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Estimation of relief supplies demands through fuzzy inference system in earthquake condition

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Abstract

Natural disasters such as earthquakes have a destructive impact on urban infrastructures and their performance. Due to the existence of inherent uncertainty in natural disasters, related organizations are not able to optimally use the critical infrastructures to reduce destructive effects. Also, estimating the demand for relief commodities according to various scenarios has always been a concern for decision makers and relief organizations. The correct estimate of demand can reduce the time of relief operations and can greatly reduce human casualties. In this paper, the demand forecast for relief commodities will be as the output of the fuzzy inference system. The proposed mechanism has been tested in a case study of Tehran city. The results of this research can be useful for many decision making centers, including the fire department, the Red Cross, hospitals and so on. Estimation of demand for relief commodities using the fuzzy inference system for different scenarios and considering a case study for a possible earthquake in Tehran are the contributions of this research.

Keywords: Fuzzy inference system, Estimation of demand, relief commodities, severity of earthquake.

1-Introduction

Humanitarian logistics or Humanitarian relief of supply chain management attracted many attentions (Sahebjamnia et al., 2017). This is important for disasters especially earthquake, since there is no alarm or warning for us. The number of fatality in tsunami earthquake in 2004 and 2010 in Haiti was approximately 500000 (Encyclopedia Britannica, 2016a; Encyclopedia Britannica, 2016b). Responding these emergency conditions effectively in real time, without warning is severely challenging and needs a coordinated and consistent decision making process (Sahebjamnia et al., 2015). One of the ways to encounter the emergency conditions is the preparation of prerequisites before the occurrence of natural disasters. Supporting models of Humanitarian decision making should consider social costs and include logistic and deprivation costs to achieve the desired social result (Holguín-Veras et al., 2012). From 1990 about 300 million of people are affected by various disasters each year and the annual damage increases about 0.17% of GDP (Guha-Sapir et al., 2013). Appropriate disaster operations management approaches, can reduce the effects of natural disasters on human life by developing humanitarian relief logistics (HRL) (Galindo & Batta, 2013). Earthquakes cause death and damages that are originated from the fire of buildings, stones fall, earth fall and tsunami.

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However, buildings collapse is the main reason of death all over the world that about 68.36% death occurs (Coburn & Spence, 2003; Daniell et al., 2011) that include 2.72 timber, 6.80 stone walls, stone masonry, 24.80 earthen / rubble masonry 13.04 adobes, 13.76 modern brick, 7.42 reinforced concrete and 0.02 steel buildings (Daniell & Schaefer, 2017). Frequency, Severity and effect of disasters increased in the recent decade, because of different factors, including climate change and the growth of residence (European Commission, 2016).

The average of worldwide annual fatality, including: earthquake, tsunamis, cyclones and flooding is 314 billion dollars (United Nations Office, 2015). In addition, about 19000 deaths and fatality in Europe, more than 29 billion euro occurred because of the earthquakes between 1998 until 2009 (European Geosciences Union, 2017). The importance of using systematic methods for the improvement of humanitarian operations in the recent decade is widely accomplished in Operation Research Management Science (OR/ MS) (Trunick, 2005; Unal et al., 2014; Van Wassenhove, 2006).

Timely and appropriate preparation of resources in disaster relief for affected people is necessary. The shortage of the resources may debilitate emergency responding and leads to the increase of the problems. When an event occurs, people and appropriate supplies should be sent with the correct amount to the needed places. Therefore, first the definition of the possible scenarios for the occurrence of earthquake is done in the next step, and then through fuzzy inference system, the rate of disaster relief supplies demands is estimated for a potential earthquake in Tehran.

In this research, in the first section, the introduction and in the second section, the literature review is mentioned. In the third part, the problem definition is expressed and in the fourth section, the research method is stated. In section 5, the computational results are described. Finally, in section 6, the results conclusions are listed.

