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A Fuzzy Multi-Objective Model For Logistic Planning In Disaster Relief Operations

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ABSTRACT

Disasters can cause many human casualties and considerable financial loss and destruction. This is mainly because of ineffective preventive measures, incomplete preparedness, and weak relief logistics systems. Quick, effective and efficient post-catastrophic actions are of great importance for lowering the losses and casualties. A key element, is an efficient logistic plan for distributing needed relief commodities efficiently and fairly among the affected people. In this paper, we propose a fuzzy multi-objective, multi-modal, multi-commodity logistic model in emergency response to disaster occurrence. The aim of the proposed model is to assign limited resources equitably to the affected regions while minimizing transfer costs of commodities as well as distribution centers activation costs, and maximizing satisfied demand. In the proposed model, the optimal location of distribution centers among candidate points to receive people donations as well as sending and receiving different kinds of relief commodities are determined. The amount of voluntary donations is subject to uncertainty and are considered as fuzzy parameters. The number of victims immediately after disaster is also vague and is expressed as fuzzy demand. A case study is presented to investigate the properties of the optimization problem and justify the practical efficiency of the formulation.

1.Introduction

A disaster is any occurrence that brings about damages, destructions, ecological disruptions, loss of human lives, human sufferings, deterioration of health and health services on a scale adequate to warrant an extraordinary response from outside the affected area [1]. Disasters have happened all over the world affecting many people and regions. It has been estimated that the number of disasters will increase fivefold over the next 50 years [2]; therefore, it is of great importance to be prepared for such incidents. Disaster management can be defined as the discipline of avoiding and dealing with risks [3]. This discipline involves preparing for and responding to disasters and supporting and rebuilding the society after initial disaster relief operations. Disaster management system consists

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of four main phases: mitigation, preparedness, response, and recovery. In preparedness phase, we can improve logistic plans to have better relief operations and assign the limited resources to the best possible usage.

Other important factors in disaster analysis are the cost of relief operations and the economic consequences of disasters. Over the last decade, huge sums of money have been either spent on or lost because of disasters. One of the major components of post-disaster costs is related to relief operations. In 2003, about $6 billion was spent on humanitarian relief operations around the world. Also, the tsunami of March 22, 2005 required allocation of about $6.4 billion for the response solely [4].

In this research, a model with two objectives of minimizing relief operation costs and maximizing the ratio of response to demands over all of the affected regions is proposed. After disaster strikes, the number of disaster victims, such as killed, trapped and injured people, are subject to uncertainties; in addition, the amount of governmental supports and people voluntary aids of different kinds of relief commodities, are also uncertain. Therefore, three fuzzy parameters for demands of affected regions, people donations and governmental supports are considered. In the proposed model vehicle capacity, destruction of routes, sending and receiving capacity of each node are taken into account. For fair distribution of relief commodities among victims of different regions and in order to make sure that each region receives at least a percentage of all kinds of needed commodities based on its population, an equity constraint is proposed.

2. Literature Review

Altay and Green [5] surveyed the literature of disasters operations management from an operations research and management science (OR/MS) point of view. They investigated 109 articles on disaster operations management from 1980 to 2003 and classified them, explained each classification and identified specific parts that needed more researches. They mentioned different subjects for future studies and guided interested researchers to variety of directions for new investigations about OR/MS researches in disaster operation management.

Haghani and Oh [6] presented a multi commodity, multi modal, linear model with time windows, with the goal of minimizing vehicular and commodities flow costs, as well as supply/demand storage costs and intermodal transfer costs. Their model can determine vehicle routing and scheduling plans; however, they did not consider uncertainties that exist in demand in affected regions and supplies available after disaster. Sheu [7] proposed multi commodity distribution model in response to disaster occurrence. He determined five phases for the relief operational procedures including forecasting time varying relief demand, fuzzy clustering approach for grouping affected areas, determining distribution priority, group-based relief distribution and dynamic relief supply. He solved two problems: (1) Distributing different relief commodities from the urgent relief distribution centers to multiple affected area groups, with goals of maximizing demand fill rate and minimizing distribution costs. (2) Transporting optimal relief supply amounts from suppliers to distribution centers with goal of minimizing transportation costs. Tzeng et al. [8] formulated a multi-objective model for distributing relief commodities among affected regions. They assumed trucks as a mode of transportation to distribute multiple commodities among accessible affected areas throughout the road network after disaster. They considered three objective functions: costs minimization, travel time minimization and satisfaction maximization for relief logistics system.

