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A P-robust model in humanitarian logistics in a non-neutral political environment

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C H R O N I C L E

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A B S T R A C T

Humanitarian assistance by foreign organizations in general and foreign military forces in particular, is typically provided in a non-neutral political environment. Local politics that range from national pride, through strained relations with the country offering military logistic support, to blatant aversion to the population in need, affect the ability to provide effective humanitarian aid. The current paper presents the use of mathematical modeling and robustness approach when the government of the affected area declines offers of aid from international organizations because of political constraints. The multi-objective model seeks to minimize unsatisfied demands and total costs of the government and suppliers. To explore the effects of various parameters and show managerial insights that can guide DMs under a variety of conditions, the sensitivity analysis of the experiments are presented.

1. Introduction

Humanitarian logistics is defined as "the process of planning, implementing, and controlling the efficient, cost-effective flow of and storage of goods and materials as well as related information from point of consumption for the purpose of meeting the end beneficiary's requirements" (Thomas & Mizushima 2005). In recent years both natural and artificial disasters have happened frequently. Especially disasters such as earthquakes, floods, or terrorist attacks, have caused huge property damage and human injuries and the effects are devastating (Jing et al., 2010). For example, fatal earthquakes in Turkey (Izmit, 1999), Taiwan (Chichi, 1999), India (Gujarat, 2001), Iran (Bam, 2003), Pakistan (Kashmir, 2005), China (Sichuan, 2008), and Haiti (2010) have killed more than 450,000 people in the past 10 years. Tsunami in Indonesia in 2004, Hurricane Katrina in the USA in 2005, and the recent flood in Pakistan in 2010 have left more than 300,000 casualties and missing people, billions of loss in assets, and more than 20 million homeless people. Application of operations research in disaster management programs has been one of the main issues in recent decades. Supply chain and logistics management are recently being used as analytical tools and techniques to provide efficient and effective relief to people who need help in devastated areas with optimized functions and activities. Thus, emergency logistics management has emerged as a worldwide noticeable theme, as disasters may occur

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anytime around the world with enormous consequences (Sheu, 2007). In urban areas, earthquakes can cause serious damages to occupancies and force people to leave their home. Therefore, at the respond planning phase of disaster management, municipal authorities should distribute aid commodities in the affected areas and evacuate injuries from the affected areas to medical centers in order to reduce the number of casualties and sufferings of people and bring relief to survivors (Esmaeili & Barzinpour, 2014). During these situations, international suppliers offer aid products to the government of the affected area. But, humanitarian assistance by international suppliers is typically provided in a non-neutral political environment. Local politics that range from national pride, through strained relations with the country offering military logistic support, to blatant aversion to the population in need, affect the ability to provide effective humanitarian aid . For example, following a magnitude 7.2 earthquake in southeast Turkey in 2011, the Turkish authorities declined an offer of aid from Israel. The Turkish foreign ministry claimed that Turkey had received offers of help from dozens of countries but had declined assistance from some of them (Kress, 2016).

In this paper a linear multi-objective model by considering distribution relief commodities in affected areas is developed. The proposed model also considers political constraints which under such situations the government of the affected area declines offers of aid from some international suppliers. To formulate this problem, we use Mont-Carlo simulation and P-robust programming to generate different scenarios. Afterward, a robust optimization model is developed to deal with all generated scenarios. In this paper, the first objective function seeks to minimize unsatisfied demands, the second one tries to minimize total cost of humanitarian logistics in the affected area, and the last one minimizes the shipping costs of relief commodities offered from international suppliers.

The remainder of this paper is organized as follows. Section 2 introduces optimization related studies in disaster management. The third section defines the considered problem and its basic assumptions. In Section 4, the proposed model is defined. Section 5 explains the p-robust modeling technique used in this study. In section 6 the numerical results are presented. Also, in this section the performance of the robust approach is compared with the deterministic approach. Finally, in section 7 conclusion and future researches are presented.

2. Literature review

Evidence indicates that the number of accidents and natural disasters occurring annually around the world in need of efficient plan and management to reduce the damages. According to studies conducted by the Association of IFRC, world have witnessed 7184 incidents from 2000 and 2009. The IFRC estimated economic losses caused by these events equal to 986691 million dollars as well as lives losses of 1,105,352 people and with 2,550,272,267 injured. These statistics reflect the high probability of crisis and the need to develop better strategies to reduce such losses. Necessary commodities and materials should be delivered immediately after an earthquake. An aid distribution plan is essential to deliver necessary commodities such as food, medicine, provisions for sanitation, shelter, and water to sustain human life and to administer the total costs. Humanitarian logistics as a part of humanitarian aid and disaster management has become an important area for researchers. Jahre et al. (2007), Altay and Green (2006), Özdamar and Ertem (2015), and Caunhye et al. (2012) have provided overviews on humanitarian logistics. Our literature on disaster relief is divided into two classifications: deterministic and uncertain models in humanitarian logistics.