2-Literature review

Paul and Wang developed and investigated robust models for the preparation of earthquake through the optimization of number, place and the capacity of DCs. They showed the practicality of their approach through a case study in Northridge region in California that had the two strongest earthquakes in 1971 and 1994. There two earthquakes are recorded in Northern America. Their aim is to minimize all the social costs that include the initiation and provision of initial supplies, logistics and deprivation costs related to accessibility to the sources that encounter delay. Their model includes various earthquakes uncertainly such as facility damage, casualty by severity and travel time. They created two models for robustness: uncertainly about a parameter in a scenario and partial dissatisfaction among the scenarios, this unique method presents 1) Social costs after an earthquake 2) The dangers of incorrect modeling of deprivation costs and 3) The effect of budget constraints (Paul & Wang, 2019). Holguin-Veras et al. (2013) tested the concept of deprivation costs in small distribution networks and estimated a deprivation cost function for water. Wang (2016) reduced their framework for special deprivation costs functions that by meta-analysis of health care literature about trauma triage, that human suffering is consistent in it, is adjusted. Rezaei-Malek et al. (2018) presented a new combinatory fuzzy multi-purpose decision making approach for priority processing of the regions that are set to disaster that considered as potential demand points (PDPs) in relation to their vulnerability in strong earthquakes. First, they determined important criteria for PDPs prioritization, Then Fuzzy DEMATEL is achieved for the definition of relations among criteria and their weight by fuzzy ANP. Finally, fuzzy PROMETHEEII is used for PDP ranking. Their proposed method is valid using a pre-determined designed network model. Their numerical results present the practicality of their approach. Cost efficiency and responses HRL networks have basic role in the appropriate management of the disasters' operations (Caunhye & Nie, 2012). HRL research can be divided to three planning stages based on life cycle: preparation/pre-disaster, response and evaluation (Özdamar & Ertem, 2015). One of the ways to increase efficiency and HRL response is to consider relief commodities (RCs) in pre-disaster stage (Tofighi et al., 2016). Relief pre-positioning (RP) is defined as the preparation, storage and distribution of RCs as a desired planning of relief related processes (Rezaei-Malek & Tavakkoli-Moghaddam, 2012). Mete and Zabinsky proposed a stochastic two-stage modeling for planning, storage and distribution of medical relief supplies. Their developed models determined warehouses, their needed inventories in the constraints and facility capacity. This model tries to minimize all the operational cost of warehouses and expected value of all the transportation time and the penalty of shortage under predicted scenarios condition in disaster (Mete & Zabinsky, 2010). Deshmukh et al. (2011) studied the effects of floods on infrastructures. These effects were considered as two categories of primary effects and secondary effects. Primary effects included the destruction of water supply and gas supply systems, road destruction and communication failure. Secondary effects included the impact of these failures on industries from three technical, social and economic points of view. Finally, the reasons for the destruction of facilities were prioritized using the AHP method.

