International Journal of Supply and Operations Management

IJSOM

February 2015, Volume 1, Issue 4, pp. 466-488
ISSN-Print: 2383-1359
ISSN-Online: 2383-2525
www.ijsom.com

A credibility-based chance-constrained transfer point location model for the relief logistics design (Case Study: earthquake disaster on region 1 of Tehran city)

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Abstract

Occurrence of natural disaster inflicts irreparable injuries and symptoms on humans. In such conditions, affected people are waiting for medical services and relief commodities. Thus, quick reaction of medical services and relief commodities supply play important roles in improving natural disaster management. In this paper, a multi-objective non-linear credibility-based fuzzy mathematical programming model under uncertainty conditions is presented, which considers two vital needs in disaster time including medical services and relief commodities through location of hospitals, transfer points, and location routing of relief depots. The proposed model approaches reality by considering time, cost, failures probability in routes, and parameters uncertainty. The problem is first linearized and then global criterion method is applied for solving the multi objective model. Moreover, to illustrate model efficiency, a case study is performed on region 1 of Tehran city for earthquake disaster. Results demonstrate that if decision-makers want to meet uncertainty with lowered risk, they have to choose a high minimum constraint feasibility degree even though the objective function will be worse.

Keywords: Relief logistic; Uncertainty; Transfer points location; Relief depot routing

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1. Introduction

Annually, natural disasters bring irreparable injuries and symptoms for people throughout the world. According to statistical reports of UN (The United Nations organization) floods, hurricanes, and earthquakes are the most destructive natural disasters, so that within a decade, devastations caused by floods and hurricanes were estimated as 21 billion dollars and earthquake damages were solely 18 billion dollars (Tayefi Nasrabadi and Rashidi Mehr Abadi 2008). Asia is the most accident-prone continent of all, and Iran is among the top ten most accident-prone countries in the world. Thus, crisis management has a special edge of urgency in Iran which disaster management as a primary side of crisis management won't be exceptional (Allahyari et al 2013). Disaster management includes four phases of mitigation, preparedness, response and recovery. Each phase is essential. In preparedness phase, the health department preparedness, as the entity of giving health services is vital to diminish fatality, and physical detriments of accidental events. The main purpose of formulating disaster management plan for hospitals is presenting quick and timely hygienic and curative cares in order to decline fatalities and symptoms of disasters (Gupta and Kant 2004). A conducted study about hospitals of Tehran showed that these hospitals, aspect of place, equipment, staff, physical resistance, structure and related protocols, had mediocre readiness in ordinary conditions, and in disaster conditions are poor in quality (Mastane et al 2013).

So, it makes necessity to consider the location and renovation of hospitals which are severely immediate requirements after disasters. Due to the fact that most fatalities occur in early hours of disasters, one of the most significant measures is quick transfer of casualties to curative centers recognized as transfer point location. In this problem, some transfer points are considered to improve transfer time in transferring casualties to hospitals. These points must be constructed in a manner that the dispatched ambulances from affected areas reach hospitals based on time criterion and through transfer points or directly.

On account of numerous casualties in disasters and intense needs of medicine and medical equipment, lack of enough space, difficulty of keeping medical commodities in huge volume at hospitals, locating some depots for storing these commodities is the other essential issue in disaster management associated with curative departments (Ingram 1987).

The most dominant trouble after occurrence of disasters is water and food supply (Ingram 1987). This problem, during incidents and after math, constantly threatens people's health. In normal circumstances, water quality is controlled continuously under strict and careful supervision so that little neglect may lead to sewage entrance into water networks; and resources subsequently cause disease outbreak. On the one hand, disaster condition and loss of water, and on the other hand, water resources pollution intensify the severity of incidents. Furthermore, in such conditions, food depletes in short range and eventually gradual death takes place. Adverse changes in society nourishment after disasters depend on disaster kind, disaster time, disaster span, level of stored food, food production in disaster place, and preventative measures of managers (Ingram 1987). Hence, locating some depots for storing water and food is indispensable.

For more efficient managing, reducing costs, and better serving, medical depots and water and food depots are accumulated in one depot known as relief depot.

Since at the time of disaster casualties are different on the basis of injury type and injury intensity, it is crucial to categorize them in order of injury priority called Triage [6]. At first, the Triage concept was used for war conditions, disasters, and events which had many casualties. But later, it was applied in urgent care centers and emergency rooms because casualties are taken to curative centers by ambulances or other vehicles without any plans or schedules. In Triage system, casualties are classified into red, orange, yellow, green and blue colors. Emergency time of the colors are definite and if they are postponed, death probability will increase; for example, casualties with breathing troubles or head and neck injuries are in red category, and emergency time for these casualties is only 10 minutes. Considering time urgency in disasters, Triage system has to be utilized in disaster management (Ministry of Health and Medical Education 2008). Principal issues of disaster management: hospitals, transfer points, and relief depots require a comprehensive literature review around transfer points. Then, we can identify gapes with a literature review about disaster management. In the second section, literature review of the issue is presented, and in the third section, the research methodology of the problem is illustrated and in the section 4, the Research methodology of the problem is presented, and in the sections 5, 6 and 7, respectively, a three-step procedure for solution method, a case study for earthquake in Tehran, and results are given. Finally, the conclusions and recommendations are proposed in section 8.

2. Literature review

Transfer point location problems have arisen in disaster management since 2005. Berman et al (2005) surveyed transfer point location problem in a continuous network. They offered an algorithm considering travel time discount rate for solving the problem. Then, Berman et al (2007) suggested a multiple location of transfer points while locating was allowed from several transfer points as an extension of transfer point location. They considered p-median and p-center methods for several fixed facilities. Mahmudian et al (2010) presented two heuristic algorithms for TPLP problem. The first algorithm clustered affected areas and the next one determined places of transfer points. Model efficiency was proved by the results. Hosseinijou and Bashiri (2011) presented a model with weighted demand points and coordinates of the points had bivariate uniform distribution. Model expansion in plane and quantifying minimax objective function were their model innovations.Furuta et al (2013) utilized minisum and minimax methods. In their model, Casualties had to be carried by ambulances or helicopters which met each other in a place called Rendezvous Points. They selected Japan for case study and acquired good results. Kalantari et al (2013) presented a model as weighted demands with fuzzy coordinates a nonlinear programming without constraints was formulated and fuzzy numbers were obtained to variables. Yaghoubi et al (2014) offered a model for minimax and minisum, which was different from former models. They had a comprehensive attitude to the problem and broadened knowledge with combination of telecom towers and transfer point location. The model was two-objective and uncertain. They used ε -Constraint approach to solve the model.

One of the earliest performed studies about disaster management is by Toregas et al (1971) who modeled the problem as a set-covering problem and solved it by linear programming. Balcik and Beamon (2008) contemplated facility location decisions in relief chain in order to respond to disasters quickly. Campbell and Jones (2011) paid to facility location before occurrence of disasters by considering the distances among facilities and affected areas and failure probability of them. Akgün et al (2014) offered facility location before occurrence of disasters as the risk of not covering demand points from located facilities to be minimized. Bakuli & Smith (1996), Brotcorne et al (2003), Akkihal (2006), Jia et al (2007), Khorsi et al (2013), also broadened knowledge in this regard.

Noticing antecedent researches, there is no comprehensive model for disaster management embracing health topics, quick reaction, food and water supply, and casualties transfer simultaneously.

The main idea of this paper is preparing a comprehensive and integrated model for disaster management problem using hospital location, transfer point location, assigning casualties to hospitals, and location routing of relief depots with regarding route failures in disaster duration. The proposed model's aims are minimizing demand in time for casualties transfer to hospitals and for medical commodities transfer from relief depots to hospitals, minimizing constant cost of vehicle usage in demand points, relief depots and minimizing constant cost of vehicle usage in demand point routes, and minimizing possibility of not reaching casualties to hospitals.