2.1 Deterministic programming in humanitarian logistics

The study of disaster management originated with the large-scale industrial and environmental disasters in the 1980s (Shrivastava et al. 1988). Logistics in providing the most important types of commodities and services were the main theme of the research during this period. A multi-objective linear model that aims to minimize transportation cost and maximize the demand for food was proposed by (Knott, 1987). He developed a vehicle routing model in his next study which aimed to maximize the amount of delivered food (Knott, 1988). Barbarosoğlu et al. (2002) presented a hierarchical model in disaster relief by using helicopters for rescue operations during natural disasters. Their research has helped DMs to make vehicle-routing and transportation decisions during the response phase. An emergency logistics model aimed to determine distribution decisions of relief commodities was developed by Özdamar et al. (2004). Tzeng et al. (2007) designed a multi-objective model about relief delivery systems. The most momentous factor in their research was enhancing the performance of the distribution of relief materials. Their model minimized total cost and travel time and maximized the minimal satisfaction. Additionally, Nolz et al. (2011) established a multi-objective model for the response phase to minimize the risk and total travel time and maximize the coverage. They considered correlated and uncorrelated risk measures to cope with both earthquake and flood risks. Another multi-objective model which minimizes the total unsatisfied demand and total travel time was developed by Lin et al. (2011) that considers different types of vehicles and relief commodities. Afshar and Haghani (2012) proposed a single-objective model to schedule the flow of commodities and locate facility positions. Their research also considered the routing problem to increase effective response. Finally, Barzinpour and Esmaeili (2014) developed a multi-objective relief chain location distribution model for the preparedness phase of disaster management. Their model aimed to maximize the coverage and minimize total costs.

Some researchers applied transportation in different ways. For some examples, (Fiedrich et al., 2000) presented a relief network to transport injured people and allocate resources to them. In addition, a dynamic model to evacuate injured people and satisfy the demands of relief commodities was introduced by Yi and Özdamar (2007). Likewise, Yi and Kumar (2007), Ozdamar (2011), and Özdamar and Demir (2012) proposed a mathematical model for transporting injured people from affected areas to medical centers and delivering relief commodities to victims in the response phase.

2.2 Uncertainty programming in humanitarian logistics

Although dynamic multi-period and multi-period models helped DMs during and after disasters, they did not capture the uncertain nature of disasters. Many researchers started considering this uncertainty in disaster relief planning in their studies. Some of them used stochastic programming to distribute relief commodities through probable scenarios. Barbaroso and Gcaron (2004) used scenario planning in a two-stage stochastic model for the response phase of an earthquake. Also, Jotshi et al. (2009) used robust optimization to schedule routes for vehicles after the disaster. In order to minimize the maximum rescue time based on all scenarios, a robust model for a disaster network with uncertainty in distances between nodes was proposed by Ma et al. (2010). A stochastic optimization in the preparedness phase of disaster management was proposed to determine the storage locations of medical supplies and requested inventory amounts for each type of medical supply. Mete and Zabinsky (2010). Salmerón and Apte (2010) proposed a two-stage stochastic programming in preparedness and response phases. In the first stage, they determined “aid-prepositioning”, and the second stage specified distribution decisions. Another study was accomplished by Rawls and Turnquist (2010). They presented a two-stage stochastic programing for location and distribution of emergency commodities under uncertain demand. According to uncertainty in demand and the availability of pathways and supply of relief commodities Zhan and Liu (2011) considered a location-allocation problem using chance constraint programming to minimize expected travel time and unsatisfied demands. Najafi et al. (2013) developed a multi-objective, multi-mode, multi-commodity and multi-period stochastic model to manage the logistics of both commodities and injured people in the earthquake response phase. Another robust disaster relief logistics network with perishable commodities was proposed by Rezaei-Malek et al. (2016) which used a scenario-based robust stochastic approach. This research aimed to determine the optimum location-allocation and distribution plan, along with the best ordering policy for restocking perishable commodities at the pre-disaster phase. Ahmadi et al. (2015) presented a two-stage stochastic program which was an operational location-routing problem (LRP) and could be used after an earthquake in the response phase. They tried to make vehicle routing and distribution decisions about a real situation. Finally, Tofighi et al. (2016) developed a novel, two-stage scenario based model to determine the location of central warehouses and local distribution centers. In addition, this research considered the distribution plan and availability level of the transportation network's routes.

The above paragraphs show several models that have been proposed for the preparedness and the response phase of disaster management, but most of these models do not consider unforeseen constraints and misassumptions that DMs face in real disasters. For example, a variety of vehicles are needed to distribute relief commodities in the affected areas. Also, most of these models do not consider international suppliers which always offer aid to the affected country. Finally, political constraints and non-neutral environment in emergency situations haven't been investigated yet. Hence, the previous model research studies may be considered to be incomplete or impractical during natural disasters. So, our three contributions of this study are summarized as follows:

- We consider different vehicles to distribute relief commodities in the affected area.
- Developing a multi-objective model which tries to minimize unsatisfied demand, logistical costs on the affected area, and shipping costs of international suppliers.
- Considering political constraints which under such situation the government of the affected area decline offered aid from some international suppliers.