Chang et al. (2007) presented a conceptual model for investigating the effects of natural disasters on infrastructures such as electric power and transportation. Case study considered was the Canadian disaster, the 1998 Ice Storm that affected the northeastern region of the country. The results indicated the validity of the performance of the proposed model. Tofighi et al.(2016) pointed to PDPs with average seismic severity, rate of buildings' damage, the number of fatality and the density of residents that have the highest vulnerability and therefore have higher priority. They prioritized PDPs using these criteria. These criteria are classified and ranked 1 to 5, where 1 and 5 show the lowest and highest priority. Final priorities were calculated through the combination of all the criteria's ranking for each PDP. Hassanzadeh, discussed the investigation of the evaluation of the fatalities during probable earthquake. But there was no research about the number of people who are stuck around Iran, therefore this study was conducted. Data was collected by two-stage cluster sampling through an interview from 396 people in Bam earthquake in 3003, about the damages of buildings and number of fatalities in each family, In addition, to investigate the validity of statistical and local results in comparison with Actual earthquake (AE), Wilcoxon signed Rank test, Root Mean square Error (RMSE), Mean Absolute Error (MAE) and (Fuzzy Inference system analyses) were done. This analysis clearly shows the improvement of estimated results about the number of fatalities in comparison with KHM model. In addition, an estimate of "the stocked people based on the collected data in Iran was hopeful", since it could play an important role in disaster response. This factor can have a key role in the efficiency of the constraint resources devotion, especially urban search and rescue operations (USAR) (Hassanzadeh, 2019). Bedini and Bronzini, pointed to the unsolved subject after an earthquake in central Italy that is from August 2016 to January 2017 in 3 stages: 1. Periodic evaluation of the ways to manage the earthquake conditions in the past and the role of today planning. 2. suggestions and operation proposals for the damaged regions. 3. Planning suggestions for the improvement of the region based on economic and social model "productive landscape". The analyses of uncertainty related to the occurrence of disasters for the creation of appropriate preparation plans is necessary for natural disasters (Bedini & Bronzini, 2018). Battarra et al., focused their attention on pre-set of emergency condition for the preparation of earthquake. They presented a new method for the calculation of probable earthquakes and the number of suffered people. Their approach is based on the predicted methods of earthquake engineering literature by using probable scenarios for showing the uncertainty related to the avoidance of the occurrence of earthquake. They considered the proposed method by using the historical data of earthquake in Turkey Where the probability of earthquake is considerable there. They also presented a case study that showed that the performance of their method is to solve the inventory allocation problem of the Turkish Red crescent (Battarra et al., 2018). Abdalzaher and Elsayed, presented road network traffic (RNT) by using data communication networks (DCNs), by focusing on the earthquake disasters to achieve more safety of evacuation. Five DCN models are proposed to show cross section control, round about cross control and cracked round about, of the corresponding RNT cases, namely, speed flow relationships, left turn effect four-way traffic analogy. By using road network (RN) for DN in these five models, DN solutions can be used to solve the problems of RN. The results of their simulations revealed that there is very close traffic density in DCN and RNT diagrams. The proposed topography is emphasized by using t- test and ANOVA analyses. In result, DCNs can be used in the management of safer destruction during disaster (Abdalzaher & Elsayed, 2019). Ghasemi et al. (2019) presented a mathematical model for managing disaster relief before and after the disaster. The proposed multi-commodities and multi-period model manages the

location and allocation decisions of distribution centers. The relief supplies considered in their study were food and medicine. Finally, the proposed model was solved by two metaheuristic algorithms.
Therefore, considering the literature review, the contributions of this research are as follows:

- Estimation of demand for relief commodities using the fuzzy inference system for different scenarios.
- Considering different scenarios in the estimation of relief supplies including: severity of earthquake (Mercalli intensity scale), fault and time of earthquake occurrence (day or night) and the probability of occurrence.
- Considering a case study for a possible earthquake in Tehran.
- Considering different kinds of relief supplies including: drinking and non-drinking water, blankets, blood, medicine, food and tents.

3-Problem definition

Iran is one of the countries in Asia that many earthquakes occur there and each year had many financial loss and fatalities. Tehran is one of the most populous cities in Asia. Zone one in Tehran is located in the highland part of the city and is about 50 square kilometers and based on the statistics there live more than 500000 people. The occurrence of an earthquake in this zone can have irrecoverable damages because of the population and the number of the buildings.
The following figure shows the severity of the occurred earthquake based on year in Tehran city.

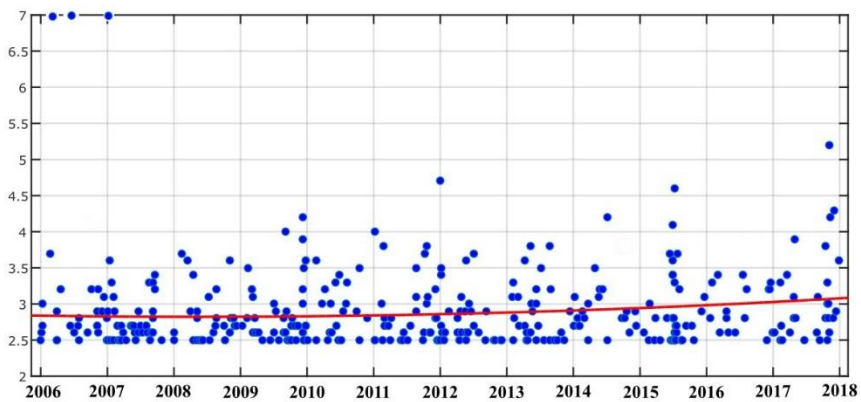

Fig 1. Historical data about Tehran's previous earthquakes

In this research through the statistics of JICA institute about the rate of the consumed relief supplies in the recent earthquakes, the rate of relief supplies demands for a possible earthquake in zone one of Tehran is estimated. Therefore, fuzzy inference system is used. This leads to the preparation and agility of responding to the injured people. The relief supplies in this research include: drinking and non-drinking water, blankets, blood, medicine, food and tents. Also the considered scenarios will change based on the severity of earthquake (Mercalli intensity scale), fault, time of earthquake occurrence (day or night) and the probability of occurrence. These scenarios are fuzzy and will be inserted to system based on fuzzy numbers.