According to mentioned papers, the differences of this paper with other previous papers are:

1. Presenting a multi-objective logistic model with simultaneous decisions for location of hospitals, transfer points, and relief depots.
2. Considering Triage system in the model, because ministry of healthcare has put an emphasis on modifying and establishing Triage system in emergency departments of hospitals (Ministry of Health and Medical Education 2008).
3. Considering nursing teams in founded transfer points in order to give first aid to casualties or to accompany with to hospitals.
4. Considering water and food transfer from relief depots to an affected area by means of routing, which improves transfer time.
5. Taking failures probability in routes into account, considering the transfer of casualties to hospitals and approaching realistic model.
6. Taking Fuzzy parameters and failures probability in routes into consideration to have a more realistic model.

3. Research methodology

This paper proposes a multi-objective mathematical model which attempts to consider different impacts of disasters. To this meaning, objective function (1) minimizes demand in the time, and objective function (2) minimizes costs, and objective function (3) is associated with failure probability of routes. The proposed model takes a step in improving conditions of disaster time by considering factors such as demand, time, cost, and failure probability simultaneously. The model is linearized by heuristic procedures due to being non-linear and because global criteria method is applied to solve the multi-objective model. Then to show model efficiency, a case study on region 1 of Tehran city is conducted. The nature of disaster conditions is dynamic, therefore, uncertainty is imposed on the model. Eventually, Gams software is applied to solve the model and then sensitivity analysis is performed.

4. Problem description

In natural disasters, casualties transfer and relief commodities supply operations are the most noticeable measures. The proper and accurate plan, considering limitations of facilities and resources, has a significant impact on minimizing physical and financial damages, and it also affects response efficiency and effectiveness. According to figure 1, the under study relief logistic network in this research includes four principle stages: affected areas, transfer points, hospitals, and relief depots.

As can be observed in figure 1, injured individuals in affected areas can be brought based on time criterion by ambulances to transfer points and then they can be taken to hospitals by helicopters (high speed) or can be carried to hospitals directly by ambulances. Also in established transfer points, in addition to helicopters, nursing teams are required to provide first aids and accompany injured and casualties if it is necessary.

Due to numerous casualties in disasters, hospitals confront intensive needs of medical goods. Each hospital can receive its medical commodity from one relief depot. To provide required water and foods of affected areas among relief depots and transfer points, allocation is considered through routing. It should be noted that various numbers of transfer points exist, but for simple comprehension, only one number is exhibited in figure 1.

The rest of this paper is organized to introduce assumptions, parameters, sets, decision making variables, and mathematical programming model of problem, respectively.

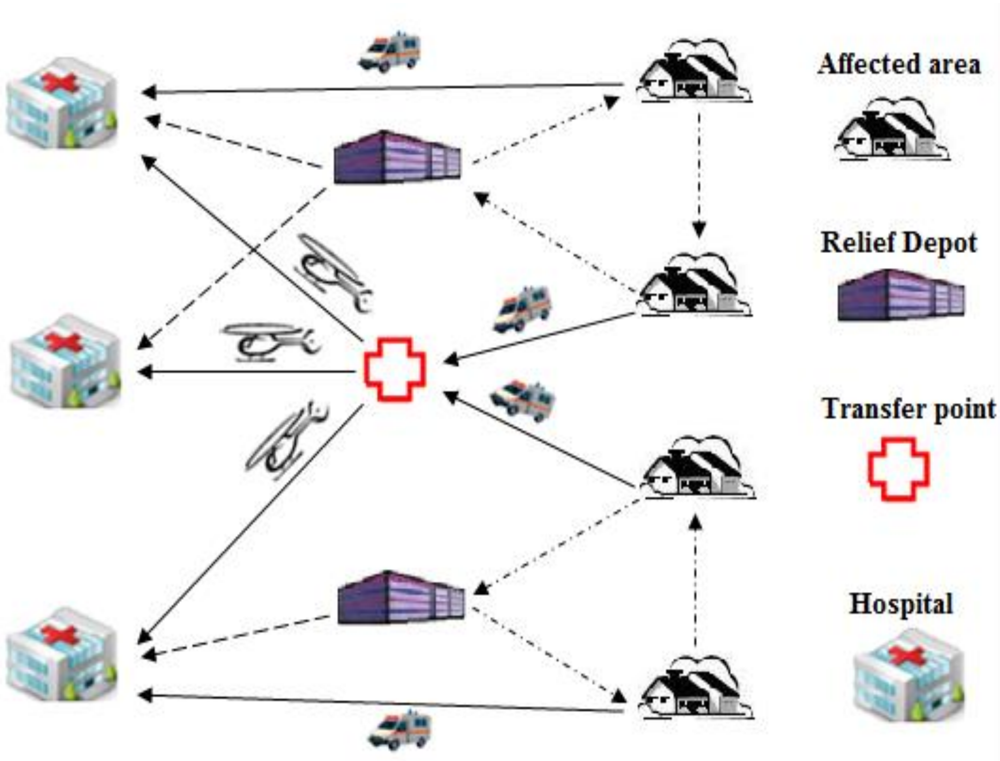

Figure 1: Overview of the issue

4.1. Assumptions

Major assumptions are as follows:

1. In this paper, there are several affected areas which are potential spots to construct hospitals or transfer points. Hospitals and transfer points cannot be overlapped according to modeling nature.
2. In this problem, several points are considered to construct the relief depot.
3. In constructed transfer points, in addition to equipped ambulances, nursing teams are considered to provide first aids or accompany injured to hospitals.
4. Casualties are divided into some different groups. Maximum time to rescue them is different according to approved regulations for modifying and establishing triage system. Therefore, it is necessary to send casualties to hospitals or nursing teams in definite time.
5. Each affected area can be allocated to one hospital or transfer point.
6. Each hospital receives its medical commodity needs from only one relief depot.
7. Relief commodity needs of affected areas supply from relief depots through routing.
8. Due to the importance of time in transferring casualties to hospitals, route failures are considered among affected areas, transfer points, and hospitals.
9. Vehicles and relief depots have limited capacities.
10. Routing among affected area and relief depots is done by several vehicles.

4.2. Sets and indices

I	Set of affected areas
J	Set of potential points for relief depot construction
S	Set of casualty triage
i	Indexes related to affected areas $i \in I$
m	Indexes related to potential transfer points $m \in I$
k	Indexes related to hospital potential points $k \in I$
j	Indexes related to relief depots $j \in J$
s	Indexes related to casualty triage $s \in S$

4.3. Parameters

Parameters of the model are as follow:

N	affected areas Number of
M	Transfer points which must be established Number of
K	Number of hospitals which must be established
A	Number of relief depots which must be established
t_{ik}	Time between affected area i and hospital k
t_{imk}	Time between affected area i and hospital k through transfer point m
t_{kj}	Time between hospital k and relief depot j
$\tilde{tr}_s$	Maximum allowed fuzzy time to rescue casualties with triage s
$\tilde{\varphi}_i$	Relief commodity demand of affected area i
$\tilde{h}_i^s$	Casualty numbers with triage s of affected area i
$\tilde{q}_{ik}$	Rout failure probability between affected area i and hospital k

$\tilde{q}_{imk}$	Rout failure probability between affected area i and hospital k through transfer point m
$\tilde{C}_{ij}$	Transportation cost between i and j
$\tilde{C}_{v}$	Constant cost of using vehicle v
$\tilde{Q}_{v}$	Capacity of vehicle v
$C\tilde{a}p_{j}$	Relief commodity capacity of relief depot j
$\tilde{L}_{j}$	Medical commodity capacity of relief depot j

4.4. Decision variables

W_k	Medical commodity demand of hospital k
X^{s}_{imk}	Will be 1, If a casualty with triage s in affected area i is transferred to hospital through transfer point m , otherwise this will be 0
X^{s}_{ik}	Will be 1, If a casualty with triage s in affected area i is transferred to hospital k directly, otherwise this will be 0
Y_{kj}	Will be 1, If hospital k is assigned to relief depot j, Otherwise this will be 0
E_m	If a transfer point is established in potential point m, this will be 1 Otherwise this will be 0
F_k	If a hospital is established in potential point k, this will be 1, Otherwise this will be 0
U_j	If a relief depot is established in potential point j this will be 1 Otherwise this will be 0
Z^{v}_{ij}	If point j in route v is located after point i this will be 1 Otherwise this will be 0
G_{lv}	Auxiliary variables for sub-tour elimination constraints in route v
μ_{ij}	If affected area i is assigned to relief depot j ,this will be 1, Otherwise this will be 0