Our model aims to determine the optimal number of needed warehouses as well as the optimal locations of them. It also assigns international suppliers to the located warehouses. Finally, it determines the amount of relief commodities which are transported from warehouses to the demand points. Moreover, we propose a p-robust model which considers possible political constraints between the affected country and international suppliers by using the Mont-Carlo simulation to generate random numbers and different scenarios.

3. Problem description

When a natural disaster occurs, international suppliers help the affected country by sending relief goods such as water, food, and medicine. They send their products to the affected country's warehouses. Since suppliers usually have communication with affected country to determine needed commodities, we assume there is a central agency coordinating affected country with local and international suppliers to avoid sending unwanted commodities and make resources more efficient. The government of the affected area distributes available relief commodities from warehouses to the demand points. These operations should be done in a specific time during earthquake occurrence. The multi-objective model tries to minimize unsatisfied demand, total costs of distribution relief commodities in the affected area, and shipping costs of international suppliers. In addition, six time periods are considered in the proposed model. Based on Jabbarzadeh et al. (2014) demands for relief commodities decrease by time. In other words, during first periods after disasters occurrence demands for relief commodities is more than later periods. Fig. 1 shows the general schema of this humanitarian logistics, which contains three nodes: international suppliers, warehouses, and affected areas.

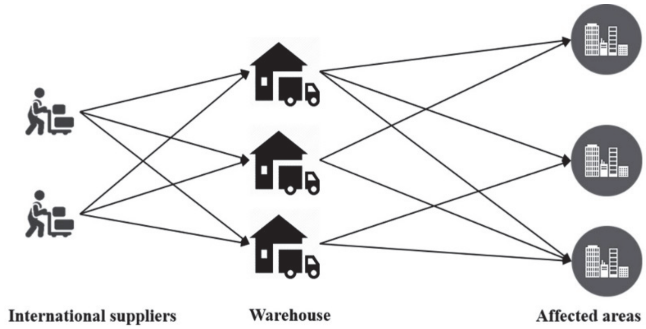

Fig. 1. General schema of the proposed humanitarian logistics network

We also consider political constraints to capture possible non-neutral relation between the affected country and international suppliers. To generate possible scenarios we use Mont-Carlo simulation. Also, to capture all generated scenarios in a unique model, we utilize p-robust approach.
The main assumptions of the proposed model is as follows:

- Warehouses have limited storages capacity.
- Warehouses are equipped with an initial inventory of aid commodities
- Distribution should be done in the specific times.
- Demand points can be satisfied by more than one warehouses, and all of them should be satisfied, at least partially.
- The position of demand points, warehouses, and suppliers are known.
- There are different type of vehicles for distributing operations with known capacities.

4. Mathematical model

Based on previous section, the proposed multi-objective model is developed. The utilized sets, parameters, and decision variables in the model are as follows:

Set	Definition
$e \in E$	Set of the international supplier
$i \in I$	Set of the affected areas
$j \in J$	Set of the warehouses
$l \in L$	Set of vehicles
$q \in Q$	Set of relief commodities
$t \in T$	Set of time periods

Paramet	Definition
D_{iq}^{t}	Demand of relief commodity type q at affected area i at period t
Tr_q	Unit of transportation cost for relief commodity type q
Tr'	Unit of transportation cost of international suppliers
Op_q	Operation cost of warehouses for each unit of commodity type q
F_j	Fixed cost to locate warehouse j
h_q	Inventory cost of warehouses for each unit of commodity type q
V_l	Average velocity of vehicle l
R_j	Radius coverage of warehouse j
T_i^t	Maximum time that distributing operations should be done at affected area i in period t
g_l	Capacity of vehicle l
g'_q	The occupied space of a unit relief commodity type q
C_{jq}	Capacity of warehouse j for aid commodity type q
λ_{lj}	Available vehicle type l in warehouse j
b_{eq}	Available aid commodity type q in international supplier e
M	A very big number
d_{ji}	Distance between affected area i and warehouse j
d''_{ej}	Distance between supplier e and warehouse j

Variables	Definition
y_j	Binary variable represents 1 if warehouse j is located, otherwise 0.
x^{t}_{ijql}	Binary variable represents 1 if vehicle type l from warehouse j is assigned to affected area i to satisfy demand of relief commodity type q in period t, otherwise 0.
x''^{t}_{ijql}	Amount of transported relief commodity type q from warehouse j to affected area i in period t by vehicle type l.
η^{t}_{qej}	Amount of transported relief commodity type q from international supplier e to warehouse j in period t.
δ^{t}_{iq}	Unsatisfied demand of relief commodity type q in affected area i in period t
I^{t}_{jq}	Inventory level of relief commodity type q in warehouse j at the end of period t.