4-Research method

The fuzzy inference system provides a systematic process for converting a knowledge base into a nonlinear mapping. So, knowledge-based systems (fuzzy systems) are used in engineering and decision-making applications. The proposed fuzzy inference system has the following components as shown in figure 2.

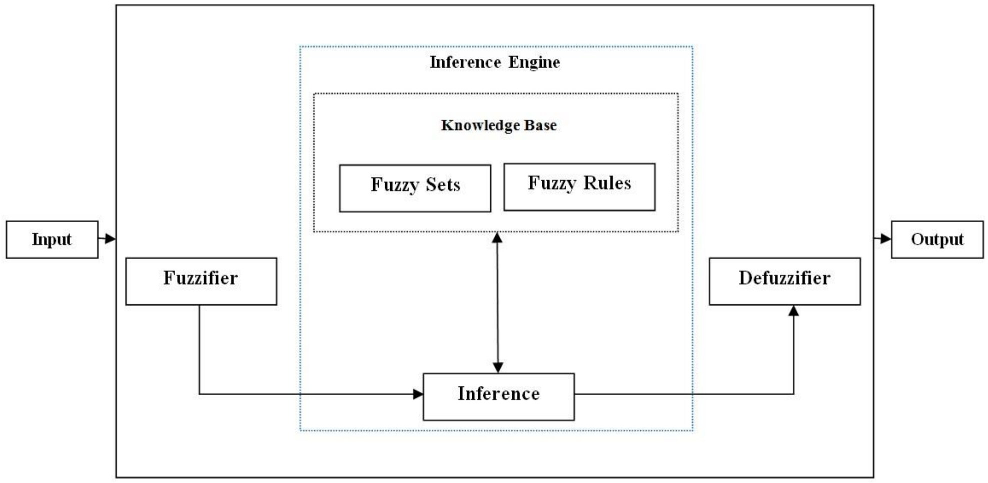

Fig 2. Structure of the proposed method

1. A fuzzifier in the input that converts the numerical value of variables to a fuzzy set. In this step, we consider the membership functions for each input variable to convert definite inputs to fuzzy and put them in the fuzzy inference system. Membership functions have different types. In this study, triangular fuzzy numbers have been used. A triangular fuzzy number (TFN) is a fuzzy number that is represented by three real numbers as F = (l, m, u). The upper bound shown with u is the maximum value of the fuzzy number F. The lower bound shown with 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 (see figure 3).

