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A robust optimization model for logistics planning in the earthquake response phase

Meysam Fereiduni[*], **Marzieh Hamzehee and Kamran Shahanaghi**

Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran

C H R O N I C L E

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A B S T R A C T

In this paper, a robust bi-level model is proposed to optimize decisions related to distribution and evacuation aid after earthquake. Usually in disastrous situation foreign countries help the affected country by sending relief commodities. In this problem, the foreign countries try to minimize their shipping costs and the affected country seeks to minimize its total costs which include inventory, operation, and transportation expenses. This situation is a game between different decision makers after a catastrophic disaster. To deal with this situation, a bi-level model is proposed in which the affected country is the leader and suppliers are the followers. To validate the proposed robust model, we consider Tehran probable earthquake in region 1 as a case study. Then the advantages of using bi-level modeling against considering just one player's point of view is provided. The sensitivity analysis of the experiments are presented to explore the effects of various parameters to show managerial insights that can guide DMs under a variety of conditions.

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1. Introduction

Humanitarian relief operations is not new idea and, in fact, the modern roots of international humanitarianism can be traced back to the formation of the Red Cross in 1863. Humanitarian logistics have gained academic attention after the 2004 Indian Ocean Tsunami and hurricane Katrina in 2005. The impact of the Indian Ocean Tsunami and hurricane Katrina was so devastating, thousands of dead and millions homeless left, these statistics reveal the problems in humanitarian logistics and disaster management. Several definitions for disaster management has been expressed in the literature. The most comprehensive and most widely accepted definition of the crisis has been presented by the World Health Organization. According to Barbarosoğlu and Arda (2004) "any event that causes destruction, environmental damage, loss of human life or even suffering, threaten the health and health services, so that affected areas need help and response from other areas is called disaster". The earthquake is one of the disasters that usually leads to widespread destruction and human injuries. Earthquake's damages

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[*] Corresponding author.
E-mail address: meysamfereiduni@gmail.com (M. Fereiduni)

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have been increased in recent years due to excessive condensation of population in accident-prone areas. This fact illustrates the need of an effective plan to respond to such possible crisis. Response phase is called actions which is proceeded after the incident and is considered as initial actions.

In this paper a linear bi-level model by considering evacuation and transportation injured people from affected areas to hospital for response stage is developed. In upper level the affected country seeks to minimize its total costs while international suppliers in lower level tries to minimize their transportation expenses. Afterward, a robust optimization model is developed to deal with uncertainty in demanded relief commodities.

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

2. Literature Review

Logistics of essential commodities and rescue operation are the most important activities after any earthquake. Aid distribution is necessary to deliver essential commodities such as food, medicine, sanitation, shelter and water to save human life and to prevent the expansion of diseases. In addition, rescue operation is vital to carry injuries from affected areas to medical centers. In fact, the efficient plan for these operations after earthquake can significantly reduce the death rate.

At the end of 1980, researchers began their studies on the crisis management. Most of the researches have studied the supply and logistics of a particular type of goods and services to the injured people. Knott (1987) proposed a linear model considering food transportation problems to minimize the transportation costs and maximized the amount of food delivered to the affected areas. Knott (1988), next, developed a linear model to schedule the rout of vehicles by maximizing the amount of food delivered. Barbarosoğlu et al. (2002) used helicopter for rescuing actions during a natural disaster by routing and transportation problem during the response phase. Özdamar et al. (2004) proposed a network model for planning logistics of commodity. They presented an algorithm that determines the origin and destination of each amount of commodities. Tzeng et al. (2007) presented a multi objective model for relief commodities that can be used for a real life relief delivery systems. Their model included three objective functions, minimizing total cost, minimizing total travel time and maximizing the minimal satisfaction in the given period. Sheu (2007) proposed an approach based on fuzzy clustering for optimization to coordinate the relief materials flow in a relief supply network during the crucial rescue period. He also presented a three-step dynamic model for emergency logistics actions under imperfect data. These steps are data fusion to estimate relief demand in affected area, classifying affected areas using fuzzy clustering and determining the priority of each group which generated in last step. Nolz et al. (2011) provided a model for post disaster with three objective functions to minimize the risk, to maximize the coverage gained by the model and to minimize the total traveling time. Lin et al. (2011) proposed a multi objective model by considering different types of vehicles and commodities to minimize the total unsatisfied demands and total travel time between affected areas. Moreover, Zhan and Liu (2011) proposed a stochastic model for a disaster network including uncertain data about demand, supply and availability of transportation paths by minimizing the expected travel time and unsatisfied demands using chance constraint and scenario planning. Afshar and Haghani (2012) proposed a disaster network model to schedule the flow of commodities and determined the optimal position for facilities. Their model considered routing problem as well.

Others focused on transportation in different ways, using different vehicles and approaches. As some example, Fiedrich et al. (2000) presented a model by considering allocation of resources to transport injuries in the best way. Also Jotshi et al. (2009) used robust optimization for scheduling routes for vehicles after the disaster. Yi and Özdamar (2007) presented a dynamic model including both evacuation of injuries and satisfaction of demands. Yi and Kumar (2007) considered medical centers to serve injuries and distribution centers for commodities. Ozdamar (2011) established a mathematical model for transporting of injuries from affected areas to hospitals and deliver medical commodities to victims using helicopter to minimize the medical mission time. Also, Özdamar and Demir (2012) used a hierarchical clustering algorithm to organize the rout of vehicles in large scale disasters in the response phase.

Many researchers considered the uncertainty in disaster management in their scientific papers. Some of them used stochastic programming to consider uncertainty. Barbarosoğlu and Arda (2007) proposed a two stage stochastic model for the response phase of an earthquake and also used scenario planning to account data uncertainty. Ma et al. (2010) presented a min-max robust model for a disaster network with uncertainty in distances between nodes. Furthermore, Zhan and Liu (2011) considered a location-allocation problem using chance constraint programming with uncertainty in demand and the availability of paths and supply of commodities. Finally 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 stage.

After earthquake, international countries and local suppliers offer to help the affected country by sending aid commodities. Regularly, local and international suppliers and affected country have different goals. This situation is a multi-decision maker problem which should consider comprehensively. Multi-decision maker models in critical situations investigated by a few studies and most of them focused on unnatural crisis such as terrorist attacks. For instance, Arroyo and Galiana (2005) considered the problem of a terrorist threat as a nonlinear mixed integer bi-level problem where the terrorist seeks to maximize the attacking damages at the upper level, while in the lower level a threatened company seeks to minimize spilled loads caused by the attack. The authors used the equivalent single-level mixed integer linear problem obtained by Karushe-Kuhne-Tucker instead of the bi-level problem. They also applied some restrictions to avoid nonlinearity. In another study, Aksen et al. (2013) formulated a static Stackelberg game between a defender as the leader and an attacker as the follower in order to investigate facility location problem. They considered facilities in both protected and unprotected modes. The leader tries to minimize the sum of install costs, protection and usage of the facility while the follower seeks to destroy unprotected facilities to affect the supply capacity of the remaining plans. In another facilities protection problem, Losada et al. (2012) proposed a mixed integer linear bi-level programming .