$$\min \sum_{i\in I}\sum_{q\in Q}\sum_{t\in T}\delta^{t}_{iq} \tag{1}$$

$$\min \sum_{j\in J}F_j y_j + \sum_{q\in Q}\sum_{i\in I}\sum_{j\in J}\sum_{l\in L}\sum_{t\in T}Op_q x''^{t}_{ijql} + \sum_{q\in Q}\sum_{i\in I}\sum_{j\in J}\sum_{l\in L}\sum_{t\in T}Tr_q d_{ij} x''^{t}_{ijql} + \sum_{j\in J}\sum_{q\in Q}\sum_{t\in T}h_q I^{t}_{jq} \tag{2}$$

$$\min \sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}\sum_{t\in T}Tr' d_{ej}\eta^{t}_{qej} \tag{3}$$

subject to:

$$y_j \ge x^{t}_{ijql} \quad \forall e\in E, \forall j\in J, \forall q\in Q, \forall t\in T \tag{4}$$

$$Mx^{t}_{ijql} \ge x''^{t}_{ijql} \quad \forall i\in I, \forall j\in J, \forall q\in Q, \forall l\in L, \forall t\in T \tag{5}$$

$$My_j \ge \eta^{t}_{qej} \quad \forall e\in E, \forall j\in J, \forall q\in Q, \forall t\in T \tag{6}$$

$$\sum_{l\in L}\sum_{j\in J}x^{t}_{ijql} \ge 1 \quad \forall i\in I, \forall q\in Q, \forall t\in T \tag{7}$$

$$\sum_{q\in Q}\sum_{i\in I}x^{t}_{ijql} \le \lambda_{lj} \quad \forall j\in J, \forall l\in L, \forall t\in T \tag{8}$$

$$\sum_{e\in E}\eta^{t}_{qej} \ge 1 \quad \forall j\in J, \forall q\in Q, \forall t\in T \tag{9}$$

$$d_{ij}x^{t}_{ijql} \le R_j \quad \forall i\in I, \forall j\in J, \forall q\in Q, \forall l\in L, \forall t\in T \tag{10}$$

$$\sum_{j\in J}\sum_{i\in I}\sum_{q\in Q}x''^{t}_{ijql}g'_q \le g_l \quad \forall l\in L, \forall t\in T \tag{11}$$

$$d_{ij}x^{t}_{ijql}/v_l \le T^{t}_{i} \quad \forall i\in I, \forall j\in J, \forall l\in L, \forall q\in Q, \forall t\in T \tag{12}$$

$$\sum_{l\in L}\sum_{j\in J}x''^{t}_{ijql} + \delta^{t}_{iq} = D^{t}_{iq} \quad \forall i\in I, \forall q\in Q, \forall t\in T \tag{13}$$

$$I^{t-1}_{jq} - I^{t}_{jq} + \sum_{e\in E}\eta^{t}_{qej} = \sum_{i\in I}\sum_{l\in L}x''^{t}_{ijql} \quad \forall i\in I, \forall t\in T \tag{14}$$

$$I^{t}_{jq} \le C_{jq} \quad \forall j\in J, \forall q\in Q, \forall t\in T \tag{15}$$

$$\begin{aligned}
&y_j \in \{0,1\} \quad \forall j\in J\\
&x^{t}_{ijql} \in \{0,1\} \quad \forall i\in I, \forall j\in J, \forall q\in Q, \forall l\in L, \forall t\in T\\
&\eta^{t}_{qej} \ge 0 \quad \forall q\in Q, \forall e\in E, \forall j\in J, \forall t\in T\\
&x''^{t}_{ijql} \ge 0 \quad \forall i\in I, \forall j\in J, \forall q\in Q, \forall l\in L, \forall t\in T\\
&I^{t}_{jq} \ge 0 \quad \forall j\in J, \forall q\in Q, \forall t\in T
\end{aligned} \tag{16}$$

Eq. (1) is the first objective function of the proposed model which minimizes unsatisfied demands of relief commodities. Eq. (2) is the second objective function which minimizes total cost of distributing operations in the affected areas, and Eq. (3) is the last objective function and minimizes shipping cost of international suppliers. Constraint (4) guarantees if a warehouse is located in point j then vehicle l can be assigned to affected area i to satisfy demands of relief commodity type q. Constraint (5) explains if vehicle l from warehouse j is assigned to affected area *i*, then that vehicle can distribute relief commodity type q. Constraint (6) shows international suppliers send their relief commodities to located warehouses. Constraint (7) shows demands for relief commodity type q for each affected area can be satisfied by more than one vehicle and warehouse. Constraint (8) demonstrates available vehicle l in warehouse j. Constraint (9) shows more than one international supplier can be assigned to a located warehouse. Constraint (10) explains than to satisfy demands of an affected area the distance between warehouse and that affected area has to be less than radius coverage. Constraint (11) explains the maximum capacity of vehicle to transport relief commodities. Constraint (12) guarantees all demands should be satisfied in a specific time. Constraint (13) determines unsatisfied demand of relief commodity type q in each affected area. Constraint (14) specifies inventory level of relief commodities at the end of each period in warehouses. Constraint (15) shows maximum capacity of warehouses to hold relief commodity type q. Finally, Constraint (16) defines decision variables of the proposed model.

4. P-robust Modeling

The proposed model in the previous part determines location and allocation decisions for the preparedness and respond phases in disaster management. Location decisions consist of specifying the number of warehouses and their location as well. Allocation decisions involve assignment of warehouses and their vehicle to affected areas to satisfy demands of relief commodities.