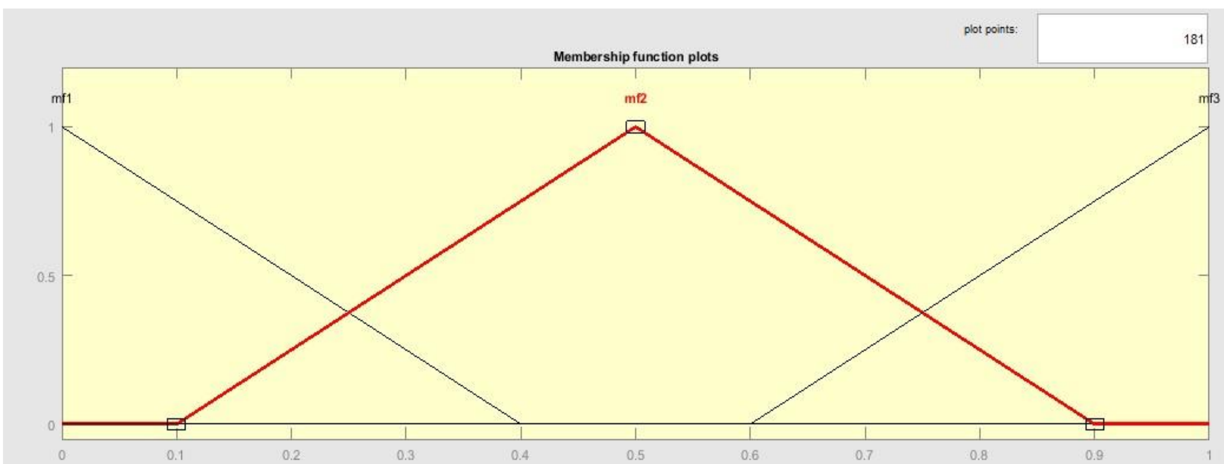

Fig 3. A Triangular fuzzy number, $\tilde{A}$

2. The fuzzy rule base is a set of if-then rules. The input of this step in this research is same as the simulation output.
3. Fuzzy Inference Engine that converts inputs into a series of outputs
4. Defuzzifier that converts the fuzzy output to a definite number

5- Computational results

The scenarios considered in this study include the type of fault (the activation of each fault has a different probability), the severity of occurrence (in terms of Mercalli) and the time of the occurrence of the earthquake (day or night). The importance of the time of earthquake occurrence is because at the resting time of the people (an average of 8 hours), the response speed and the level of safety measures, especially during sleep, are reduced. So, naturally, the amount of casualties and the demand for relief commodities at night is much greater than the day. Also, the probability of occurrence of the earthquake and activation of the fault is determined as fuzzy based on experts' opinions and geographic information on fault length, fault activation records and etc (see table 1).

Table 1. The probability of occurrence of each scenario

Scenario number	The name of the scenario	Mercalli intensity scale	The probability of occurrence
1	Mosha fault- night	(0,6,12)	(0.2547,0.2747,0.2947)
2	Mosha fault- day	(0,6,12)	(0.1174,0.1374,0.1574)
3	North Tehran fault-night	(0,6,12)	(0.0972,0.1172,0.1372)
4	North Tehran fault-day	(0,6,12)	(0.0063,0.0263,0.0463)
5	South Ray fault-night	(0,6,12)	(0.0325,0.0525,0.0725)
6	South Ray fault-day	(0,6,12)	(0.0851,0.1051,0.1251)
7	Floating fault-night	(0,6,12)	(0.2143,0.2343,0.2543)
8	Floating fault-day	(0,6,12)	(0.0325,0.0525,0.0725)

Mosha fault is 400 km long. This fault activated in an earthquake that occurred in 1830. Mosha fault ends from the north to the dam of Latian. The Ray fault is south of Tehran and is 20 km long. This fault is from the south side leading to Yevanky. North Tehran fault is 75 km long. North Tehran fault is near the Mosha fault. The floating fault is 13 kilometers long. Nearly 2,000 residential units are located on this fault.

Figure 4 shows a drawing of inputs and outputs in the Mamdani fuzzy operator in MATLAB software. As it is obvious, the input scenarios of the system include three scenarios of severity of earthquake (Mercalli), time of occurrence (morning or night), and the probability of occurrence of the scenario in the corresponding fault. In the fuzzy rule base, simulation rules enter the Mamdani system. These rules are in fact the relationship between defined scenarios and the demand for relief commodities. Eventually, the system output includes the demand for relief commodities such as food, medicine, blood, blankets, drinking and non-drinking water and tents.