There are a few researches concern about bi-level programming in natural disasters. with focusing on preparation stage, Barbarosoğlu et al. (2002) investigated the helicopter relief mission using bi-level programming to minimize the total cost of assigning pilots to helicopters and then, minimizing the relief operation time. Feng and Wen (2005) proposed a bi-level model to manage roads traffic after earthquake. In upper level, the leader attempts to send more vehicles for relief operations while the evacuees in lower level seek to travel through unaffected roads in order to minimize their total travel time. This process causes heavy traffic in roads and interrupts sending aids and evacuation operations. Kongsomsaksakul et al. (2005) used bi-level programming to model a Stackelberg game in order to describe a shelter location model. They considered authority as the leader and evacuees as follower while leader determines the shelter locations to minimize the total evacuation time and the followers choose the destinations and routes for evacuation. To solve the model, authors developed a genetic algorithm using real data from a dam located in Utah. Li et al. (2012) also considered the same problem but for hurricane situation. The upper level decides about location and allocation the shelters and evacuees in lower level seek to find better routs. Finally, Camacho-Vallejo et al. (2014) proposed a bi-level model to optimize decisions related to aid distribution after earthquake. They considered international organization and foreign countries as suppliers. In upper level the affected county tries to minimize total response time while international organization and foreign countries in lower level seek to minimize their total transportation cost. The authors also considered an earthquake in Chile in 2010 to illustrate the application of their proposed model.

It appears there are some scientific gaps in multi-level models especially for natural disasters. In every catastrophe there are numerous decision makers and victims, so taking them into account is necessary to model the disaster situation properly. In this paper, a bi-level model by considering supply and transportation of relief commodities for response stage is developed. In upper level the affected country seeks to minimize the total cost of evacuation and distribution while international suppliers in the lower level try to minimize their transportation costs. We assume the existence of a coordinator agency between affected country and local and international suppliers to avoid sending unnecessary relief commodities. To deal with the uncertainty in demands of essential commodities, a robust model based on Mulvey et al.'s (1995) research is developed. Finally Tehran probable earthquake is investigated and sensitivity analysis and numerical experiments are proposed.

3. Statement of the Problem

When an earthquake occurs, foreign countries help the affected country by sending relief goods such as water, food, medicine and shelter. At the upper level, the affected country is responsible for transporting aids from warehouses to affected sites and also carrying injuries from affected areas to medical centers. At the lower level, international suppliers should deliver relief commodities to the located warehouses and try to minimize their transportation expenses. 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. Fig. 1 shows the general schema of this humanitarian logistics, which contains four nodes: foreign suppliers, warehouses, affected areas, and hospitals.

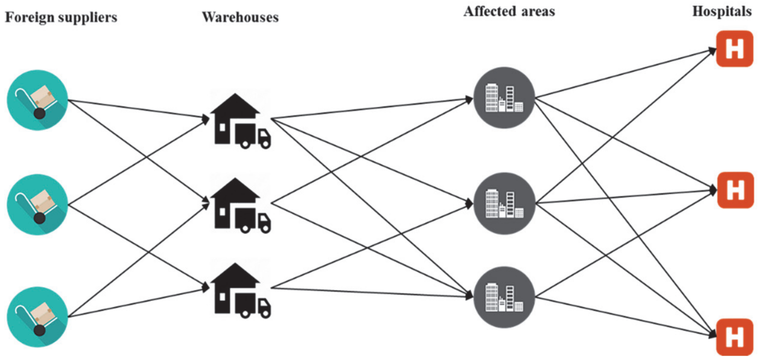

Fig. 1. General schema of humanitarian logistics network

We proposed a bi-level multi-commodity and multi-modal model to optimize decisions related to aid distribution and evacuation after earthquake by considering international suppliers. At the upper level the affected country decides how to distribute aids from warehouses to demand nodes, and how to save injuries and transport them to the medical centers in order to minimize the total costs. At the lower level, international suppliers send their aid commodities to the located warehouses and try to minimize their shipping costs.

The main assumptions of the proposed model is as follows:

- The locations of warehouses and hospitals are known.
- Warehouses have limited storages capacity.

- Warehouses are equipped with an initial inventory of aid commodities
- Rescue operation should be done in the specific times.
  Demand points can be satisfied by more than one warehouse, and all of them should be satisfied, at least partially.
- The position of demands, intermediates, and suppliers and warehouses nodes and distance between them are known.
- There are different type of vehicles for evacuation with known capacities.

4. Mathematical model

Based on previous section, the proposed bi-level model is developed. The sets used in model are as follows:

Set	Definition	Set	Definition
$e \in E$	Set of foreign supplier points	$l \in L$	Set of rescue vehicles
$i \in I$	Set of affected area points	$q \in Q$	Set of relief commodities
$j \in J$	Set of warehouse points	$t \in T$	Set of time periods
$k \in K$	Set of hospital points		

Also the parameters used in model are as follows:

Parameter	Definition
D_{iq}^{t}	Demand of aid commodity type q at affected area i at period t
$D_{i}'^{t}$	Demand of rescue operation at affected area i at period t
Tr_{q}	Unit of transportation cost of warehouses for each unit of commodity type q
Tr_{l}'	Unit of transportation cost for rescue vehicle type l
Tr_{eq}''	Unit of transportation cost of supplier e for each unit of commodity type q
Op_{q}	Operation cost of warehouses for each unit of commodity type q
Op_{l}'	Operation cost for rescue vehicle type l
Inv_{q}	Inventory cost of warehouses for each unit of commodity type q
V_{l}	Average velocity of rescue vehicle l
R_{j}	Radius coverage of warehouse j
T_{i}^{t}	Maximum time that rescue operations should be done at affected area i in period t
g_{l}	Capacity of rescue vehicle l
U_{k}	Available beds in hospital k
C_{jq}	Capacity of warehouse j for aid commodity type q
b_{eq}^{t}	Available aid commodity type q in foreign supplier e in period t
M	A very big number
d_{ji}	Distance between affected area i and warehouse j
d_{ik}'	Distance between affected area i and hospital k
d_{ej}''	Distance between supplier e and warehouse j

Finally decision variables are as follows:

Parameter	Definition
x_{ijq}^{t}	Binary variable represents 1 if demand for aid commodity type q at affected are n is satisfied by warehouse j in period t, otherwise 0
$x_{ijq}'^{t}$	Amount of transported aid commodity type q from warehouse j to affected area i at time t.
I_{jq}^{t}	Amount of transported aid commodity type q in warehouse j at the end of time t.
η_{ijlk}^{t}	Binary variable represents 1 if rescue vehicle l from warehouse j at time t transports injuries from affected area i to hospital k, otherwise 0
y_{ejq}^{t}	Amount of transported aid commodity type q from supplier e to warehouse j at time t.