Haghani and Afshar [9] proposed a mathematical model in response to disaster that is incompliance with Federal Emergency Management Agency (FEMA) logistics structure and minimizes the weighted unsatisfied demand. Their model identifies optimal locations for temporary facilities and controls flows of vehicles and commodities as well as considering facilities and transportation system’s capacities. Najafi et al. [10] introduced a multi-objective stochastic model for logistics planning in response to earthquakes. They aimed to minimize unfulfilled demand, unserved injured people and number of vehicles utilized in relief operations. They considered demand, supply and capacity uncertainties in post-disaster situations and addressed vehicle routing in their solution. Kumar and Havey [14] proposed a decision support risk assessment and mitigation frame work for disaster relief supply chain. The frame work was used in example of the March 2011 disaster in Japan. They calculated critical index of each logistical stage in disaster relief supply chain, and ranked the stages due to the criticality index priority. Based on this, phase one “planning and preparedness“, was the most important phase, which dictates all other response phases. This model is applicable for other disaster relief supply chains by adapting the probabilities of failure, failure rates, and other variables to fit the supply chain situations.

Barzipour and Esmaeili [15] developed a multi-objective MILP model for two echelons relief supply chain, in order to have maximum urban population coverage and minimum logistics costs. They used RADIUS software for damage estimation of a hypothetical earthquake in the urban district of Tehran to provide useful insight about disaster aftermath and consider proper response requirement. To improve the applicability of their model, a virtual zoning approach was followed and the results showed advantages of considering auxiliary sub regions.

Ahmadi et al. [16] developed a multi-depot location-routing problem model to minimize total distribution time, penalty costs of unsatisfied demand and fixed costs of opening logistics distribution centers, and cost of unsatisfied demand. A real world case study in San Francisco district was carried out to demonstrate the capability of the formulation. Also a VNS algorithm was devised to solve a large instance of the case study for deterministic operational model.

3. Problem Description

After disaster strikes, serving the victims is a vital task. As a part of this complex task, the relief commodities should be delivered to the hands of people in need in a way that the total cost of relief operations is minimized and the response to demands ratio over all of the affected regions is maximized.

A three-level emergency supply chain structure is considered in this study:

1. Level one consists of supply centers which are permanent facilities with pre-determined locations that receive governmental supplies and store relief commodities for dispatching in emergency situations.
2. Level two are distribution centers which are temporary facilities with identified candidate locations to which people voluntarily donate relief commodities. The model is expected to be chosen such that the objective functions are minimized and the related constraints are considered.
3. Affected areas are constitute the third level of the emergency supply chain. Different kinds of Relief commodities that are gathered from volunteer donators and governmental supplies would be received at this level of supply chain.

After disaster hits, precise data about disaster victims may not be available; in addition, their needs would be uncertain. Here, fuzzy demand parameters are utilized to model these uncertainties. Since people voluntary donations and governmental supports of relief commodities have vagueness in types and quantities, we have assumed them as fuzzy parameters. Voluntary donations would be dispatched to the distribution centers, while governmental supports are sent to the supply centers. Supply centers have primary inventory for relief commodities at the beginning of the emergency response period.

Assuming the emergency supply chain as a network, then the supply centers are regarded as supply nodes, distribution centers are considered as intermediate nodes and affected areas are the demand points. Here, we have three types of arcs. First, the arcs which connect supply nodes to intermediate nodes. Second, the arcs which link intermediate nodes to demand nodes and third, the arcs that directly connect supply points to demand points (see figure 1). In this research, we have considered multiple types of vehicles, as well as assuming open and blocked routes after disaster. The goals of this research are fair distribution of relief commodities among affected regions in a way that every demand point receives a minimum amount of each type of relief commodities according to population that reside in that demand point, and simultaneously minimizing relief operation costs.

4. Problem Formulation

4.1- Notations

The indices, sets, parameters and decision variables which are used to formulate the mathematical model are introduced in what follows.

4.1.1- Indices

s = Supply center index.

i = Distribution center index.

d = Demand point index.

m = Type of vehicle index.

r = Type of relief commodity index.

4.1.2- Sets

SP = Set of supply centers (supply point).

IP = Set of distribution centers (intermediate point).

DP = Set of affected areas (demand points).

MV = Set of different types of vehicles.

RC = Set of different kinds of relief commodities.

4.1.3- Parameters

W_r = Unit weight of commodity type r.

$\widetilde{O}_{sr}$ = Amount of governmental supports of relief commodity type r which is sent to supply point s.

$\widetilde{P}_{ir}$ = Amount of people volunteer donations of relief commodity type r which is sent to intermediate point i.

$D\widetilde{e}m_{dr}$ = Demand of demand point d for relief commodity type r.

