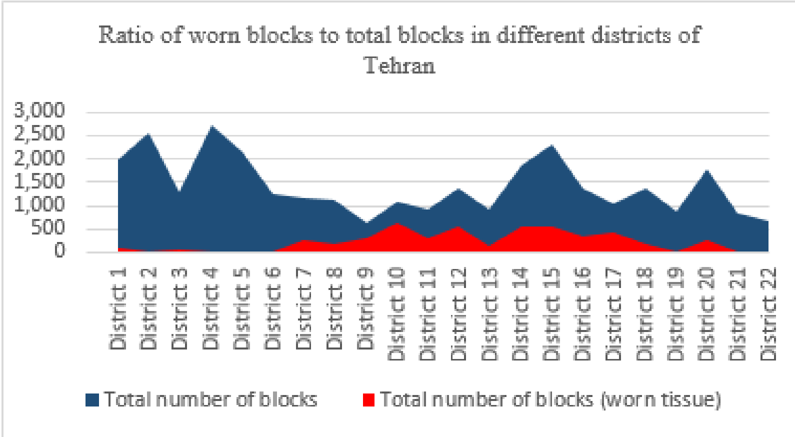

Figure 6: Graph of the ratio of worn blocks to total blocks in different districts of Tehran

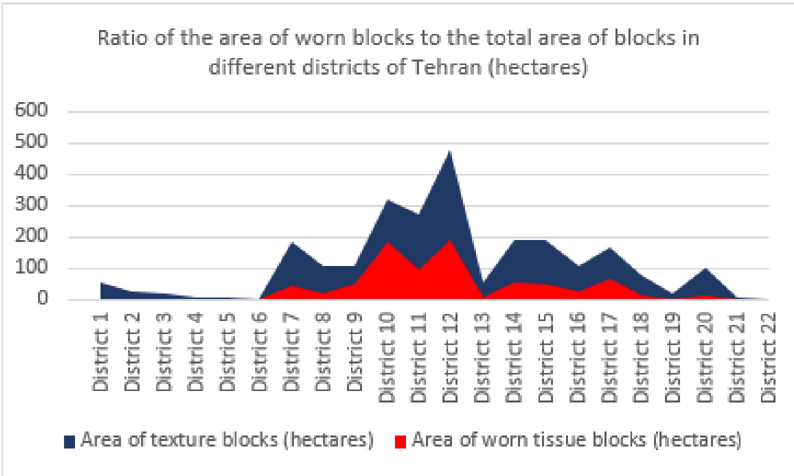

Figure 7: Graph of the ratio of the area of worn blocks to the total area of blocks in different districts of Tehran

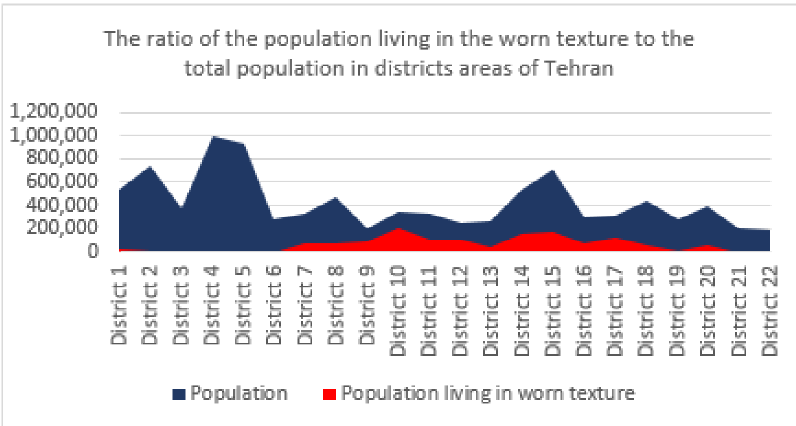

Figure 8: Graph of the ratio of the population living in the worn area to the total population in different districts of Tehran

In the first stage of Mamdani fuzzy inference system, 4 inputs and 4 outputs are defined according to Figure 9. It should be noted that the centeriod method has been used for defuzzification.