Upper level

$$\begin{aligned} \min \sum_{i\in I}\sum_{j\in J}\sum_{q\in Q}\sum_{t\in T} Tr_q d_{ji} x_{ijq}'^{t} + \sum_{k\in K}\sum_{i\in I}\sum_{j\in J}\sum_{l\in L}\sum_{t\in T} Tr_l'(d_{ji}+d_{ik}')\eta_{ijlk}^{t} \\ +\sum_{i\in I}\sum_{j\in J}\sum_{q\in Q}\sum_{t\in T} Op_q x_{ijq}'^{t} + \sum_{k\in K}\sum_{i\in I}\sum_{j\in J}\sum_{l\in L}\sum_{t\in T} Op_l'\eta_{ijlk}^{t} + \sum_{j\in J}\sum_{q\in Q}\sum_{t\in T} Inv_q I_{jq}^{t} \end{aligned} \tag{1}$$

subject to

$$Mx_{ijq}^{t} \geq x_{ijq}'^{t} \quad \forall i\in I, \forall j\in J, \forall q\in Q, \forall t\in T \tag{2}$$

$$\sum_{j\in J} x_{ijq}^{t} \geq 1 \quad \forall i\in I, \forall q\in Q, \forall t\in T \tag{3}$$

$$\sum_{q\in Q}\sum_{i\in I} x_{ijq}^{t} \geq 1 \quad \forall j\in J, \forall t\in T \tag{4}$$

$$\sum_{k\in K}\sum_{l\in L}\sum_{j\in J} \eta_{ijlk}^{t} \geq 1 \quad \forall i\in I, \forall t\in T \tag{5}$$

$$d_{ij} x_{ijq}^{t} \leq R_j \quad \forall i\in I, \forall j\in J, \forall q\in Q, \forall t\in T \tag{6}$$

$$d_{ij} \eta_{ijlk}^{t} \leq R_j \quad \forall i\in I, \forall j\in J, \forall l\in L, \forall k\in K, \forall t\in T \tag{7}$$

$$I_{jq}^{t} \leq C_{jq} \quad \forall j\in J, \forall q\in Q, \forall t\in T \tag{8}$$

$$(d_{ji}+d_{ik}')\eta_{ijlk}^{t} / v_l \leq T_i^{t} \quad \forall i\in I, \forall j\in J, \forall l\in L, \forall k\in K, \forall t\in T \tag{9}$$

$$\sum_{j\in J} x_{ijq}'^{t} = D_{iq}^{t} \quad \forall i\in I, \forall q\in Q, \forall t\in T \tag{10}$$

$$\sum_{k\in K}\sum_{j\in J}\sum_{l\in L} g_l \eta_{ijlk}^{t} = D_i'^{t} \quad \forall i\in I, \forall t\in T \tag{11}$$

$$\sum_{t\in T}\sum_{i\in I}\sum_{j\in J}\sum_{l\in L} g_l \eta_{ijlk}^{t} \leq U_k \quad \forall k\in K \tag{12}$$

$$\begin{aligned} & x_{ijq}^{t} \in \{0,1\} \quad \forall i\in I, \forall j\in J, \forall q\in Q, \forall t\in T \\ & \eta_{ijlk}^{t} \in \{0,1\} \quad \forall i\in I, \forall j\in J, \forall l\in L, \forall k\in K, \forall t\in T \\ & x_{ijq}'^{t} \geq 0 \quad \forall i\in I, \forall j\in J, \forall q\in Q, \forall t\in T \\ & I_{jq}^{t} \geq 0 \quad \forall j\in J, \forall q\in Q, \forall t\in T \end{aligned} \tag{13}$$

Lower level

$$\min \sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}\sum_{t\in T} Tr_q'' d_{ej} y_{ejq}^{t} \tag{14}$$

subject to:

$$\sum_{j\in J} y_{ejq}^{t} \leq b_{eq}^{t} \quad \forall e\in E, \forall q\in Q, \forall t\in T \tag{15}$$

$$I_{jq}^{t-1} + \sum_{e\in E} y_{ejq}^{t} - \sum_{i\in I} x_{ijq}'^{t} = I_{jq}^{t} \quad \forall j\in J, \forall q\in Q, \forall t\in T \tag{16}$$

$$y_{ejq}^{t} \geq 0 \quad \forall e\in E, \forall j\in J, \forall q\in Q, \forall t\in T \tag{17}$$

At the upper level, objective function (1) is the leader's goal which minimizes the total costs (transportation, operation, and inventory costs of distribution and evacuation). Constraint (2) shows for distribution, the warehouse should be assigned to the affected area. Constraint (3) assures each demand point can be satisfied by more than one warehouses. Constraint (4) ensures all warehouses attend in distribution operation. Constraint (5) shows demands for rescue operation must be satisfied. Constraint (6) and (7) demonstrate raduis covegare for distribution evacuation. Constraint (8) assures the inventory level of aid commodities at warehouses. Constraint (9) shows rescue operation for each demand point must be done in the specific time. Constraint (10) and (11) show how demands for aid commodities and resuce operation satisfy. Constraint (12) ensures injuries who are carried to each hospital must be less than the hosptial's available beds. constraint (13) is related to upper level decision variables. At the lower level, objective function (14) shows the followers' goal which minimizes transportation costs. Constraint (15) assures maximum capacity of foreign suppliers to transport aid commodities. Constraint (16) asserts the relation between transported aid commodities from foreign suppliers and distributed commodities at the affected areas. Finally, constraint (17) definess the followers' decision variables.

5. Robust Modeling

Mulvey et al. (1995) introduced a robust optimization due to optimal design of supply chain in the real world and uncertain environments. By expressing the value of vital input data in a set of scenarios, robust optimization tries to approach the preferred risk aversion. This approach results in a series of solutions that are less sensitive to the model data from a scenario set. Two sets of variable act in this approach control and design variables. The first ones are subject to adjustment once a specific realization of the data is obtained, while design variables are determined before realization of the uncertain parameters and cannot be adjusted once random parameters are observed. Constraints can be divided into two types as well too: structural and control constraints. Structural constraints are typical linear programming constraints which are free of uncertain parameters, while the coefficients of control constraints are subject to uncertaint. Since the uncertainty is an integral part of demand after earthquake, the demand considered as an uncertain parameter which represents by defined scenarios. The symbol S represents different scenarios. Now to determine the robust model the following additional parameters and decision variables are defined.