POP_d = Population of demand point d.

AC_i = Fixed activation cost of distribution center i.

CX_{sim} = Transportation cost of relief commodities from supply point s to distribution center i, by vehicle type m.

CY_{idm} = Transportation cost of relief commodities from distribution center i to demand point d, by vehicle type m.

CZ_{sdm} = Transportation cost of relief commodities from supply point s to demand point d, by vehicle type m.

$VCAP_m$ = Capacity of vehicle mode m.

I_{sr} = Primary inventory for commodity type r, at supply point s, at the beginning of emergency response period.

γ_{sim} = 1 If vehicle type m can pass through supply point s to distribution center i; 0 otherwise.

ζ_{idm}= 1 If vehicle type m can pass through distribution center i to demand node d; 0 otherwise.

η_{sdm}= 1 If vehicle type m can pass through supply point s to demand node d; 0 otherwise.ondon (2006).

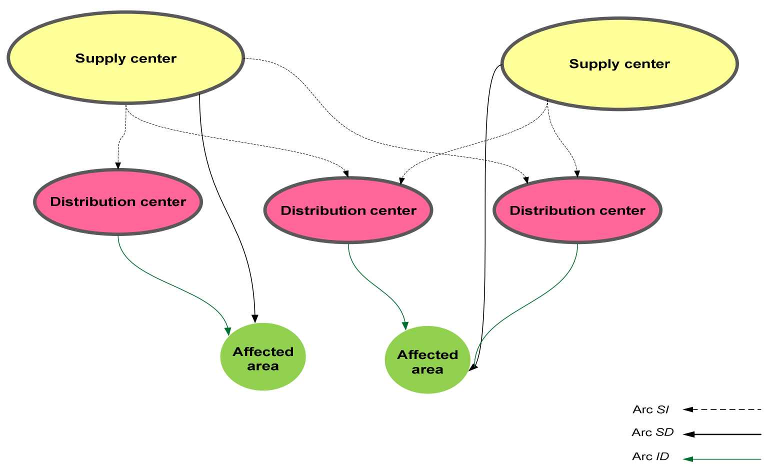

Fig. 1. Supply chain structure

4.1.4- Decision variables

F_i = 1 if distribution center i is open; 0 otherwise

X_{sirm} = Amount of relief commodity type r which is carried by vehicle type m from supply point s to distribution center i.

Y_{idrm} = Amount of relief commodity type r which is carried by vehicle type m from distribution center i to demand point d.

Z_{sdrm} = Amount of relief commodity type r which is carried by vehicle type m from supply point s to demand point d.

VN_{sim} = Number of vehicle type m, transporting relief commodities from supply point s to distribution center i.

VP_{idm} = Number of vehicle type m, transporting relief commodities from distribution center i to demand point d.

VL_{sdm} = Number of vehicle type m, transporting relief commodities from supply point s to demand point d.

4.2- Objective Functions

$$Min\ Z_1= \sum_m\sum_s\sum_i VN_{sim}\times CX_{sim}+\sum_m\sum_i\sum_d VP_{idm}\times CY_{idm}+\sum_m\sum_s\sum_d VL_{sdm}\times CZ_{sdm}+\sum_i f_i\times AC_i \quad (1)$$

$$Max\ Z_2=\sum_d \frac{\sum_s\sum_r\sum_m Z_{sdrm}+\sum_i\sum_r\sum_m Y_{idrm}}{\sum_r D\tilde{e}m_{dr}} \quad (2)$$

Objective function Z_1 minimizes relief commodities transfer costs as well as minimizing distribution centers activation costs. In order to calculate the total transportation cost we multiply the number of each vehicle type assigned to each route with the corresponding transfer costs and sum up over all types of vehicles and all of the corresponding points. Z_1 also minimizes activation costs of distribution centers; i.e., minimum possible number of distribution centers at optimal locations would be activated to minimize total costs while satisfying all the related constraints of the model.

Objective function Z_2 maximizes the ratio of response to demands over all of the affected regions. Numerator of the ratio equals the amounts of different types of relief commodities carried to affected area d, by all types of vehicles from all the supply points and active intermediate points. Denominator of the ratio represents the total demand for all types of relief commodities at affected area d. For this objective function, maximum response to the demands of affected regions is required; while for first objective we want to transport relief commodities at minimum transportation cost with minimum transport of relief commodities and activating distribution centers at optimum location. Therefore, these objective functions are in conflict with each other.