In the next stage, fuzzy rules are created using the opinions of experts. Figure 12 shows the output changes based on the inputs. For example, if the intensity of the earthquake is 4.5 Richter, the texture type is medium (semi-worn),

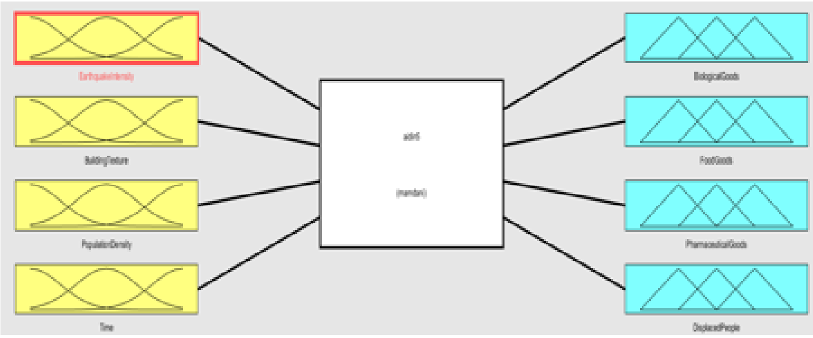

Figure 9: Inputs and outputs in the fuzzy inference system

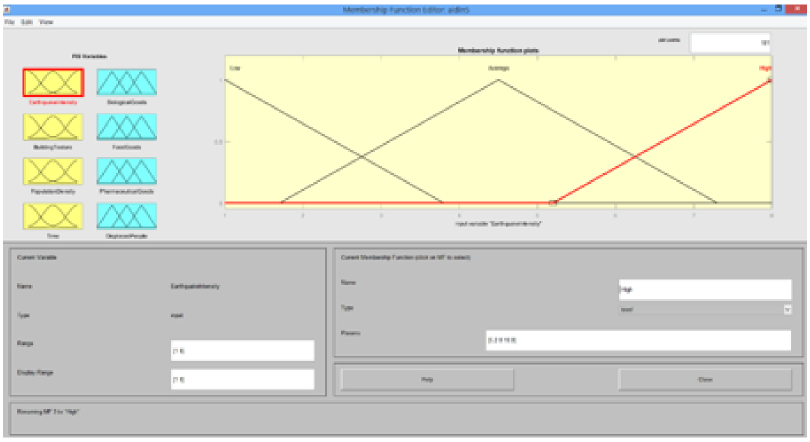

Figure 10: Definition of input variables in the fuzzy inference system

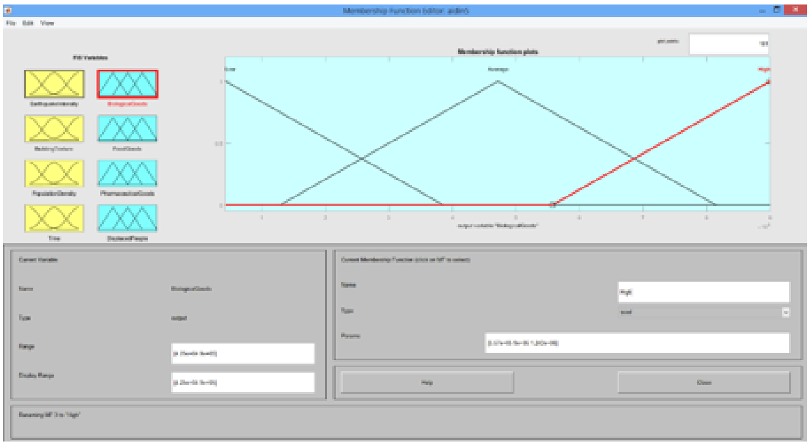

Figure 11: Definition of output variables in the fuzzy inference system

the population is 535 thousand and the occurrence time is night, the outputs of the fuzzy inference system will be as biological goods package 100,000 thousand, food goods package 500 thousand, 500,000 pharmaceutical goods package, 500,000 injured and 400,000 displaced people.

Figure 13 shows the changes in earthquake intensity and texture with the number of packages of biological goods, which as the intensity of the earthquake increases and the texture weakens, the need for the number of biological goods packages increases.

Figure 14 shows that as the earthquake intensity increases and the population increases, the need for biological goods packages will increase.

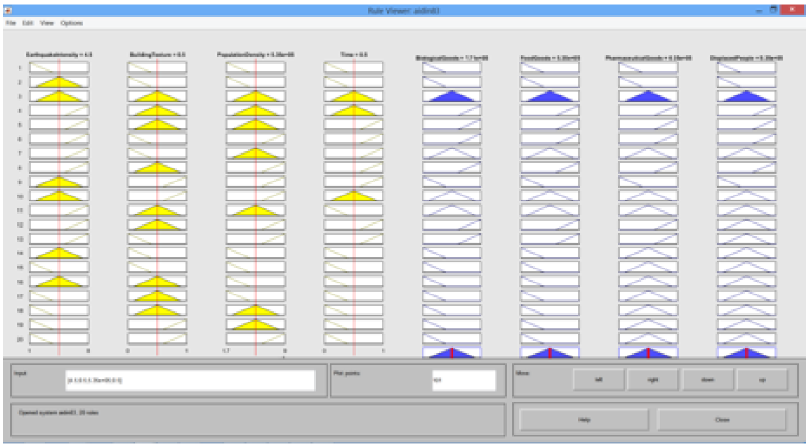

Figure 12: Change in the outputs based on the inputs of the fuzzy inference system