4.5. Objective functions and limitations

$$Min\ Z_1 = \sum_{s\in S}\sum_{i\in I}\sum_{m\in I}\sum_{k\in I}\tilde{h}^{s}_{i}\left(t_{imk}X^{s}_{imk} + t_{ik}X^{s}_{ik}\right) + \sum_{k\in I}\sum_{j\in J}W_k Y_{kj} t_{kj} \tag{1}$$

$$Min\ Z_2 = \sum_{i\in I\cup J}\sum_{j\in I\cup J}\tilde{C}_{ij}Z^{v}_{ij} + \sum_{v\in V}\tilde{C}_{v}\sum_{i\in I}\sum_{j\in J}Z^{v}_{ij} \tag{2}$$

$$Min\ Z_3 = \sum_{s\in S}\prod_{i\in I}\prod_{m\in I}\prod_{k\in I}(\tilde{q}_{imk}X^{s}_{imk} + \tilde{q}_{ik}X^{s}_{ik}) \tag{3}$$

$$\sum_{v\in V}\sum_{j\in I\cup J}Z^{v}_{ij} = 1 \quad i\in I \tag{4}$$

$$\sum_{i\in I}\sum_{j\in I\cup J}\tilde{\varphi}_{i}Z^{v}_{ij} \le \tilde{Q}_{v} \quad v\in V \tag{5}$$

$$G_{lv} - G_{iv} + NZ^{v}_{li} \le N - 1 \quad l, i\in I \quad v\in V \tag{6}$$

$$\sum_{i\in I\cup J}Z^{v}_{ij} - \sum_{i\in I\cup J}Z^{v}_{ji} = 0 \quad v\in V, j\in I\cup J \tag{7}$$

$$\sum_{i\in I}\sum_{j\in J}Z^{v}_{ij} \le 1 \quad v\in V \tag{8}$$

$$\sum_{i\in I}\tilde{\varphi}_i Z_{ij}^{v} \le C\tilde{a}p_j U_j \quad j\in J \tag{9}$$

$$-\mu_{ij} + \sum_{u\in I\cup J}(Z_{ju}^{v}+Z_{ui}^{v}) \le 1 \quad i\in I, j\in J, v\in V \tag{10}$$

$$\sum_{j\in J} U_j = A \tag{11}$$

$$\sum_{m\in I}\sum_{k\in I} X_{imk}^{s} + \sum_{k\in I} X_{ik}^{s} = 1 \qquad \forall i\in I, s\in S \tag{12}$$

$$X_{imk}^{s} \le E_m \qquad \forall\, i, m, k \in I, s\in S \tag{13}$$

$$X_{imk}^{s} \le F_k \qquad \forall\, i, m, k \in I, s\in S \tag{14}$$

$$X_{ik}^{s} \le F_k \qquad \forall\, i, k \in I, s\in S \tag{15}$$

$$\sum_{m\in I} E_m = M \tag{16}$$

$$\sum_{k\in I} F_k = K \tag{17}$$

$$\sum_{s\in S}\sum_{i\in I}\sum_{m\in I}\left(X_{ik}^{s} + X_{imk}^{s}\right)\tilde{h}_i^{s} = W_k \quad \forall k\in I \tag{18}$$

$$\sum_{m}\sum_{k} t_{im} X_{imk}^{s} + \sum_{k} t_{ik} X_{ik}^{s} \le t\tilde{r}_s \quad \forall i\in I, s\in S \tag{19}$$

$$\sum_{j} Y_{kj} = F_k \qquad \forall k\in I \tag{20}$$

$$\sum_{k\in K} W_k Y_{kj} \le \tilde{L}_j U_j \quad \forall j\in J \tag{21}$$

$$Y_{kj} \le U_j \quad \forall\, k\in I \;\; j\in J \tag{22}$$

$$W_k \ge 0, X_{imk}^{s}, X_{ik}^{s}, E_m, F_k, U_j, G_{lv}, Z_{ij}^{v}, \mu_{ij} \in \{0,1\} \tag{23}$$

Objective function (1) minimizes demand in time, while the first term indicates decision making in allocating affected areas to hospitals through transfer points or directly. And second term assigns hospitals to relief depots for receiving medical commodities. Objective function (2) minimizes transfer cost among affected areas and relief depots and also minimizes constant cost of vehicle usage in affected area routes. Objective function (3) minimizes probability of not reaching casualties to hospitals. Objective function (3) minimizes probability of not reaching casualties to hospitals. Constraint (4) indicates that each affected area has to be assigned to one route. Constraint (5) shows capacities of vehicles. Constraint (6) is the new sub-tour elimination constraint. Constraint (7) is associated with flow among affected areas and relief depots. Constraint (8) shows that maximum number of routes between affected areas and relief depots can be only one. Constraint (9) shows capacity of relief depot related to relief commodities. Constraint (10) indicates that affected areas can be assigned to relief depots only when there is a route from that depot to the affected area. Constraint (11) illustrates that how many relief depots must be established. Constraint (12) indicates that each injured with special triage must be transferred to hospitals directly or through transfer points. Constraints (13) and (14), respectively, show that an injured person can be transferred to hospital through transfer point if the transfer point and the hospital have been already established. Constraint (15) shows that a casualty can be transferred to a hospital directly if the hospital has been already established. Constraints (16) and (17), respectively, show that how many transfer points and hospitals must be established. Constraint (18) represents required capacity of hospital to serve points in its coverage area. Constraint (19) shows that it is essential to transfer the injured and casualties with special triage to the nearest hospital or to the nearest nursing team placed on transfer point in definite time of the triage. Constraint (20) displays if a hospital is established then the established hospital and a relief depot can be connected. Constraint (21) is about capacity of relief depot associated with medical commodities. Constraint (22) shows that a hospital can be assigned to a depot if the depot has been already established. Constraint (23) shows positive and binary variables.

5. Solution Method

At the beginning, objective function (3) is linearized with heuristic approaches and next the model is defuzzified and linearized. Finally, global criterion method is applied to solve the multi-objective model.

5.1. Linearization and heuristic approaches

Objective function (3) is non-linear, so heuristic approaches based on math principles are proposed to linearize.

$$Min\, Z_3 = \sum_s \prod_i \prod_m \prod_k (\tilde{q}_{imk} X^s_{imk} + \tilde{q}_{ik} X^s_{ik}) \tag{24}$$

The objective function is non-linear, and on the other hand, if in one of the cases $\tilde{q}_{imk} X^s_{imk} + \tilde{q}_{ik} X^s_{ik} = 0$ the entire phrase will be equal to zero. Therefore, a heuristic approach is required to provide necessary changes and to achieve linearization. Instead of minimizing $Z_3 = f(x)$, we can minimize $Z_3 = f(x) + B$. Thus, objective function is rewritten into a linear form [23]:

$$Min\, Z_3 = \sum_s \prod_i \prod_m \prod_k (\tilde{q}_{imk} X^s_{imk} + \tilde{q}_{ik} X^s_{ik} + 1 - X^s_{imk} - X^s_{ik}) \tag{25}$$

With this change, it will never equal to zero:

$$\tilde{q}_{imk} X^s_{imk} + \tilde{q}_{ik} X^s_{ik} + 1 - X^s_{imk} - X^s_{ik} = \begin{cases} \tilde{q}_{ik} & X^s_{imk} = 0, X^s_{ik} = 1 \quad \forall i, m, k, s \\ \tilde{q}_{imk} & X^s_{imk} = 1, X^s_{ik} = 0 \quad \forall i, m, k, s \\ 1 & X^s_{imk} = 0, X^s_{ik} = 0 \quad \forall i, m, k, s \end{cases} \tag{26}$$

Note that according to constraint (12) $x^s_{imk} = 1, x^s_{ik} = 1 \ \forall i, m, k, s$ will never occur.