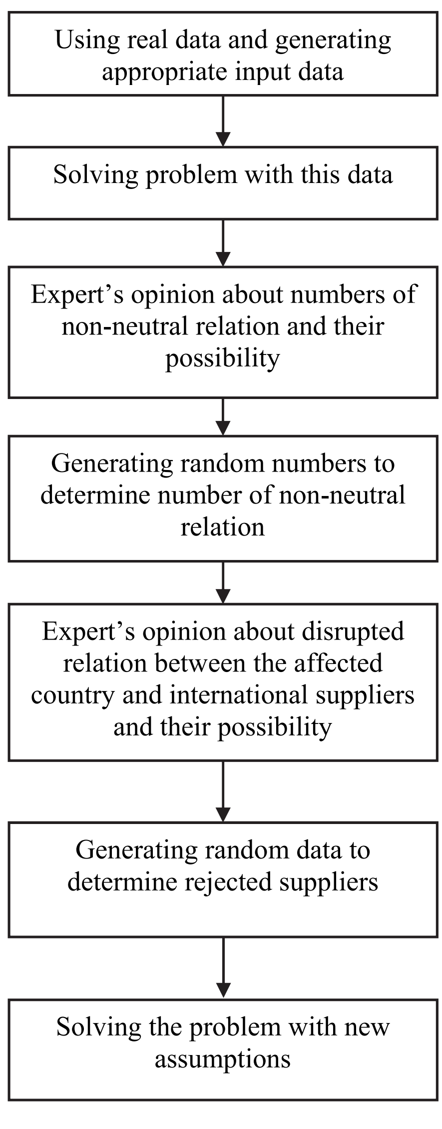

Fig. 2. Simulation flow chart to generate input parameters

Here we complete this model to be more practical in real world. As it is stated in the previous sections political constraints is an inseparable part of humanitarian logistics because of non-neutral relation between the affected country and international suppliers. Under such situation the affected country decline offers of aid from some suppliers. To formulate this problem, we use Mont-Carlo simulation to generate scenarios and p-robust method to solve these problems for respond phase in disaster management. The method of generating scenarios for affected sites has been shown in Fig. 2. To introduce the robustness measure we use in this paper, let S be a set of scenarios. Let (P_s) be a deterministic (i.e., single-scenario) minimization problem, indexed by the scenario index s. (That is, for each scenario s ∈ S, there is a different problem (P_e)). The structure of these problems is identical; only the data is different. For each e, let z^*_s be the optimal objective value for (P_s); we assume $z^*_s > 0$ for each s. The notion of p-robustness was first introduced in the context of facility layout (Kouvelis et al., 1992) and used subsequently in the context of an international sourcing problem (Gutierrez & Kouvelis 1995) and a network design problem (Gutiérrez et al., 1996). Let $p \geq 0$ be a constant. Let X be a feasible solution to (P_s) for all e ∈ E, and let z^*_s (X) be the objective value of problem (P_s) under solution x. x is called p-robust if for all e ∈ E,

$$Z_s^*(X) - Z_s^* \leq (1+p)Z_s^* \tag{17}$$

The left-hand side of the Equation above is the relative regret for scenario s; the absolute regret is given by z^*_s (X) - z^*_s (Snyder & Daskin, 2006). According to the given explanation variables must be changed as bellow:

variables	Definition
y_j^s	Binary variable represents 1 if warehouse j is located under scenario s, otherwise 0.
x_{ijql}^{ts}	Binary variable represents 1 if vehicle type l from warehouse j is assigned to affected area i to satisfy demand of relief commodity type q in period t under scenario s, otherwise 0.
$x_{ijql}'^{ts}$	Amount of transported relief commodity type q from warehouse j to affected area i in period t by vehicle type l under scenario s.
η_{qej}^{ts}	Amount of transported relief commodity type q from international supplier e to warehouse j in period t under scenario s.
δ_{iq}^{ts}	Unsatisfied demand of relief commodity type q in affected area i in period t under scenario s.
I_{jq}^{ts}	Inventory level of relief commodity type q in warehouse j at the end of period t under scenario s.

For each scenario (s) the optimum value of the objective functions regarding model 2 must be calculated. Model 2 is described as follows

$$\min \sum_{i\in I}\sum_{q\in Q}\sum_{t\in T}\delta_{iq}^{ts} \tag{18}$$

$$\min \sum_{j\in J}F_j y_j^s + \sum_{q\in Q}\sum_{i\in I}\sum_{j\in J}\sum_{l\in L}\sum_{t\in T}Op_q x_{ijql}''^{ts} + \sum_{q\in Q}\sum_{i\in I}\sum_{j\in J}\sum_{l\in L}\sum_{t\in T}Tr_q d_{ij} x_{ijql}''^{ts} + \sum_{j\in J}\sum_{q\in Q}\sum_{t\in T}h_q I_{jq}^{ts} \tag{19}$$

$$\min \sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}\sum_{t\in T}Tr' d_{ej}\eta_{qej}^{ts} \tag{20}$$

subject to:

Eqs. (4-16) (21)

The constraints of the above model are the same as the deterministic model's constraints, however, based on new definition on some variable, these constraints consider each scenario $s \in S$. Model 2 is solved for each scenario and the optimum value of the objective functions named Z^*_s. According to p-robust method, the effect of each scenario must be involved in the optimum structure of the humanitarian logistics network. So Model 3 is used to build the network.

$$\min \sum_{i\in I}\sum_{q\in Q}\sum_{t\in T}\delta_{iq}^{t0} \tag{22}$$

$$\min \sum_{j\in J} F_j y_j^0 + \sum_{q\in Q}\sum_{i\in I}\sum_{j\in J}\sum_{l\in L}\sum_{t\in T} Op_q x_{ijql}^{\prime t0} + \sum_{q\in Q}\sum_{i\in I}\sum_{j\in J}\sum_{l\in L}\sum_{t\in T} Tr_q d_{ij} x_{ijql}^{\prime t0} + \sum_{j\in J}\sum_{q\in Q}\sum_{t\in T} h_q I_{jq}^{t0} \tag{23}$$

$$\min \sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}\sum_{t\in T} Tr' d_{ej} \eta_{qej}^{t0} \tag{24}$$

subject to:

Eq. (21) (25)

$$\sum_{i\in I}\sum_{q\in Q}\sum_{t\in T}\delta_{iq}^{ts} \le (1+p) Z_s^* \quad \forall s \in S-\{0\} \tag{26}$$

$$\sum_{j\in J} F_j y_j^e + \sum_{q\in Q}\sum_{i\in I}\sum_{j\in J}\sum_{l\in L}\sum_{t\in T} Op_q x_{ijql}^{\prime te} + \sum_{q\in Q}\sum_{i\in I}\sum_{j\in J}\sum_{l\in L}\sum_{t\in T} Tr_q d_{ij} x_{ijql}^{\prime te} + \sum_{j\in J}\sum_{q\in Q}\sum_{t\in T} h_q I_{jq}^{te} \le (1+p) Z_s^{\prime *} \quad \forall s \in S-\{0\} \tag{27}$$

$$\sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}\sum_{t\in T} Tr' d_{ej} \eta_{qej}^{ts} \le (1+p) Z_s^{\prime\prime *} \quad \forall s \in S-\{0\} \tag{28}$$

Eqs. (22-24) are the p-robust model's objective functions which considers all scenarios $s \in S$. Eqs. (26-28) enforce, for each scenario, each objective function cannot be more than 100(p +1) % of its optimal solution Z^*_s (value of p is related to the necessity of its scenario). Other constraints are the same as model 1 and 2.

5. Computational Result and Discussion

Because of the strategic and geographical location of Iran, and owing to the fact that 90 percent of Iran is located on faults, earthquakes have always been the most devastating disaster in the country among other natural disasters. Tehran, as a strategic city in Iran, has always been exposed to such disasters. Regarding earthquakes, Tehran is considered a dangerous region (8 to 10 Mercalli scales). The fault in the north of Tehran is the biggest fault of the city located in the south foothill of Alborz ranges and in the north of Tehran. This fault starts in Lashkarak and Sohanak, continues in Farahzad and Hesarak, and continues towards the west. This fault encompasses Niavaran, Tajrish, Zaferanieh, Elahieh, and Farmanieh on its way. The necessity of paying attention to crisis management is an obvious issue regarding the dangerous and risky situation of Tehran (Sabzehchian et al., 2006).

To illustrate and apply our proposed model, we consider the probable earthquake in Tehran region 1. The north Tehran fault is one of the most active faults in Tehran which can lead to an earthquake in this city. In this paper we consider the effect of this fault on Tehran region 1 as our case study.

After occurrence of earthquake, groups of foreign countries will help the affected zone by sending necessary commodities. Suppliers choose the cheapest transportation plan in order to send commodities to located warehouses, and the affected country will distribute commodities from warehouses to demanded nodes. We assume ten countries will help Tehran after earthquake including Iraq, Turkey, Azerbaijan, Syria, UAE, Qatar, Germany, Turkmenistan, Kuwait, and Afghanistan. The relief commodities are in three groups, food and water, and medicine. Four located warehouses and three medical centers are considered in this model. We also assume Red Cross and Helal-e Ahmar agency coordinating Tehran with foreign countries to avoid sending unnecessary commodities to warehouses.