Parameter	Definition
D_{iq}^{ts}	Demand of aid commodity type q at affected area i at period t under scenario s
$D_i'^{t}$	Demand of rescue operation at affected area i at period t under scenario s
T_i^{ts}	Maximum time that rescue operations should be done at affected area i in period t under scenario s
p_s	Probability of scenario s
λ, ω	Weight used in objective functions to show the importance of expected value against the standard deviation and penalty at the upper level
λ', ω'	Weight used in objective functions to show the importance of expected value against the standard deviation and penalty at the lower level

Decision variable	Definition
θ^s, θ'^s	Variables used to linearization the objective function terms
δ_{iq}^{ts}	Unsatisfied demand of aid commodity type q at affected area i at period t under scenario s
$\delta_i'^{ts}$	Unsatisfied demand of aid commodity type q at affected area i at period t under scenario s
$\delta_{jq}''^{ts}$	Unsatisfied demand of aid commodity type q at warehouse j at period t under scenario s
ϕ^s	The objective function of the leader under scenario s

Finally the robust model is as follows:

Upper level

$$\min \sum_{s\in S}\phi^{s} + \lambda \sum_{s\in S} p_{s}[(\phi^{s}) - \sum_{s'\in S} p_{s'}\phi^{s'} + 2\theta_{s}] + \omega(\sum_{s\in S}\sum_{I\in I}\sum_{q\in Q}\sum_{t\in T} p_{s}\delta_{iq}^{ts} + \sum_{I\in I}\sum_{t\in T}\sum_{s\in S} p_{s}\delta_{i}^{\prime ts}) \tag{18}$$

subject to:

$$Mx_{ijq}^{ts} \geq x_{ijq}^{\prime ts} \quad \forall i\in I, \forall j\in J, \forall q\in Q, \forall t\in T, \forall s\in S \tag{19}$$

$$\sum_{j\in J} x_{ijq}^{ts} \geq 1 \quad \forall i\in I, \forall q\in Q, \forall t\in T, \forall s\in S \tag{20}$$

$$\sum_{q\in Q}\sum_{i\in I} x_{ijq}^{ts} \geq 1 \quad \forall j\in J, \forall t\in T, \forall s\in S \tag{21}$$

$$\sum_{k\in K}\sum_{l\in L}\sum_{j\in J} \eta_{ijlk}^{ts} \geq 1 \quad \forall i\in I, \forall t\in T, \forall s\in S \tag{22}$$

$$d_{ij}x_{ijq}^{t} \leq R_{j} \quad \forall i\in I, \forall j\in J, \forall q\in Q, \forall t\in T \tag{23}$$

$$d_{ij}\eta_{ijlk}^{ts} \leq R_{j} \quad \forall i\in I, \forall j\in J, \forall l\in L, \forall k\in K, \forall t\in T, \forall s\in S \tag{24}$$

$$I_{jq}^{ts} \leq C_{jq} \quad \forall j\in J, \forall q\in Q, \forall t\in T, \forall s\in S \tag{25}$$

$$(d_{ji} + d'_{ik})\eta_{ijlk}^{ts} / v_{l} \leq T_{i}^{ts} \quad \forall i\in I, \forall j\in J, \forall l\in L, \forall k\in K, \forall t\in T, \forall s\in S \tag{26}$$

$$\sum_{j\in J} x_{ijq}^{\prime ts} = D_{iq}^{ts} \quad \forall i\in I, \forall q\in Q, \forall t\in T, \forall s\in S \tag{27}$$

$$\sum_{k\in K}\sum_{j\in J}\sum_{l\in L} g_{l}\eta_{ijlk}^{ts} = D_{i}^{\prime ts} \quad \forall i\in I, \forall t\in T, \forall s\in S \tag{28}$$

$$\sum_{t\in T}\sum_{i\in I}\sum_{j\in J}\sum_{l\in L} g_{l}\eta_{ijlk}^{ts} \leq U_{k} \quad \forall k\in K, \forall s\in S \tag{29}$$

$$\phi^{s} - \sum_{s'\in S} p_{s'}(\phi^{s'}) + \theta_{s} \geq 0 \quad \forall s\in S \tag{30}$$

$$\begin{aligned} & x_{ijq}^{ts} \in \{0,1\} \quad \forall i\in I, \forall j\in J, \forall q\in Q, \forall t\in T, \forall s\in S \\ & \eta_{ijlk}^{ts} \in \{0,1\} \quad \forall i\in I, \forall j\in J, \forall l\in L, \forall k\in K, \forall t\in T, \forall s\in S \\ & x_{ijq}^{\prime ts} \geq 0 \quad \forall i\in I, \forall j\in J, \forall q\in Q, \forall t\in T, \forall s\in S \\ & I_{jq}^{ts} \geq 0 \quad \forall j\in J, \forall q\in Q, \forall t\in T, \forall s\in S \end{aligned} \tag{31}$$

Lower level

$$\begin{aligned} & \min \sum_{s\in S}\sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}\sum_{t\in T} p_{s}Tr_{q}''d_{ej}y_{ejq}^{ts} + \\ & \lambda' \sum_{s\in S} p_{s}[(\sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}\sum_{t\in T} Tr_{q}''d_{ej}y_{ejq}^{ts}) - (\sum_{s\in S'}\sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}\sum_{t\in T} p_{s}Tr_{q}''d_{ej}y_{ejq}^{ts}) + 2\theta_{s}'] \\ & +\omega' \sum_{j\in J}\sum_{q\in Q}\sum_{t\in T}\sum_{s\in S} p_{s}\delta_{jq}^{\prime\prime ts} \end{aligned} \tag{32}$$

subject to:

$$\sum_{j\in J} y_{ejq}^{ts} \leq b_{eq}^{t} \quad \forall e\in E, \forall q\in Q, \forall t\in T, \forall s\in S \tag{33}$$

$$I_{jq}^{t-1,s} + \sum_{e\in E} y_{ejq}^{ts} - \sum_{i\in I} x_{ijq}^{\prime ts} + \delta_{jq}^{ts} = I_{jq}^{t,s} \quad \forall j\in J, \forall q\in Q, \forall t\in T, \forall s\in S \tag{34}$$

$$(\sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}\sum_{t\in T} Tr_{q}''d_{ej}y_{ejq}^{ts}) - (\sum_{s\in S'}\sum_{e\in E}\sum_{j\in J}\sum_{q\in Q}\sum_{t\in T} p_{s}Tr_{q}''d_{ej}y_{ejq}^{ts}) + \theta_{s}' \leq 0 \quad \forall s\in S \tag{35}$$

$$y_{ejq}^{ts} \geq 0 \quad \forall e\in E, \forall j\in J, \forall q\in Q, \forall t\in T, \forall s\in S \tag{36}$$

Where constraints (30) and (35) are used to linearize the robust model and rest of constraint are the same as previous model.