As $Min\, f(x)$ is parallel with $Min\, Ln(f(x))$, hereby:

$$Min\, Z_3 = Ln \sum_s \prod_i \prod_m \prod_k (\tilde{q}_{imk} X^s_{imk} + \tilde{q}_{ik} X^s_{ik} + 1 - X^s_{imk} - X^s_{ik}) \tag{27}$$

As a result of $Ln(B_1 * B_2) = Ln(B_1) + Ln(B_2)$:

$$Min\, Z_3 = \sum_s \sum_i \sum_m \sum_k Ln(\tilde{q}_{imk} X_{imk}^s + \tilde{q}_{ik} X_{ik}^s + 1 - X_{imk}^s - X_{ik}^s) \tag{28}$$

As $Min\, f(x)$ is parallel with $Min\, Ln(f(x))$ so:

$$Min\ Z_3 = \sum_s \sum_i \sum_m \sum_k (\tilde{q}_{imk} X_{imk}^s + \tilde{q}_{ik} X_{ik}^s + 1 - X_{imk}^s - X_{ik}^s) \tag{29}$$

By simplification:

$$Min\, Z_3 = \sum_s \sum_i \sum_m \sum_k ((\tilde{q}_{imk} - 1) X_{imk}^s + (\tilde{q}_{ik} - 1) X_{ik}^s + 1) \tag{30}$$

Moreover:

$$Min\, Z_3 = \sum_s \sum_i \sum_m \sum_k ((-\tilde{p}_{imk}) X_{imk}^{sf} + (-\tilde{p}_{ik}) X_{ik}^s + 1) \tag{31}$$

Instead of minimizing $Z_3 = f(x)$, $Z_3 = f(x) + B$ can be minimized. So:

$$Min\, Z_3 = \sum_s \sum_i \sum_m \sum_k ((-\tilde{p}_{imk}) X_{imk}^s + (-\tilde{p}_{ik}) X_{ik}^s) \tag{32}$$

$$Max\, Z_3 = \sum_s \sum_i \sum_m \sum_k (\tilde{p}_{imk} X_{imk}^s + \tilde{p}_{ik} X_{ik}^s) \tag{33}$$

5.2. Defuzzification

For solving the proposed fuzzy model, fuzzy chance constraint programming is utilized to convert uncertain model to certain model. If $\tilde{\xi}$ is assumed as a fuzzy parameter and r is assumed as a real number according to Liu & Liu (2002) and Liu (2004):

$$E\left[\tilde{\xi}\right] = \int_0^{\infty} Cr\left\{\tilde{\xi} \geq r\right\} dr - \int_{-\infty}^{0} Cr\left\{\tilde{\xi} \leq r\right\} dr \tag{34}$$

Now, we assume that $\tilde{\xi}$ is a trapezoidal fuzzy parameter with $\xi^{(1)}$ ، $\xi^{(2)}$ ، $\xi^{(3)}$ و $\xi^{(4)}$ amounts. Considering equation 24, the expected value of $\tilde{\xi}$ is exhibited as $\left(\xi^{(1)} + \xi^{(2)} + \xi^{(3)} + \xi^{(4)}\right)/4$ and the corresponding credibility measures are as follow:

$$Cr\left\{\tilde{\zeta} \le r\right\} = \begin{cases} 0 & r \in \left(-\infty, \zeta_{(1)}\right] \\ \dfrac{r-\zeta_{(1)}}{2\left(\zeta_{(2)}-\zeta_{(1)}\right)} & r \in \left(\zeta_{(1)}, \zeta_{(2)}\right] \\ \dfrac{1}{2} & r \in \left(\zeta_{(2)}, \zeta_{(3)}\right] \\ \dfrac{r-2\zeta_{(3)}+\zeta_{(4)}}{2\left(\zeta_{(4)}-\zeta_{(3)}\right)} & r \in \left(\zeta_{(3)}, \zeta_{(4)}\right] \\ 1 & r \in \left(\zeta_{(4)}, +\infty\right] \end{cases} \tag{35}$$

$$Cr\left\{\tilde{\zeta} \ge r\right\} = \begin{cases} 1 & r \in \left(-\infty, \zeta_{(1)}\right] \\ \dfrac{2\zeta_{(2)}-\zeta_{(1)}-r}{2\left(\zeta_{(2)}-\zeta_{(1)}\right)} & r \in \left(\zeta_{(1)}, \zeta_{(2)}\right] \\ \dfrac{1}{2} & r \in \left(\zeta_{(2)}, \zeta_{(3)}\right] \\ \dfrac{\zeta_{(4)}-r}{2\left(\zeta_{(4)}-\zeta_{(3)}\right)} & r \in \left(\zeta_{(3)}, \zeta_{(4)}\right] \\ 0 & r \in \left(\zeta_{(4)}, +\infty\right] \end{cases} \tag{36}$$

According to Zhu & Zhang (2009):

$$Cr\left\{\tilde{\xi} \le r\right\} \ge \alpha \Leftrightarrow r \ge (2-2\alpha)\,\xi^{(3)} + (2\alpha-1)\,\xi^{(4)} \tag{37}$$

$$Cr\left\{\tilde{\xi} \ge r\right\} \ge \alpha \Leftrightarrow r \le (2\alpha-1)\,\xi^{(1)} + (2-2\alpha)\,\xi^{(2)} \tag{38}$$

Besides, according to Pishvaee et al (2012):

$$Cr\left\{\tilde{\xi} = r\right\} \ge \alpha \Leftrightarrow \xi^{(2)} \le r \le \xi^{(3)} \tag{39}$$

α is minimum constraint feasibility degree which is determined by the decision-maker. Eventually, uncertain terms of objective function (1)&(2)&(3) and constraints (5),(9),(18),(19)&(21)can be certain as follow:

$$Min\ Z_1 = \sum_s \sum_i \sum_m \sum_k \left(\frac{h_i^{s(1)} + h_i^{s(2)} + h_i^{s(3)} + h_i^{s(4)}}{4} \right) \left(t_{imk} X_{imk}^{s} + t_{ik} X_{ik}^{s} \right) + \sum_k \sum_j W_k Y_{kj} t_{kj} \tag{40}$$

$$Min\ Z_2 = \sum_{i \in I \cup J} \sum_{j \in I \cup J} \left(\frac{C_{ij}^{(1)} + C_{ij}^{(2)} + C_{ij}^{(3)} + C_{ij}^{(4)}}{4} \right) Z_{ij}^{v} + \sum_{v \in V} \left(\frac{C_v^{(1)} + C_v^{(2)} + C_v^{(3)} + C_v^{(4)}}{4} \right) \sum_{i \in I} \sum_{j \in J} Z_{ij}^{v} \tag{41}$$

$$Max\ Z_3 = \sum_s \sum_i \sum_m \sum_k \left(\frac{p_{imk}^{(1)} + p_{imk}^{(2)} + p_{imk}^{(3)} + p_{imk}^{(4)}}{4} \right) X_{imk}^{s} + \left(\frac{p_{ik}^{(1)} + p_{ik}^{(2)} + p_{ik}^{(3)} + p_{ik}^{(4)}}{4} \right) X_{ik}^{s} \tag{42}$$

$$\sum_{i \in I} \sum_{j \in I \cup J} \left((2-2\alpha)\varphi^{(3)} + (2\alpha-1)\varphi^{(4)} \right) Z_{ij}^{v} \leq \left((2\alpha-1)Q_v^{(1)} + (2-2\alpha)Q_v^{(2)} \right) \ v \in V \tag{43}$$

$$\sum_{i \in I} \left((2-2\alpha)\varphi^{(3)} + (2\alpha-1)\varphi^{(4)} \right) Z_{ij}^{v} \leq \left((2\alpha-1)Cap_j^{(1)} + (2-2\alpha)Cap_j^{(2)} \right) U_j \quad j \in J \tag{44}$$

$$\sum_s \sum_i \sum_m \left(X_{ik}^{s} + X_{imk}^{s} \right) \left(h_i^{s(2)} \right) \leq W_k \quad \forall k \in I \tag{45}$$

$$\sum_s \sum_i \sum_m \left(X_{ik}^{s} + X_{imk}^{s} \right) \left(h_i^{s(3)} \right) \geq W_k \quad \forall k \in I \tag{46}$$

$$\sum_m \sum_k t_{im} X_{imk}^{s} + \sum_k t_{ik} X_{ik}^{s} \leq \left((2\alpha-1) tr_s^{(1)} + (2-2\alpha) tr_s^{(2)} \right) \quad \forall i \in I, s \in S \tag{47}$$

$$\sum_k W_k Y_{kj} \leq \left((2\alpha-1) L_j^{(1)} + (2-2\alpha) L_j^{(2)} \right) U_j \quad \forall j \tag{48}$$