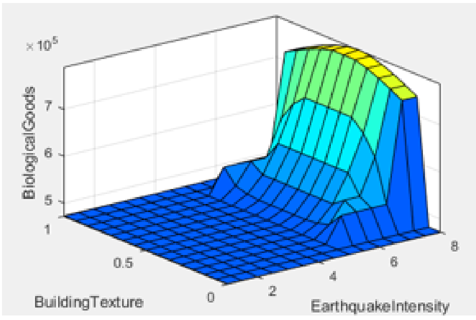

Figure 13: Earthquake intensity and texture changes with the number of packages of biological goods

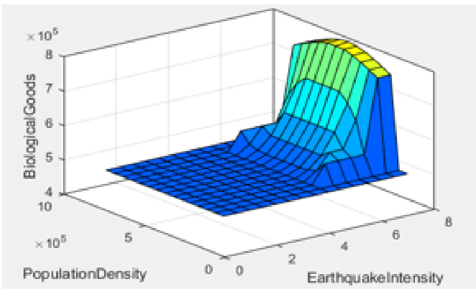

Figure 14: Changes in earthquake intensity and population with the number of biological packages

Figure 15 shows that if the occurrence time is night, the number of packages of biological goods increases as the intensity of the earthquake increases.

In the last stage, a plot has been considered for each district of Tehran and the number of relief packages and the number of displaced and injured people have been estimated. According to geological evidence, the intensity of the earthquake is approximately 7 for all districts and night time, which is the worst case plot. Based on this, the results are as shown in Table 6.

5 Conclusion

In this study, first, factors such as earthquake severity, time of occurrence, texture type, and population density were selected as the factors affecting earthquake damage and losses, then these factors using experts' opinions as inputs of the fuzzy inference system were used as triangular fuzzy numbers to extract the desired outputs from the system.

The outputs of the fuzzy inference system used in this study included the closed demand for packages of relief

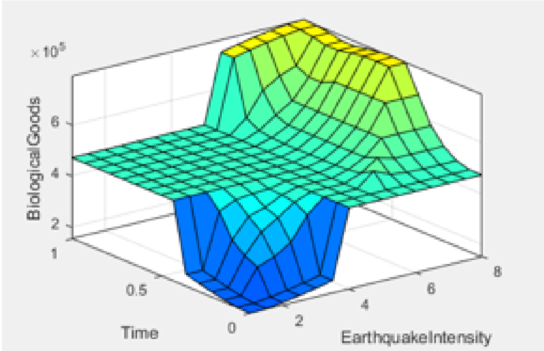

Figure 15: Changes in the earthquake intensity and time with the number of biological goods packages

Table 6: Plot definition for 22 districts of Tehran and fuzzy inference system outputs

District	Input variable				Output variable (thousand people)				
	Intensity or strength of earthquake damage	Building texture of the area	Population density	Earthquake time (night or day)	Number of packages of biological goods demanded	Number of packages of food goods demanded	Number of packages of pharmaceutical goods demanded	Number of the displaced	Number of the injured
1	7	Strong	Medium	Night	123	492	25	492	25
2	7	Strong	High	Night	173	692	35	692	35
3	7	Strong	Low	Night	82	328	16	328	16
4	7	Strong	High	Night	220	880	44	880	44
5	7	Strong	High	Night	214	856	43	856	43
6	7	Strong	Low	Night	62	248	12	248	12
7	7	Strong	Low	Night	78	312	16	312	16
8	7	Strong	Medium	Night	100	400	20	400	20
9	7	Medium	Low	Night	43	172	9	172	9
10	7	Medium	Low	Night	81	324	16	324	16
11	7	Medium	Low	Night	77	308	15	308	15
12	7	Medium	Low	Night	60	240	12	240	12
13	7	Medium	Low	Night	63	252	13	252	13
14	7	Medium	Medium	Night	100	400	20	400	20
15	7	Weak	High	Night	160	640	32	640	32
16	7	Weak	Low	Night	66	264	13	264	13
17	7	Weak	Low	Night	69	276	14	276	14
18	7	Weak	High	Night	100	400	20	400	20
19	7	Weak	Low	Night	63	252	13	252	13
20	7	Weak	Low	Night	91	364	18	364	18
21	7	Weak	Low	Night	46	184	9	184	9
22	7	Weak	Low	Night	43	172	9	172	9

goods in three types: biological, food, and pharmaceutical, as well as the number of displaced and injured people.