4.3. Constraints

$$\sum_r X_{sirm}.w_r = VN_{sim}.VCap_m.\gamma_{sim} \qquad \forall m,i,s \qquad (3)$$

$$\sum_r Y_{idrm}.w_r = VP_{idm}.VCap_m.\zeta_{idm} \qquad \forall m,i,d \qquad (4)$$

$$\sum_r Z_{sdrm}.w_r = VL_{sdm}.VCap_m.\eta_{sdm} \qquad \forall m,s,d \qquad (5)$$

Equation (3) explains that, total weight of relief commodities transported by each type of vehicle from each supply point to each active intermediate point, should be equal to total weight capacity assigned to that route. If the route for vehicle type m (from supply point s to intermediate point i) is blocked or disrupted, or intermediate point i is not activated, then no vehicle can be assigned to that route and no relief commodity may pass through that route. Constraint (4) is same as constraint (3) but for routes of type two which connect intermediate points to demand points. Constraint (5) is the same as constraint (3), but for routes of type three which link supply points to demand points.

$$VN_{sim} \le M.\gamma_{sim}.F_i \qquad \forall m,i,s \qquad (6)$$

$$VP_{idm} \le M.\zeta_{idm}.F_i \qquad \forall m,i,d \qquad (7)$$

$$VL_{sdm} \le M.\eta_{sdm} \qquad \forall m,s,d \qquad (8)$$

Obviously, no vehicles can be assigned to the block or destroyed routes and if intermediate node *i* is not activated no vehicle may pass through the route that starts from or ends with that inactive intermediate point *i*. However, there is no limit for the number of vehicles assigned to the open routes. These facts are modeled through Constraints (6), (7) and (8) in which *M* is a large positive number.

Constraint (9) ensures that, maximum relief commodity type *r* that are sent by all active intermediate nodes and all supply points to affected area *d*, is bounded by the demand of that type of relief commodity at infected region *d*.

$$\sum_m \sum_i Y_{idrm} + \sum_m \sum_s Z_{sdrm} \le D\tilde{e}m_{dr} \qquad \forall d,r \qquad (9)$$

$$\sum_m \sum_d Y_{idrm} \le \sum_m \sum_s X_{sirm} + \tilde{P}_{ir}.F_i \qquad \forall i,r \qquad (10)$$

$$\sum_m \sum_i X_{sirm} + \sum_m \sum_d Z_{sdrm} \le \tilde{O}_{sr} + I_{sr} \qquad \forall s,r \qquad (11)$$

Constraint (10) shows sending limit for each type of relief commodity at each active intermediate node *i* that is equal to the amount of relief commodity type *r* sent either by volunteer donators or several supply points to intermediate node *i*.

Constraint (11) shows sending boundary of relief commodity type *r*, at supply point *s* which is equal to the amount of governmental supports and primary inventory for that type of relief commodity at supply point *s*.

$$\sum_m \sum_s Z_{sdrm} + \sum_m \sum_i Y_{idrm} \ge \alpha_d.D\tilde{e}m_{dr} \qquad \forall d,r \qquad (12)$$

$$\alpha_d = \frac{\beta_d \, pop_d}{\sum_d pop_d} \qquad 0.1 \le \beta_d \le 1$$

Constraint (12) identifies equity condition in distributing relief commodities. It defines a minimum fulfillment level for each type of relief commodity to be dispatched to each demand point from all supply nodes and all of the active intermediate nodes by means of all types of vehicles. This minimum level is equal to a proportion (α_d) of demand for each type of relief commodity, at each demand point *d*. α_d is equal to a percentage of population of that demand point in division to total population of demand nodes. By this constraint we ensure that a minimum level of demands for each type of relief commodities received at each demand point *d*.

4.4. Variables

$$X_{sirm}, Y_{idrm}, Z_{sdrm}, VN_{sim}, VP_{idm}, VL_{sdm} \ge 0 \text{ and integer} \qquad \forall s,i,d,r,m$$

$$F_i \in \{1,0\} \qquad \forall i$$

5. Solution Method

In this section solution methodologies are discussed. As the first step, the fuzzy linear mathematical programming is converted to the crisp model by considering parametric approach introduced by Carlsson and korhonen [11]. As the second step, a weighted goal programming technique is utilized to solve the multi-objective problem.