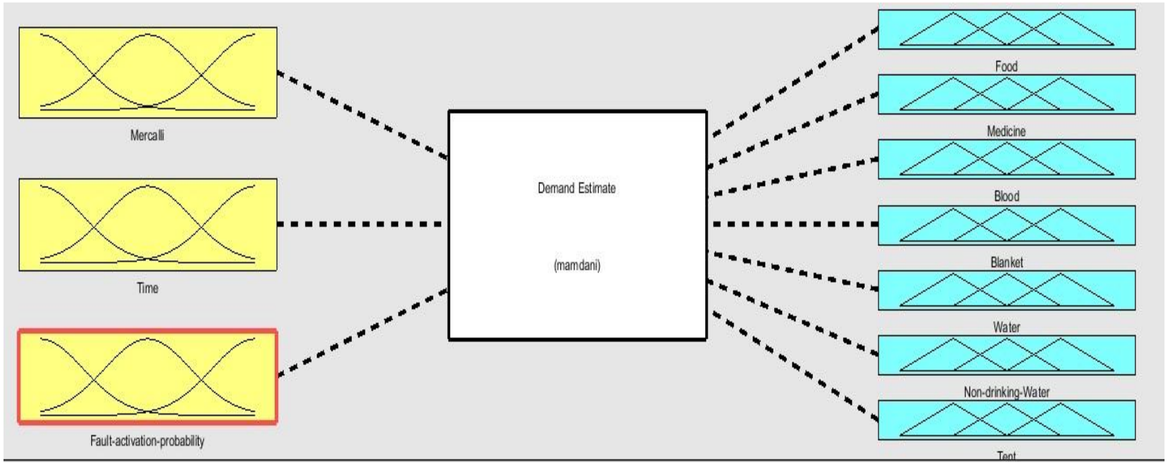

Fig 4. The Structure of designed fuzzy inference system

For example, the calculations for scenario 5 are given here: Almost all buildings in the experimental area will be destroyed or hardly damaged by the Ray fault earthquake. The damage ratio is estimated to be more than 80% based on the existing building damage function data. Within the scope of the experimental study, not only construction costs, but also human casualties will be high. Although human casualties will vary depending on the structure type of the buildings, it is estimated that 3,048 people of the total population of 32,239 will be killed at night. If the relief groups of people and relief teams of other organizations arrive on time and act effectively and cover the demand, the total number of casualties will drop to 2151 people. The study group, based on the GIS database related to the experimental study area, provided a three-dimensional model of vertical perspective views that indicates the special status before and after the occurrence of the earthquake within the scope of the case study (sees figure 5).

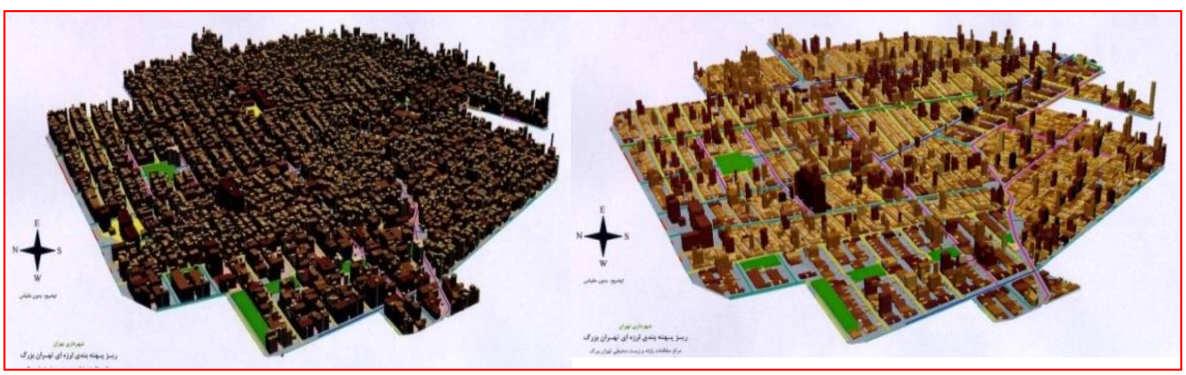

Fig 5. Three-dimensional view of damage to the studied area and comparing it with the pre-earthquake condition

Figure 6 shows the demand forecast for medicine for the scenarios of time and severity of the earthquake. As can be seen, with the increase in the Mercalli scale, the amount of forecasted demand will also increase. Also, with the occurrence time of the earthquake being closer to the night, the demand for medicine will increase. Therefore, the highest amount of demand for medicine is for Mercalli 12 and at night.