5. Numerical Results

To illustrate and apply our proposed model, we consider the probable earthquake in Tehran region one as a case study. After occurrence of earthquake, groups of foreign will help the affected zone by sending necessary commodities. Suppliers choose the cheapest transportation plan in order to distribute commodities among warehouses. Commodities send to pre-considered storage centers by suppliers and affected country will distribute them from storage centers to demanded points. The suppliers try to minimize their transportation costs. The affected country, Iran, also must satisfy rescue demand at affected areas and transport injuries from these points to medical centers. Iran, in this paper, would have like to minimize total costs. Given the magnitude of the event, the demand of products and services are corresponded to a planning horizon of 2 days_ the maximum time in which human can survive without water. Shahr-e Rey, Mosha and the south and north Tehran faults are four active faults which can lead to an earthquake in Tehran. The model's scenarios is defined according to which one of this faults will be activated. Each fault causes earthquake with different magnitude in Region 1.We assume ten countries including Iraq, Turkey, Azerbaijan, Syria, UAE, Qatar, Germany, Turkmenistan, Kuwait, and Afghanistan will help Tehran after earthquake and send their products. The products are including food, water, medicine, and shelter. Rescue operation can be done by air and land transportation for transporting injuries to medical centers. Trucks, ambulances and helicopters considered as rescue vehicles. We also assume Red Cross and Helal-e Ahmar agency coordinating Tehran with foreign to avoid sending unnecessary commodities to warehouses. Region 1 consists of ten area. We assume the center of each area as the demand points. Fig. 2 displays the location of warehouses and hospitals in this region. The used parameters for Tehran case study are shown in Table 1 to Table 4.

Table 1
The latitude and longitude of the affeced areas, located hospitals and located warehouses and foreign suppliers

Points	latitude	longitude
Affected area 1	35.810363	51.422087
Affected area 2	35.794213	51.433588
Affected area 3	35.815931	51.442772
Affected area 4	35.797554	51.451183
Affected area 5	35.804725	51.461569
Affected area 6	35.815444	51.475559
Affected area 7	35.809736	51.483198
Affected area 8	35.799782	51.483971
Affected area 9	35.805699	51.509806
Affected area 10	35.791915	51.504484
Hospital 1	35.789043	51.431951
Hospital 2	35.793012	51.487226
Hospital 3	35.816349	51.494700
Warehouse 1	35.803983	51.395945
Warehouse 2	35.795671	51.430301
Warehouse 3	35.804569	51.460470
Warehouse 4	35.803398	51.490350
Turkey	39.907253	32.835508
Azerbaijan	38.755752	48.838380
Iraq	33.335705	44.347654
Syria	36.455217	40.790400
UAE	24.324056	54.815086
Germany	49.410104	11.087382
Turkmenistan	37.951214	58.325804
Qatar	25.286020	51.597424
Kuwait	29.390573	47.982057
Afghanistan	34.554518	69.115289

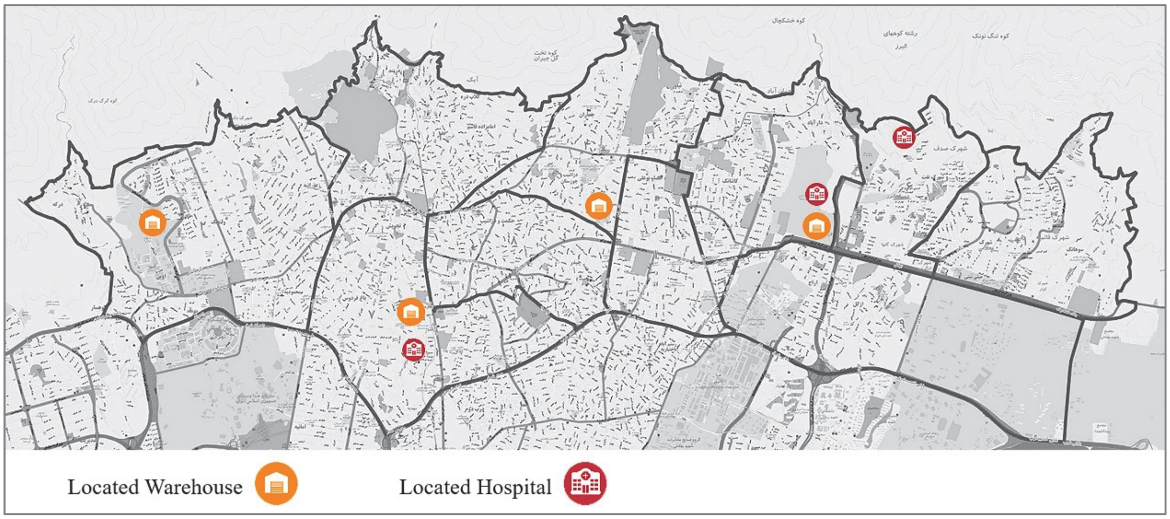

Fig. 2. The location of hospitals and warehouses in Region one

Table 1 shows the latitude and longitude of the affeced areas, located hospitals and located warehouses and foreign suppliers. according to the following equation and Table 1 disances between nodes can be calculated. Warehouses' capacity of aid commodities are seen in Table 2. Package of aid commodities including water, food and shelter and medicine consist 1000, 1000, 1 and 1000 units, respectively. Table 3 consists of information about rescue vehicles and their characteristics.

$$d_{ij} = 6371.1 \times \arccos[\sin(LAT_i) \times \sin(LAT_j) + \cos(LAT_i) \times \cos(LAT_j) \times \cos(LONG_j - LONG_i)]$$

Table 2
Warehouses' capacity of aid commodities and rescue vehicles

Relief base	Relief commodity package			Drugs		Rescue vehicle		
	Water	Food	Shelter	Type1	Type 2	Type 1	Type 2	Type 3
1	70	70	10	30	40	10	6	1
2	60	50	20	30	40	12	6	2
3	50	60	30	30	40	9	4	1
4	70	40	60	30	40	8	7	1

Table 3
rescue vehicles' information and characteristics

Rescue vehicle	Average velocity (km/h)	Capacity	Increasing the coverage radius (km)
1	70	2	0.3
2	60	7	0.5
3	180	4	1

Warehouses' radius coverage for distributing aid commodities and evacuating is about 4 km. In addition, based on: (1) earthquake intensity, (2) population of the affected area we defined five scenarios, so Table 4 and Table 5 respectively show demand for aid commodity and rescue vehicle and maximum time related to rescue operation under each scenario and for two time periods. We assume that operation costs of rescue vehicles are \$100, \$200, and \$1000. Unit of transportation cost for these vehicles are \$0.01, \$ 0.01 and \$0.15. Finally Table 6 shows foreign suppliers' available package of aid commodities for each periods. Each package of these commodities consist of 1000, 1000, 1, 1000, 1000 units of water, food, shelter, and medicine type 1 and type 2, respectively.