5.1- Crisp Model

Carlsson and Korhonen [11] introduced a parametric approach to deal with linear programming with fuzzy parameters. They assumed user defined intervals that include possible values of the parameters. The lower bound of each interval represents for the ‘risk free’, and the upper bound shows the unrealistic or ‘impossible’ value of the parameter. The intervals, which are assumed here, are

$$D\widetilde{e}m_{dr} \in [Dem_{dr}^{L}, Dem_{dr}^{U}], \widetilde{O}_{sr} \in [O_{sr}^{L}, O_{sr}^{U}] \text{ and } \widetilde{P}_{ir} \in [P_{ir}^{L}, P_{ir}^{U}]$$

$$\mu(D\widetilde{e}m_{dr}) = \frac{(Dem_{dr}^{U} - D\widetilde{e}m_{dr})}{Dem_{dr}^{U} - Dem_{dr}^{L}} \qquad \forall d,r \qquad (13)$$

$$D\widetilde{e}m_{dr} = Dem_{dr}^{U} - \mu(D\widetilde{e}m)(Dem_{dr}^{U} - Dem_{dr}^{L}) \qquad \forall d,r \qquad (14)$$

$$\mu(\widetilde{O}_{sr}) = \frac{(O_{sr}^{U} - \widetilde{O}_{ds})}{O_{sr}^{U} - O_{sr}^{L}} \qquad \forall s,r \qquad (15)$$

$$\widetilde{O}_{sr} = O_{sr}^{U} - \mu(\widetilde{O}_{sr})(O_{sr}^{U} - O_{sr}^{L}) \qquad \forall s,r \qquad (16)$$

$$\mu(\widetilde{P}_{sr}) = \frac{(P_{ir}^{U} - \widetilde{P}_{ir})}{P_{ir}^{U} - P_{ir}^{L}} \qquad \forall i,r \qquad (17)$$

$$\widetilde{P}_{ir} = P_{ir}^{U} - \mu(\widetilde{P}_{ir})(P_{ir}^{U} - P_{ir}^{L}) \qquad \forall i,r \qquad (18)$$

Moving forward from 'risk free' to 'impossible' values, is moving from solutions with high degree toward low degree of implementation, from secure to optimistic solutions. Though, it is reasonable to assume that membership functions are monotonically decreasing functions of the parameters [11]. Here we assume linear membership function for each of the fuzzy parameters and then attain the fuzzy parameters such as equation (14), (16) and (18). By substituting fuzzy parameters in equation (2) and constraints (9), (10), (11) and (12) by the related right hand side of equations (14), (16) and (18), the following formulation is obtained.

$$Min \quad Z_1$$

$$Max \quad Z_2 = \sum_{d} \frac{\sum_{s}\sum_{r}\sum_{m} Z_{sdrm} + \sum_{i}\sum_{r}\sum_{m} Y_{idrm}}{\sum_{r}(Dem_{dr}^{U} - \mu(D\widetilde{e}m)(Dem_{dr}^{U} - Dem_{dr}^{L}))} \qquad (19)$$

$s.to.$

(3),(4),(5),(6),(7),(8)

$$\sum_{m}\sum_{i} Y_{idrm} + \sum_{m}\sum_{s} Z_{sdrm} \leq (Dem_{dr}^{U} - \mu(D\widetilde{e}m)(Dem_{dr}^{U} - Dem_{dr}^{L})) \qquad \forall d,r \qquad (20)$$

$$\sum_{m}\sum_{d} Y_{idrm} \leq \sum_{m}\sum_{s} X_{sirm} + (P_{ir}^{U} - \mu(\widetilde{P}_{ir})(P_{ir}^{U} - P_{ir}^{L})).F_i \qquad \forall i,r \qquad (21)$$

$$\sum_{m}\sum_{i} X_{sirm} + \sum_{m}\sum_{d} Z_{sdrm} \leq (O_{sr}^{U} - \mu(\widetilde{O}_{sr})(O_{sr}^{U} - O_{sr}^{L})) + I_{sr} \qquad \forall s,r \qquad (22)$$

$$\sum_{m}\sum_{s} Z_{sdrm} + \sum_{m}\sum_{i} Y_{idrm} \geq \alpha.(Dem_{dr}^{U} - \mu(D\widetilde{e}m)(Dem_{dr}^{U} - Dem_{dr}^{L})) \qquad \forall d,i,s,r \qquad (23)$$

The best value of the objective function at a fixed level of precision can be found by using parameter values of the same level of precision [11]. By considering $\mu(D\widetilde{e}m) = \mu(\widetilde{O}_{sr}) = \mu(\widetilde{P}_{sr}) = \mu$, and determined values of μ the above formulation would be the crisp linear multi-objective model.

5.2- Goal programming approach

Goal programming is one of the first methods specifically proposed for multi-objective optimization [12]. In goal programming, the decision maker is asked to specify aspiration levels for the objective functions. Then, deviations from these aspiration levels are minimized. An objective function jointly with an aspiration level is referred to as a goal. The method has several variants. In the weighted goal programming approach [13], the weighted sum of the deviations is minimized.