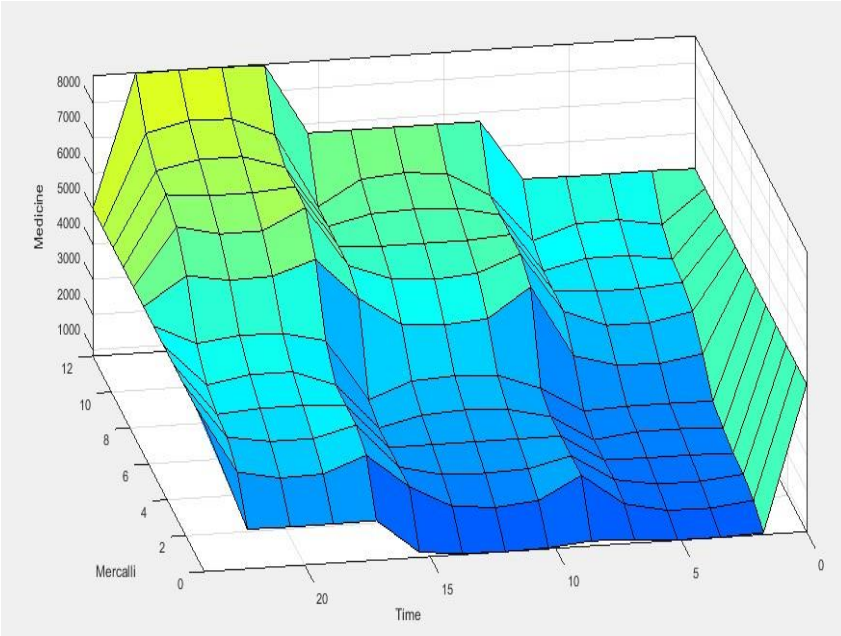

Fig 6. Output surface for medicine estimate

Figures 7 and 8 show the average demand in different scenarios for the Ray fault. Figure 7 shows the earthquake scenarios in the morning and figure 8 shows earthquake scenarios at night.

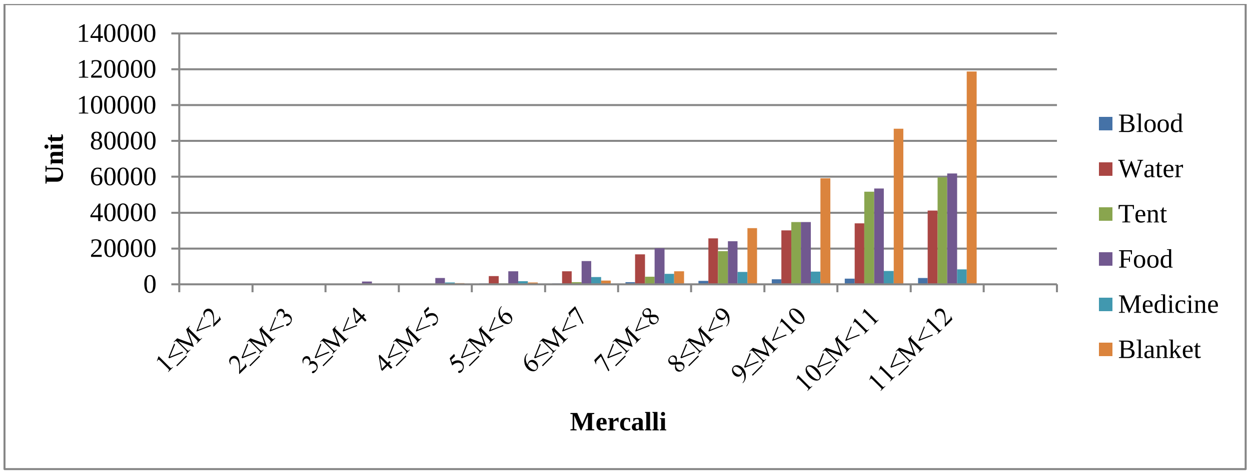

Fig 7. The average demand for relief commodities for the Ray fault in the morning