Table 4

Demand for aid commodities and rescue operation under each scenario and for two time periods

				S1	S2	S3	S4	S5			S1	S2	S3	S4	S5
Affected area 1	Period 1	Relief commodity	Water	4	10	4	12	19	Affected area 6	Period 1	8	6	8	15	20
			Food	8	10	3	10	15			9	10	7	10	15
			Shelter	10	8	4	6	15			9	9	3	6	16
		Drug	Type 1	10	6	2	4	10			13	12	5	11	10
			Type 2	12	3	2	5	12			10	13	2	10	14
		Rescue operation		4	8	2	10	15			5	8	3	10	18
	Period 2	Relief commodity	Water	5	8	6	10	17		Period 2	7	7	10	12	19
			Food	7	9	1	10	15			10	11	5	11	14
			Shelter	11	9	3	7	15			10	8	4	6	15
		Drug	Type 1	10	7	1	4	8			10	12	4	7	10
			Type 2	5	3	0	5	10			8	11	1	9	12
		Rescue operation		4	6	2	7	15			5	7	2	9	15
Affected area 2	Period 1	Relief commodity	Water	5	10	9	18	20	Affected area 7	Period 1	6	12	10	15	18
			Food	3	4	2	2	9			4	7	3	10	11
			Shelter	4	8	2	6	17			5	10	3	8	20
		Blood		8	10	3	10	12			6	7	1	4	15
		Drug	Type 1	10	9	6	11	15			11	3	6	7	14
			Type 2	12	10	7	12	13			7	10	8	6	16
		Rescue operation		9	12	7	15	20			10	11	5	10	18
	Period 2	Relief commodity	Water	6	9	10	17	20		Period 2	7	13	15	7	15
			Food	2	4	1	3	10			2	5	4	10	11
			Shelter	5	7	3	9	12			1	3	4	5	13
		Drug	Type 1	11	4	1	10	10			10	2	6	5	14
			Type 2	11	9	5	11	10			6	9	6	2	10
		Rescue operation		8	6	6	15	19			9	9	4	10	16
Affected area 3	Period 1	Relief commodity	Water	12	10	17	8	21	Affected area 8	Period 1	13	15	16	9	22
			Food	8	8	5	7	15			9	10	6	6	14
			Shelter	4	9	10	5	10			10	12	10	11	15
		Blood		10	9	7	9	14							
		Drug	Type 1	10	11	0	4	8			8	8	0	8	9
			Type 2	13	12	5	7	9			11	10	5	6	11
		rescue operation		4	8	8	14	15			10	8	7	10	10
	Period 2	Relief commodity	Water	10	9	18	7	20		Period 2	14	17	10	5	12
			Food	7	5	6	6	15			8	10	4	7	13
			Shelter	4	6	11	4	13			14	11	3	9	10
		Drug	Type 1	9	9	1	2	6			4	9	1	5	9
			Type 2	11	10	0	2	5			10	9	4	3	10
		rescue operation		5	9	6	10	15			9	8	6	8	9
Affected area 4	Period 1	Relief commodity	Water	12	10	13	7	22	Affected area 9	Period 1	13	12	16	9	22
			Food	7	6	5	7	13			7	11	5	8	15
			Shelter	4	4	11	4	10			13	12	5	10	10
		Drug	Type 1	6	5	6	11	16			10	4	2	10	11
			Type 2	3	5	5	12	15			11	8	7	8	12
		rescue operation		12	14	10	10	19			13	14	8	11	20
	Period 2	Relief commodity	Water	12	9	7	15	20		Period 2	14	11	4	17	21
			Food	10	6	3	7	20			9	7	5	6	17
			Shelter	12	14	7	10	11			11	12	10	14	12
		Drug	Type 1	5	2	6	11	10			9	4	0	9	12
			Type 2	0	6	4	11	9			10	7	5	9	10
		rescue operation		10	12	7	10	18			8	6	7	10	20
Affected area 5	Period 1	Relief commodity	Water	17	15	18	13	27	Affected area 10	Period 1	19	27	8	5	30
			Food	5	11	7	15	15			10	12	8	17	18
			Shelter	10	6	4	10	10			11	10	9	12	11
		Drug	Type 1	9	7	4	10	17			4	3	3	4	10
			Type 2	10	7	0	1	10			10	9	2	6	9
		rescue operation		12	12	9	16	21			8	10	3	7	10
	Period 2	Relief commodity	Water	14	15	19	10	25		Period 2	19	4	10	5	28
			Food	16	8	10	10	6			6	10	9	18	17
			Shelter	9	4	4	8	11			10	9	8	10	11
		Drug	Type 1	5	3	0	4	7			10	8	4	6	11
			Type 2	6	4	0	1	7			2	0	2	4	5
		rescue operation		10	9	8	15	16			8	9	3	6	8

Table 5

Maximum time related to rescue operation under each scenario and for two time periods

Affected area										
	1	2	3	4	5	6	7	8	9	10
S1	0.5	1	0.7	0.6	0.5	1	0.4	0.7	0.5	1
S2	0.3	0.6	0.6	0.7	0.3	0.6	0.5	0.8	0.6	0.8
S3	1	1.2	2	0.9	0.5	0.7	0.4	1	1.1	0.7
S4	0.4	0.7	0.9	2	0.4	0.4	0.8	0.5	07	1

Table 6

Foreign suppliers' available package of aid commodities for each period

Suppliers	Relief commodity package			Medicine	
	Water	Food	Shelter	Type1	Type 2
Turkey	10	15	50	10	15
Azerbaijan	10	15	20	10	15
Iraq	20	10	50	10	15
Syria	20	25	40	10	15
UAE	15	10	20	10	15
Germany	10	20	30	10	15
Turkmenistan	10	10	20	10	15
Qatar	15	15	10	10	15
Kuwait	20	20	30	10	15
Afghanistan	10	10	40	10	15

In this section we propose the numerical results conducted to the proposed case study. To show the benefits of bi-level modeling, a comparison between three points of view proposed. First, the model is investigated from the standpoint of Iran, the leader of bi-level model. Second, the standpoint of foreign countries and finnaly the leader-follower model in a bi-level structure is investigated. In order to solve the bi-level model, we used Fuzzy Goal Programming (FGP) approach and reduced the bi-level model to an equivalent single level model. Obviously, considering just one player's perspective will improve his/her objective function but cause disregarding others point of view which may be important and vital.

Table 7

The objective functions from different points of view

	Leader Perspective (Iran)	Follower Perspective (foreign countries)	Bi-Level model
First Level	3085604	7764967	4754996
Second Level	2691875	652348	824842

As shown in Table 7 Considering just Iran's point of view will decrease the first level objective function but hugely increases second level objective functions while considering second level point of view will reduce suppliers transportation costs and increases the amount of Iran's total cost. Proposed bi-level model stablished a trade off between leader anf follower goals. As shown in Table 7, the bi-level model performance is more reseonable since both leader and followers points of view are considered. In bi-level model, affected country's objective function value is between leader's perspective and follower's perspective value. In fact, considering just one perspective generates extreme solutions while bi-level model presents resoanable and moderate solutions. In other words, bi-level model results an equilibirium as $f_{leader} \le f_{bi-level} \le f_{follower}$ for the affected country and $f_{follower} \le f_{bi-level} \le f_{leader}$ for suppliers. Fig. 3 is a graphical representation of the three points of view performance. In Table 8 a comparison between each perspective against the best decision are made to show the advantages of using bi-level model for Tehran earthquake. First the amount of leader objective function in bi-level and follower based models compared with the leader's perspective objective function. Then the transportation costs of suppliers compared with the follower's perspective objective functions. The bi-level solution increases both upper and lower level objective functions but takes all decision makers points of view into account. On the other words, in leader's perspective the amount of its total costs will decrease but suppliers costs ignore. This can affect the performance of model in real situation. Also followers perspective model presents the cheapest transportation plan but larger total cost for Iran will accur.