If we denote the aspiration level for Z_1 by g_1 and the aspiration level for Z_2 by g_2 and apply the weighted goal programming method to the formulation in section *5.1*, then the mathematical model is as follows:

$$MIN \quad Z = w_1(d_1^+ + d_1^-) + w_2(d_2^+ + d_2^-) \tag{24}$$

$$\sum_m\sum_s\sum_i VN_{sim}.CX_{sim} + \sum_m\sum_i\sum_d VP_{idm}.CY_{idm} + \sum_m\sum_s\sum_d VL_{sdm}.CZ_{sdm} + \sum_i F_i.AC_i - d_1^+ + d_1^- = g_1 \tag{25}$$

$$\sum_d \frac{\sum_s\sum_r\sum_m Z_{sdrm} + \sum_i\sum_r\sum_{m\in} Y_{idrm}}{\sum_r (Dem_{dr}^U - \mu(\tilde{Dem})(Dem_{dr}^U - Dem_{dr}^L))} - \tag{26}$$

$$d_2^+ + d_2^- = g_2$$

$$d_1^+, d_1^-, d_2^+, d_2^- \geq 0$$

The above objective is subject to all the other constraints (3) to (8), and (20) to (23). In the above equations, the subscript *d* stands for deviations and coefficient *w* refers to importance weight of deviations of achievements from aspiration level.

6. Case Study

In this section, a natural disaster such as an earthquake is considered that strikes two cities in Iran, Ardebil with population of 564365, and Bushehr with population of 258906. In this case, we have considered 5 kinds of relief commodities for which the information is presented at Table 1. As it is mentioned in section 3, the three-layer structure is utilized for emergency supply chain. At first level we have supply centers (storage sites), which are located at Tehran, Esfahan and Shiraz. The supply centers have primary inventory level for each type of relief commodities, as presented in Table 2. Governmental supplies of different types of relief commodities, at each supply center have upper limit and lower limit as they are presented in Table 2. Commodities are gathered at supply centers, to be dispatched to the affected cities. Fuzzy parameters, i.e. governmental supports, voluntary donations and demand for different types of relief commodities have linear membership functions.

Different amounts of fuzzy governmental supports can be accounted by limits of supports through Tables 2, by applying favorable membership degree and using equation (16).

As we move from lower to higher membership degrees, we pass from higher risk to the lower risk amounts of supplies, i.e. from optimistic to pessimistic amounts of supports. Here, we have determined three candidate sites for distribution centers: Tabriz, Kazerun and Firuzabad. In Table 3, we have lower and upper bound of voluntary donations of different types of relief commodities in correspondence with each distribution center. Fuzzy amounts of these donations corresponding to each type of relief commodities and each distribution center can be obtained by using Equation (18).

Upper and lower limits of demands for relief commodities for two affected cities are presented in Table 4. Two types of vehicles, M17 helicopter and Scania trailer are utilized to transfer cargos for which weight capacities are 4 and 27 tons, respectively. In Tables 5, 6 and 7 transportation costs of relief commodities by means of trailer, from level 1 to 2, level 1 to 3 and level 2 to layer 3 of emergency relief supply chain are presented, respectively. Transfer costs by means of M17 helicopter from second to third level of emergency supply chain are given in Table 8. We assume that only trailer (not the helicopter) can pass through all supply centers to all distribution centers or to the two affected regions.

Open and closed arcs for trailer and helicopter to pass through distribution centers to affected areas are given in Table 9 in which 1 stands for open and 0 stands for closed arcs.

Tab. 1. Relief commodities definitions.

Item	Canned tuna	Canned beans	Blanket	Tent	Water
Unit Weight (kg)	0.2	0.5	2	40	4.5

Tab. 2. Primary inventory and limits of governmental supports for each commodity to each supply center.

	Tehran supply center			Esfahan supply center			Shiraz supply center		
Item	Primary inventory	Lower bound	Upper bound	Primary inventory	Lower bound	Upper bound	Primary inventory	Lower bound	Upper bound
Canned tuna	180000	200000	500000	720000	40000	80000	180000	100000	200000
Canned beans	100000	90000	250000	0	30000	70000	320000	100000	200000
Blanket	30000	220000	539000	20000	20000	40000	20000	240000	640000
Tent	200	20000	50000	100	14000	22000	400	18000	46000
water	15360	18000	40000	15360	62000	102000	15360	150000	250000

Tab. 3. Limits of people volunteer donations for each type of relief commodity, and each distribution center

Item	Tabriz distribution center		Kazerun distribution center		Firuzabad distribution center	
	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
Canned tuna	500022	102345	30700	153500	30700	153500
Canned beans	250032	54327	30700	153500	30700	153500
Blanket	204000	42876	62000	307000	62000	307000
Tent	221000	43500	62000	307000	62000	307000
water	352467	78850	62000	307000	62000	307000

Tab. 4. Limits of demands for each type of relief commodity and each distribution center.