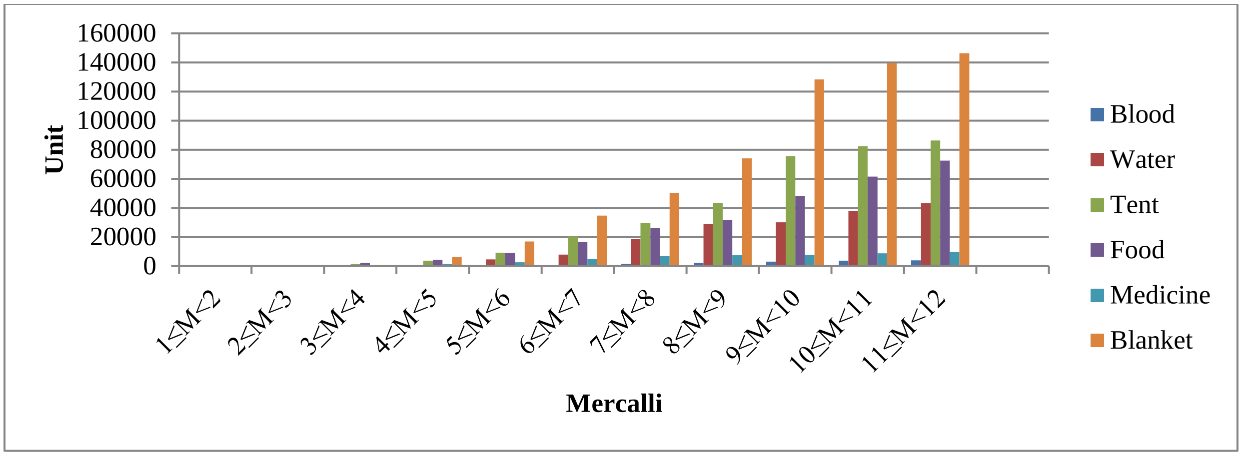

Fig 8. The average demand for relief commodities for the Ray fault at night

The horizontal axis shows different scenarios of the severity of the earthquake in terms of Mercalli and the vertical axis shows the unit amount of demand. The considered unit for blood and water is liters, for food and medicine is kilogram, and for blankets and tents is number. Observing the two graphs indicates that the increase in the severity of the earthquake will increase the amount of demand, and this increase in demand is obvious from Mercalli 9. Also, by comparing the two graphs, it can be seen that the demand at night is far more than that of the day for the earthquakes with the same amount of severity. For example, the amount of medicine required for an earthquake with a Richter intensity of 9 is 7,012 kilograms in the morning and 7721 kilograms at night.

6-Conclusion

In this research, we investigated the critical infrastructures under the influence of the earthquake and the impact of these infrastructures on each other. After determining the structure of the infrastructures, it was simulated and various scenarios that lead to the demand forecast have been studied. The considered scenarios included the severity of the earthquake, the occurrence time and the probability of activation of the fault based on its geographic features. In the next step, the demand for relief commodities was forecasted using the fuzzy inference system. The input of this step was the result of the simulation. The case study considered was the district 6 of Tehran. The results indicated that increasing the severity of earthquake increases the demand for relief commodities, especially at night. The speed of increase in the relief commodities is more at night according to the results of the research. This shows the need for on-time preparation and response at this time for planning organizations.

The results of this research can be useful for many decision making centers, including the fire department, the Red Cross, hospitals, and so on. Currently, in district 6, no safety measures have been taken to reduce the damage of disasters. Although the Iranian Red Crescent Society will be able to initiate relief operations immediately after the occurrence of the earthquake, the damage estimated in Tehran will be much higher than the one that the Red Crescent can manage alone. Therefore, bases should be established at the regional or district level independently, and emergency relief commodities such as food, water, medicine, etc. should be provided in them. Within the scope of the experimental study, there are 13 schools that range from elementary to high school. The building structure of these schools is of steel and brick, and only one building of reinforced concrete is located in this area. Structural resistance of buildings against severe earthquakes is not enough. In addition, the school lands are relatively small and using them as a temporary evacuation space at the time of an earthquake is not easy for students. Schools' building resistance to a severe earthquake must be rapidly controlled and enforcement measures must be implemented. Each school should provide a safety guidance booklet for students at the time of the earthquake.

Research limitations include the following:

- In this research, only relief supplies, such as blood, blankets, drinking water, medicine, food and tent have been estimated.
- Due to lack of accurate information, scenarios are considered as fuzzy

The following suggestions are recommended for future researches:

1- Considering different disasters simultaneously, such as the occurrence of flood and earthquake simultaneously, and examining the domino effect caused by them.
2- Use of other methods, such as the neural network, to forecast relief commodities.
3- Locating distribution centers of relief commodities for their on-time delivery and distribution.
4- Using and customizing the proposed model for other districts and cities

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