Region 1 consists of ten area. We assume the center of each area as the demand nodes. The utilized parameters are shown from Table 1 to Table 5. Table 1 displays the latitude and longitude of the affected areas, warehouses and international suppliers. Based on Eq. (29) and Table 1 distances between nodes can be calculated.

$$d_{ij} = 6371.1 \times \arccos[\sin(LAT_i) \times \sin(LAT_j) + \cos(LAT_i) \times \cos(LAT_j) \times \cos(LON_j - LON_i)] \quad (29)$$

Table 1

The latitude and longitude of the affected areas, warehouses and international suppliers

Points	latitude	longitude	Points	latitude	longitude
Affected area 1	35.810363	51.422087	Warehouse 5	35.821693	51.429705
Affected area 2	35.794213	51.433588	Warehouse 6	35.798966	51.491074
Affected area 3	35.815931	51.442772	Warehouse 7	35.802693	51.513316
Affected area 4	35.797554	51.451183	Turkey	39.907253	32.835508
Affected area 5	35.804725	51.461569	Azerbaijan	38.755752	48.838380
Affected area 6	35.815444	51.475559	Iraq	33.335705	44.347654
Affected area 7	35.809736	51.483198	Syria	36.455217	40.790400
Affected area 8	35.799782	51.483971	UAE	24.324056	54.815086
Affected area 9	35.805699	51.509806	Germany	49.410104	11.087382
Affected area 10	35.791915	51.504484	Turkmenistan	37.951214	58.325804
Warehouse 1	35.789043	51.431951	Qatar	25.286020	51.597424
Warehouse 2	35.793012	51.487226	Kuwait	29.390573	47.982057
Warehouse 3	35.816349	51.494700	Afghanistan	34.554518	69.115289
Warehouse 4	35.780308	51.429619			

Table 2

Demands for relief commodities of 10 areas in Tehran region 1 for 6 time periods

area	Period	Food	Water	Medicine	Period	Food	Water	Medicine
1	The first period	17038	17038	17038	The second period	16527	16527	16527
2		28410	28410	28410		27557	27557	27557
3		27570	27570	27570		26743	26743	26743
4		19400	19400	19400		18818	18818	18818
5		16266	16266	16266		15778	15778	15778
6		8207	8207	8207		7960	7960	7960
7		25887	25887	25887		25110	25110	25110
8		12223	12223	12223		11857	11857	11857
9		9599	9599	9599		9311	9311	9311
10		1582	1582	1582		1535	1535	1535
1	The third period	13971	13971	13971	The fourth period	10563	10563	10563
2		23296	23296	23296		17614	17614	17614
3		22608	22608	22608		17093	17093	17093
4		15908	15908	15908		12028	12028	12028
5		13338	13338	13338		10085	10085	10085
6		6729	6729	6729		5088	5088	5088
7		21227	21227	21227		16049	16049	16049
8		10023	10023	10023		7578	7578	7578
9		7871	7871	7871		5951	5951	5951
10		1297	1297	1297		981	981	981
1	The fifth period	6645	6645	6645	The sixth period	2555	2555	2555
2		11079	11079	11079		4261	4261	4261
3		10752	10752	10752		4135	4135	4135
4		7566	7566	7566		2910	2910	2910
5		6343	6343	6343		2439	2439	2439
6		3200	3200	3200		1231	1231	1231
7		10095	10095	10095		3883	3883	3883
8		4767	4767	4767		1833	1833	1833
9		3743	3743	3743		1439	1439	1439
10		617	617	617		237	237	237

Table 2 shows demands for relief commodities of 10 areas in Tehran region 1 for 6 time periods. Table 3 demonstrates vehicles characteristics containing their capacity to carry relief commodities, available number of them in warehouses, and their average velocity. Table 4 shows acceptable times to satisfy demands of relief commodities. We assume that these times are consistent in all time periods. Table 5 shows international suppliers' capacities for relief commodities. Table 6 displays operational, transportation, and holding costs for relief commodities in warehouses for the government of the affected area. Finally, average fixed cost for warehouses is $35000.

Table 3
Vehicles characteristics

Rescue vehicle	Average velocity (km/h)	Capacity (m^3)	available in each warehouse
1	60	2	10
2	70	6	12
3	100	4	9

Table 4
Acceptable times to satisfy demands of relief commodities

Affected area	1	2	3	4	5	6	7	8	9	10
Time (hour)	0.5	1	0.7	0.6	0.5	1	0.4	0.7	0.5	1

Table 5
International suppliers' capacities for relief commodities

Suppliers	Relief commodity		
	Water	Food	Medicine
Turkey	84500	92000	26000
Azerbaijan	47500	74500	90000
Iraq	64400	14000	34000
Syria	72300	73900	52000
UAE	27700	24500	73000
Germany	46200	63800	30000
Turkmenistan	62300	29800	79000
Qatar	42900	23200	30000
Kuwait	32400	43100	63000
Afghanistan	53100	74300	52000

Table 6
Operational, transportation, and holding costs for relief commodities

	Water	Food	Medicine
Operational cost	0.2	0.4	0.3
Transportation cost	0.1	0.2	0.09
Holding cost	0.01	0.02	0.015

This proposed model has been coded in GAMS on a laptop with Intel Core i2, 2.8 GHz and 8GB of RAM. Based on the deterministic model the values of the first, second, and third objective functions are 11818 units, $1264040 and $584056, respectively. Three warehouses are located which receive relief commodities from international suppliers and distribute them in the affected areas. During first periods unsatisfied demands for relief commodities have more values than later periods. This section proposes a sensitivity analysis of the vital parameters for deterministic models. The first parameter for this purpose is the demand of relief commodities. For each iteration we increase demands' values of relief commodities. Fig. 3 and Fig. 4 show the sensitivity of objective functions by variation in demands for relief commodities. Based on the proposed flowchart in Fig. 2, we generate four scenarios. In the first scenario Iran doesn't accept proposed offer from Turkey, in the second scenario the government accepts all offers, in the third scenario Qatar and UAE's offers are declined, and finally, in the last scenario Iran rejects Kuwait's offer. The values of the objective functions for four scenarios are seen in Table 7. As stated before, these values are used at the p-robust model as Ze^* parameter. The last row in Table 7 shows the objective functions' values of the p-robust model.