Item	**Ardebil's demand**		**Bushehr's demand**	
	Lower bound	Upper bound	Lower bound	Upper bound
Canned tuna	752487	1504974	345208	690416
Canned beans	752487	1504974	345208	690416
Blanket	376244	752487	172604	345208
Tent	188122	376244	17260	34521
water	1504974	3009947	138083	276166

Tab. 5. Transportation costs (Thousand Rials) from supply centers to distribution centers by trailer.

	Tehran	Esfahan	Shiraz
Tabriz	5559	9909	14431
Kazerun	8676	4326	1565
Firuzabad	9972	5622	1100

Tab. 6. Transportation costs (Thousand Rials) from supply centers to affected regions by trailer.

	Tehran	Esfahan	Shiraz
Ardebil	5477	9827	14349
Bushehr	9846	5496	2735

Tab. 7. Transportation costs (Thousands Rials) from distribution centers to affected regions by trailer.

	Tabriz	Kazerun	Firuzabad
Ardebil	1952	14153	15449
Bushehr	15405	1530	2350

Tab. 8. Transportation costs (Thousands Rials) from distribution centers to affected regions by helicopter.

	Tabriz	Kazerun	Firuzabad
Ardebil	5309	29830	33106
Bushehr	32663	3497	5158

Tab. 9. Open and closed routes for trailer and helicopter from distribution centers to affected areas.

	Trailer		Helicopter	
	Ardebil	Bushehr	Ardebil	Bushehr
Tabriz	0	1	1	1
Kazerun	1	1	1	1
Firuzabad	1	0	1	1

By utilizing the 2 phase approach introduced in Section 5, and coding the model in lingo 10 software, solutions are obtained and are depicted in Table 10 in which decision variables and deviations from goals, at different levels of precisions are provided. All of the intermediate nodes are activated to response the demands of affected regions. Here we have no deviations from the first goal and we have negative deviation from the second one (respond to demand ratio). In Table 11 achievement levels of first and second objectives corresponding to membership degrees of parameters are shown. Z is equal to total weighted deviations. As we move from lower to higher degrees of membership function total costs will be reduced, because of demand and supply reductions.

7. Conclusions

Increasing number of disasters, increase the need of emergency relief operations plans. Transportation of supplies and relief personnel must be done effectively and efficiently to maximize the survival rate of the affected population and minimize cost of such operations [8]. In this study, we propose a model for planning response to disasters in a certain rescue period, and deliver different types of relief commodities to the affected areas fairly using different modes of vehicles. We considered constraints of relief supply chain, uncertainties in demands and supplies, and destructions of roads that may happen after disaster strikes. Two objectives are considered: minimizing transportation costs and maximizing the ratio of respond to demand. A case study is presented that approves the applicability of the model.

For future researches, serving disaster victims in hospitals could be assigned as another goal to be maximized. Multi-relief periods may also be considered to be part of the problem and Travel time minimization can be thought of as another objective. Meta-heuristics algorithms can be applied for solving the large-scale instances of the problem.

Tab. 10. Decision variables and deviation gain through solving the model by LINGO 10.

$\mu(D\tilde{e}m_{dr}) = \mu(\tilde{O}_{sr}) = \mu(\tilde{p}_{sr}) = 0.1$					$\mu(D\tilde{e}m_{dr}) = \mu(\tilde{O}_{sr}) = \mu(\tilde{p}_{sr}) = 0.3$				
Y_{1211}=9193	VP_{121}=13	Z_{1111}=530023	VL_{111}=107	d_2^- =0.37	Y_{1152}=23111	VP_{112}=26	Z_{1111}=532383	VL_{111}=94	d_2^- =0.35
Y_{1251}=77591	VP_{211}=127	Z_{1121}=334000	VL_{211}=51		Y_{1221}=7543	VP_{121}=12	Z_{1121}=302000	VL_{211}=48	
Y_{2141}=54497	VP_{221}=28	Z_{1131}=245025	VL_{311}=44		Y_{1251}=71162	VP_{211}=111	Z_{1131}=216793	VL_{311}=41	
Y_{2151}=277583	VP_{311}=47	Z_{1141}=47168	VL_{321}=2		Y_{2141}=48956	VP_{221}=24	Z_{1141}=40688	VL_{321}=2	
Y_{2211}=141220		Z_{1151}=53160			Y_{2151}=230839	VP_{311}=39	Z_{1151}=48760		
Y_{2221}=141220		Z_{2121}=66000			Y_{2211}=116660		Z_{2121}=58000		
Y_{2231}=111251		Z_{2141}=20847			Y_{2221}=116660		Z_{2131}=2440		
Y_{2241}=10313		Z_{2151}=113360			Y_{2231}=92622		Z_{2141}=19700		
Y_{2251}=4917		Z_{3121}=77760			Y_{2241}=9228		Z_{2151}=105360		
Y_{3121}=12289		Z_{3151}=255360			Y_{2251}=2661		Z_{3121}=73965		
Y_{3151}=280635		Z_{3211}=107378			Y_{3121}=4500		Z_{3141}=272		
		Z_{3221}=65049			Y_{3151}=233500		Z_{3151}=235360		