5.3. Objective function linearization:

The phrase $W_k Y_{kj}$ in the first objective function is non-linear. A linear tie can be obtained by replacing $W_k Y_{kj}$ with R_{kj} variable (Banerjee and Roy 2001):

By replacing $W_k Y_{kj}$ with R_{kj} variable, and by adding following constraints:

$$R_{kj} \leq W_k \quad \forall k \in I, j \in J \tag{49}$$

$$R_{kj} \leq MY_{kj} \quad \forall k \in I, j \in J \tag{50}$$

$$R_{kj} \geq M\left(Y_{kj} - 1\right) + W_k \quad \forall k \in I, j \in J \tag{51}$$

$$R_{kj} \geq 0 \quad \forall k \in I, j \in J \tag{52}$$

5.4. Global criterion method for solving the multi-objective model:

The problem is stated as follows:

$$Min\left[Z_1, \ldots, Z_3\right] \tag{53}$$

$$g_i(x) \geq 0$$

For applying this procedure, each objective-function is optimized separately over constraints. If we display separate optimal results of each problem with Z_i^* and weigh the coefficient with λ, the model can be written as follows (Rao and Rao 2009):

$$Min\ Z_T^* = \left[\sum_i \lambda_i \left(\frac{Z_i - Z_i^*}{Z_i^*} \right)^r \right]^{\frac{1}{r}} \tag{54}$$

$$g_i(x) \geq 0$$

6. Case study

According to UN report in 2005, Iran has the first rank among countries in the world in terms of frequent earthquakes over 5.5 on the Richter scale and also is one of the most vulnerable countries against earthquakes which has had abundant a large number or plenty of victims (Pelling et al 2004). Iran's capital, as the most crowded city with population of 9,042,802 from 2011 census is exposed to damages. One of the most significant Tehran's faults is the fault in north of Tehran located on southern foothills of north of Tehran mountains with 75 km length. Because of lying on this fault since it is located at the center of this fault, district #1 of Tehran is so vulnerable. This region contains 10 districts and 26 sectors. Its population, according to 2011 census, is 439467 people, which makes it one of the most crowded regions of Tehran. Table 1 and figure 1 show this under study region with its districts and sectors.
To validate the case study and precise programming in region 1 of Tehran, two valid researches are mainly used:
1. In 2000, a panel of Japanese experts had an expedition to Iran, under an agreement between Japan international cooperation agency (JICA) and provisional government. They presented a comprehensive study on seismic micro zoning of the Greater Tehran Area documentary (JICA 2000).
2. In 2011, a research over region 1 of Tehran was conducted by a research group of Tarbiat Modares University entitled radius model evaluation in estimating damages and loss resulted from earthquakes in geographic environment. It was published in scientific journal of urban -regional studies and research. It proves that it is valid and documentary (Amini et al 2012).
Using these studies, comprehensive information about damages magnitude, and number of casualties, devastation percentage related to each sector and other input parameters can be obtained.
The assumptions of this case study are generally as follow:
1. There are 26 sectors in this region. The center of each sector is considered as an affected area. Besides, these points are potential places to hospital and transfer point construction. The names of these sectors are displayed in table 1 and their location in figure1.
2. there are 6 hospitals with suitable facilities in this region, according to Amini et al (2012), and the policy of ministry of health in replacing and reconstructing new hospitals as restoring old hospitals and with combination of factors such as place and resistance of hospital buildings and failure probability, three hospitals in Velenjak and Araj and Tajrish sectors are selected for restoring. Moreover, 23 other sectors are selected to build new hospitals. The selected places for establishing and restoring are shown in figure 1.
3. There are 10 sectors in this region. In each district, one candidate point regarding failure probability and noticing that these points must be in the vicinity of the highways is considered as a potential place for relief depots.

4. According to researches, after earthquake, there will be congestion and heavy traffic on the related ways to the affected area, so vehicle speed is estimated 25 km/h (Hadavi 2011).
5. In this paper, earthquake casualties are divided into two groups of emergency casualties and the non-emergency casualties. According to approved regulation to modify and establish triage system. Casualties with breathing troubles or head and neck injuries are emergency patients and the maximum time for rescuing them is 10 minutes. of the current affected people in earthquake have this type of injury that is, very emergency injury) (Mohebi et al 2007). Fuzzy numbers of casualties are shown in table 2. To estimate emergency casualties, numbers are multiplied by 0.8 and to estimate non-emergency casualties, numbers are multiplied by 0.2.
6. It is necessary to consider special routes for ambulances. The speed of equipped ambulances on special routes is regarded as 50 km/h
7. To estimate the time between departure and destination, at first, the shortest route is selected using Tehran GPS and then based on speeds, the related time is estimated (map.tehran.ir)
8. Number of casualties in north of Tehran fault scenario based on Amini et al. (2012) is mentioned in Table 2.
9. For transferring commodities, two kinds of vehicles, trucks and big trucks, are considered. Constant cost of truck is (7, 9, 10, 12) based on 1000 units and constant cost of big truck is (10, 20, 25, 30) based on 1000 units.40 trucks and 20 big trucks are used. Fuzzy capacity of trucks is estimated (4000, 3500, 3000, and 2500) and fuzzy capacity of big trucks is estimated (11000, 10000, 9000, and 8000).
10. Failure probability of routes is estimated according to figure 2.
11. Capacity of relief commodities in relief depots is estimated fuzzy number of (5500, 5000, 4500, and 4000) and capacity of medical commodities in relief depots is estimated fuzzy number of (3000, 2500, 2000, and 1500)
12. As there are 6 hospitals on region 1 of Tehran, decisions are made to establish or restore 6 hospitals.
14. Due to the region span 0, 1, 2, 3, 6, 9, transfer points are considered, and sensitivity analysis is performed.
15. Due to the region span 4, 6, relief depots are considered, and sensitivity analysis is performed.

Table 1: sector names with the number of affected areas on each sector associated with region #1 of tehran

1	2	3	4	5	6	7
Hesarboali	Rostam abad	Darake	Evin	Velenjak	Mahmodie	Zaferanie
8	9	10	11	12	13	14
Darband	Imamzade ghasem	Golabdare	Niavaran	Jamaran	Dezashib	Darabad
15	16	17	18	19	20	21
Kashanak	Araj	Shahraknaft	Golha	Ferdos	Tajrish	Gheytarie
22	23	24	25	26		
Chizar	Hekmat	Ozgol	Sohanak	Mahlati		