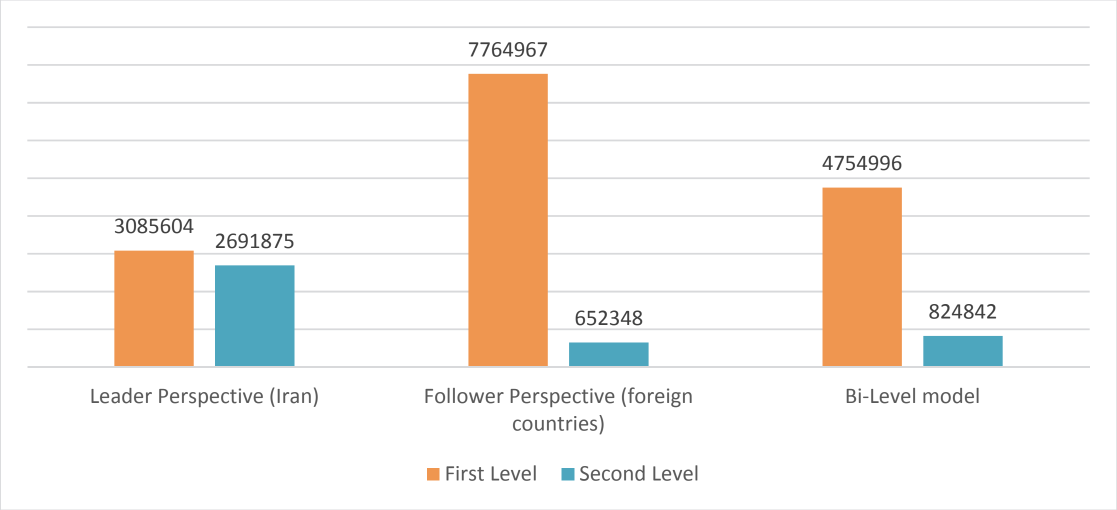

Fig. 3. The objective functions from different points of view

Table 8
Percentage of increase in the respective models against the best decision

	Increase in Iran total costs	Increase in international suppliers cost
Leader perspective	-	3.12644043
Follower perspective	1.516514732	-
Bi-level model	0.54102613	0.26442051

According to (Camacho-Vallejo et al. 2014) the increases in objective functions derive from the following formula:

$$increase = \frac{current\ value - best\ value}{best\ value} \tag{37}$$

To show the benefits of the proposed bi-level model, we compute the gaps of the savings provided by this model against the Leader and Follower's perspectives. The gaps appear in Table 8 and derive from the formula (37) adjusting the values in the correct way.

Table 9
Percentage of decrease provided by the bi-level model

	Decrease in Iran's total costs	Decrease in international suppliers cost
Leader perspective	-0.35108168	2.2635037
Follower perspective	0.63301230	-0.2091236
Bi-level model	-	-

As Table 9 shows, by choosing the bi-level solution instead of the Leader's perspective solution, we hugely reduce the total transportation costs 226.35% for international s. Then again, choosing the bi-level solution instead of the Follower's perspective gives us total cost reduction about 63.30%. In both cases, the reductions are more significant than the expected increase shown in Table 8. The negative values in Table 9 represent an increase in Iran's total costs and suppliers' transportation costs. To explore the effects of various problem parameters, the example problem is accompanied by sensitivity analysis experiments and corresponding managerial insights that can guide DMs under a variety of conditions.

Table 10
Impact of warehouses capacity on optimal bi-level model solutions

C(q)	Leader's objective function	Follower's objective function	C(q)	Leader's objective function	Follower's objective function
10	4.91E+06	9.20E+05	155	4.74E+06	6.98E+05
40	4.86E+06	8.50E+05	175	4.74E+06	6.87E+05
80	4.83E+06	7.97E+05	185	4.73E+06	6.74E+05
100	4.79E+06	7.26E+05	200	4.72E+06	6.65E+05
130	4.76E+06	7.20E+05	215	4.71E+06	6.51E+05
145	4.76E+06	7.08E+05	225	4.71E+06	6.49E+05

Fig. 4 and Table 10 represent the sensitivity analysis of warehouses' capacities for relief commodities including water, food, and shelter. For capacity values equal or lower than 10 for each relief commodity the solution will be infeasible. By increasing the capacity of warehouses for each relief commodity at beginning the objective functions start decreasing exponentially, because of decreasing in unsatisfied demand. But after turning point the objective function starts growing because of increasing in operational and inventory costs. Increasing in warehouses capacity for more than 225 does not create changes in first level objective function. In fact, capacities for more than 225 applies as big M since this parameter located in right hand side of constraints.

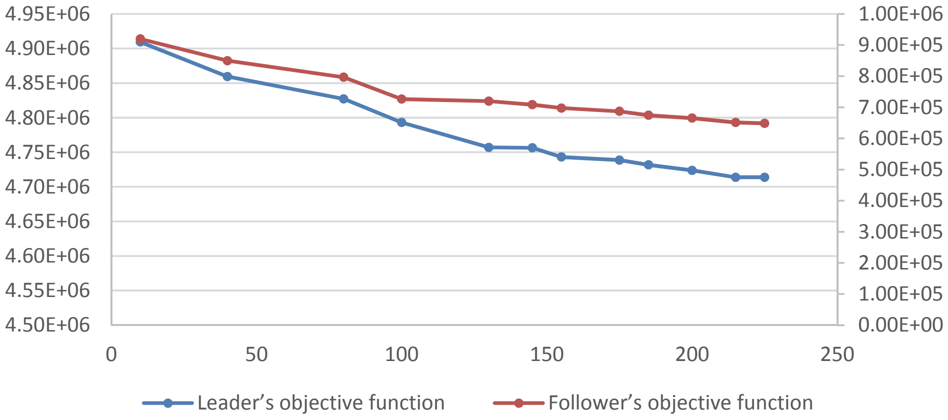

Fig. 4. Impact of warehouse capacity on the amount of transportation costs

Table 11
Impact of warehouses radius coverage on optimal bi-level model solutions

R	Leader's objective function	Follower's objective function
3	4.87E+06	8.41E+05
4	4.81E+06	8.17E+05
5	4.78E+06	8.11E+05
6	4.77E+06	8.01E+05
7	4.76E+06	7.91E+05
8	4.75E+06	7.90E+05

Table 11 represents the sensivity analysis of proposed model to warehouses' radius coverage. The first level objective function reveals sensivity to changes in radius coverage values. But second level objective function does not show noticeable sensitivity to changes in raduis coverage values. Fig 5 is the graphical representation of these objective functions sensitivity. For radius coverage values equal or lower than 2.5 for each warehouse the solution will be infeasible.