For the case study, 22 districts of Tehran were selected because the potential for high-intensity earthquakes in this area is high due to the presence of dangerous faults. For this purpose, a plot was considered and its outputs were extracted and displayed.

The results showed that an increase in the intensity of the earthquake, weak texture, and high population density increases the demand for various types of relief packages and the number of displaced and injured people, especially at night. By using such research and focusing on methods of predicting important factors due to the occurrence of natural disasters, in a timely response and reducing the effects of these disasters, both financially and physically, it is possible to act better and more accurately and reduce the number of destructive effects of these disasters as much as possible.

Specifically, the following organizations can be among the beneficiaries of this research.

1. Rescue Organization
2. Crisis Management Organization
3. Red Crescent Organization
4. Fire department
5. Hospitals
6. Blood transfusion organization

Also, in general, the results of this research can benefit the public. The ruin caused by the earthquake in Tehran will be far greater than the Red Crescent be able to handle by itself, while Red Crescent Society in Iran will manage to organize the relief operations right after the earthquake begins. So, emergency aid goods and necessities like water, food, drugs, and other things should be presented in them, and bases should be made at the local or county level separately. There are several schools at the elementary to high school level in the context of empirical research. The school buildings are made of steel and brick, and a few constructions built of ferroconcrete can be seen in this region. Against great earthquakes, constructions' skeletal stability is not sufficient. Additionally, the ground of schools is pretty small, and it is not easy for students to use it as a temporal vacuum area during an earthquake time. The schools' skeletal stability immediately must be checked against a great earthquake and implementing acts must be enforced. During the earthquake time, every school should present safety instructions for all the students.

Training of local people, public aid management, participation of local organizations and institutions, the familiarity of organizations with the structure of the affected community, how to inform people and organizations, access to reliable and timely information on the needs of the region and services provided, coordination Organizing and planning relief groups and organizations, managing human resources, equipment, and aids, distributing facilities and proper division of labor and duties without a trustee, traffic at the entrances, city security, aid workers and aid sent, and establishing order and security in the region are the solutions to deal with these challenges.

The disaster risk reduction strategies to overcome these problems based on National Incident Management System (NIMS) are as follows [28]:

- Management by objectives - this involves creating specific objectives that can be measured to ensure that they are being met.
- Incident action planning to guide incident activities.
- Manageable span of control allows supervisors to efficiently lead their subordinates on an incident.
- Comprehensive resource management involves keeping an accurate inventory of all resources available.
- Integrated communications involve using communication software such as video conferencing, and common radio frequencies.
- Information and intelligence management: This principle establishes the process for gathering information and processing that information.

There are some limitations to the study. First, the study database complementarity should be more sufficient. CBR relies mostly on background information. Assuming a limited data set, that is hard to match a greatly same case study as a decision-making process. Data sets including the catastrophe cases are insufficient for higher matching every case and having greater decision support. Having a case base with more integrated data is essential. Sharing the global catastrophe data will present more background information. We understood that the greater the catastrophes' damaging force, the lower the occurrence due to data statistics. It is harder to match a high same case when the catastrophe is greater, which is due to two reasons; first due to very limited background information, and second due to more evidently special traits. More cases can present more outputs for experts and develop the accuracy of the forecast. Other limitations are as follows:

- Fuzzy Inferences System requires access to a computer system equipped with features such as high RAM and CPU.
- The final solution in the Fuzzy Inferences System depends on the expert opinion in defining inputs variables.
- Due to the uncertainty in the input data, they are considered fuzzy numbers.

To overcome these limitations, a powerful hardware system must be accessed to run the fuzzy inference system. It is also necessary to get help from knowledgeable and skilled experts so that they can choose the appropriate criteria and inputs.

6 Future suggestions

The following suggestions are made for enthusiasts and researchers in this field:

1. Using a cooperative game approach to distribute relief goods to reduce the golden time of relief
2. Using the method used with related inputs to estimate demand due to other natural disasters and simultaneous disasters
3. Considering other types of uncertainty approaches such as scenario-based and stochastic and solve the model using robust optimization or stochastic chance constraint method
4. Using other prediction methods such as fuzzy neural networks and other methods to estimate the desired parameters
5. Customizing the proposed model for other areas prone to any natural disaster
6. Estimating the number of rescue teams to be sent to the scene of the accident

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