							Z_{3211}=119118 Z_{3221}=60353		
$\mu(D\tilde{e}m_{dr}) = \mu(\tilde{O}_{sr}) = \mu(\tilde{p}_{sr}) = 0.5$					$\mu(D\tilde{e}m_{dr}) = \mu(\tilde{O}_{sr}) = \mu(\tilde{p}_{sr}) = 0.7$				
Y_{1152}=48000	VP_{112}=54	Z_{1111}=439752	VL_{111}=82	d_2^-=0.35	Y_{1152}=79111	VP_{112}=89	Z_{1111}=352108	VL_{111}=69	d_2^-=0.35
Y_{1221}=10620	VP_{121}=11	Z_{1121}=270000	VL_{211}=44		Y_{1221}=6660	VP_{121}=9	Z_{1121}=238000	VL_{211}=40	
Y_{1251}=64820	VP_{211}=95	Z_{1131}=193000	VL_{311}=37		Y_{1251}=53260	VP_{211}=79	Z_{1131}=167648	VL_{311}=33	
Y_{2141}=43405	VP_{311}=31	Z_{1141}=35136	VL_{321}=2		Y_{2141}=38441	VP_{221}=18	Z_{1141}=28962	VL_{321}=2	
Y_{2151}=184182		Z_{1151}=44360			Y_{2151}=132307	VP_{311}=23	Z_{1151}=39960		
Y_{2211}=92100		Z_{2121}=50000			Y_{2211}=67540		Z_{2121}=42000		
Y_{2221}=92100		Z_{2131}=440			Y_{2221}=67540		Z_{2141}=16422		
Y_{2231}=87710		Z_{2141}=18100			Y_{2231}=71037		Z_{2151}=89360		
Y_{2241}=8142		Z_{2151}=97360			Y_{2241}=7057		Z_{3121}=23760		
Y_{2251}=318		Z_{3121}=53381			Y_{2251}=3193		Z_{3151}=195360		
Y_{3121}=13500		Z_{3141}=80			Y_{3121}=31537		Z_{3211}=102673		
Y_{3151}=184500		Z_{3151}=215360			Y_{3151}=134496		Z_{3221}=66931		
		Z_{3211}=119690							
		Z_{3221}=60124							
$\mu(D\tilde{e}m_{dr}) = \mu(\tilde{O}_{sr}) = \mu(\tilde{p}_{sr}) = 0.9$									
Y_{1152}=56751	VP_{112}=64	Z_{1111}=311448	VL_{111}=56	d_2^-=0.33					
Y_{1251}=47768	VP_{121}=8	Z_{1121}=201349	VL_{211}=36						
Y_{2141}=27131	VP_{211}=55	Z_{1131}=130508	VL_{311}=30						
Y_{2151}=86500	VP_{221}=15	Z_{1141}=23200	VL_{321}=3						
Y_{2211}=42980	VP_{311}=15	Z_{1151}=35560							
Y_{2221}=42980		Z_{2121}=34000							
Y_{2231}=59709		Z_{2141}=14722							
Y_{2241}=5971		Z_{2151}=81360							
Y_{3151}=86500		Z_{3121}=25667							
		Z_{3141}=202							
		Z_{3151}=175360							
		Z_{3211}=213903							
		Z_{3221}=76439							

Tab. 11. Achievement levels of objective functions and total weighted deviations amount.

μ	Z1 (rials)	Z2	Z
0.1	4493681000	0.35	0.18
0.3	4116425000	0.36	0.178
0.5	3732618000	0.35	0.176
0.7	3365093000	0.34	0.175
0.9	2581397000	0.35	0.164

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