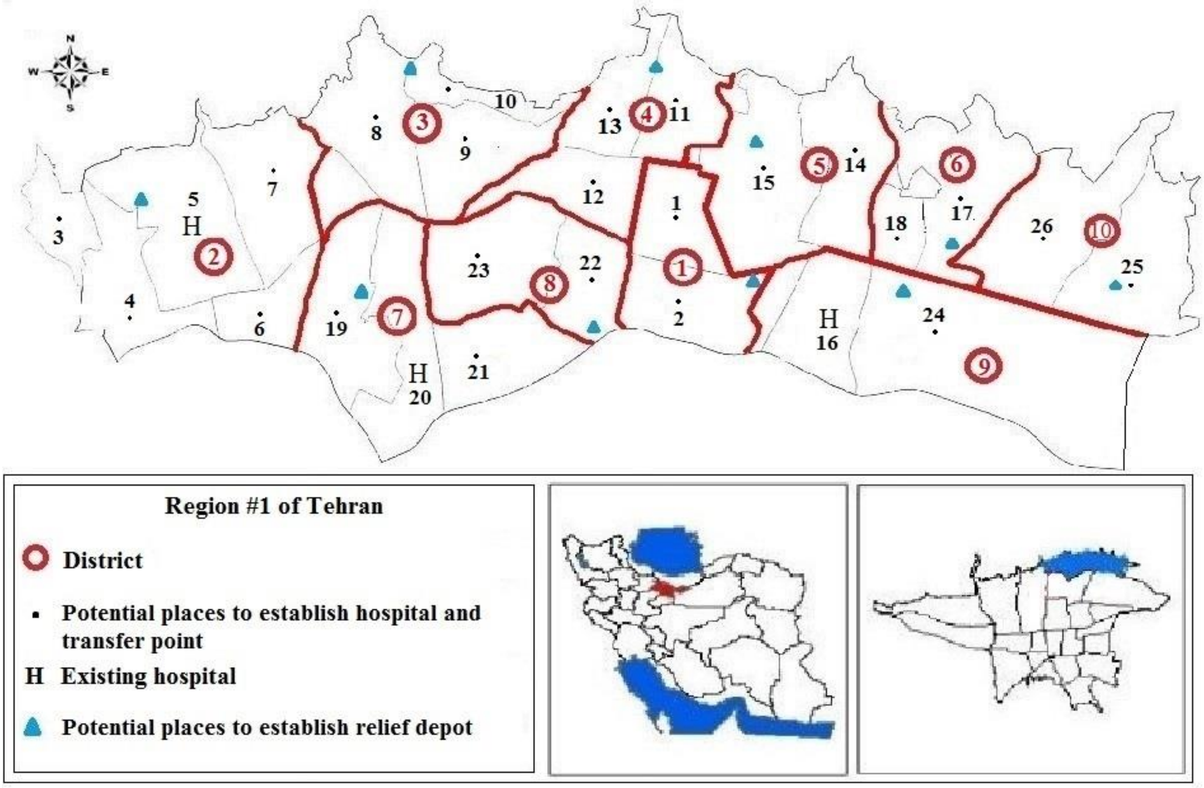

Figure 2: Topography of the under study region and potential points to establish centers

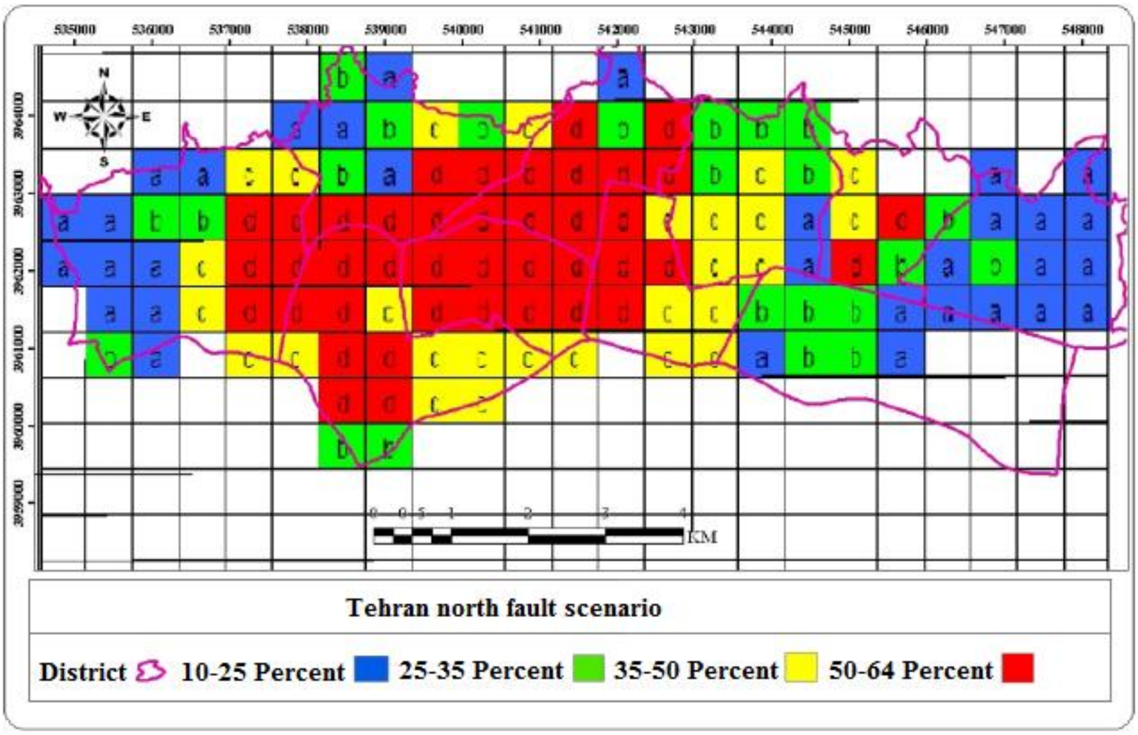

Figure 3: The map of buildings destruction percentage based on Tehran north fault scenario (according to (Amini et al 2012))

Table 2: Number of casualties in each sector (according to (Amini et al 2012))

DP	$(h_i^{s(1)}, h_i^{s(2)}, h_i^{s(3)}, h_i^{s(4)})$	DP	$(h_i^{s(1)}, h_i^{s(2)}, h_i^{s(3)}, h_i^{s(4)})$
Number 1	(324,405,486,567)	Number14	(1353,1692,2030,2368)
Number 2	(5421,6777,8132,9487)	Number15	(1814,2268,2721,3175)
Number 3	(757,947,1136,1325)	Number16	(1518,1898,2277,2657)
Number 4	(472,591,709,827)	Number17	(1560,1951,2341,2731)
Number 5	(2958,3698,4437,5177)	Number18	(2068,2585,3102,3619)
Number 6	(808,1011,1213,1415)	Number19	(2523,3154,3784,4415)
Number 7	(3176,3971,4765,5559)	Number20	(4729,5912,7094,8276)
Number 8	(1270,1588,1905,2223)	Number21	(2998,3748,4497,5247)
Number 9	(2711,3389,4066,4744)	Number22	(1399,1749,2098,2448)
Number10	(1643,2054,2464,2875)	Number23	(4143,5179,6214,7250)
Number11	(2374,2968,3561,4155)	Number24	(2358,2948,3537,4127)
Number12	(1612,2015,2418,2821)	Number25	(1147,1434,1720,2007)
Number13	(2723,3404,4084,4765)	Number26	(4290,5363,6435,7508)

Table 3: Demands of relief commodities for each sector (according to (Amini et al 2012))

DP	$(\varphi_i^{(1)}, \varphi_i^{(2)}, \varphi_i^{(3)}, \varphi_i^{(4)})$	DP	$(\varphi_i^{(1)}, \varphi_i^{(2)}, \varphi_i^{(3)}, \varphi_i^{(4)})$
Number 1	(810,1012,1215,1417)	Number14	(3384,4230,5076,5922)
Number 2	(13554,15214,17421,19452)	Number15	(4536,5670,6804,7938)
Number 3	(1894,2367,2841,3314)	Number16	(3796,4745,5694,6643)
Number 4	(1182,1477,1773,2068)	Number17	(3902,4877,5853,6828)
Number 5	(7396,9245,11094,12943)	Number18	(5170,6462,7755,9047)
Number 6	(2022,2527,3033,3538)	Number19	(6308,7885,9462,11039)
Number 7	(7942,9927,11913,13898)	Number20	(11824,13485,14524,16485)
Number 8	(3176,3970,4760,5558)	Number21	(7496,9370,10475,11245)
Number 9	(6778,8472,10167,11861)	Number22	(3498,4372,5247,6121)
Number10	(4108,5135,6162,7189)	Number23	(10358,12947,15537,18126)
Number11	(5936,7420,8904,10388)	Number24	(5896,7370,8844,10318)
Number12	(4030,5037,6045,7052)	Number25	(2868,3585,4302,5019)
Number13	(6808,8510,10212,11914)	Number26	(10726,13407,16089,18770)

7. Results

In this section, results are evaluated and examined.