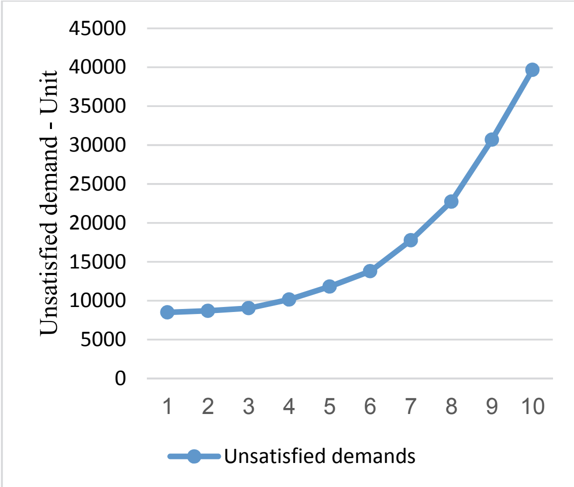

Fig. 3. sensitivity of the first objective function by variation in demands for relief commodities

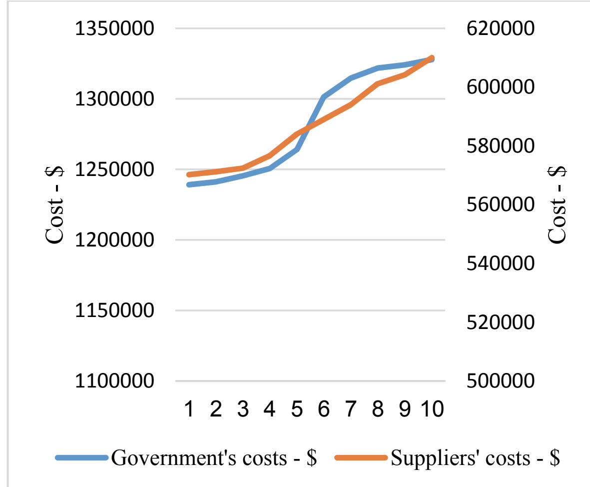

Fig. 4. sensitivity of the second and third objective functions by variation in demands for relief commodities

Table 7

Objective functions' values of the proposed model

	First objective function	Second objective function	Third objective function
Scenario 1	16231	1252700	537610
Scenario 2	11818	1264040	584056
Scenario 3	21809	1248200	472280
Scenario 4	15321	1260100	557200
P- robust	16021	1259900	543120

To evaluate both the p-robust model two performance measures are used: the mean and the standard deviation of the first objective function under random realizations. Additionally, we vary the p-robust parameter between [0 1] and calculate mean and standard deviation of the first objective function for the p-robust and deterministic models. The results show the p-robust model gained the solutions with both lower mean and standard deviation than deterministic model.

Table 8

Summary of test results of the first objective function mean and the standard deviation of both models

P-robust parameter (p)	Mean of the first objective function values under realizations		Standard deviation of the first objective function values under realizations	
	Deterministic	P-Robust	Deterministic	P-Robust
0.0	23501	17010	551	54
0.4	23002	16021	483	72
0.8	22983	15382	492	91
1.0	23174	15013	519	112

In most problems, the p-robust approach dominates the deterministic model with respect to the mean of the first objective function value and its standard deviation. These results are seen in Table 8.

6. Conclusion and Future Research

In this paper a p-robust model for humanitarian logistics was presented in emergency situations to minimize unsatisfied demands, the government's total cost and the suppliers' shipping costs. This model determined location and distribution decisions for a multi-period network. The location decisions consist of the number and location of warehouses. Distribution decisions involve the quantity of transported relief commodities from international suppliers to warehouses, and also, from warehouses to the affected areas. In order to improve the application of the model against unforeseen events and possible political constraints between the government and international suppliers, the p-robust approach was used. To evaluate the application of the deterministic model, we presented sensitivity analysis experiments from which important implications were drawn. We demonstrated how the objective functions of the proposed model change when demands for relief commodities alter. In the last part of our numerical example, we compared the “deterministic” and “p-robust” models performance by their first objective function’s mean and standard deviation. The results explained that “p-robust” model dominated the “deterministic” model.

In brief, our contributions can be summarized as follows:

- We consider different vehicles to distribute relief commodities in the affected area.
- Developing a multi-objective model which tries to minimize unsatisfied demand, logistical costs on the affected area, and shipping costs of international suppliers.
- Considering political constraints which under such situation the government of the affected area decline offered aid from some international suppliers.

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