The problem is executed using CPLEX solver of 24.1.3 GAMS software by a computer with features of Core (TM) i3 and 4GB RAM. The problem is considered with 6 hospitals and 4, 6 relief depots and 0, 1, 2, 3, 6, 9 transfer points, and sensitivity is done.

Moreover, minimum constraint feasibility degree is studied for 0.7, 0.9,0 options. Increasing transfer points decreases service time and route failures and minimizes objective function and total objective function (Z_T^*). Increasing number of relief depots decreases service time in first objective function and cost of transportation and vehicle usage in second objective function, as a result of this, total objective function (Z_T^*) is minimized. Noticing tables 7&8, the amount of decrease of total objective function(Z_T^*) in case of increasing transfer points is more than increasing relief depots, so that relief depots are important in modeling because relief depots on the one hand are connected to hospitals and on the other hand are connected to affected areas.

Table 4: Calculated results for case ($\alpha = 0.7$)

Selected Sector to fortify hospitals	Selected points to establish hospitals	Selected points to establish transfer points	Selected points to establish relief depots	Objective function Z_T^*	Relief commodity depot numbers	Transfer point numbers
20	2,10,13,20,23,26	5,13,17	1,3,7.10	0/434875	4	3
20	2,10,13,20,23,26	5,13,17	1,4,5,7,8,10	0/385487	6	
20	2,10,11,20,23,26	5,13,14,18,19,24	1,4,8,10	0/353458	4	6
20	2,10,11,20,23,26	5,13,14,18,19,24	1,3,4,7,8,10	0/314477	6	
20	2,9,11,20,23,26	5,10,13,14,16,18,19,21,24	1,7,8,10	0/275424	4	9
20	2,9,11,20,23,26	5,10,13,14,16,18,19,21,24	1,3,4,6,7,10	0/225875	6	

Considering congested population and huge number of casualties in central areas of region 1, most hospitals have been established in these areas, until they can serve casualties at the time of earthquake. The hospital located in Tajrish sector in all cases was selected among established hospitals for restoring because of suitable location, and the numerous casualties of that sector. Furthermore, transfer points are located on boundary areas of region 1 in order to serve the injured in time.

Table 5: Calculated results for case ($\alpha = 0.9$)

Selected sector to fortify hospitals	Selected points to establish hospitals	Selected points to establish transfer points	Selected points to establish relief depots	Objective function Z_T^*	Relief commodity depot numbers	Transfer point numbers
20	2,10,13,20,23,26	5,18,24	1,3,8,10	0/574827	4	3
20	2,10,13,20,23,24	5,18,24	1,3,5,7,8,10	0/526547	6	
20	2,7,11,20,23,26	5,9,14,18,22,24	1,4,7,10	0/481453	4	6
20	2,7,11,20,23,26	5,9,14,18,22,24	1,3,4,5,7,10	0/442145	6	
20	1,2,10,13,20,26	5,9,13,14,16,18,19,22,24	1,3,7,10	0/414525	4	9
20	1,2,10,13,20,26	5,9,13,14,16,18,19,22,24	1,3,4,6,7,10	0/364587	6	

If α amount increases, objective function (Z_T^*) will increase. Therefore, the planner has to determine environmental conditions which enter as parameters strictly to meet uncertainty with higher reliability degree. By increasing α, relief depots will be established in places with high population to minimize routing cost of relief commodities, Therefore distances among depots to hospitals will be optimized owing to storing medical commodities. Thus, hospital will be established as they cover high affected population and will be located with optimal distance from relief depots.

Considering the (14),(15)& (20) constraints, the importance of hospital location toward other location of the model, and high population of casualties in some special sectors, the places of locating hospitals in all cases has a few tolerance.

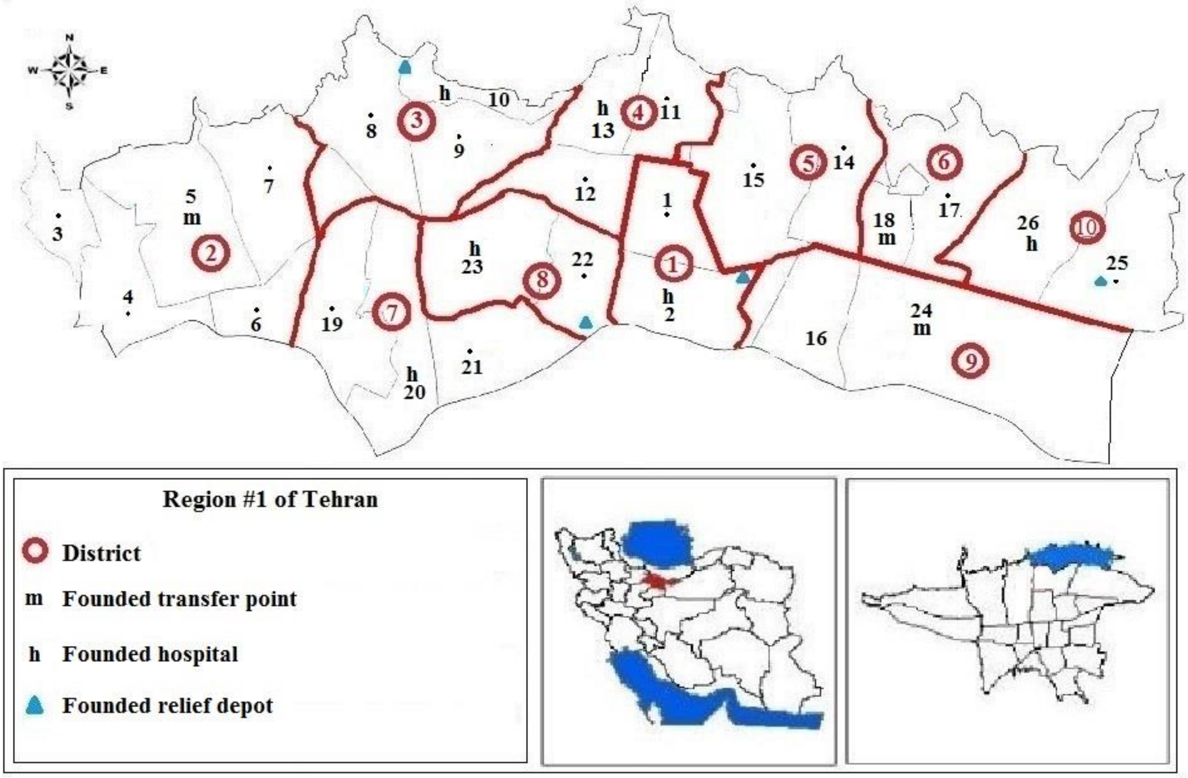

Figure 4: Establishment or fortifying for 3 transfer points and 4 depots

Noticing the results, the case study scope and the experts' comments, the case of 3 transfer points, 4 relief depots, 6 hospitals and minimum constraint feasibility degree 0.9 is chosen. In this case, the decision-maker attempts to meet uncertainty with less risk. Established centers of this case are exhibited in figure 4:

As can be observed in fig 3, hospitals are established in places with rather ample casualties. Because in this case, decision-makers decide according to minimum constraint feasibility degree cautiously even if these decisions cause increasing objective function.

Variables of this case are given in tables 4, 5, and 6.

For example, during earthquakes, casualties with normal triage (index S=1) on section 3 are recommended to be sent to transfer point 5 and then from there to hospital 20 or casualties with red triage (index S=2) affected on section 1 are recommended to be sent to a hospital on section 2.

Table 6: Assigning casualties of triage 1 to hospitals through transfer points or directly ($\alpha = 0.9$)

DP	Tp-h or h	DP	Tp-h or h
Number 1	2	Number14	2
Number 2	2	Number15	2
Number 3	5-20	Number16	2
Number 4	20	Number17	26
Number 5	5-20	Number18	18-26
Number 6	20	Number19	20
Number 7	5-20	Number20	20
Number 8	23	Number21	20
Number 9	23	Number22	2
Number10	10	Number23	23
Number11	13	Number24	24-26
Number12	13	Number25	26
Number13	13	Number26	26

Table 7: Assigning casualties of triage 2 to hospitals through transfer points or directly ($\alpha = 0.9$)

DP	Tp-h or h	DP	Tp-h or h
Number 1	2	Number14	18-2
Number 2	2	Number15	2
Number 3	5-20	Number16	2
Number 4	5-20	Number17	26
Number 5	5-20	Number18	18-26
Number 6	20	Number19	20
Number 7	5-20	Number20	20
Number 8	23	Number21	20
Number 9	23	Number22	2
Number10	10	Number23	23
Number11	13	Number24	24-26
Number12	13	Number25	26
Number13	13	Number26	26

Table 8: Assigning hospitals to depots for receiving medical commodities ($\alpha = 0.9$)

Hospital	D	DP	D
Number 2	1	Number20	7
Number 10	3	Number23	7
Number 13	1	Number26	10

In this section, the two following quantities are used to show model efficiency:

1. The problem is solved as a certain problem and Deterministic Problem (DP) quantity is obtained.
2. The problem is solved as a credibility-based fuzzy problem with fuzzy parameters and Fuzzy Problem (FP) quantity is obtained.

Now the results are analyzed by comparing these two quantities for slightly case of experts, that is, the case of 3 transfer points, 4 relief depots, 6 hospitals and minimum constraint feasibility degree 0.9.

As can be seen in table 12, objective function quantities of DP in all cases are better than objective function quantities of FP. Because if planners want to deal with uncertainty with less risk, they have to pay more cost, so total objective function will be increased.

To better recognizing of these comparisons, sensitivity analysis is done over the number of relief depots and the number of transfer points. In fig 5, in case of 3 transfer points, 6 hospitals and minimum constraint feasibility degree 0.9, sensitivity analysis is done for 4 to 6 relief depots. As can be seen, by increasing number of depots, total objective function is decreasing .In addition, objective function quantity of FP is greater than objective function quantity of DP.

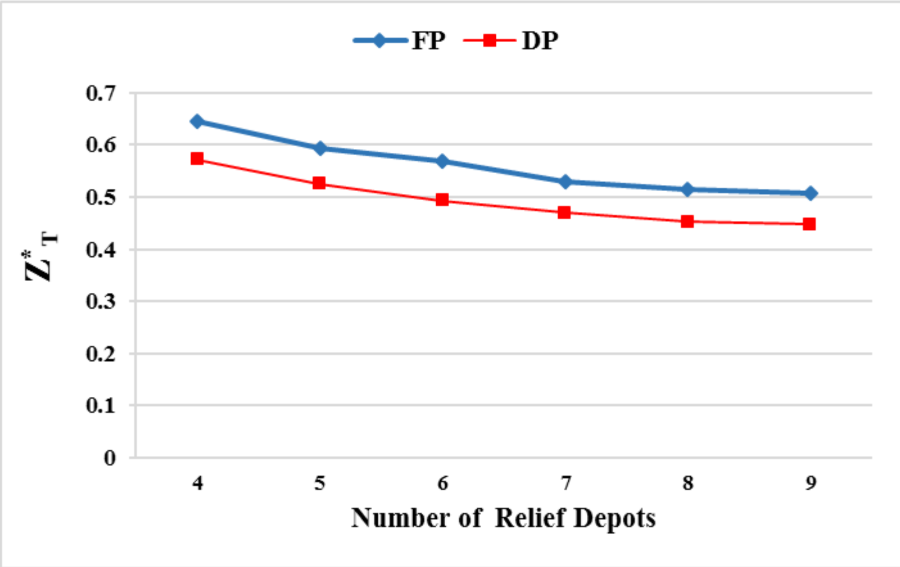

Figure 5: Sensitivity analysis of relief depot numbers

In figure 6, in case of 4 relief depots and 6 hospitals and minimum constraint feasibility degree 0.9, sensitivity analysis is done for 3 to 9 transfer points. As can be seen, by increasing number of transfer points, total objective function is decreasing. Besides, FP has more objective function quantity.

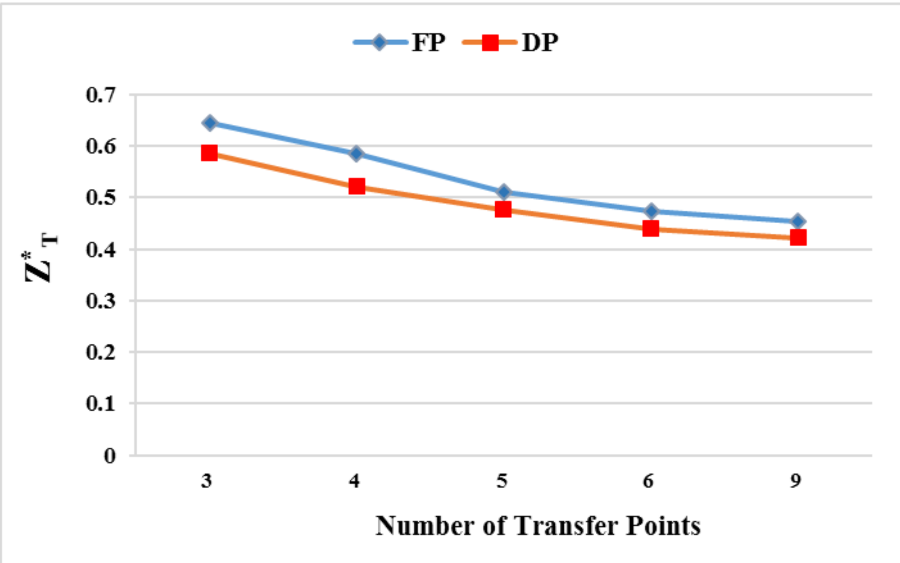

Figure 6: Sensitivity analysis of transfer point numbers

8. Conclusions and recommendations:

This paper developed a credibility-based fuzzy non-linear multi-objective mathematical programming of disaster relief logistic network under uncertainty. Occurrence of uncertainty is inevitable in disaster time. Location of hospitals and transfer points was utilized to provide medical needs; and location routing to solve communicative problems. In addition, route failures were considered to approach reality. The main aim of this paper was presenting a comprehensive and integrated model for disaster management problem including hospital and transfer point location and location routing of relief depots in disaster duration. Objective function (2) was associated with minimizing transfer costs among affected areas and relief depots, and also minimizing vehicle usage in affected area routes and objective function (3) with minimizing probability of not reaching casualties to hospitals. The purposes of the proposed model were minimizing demand magnitudes in time for transferring casualties, minimizing transportation cost, and minimizing probability of not reaching casualties to hospitals. Region 1 of Tehran was chosen as case study owing to high population and high vulnerability versus earthquakes; the problem was considered with 6 hospitals, 4&6 relief depots, 1,2,3,6, and 9 transfer points, and minimum constraint feasibility degree 0.9 and 0.7 and the results were also examined by solving the model. For timely attendance to casualties in case of occurrence earthquakes, transfer points were established in boundary areas and most hospitals in central areas considering congested population and large number of casualties on central areas of region 1. Our findings indicated that whatever the decision-maker considers greater minimum constraint feasibility degree means planning with less risk about uncertainty. By increasing α, relief depots will be established in places which have high population to minimize costs of relief commodity routing and the distances of these depots to hospitals will be optimal due to storing medical commodities, and hospitals as well cover high affected population and with optimal distance from relief depots.In future researches, inventory subjects of depots can be considered. Moreover, providing some shelters for affected people will have a remarkable role in attending during disasters

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