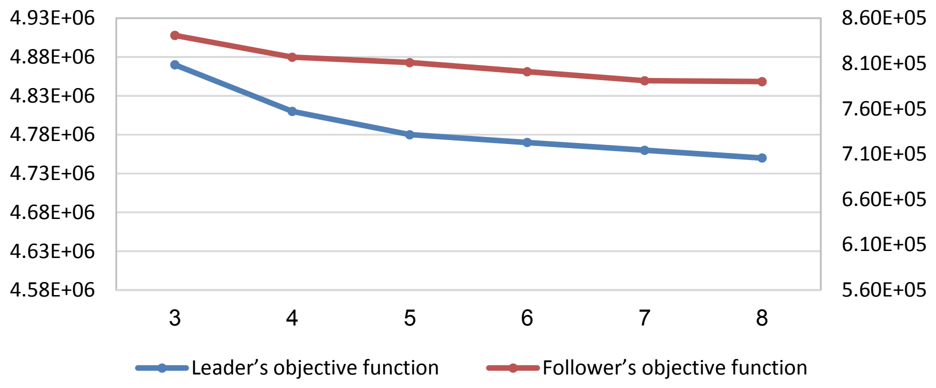

Fig. 5. Impact of warehouses radius coverage on optimal bi-level model solutions

6. Conclusion and future research

In this paper, a robust bi-level optimization model for supplying and distributing of aid products after an earthquake has been developed. Supplires consist of foreign countries which play as the followers in the game and the affected country plays as the leader. To illustrate and apply the proposed model, Tehran probable earthquake in Region 1 was investigated. To show the advantages of using bi-level model, a comparison between leader, follower and bi-level model points of views was proposed. The results have been indicated that considering just leader or follower perspective generates extrem solutions while bi-level model offers reseonable solutions concerning both the affected country and suppliers points of view. The amount of savings obtained by bi-level model also provided. In addition the experiments of sensitivity analysis for the capacity of warehouses and their radius coverage were proposed. To put in a nutshell, our contributions can be summarized as follow:

1. We developed a multi-period robust model for humanitarian logistics which captured uncertainty in the value of some input data.
2. According to the absolute scientific gap in multi-level models we presented a bi-level model to capture different DMs points of view.
3. Our model was developed not only to distribute aid commodities but also to evacuate injured people from affected areas.

Future studies can be aimed at new game conditions such as defining priority for suppliers to access to the warehouses vacant spaces. In addition, the proposed bi-level model could be modeled as a multi non-indipendent followers for example researchers can consider foreign and local supplier as non-independent followers. Finally, another intresting extension of this problem is considering roads condition stochasticity and model it by fuzzy programming to show the partial availability of roads after catasrophic earthquakes.

References

Afshar, A., & Haghani, A. (2012). Modeling integrated supply chain logistics in real-time large-scale disaster relief operations. *Socio-Economic Planning Sciences, 46*(4), 327-338.

Aksen, D., Aras, N., & Piyade, N. (2013). A bi-level p-median model for the planning and protection of critical facilities. *Journal of Heuristics, 19*(2), 373-398.

Arroyo, J. M., & Galiana, F. D. (2005). On the solution of the bi-level programming formulation of the terrorist threat problem. *Power Systems, IEEE Transactions on, 20*(2), 789-797.

Barbarosoğlu, G., Arda, Y. (2004). A two-stage stochastic programming framework for transportation planning in disaster response. *Journal of the Operational Research Society, 55*(1), 43-53.

Barbarosoğlu, G., Özdamar, L., & Cevik, A. (2002). An interactive approach for hierarchical analysis of helicopter logistics in disaster relief operations. *European Journal of Operational Research, 140*(1), 118-133.

Camacho-Vallejo, J. F., González-Rodríguez, E., Almaguer, F. J., & González-Ramírez, R. G. (2015). A bi-level optimization model for aid distribution after the occurrence of a disaster. *Journal of Cleaner Production, 105*, 134-145.

Feng, C. M., & Wen, C. C. (2005). A bi-level programming model for allocating private and emergency vehicle flows in seismic disaster areas. *Proceedings of the Eastern Asia Society for Transportation Studies, 5*(5), 1408-1423.

Fiedrich, F., Gehbauer, F., & Rickers, U. (2000). Optimized resource allocation for emergency response after earthquake disasters. *Safety Science, 35*(1), 41-57.

Jotshi, A., Gong, Q., & Batta, R. (2009). Dispatching and routing of emergency vehicles in disaster mitigation using data fusion. *Socio-Economic Planning Sciences, 43*(1), 1-24.

Knott, R. (1987). The logistics of bulk relief supplies. *Disasters, 11*(2), 113-115.

Knott, R. P. (1988). Vehicle Scheduling for Emergency Relief Management: A Knowledge-Based Approach. *Disasters, 12*(4), 285-293.

Kongsomsaksakul, S., Yang, C., & Chen, A. (2005). Shelter location-allocation model for flood evacuation planning. *Journal of the Eastern Asia Society for Transportation Studies,* 6, 4237-4252.

Li, A. C., Nozick, L., Xu, N., & Davidson, R. (2012). Shelter location and transportation planning under hurricane conditions. *Transportation Research Part E: Logistics and Transportation Review, 48*(4), 715-729.

Lin, Y. H., Batta, R., Rogerson, P. A., Blatt, A., & Flanigan, M. (2011). A logistics model for emergency supply of critical items in the aftermath of a disaster. *Socio-Economic Planning Sciences, 45*(4), 132-145.

Losada, C., Scaparra, M. P., Church, R. L., & Daskin, M. S. (2012). The stochastic interdiction median problem with disruption intensity levels. *Annals of Operations Research, 201*(1), 345-365.

Ma, X., Song, Y., & Huang, J. (2010, May). Min-max robust optimization for the wounded transfer problem in large-scale emergencies. In Control and Decision Conference (CCDC), 2010 Chinese (pp. 901-904). IEEE.

Mulvey, J. M., Vanderbei, R. J., & Zenios, S. A. (1995). Robust optimization of large-scale systems. *Operations Research, 43*(2), 264-281.

Najafi, M., Eshghi, K., & Dullaert, W. (2013). A multi-objective robust optimization model for logistics planning in the earthquake response phase. *Transportation Research Part E: Logistics and Transportation Review, 49*(1), 217-249.

Nolz, P. C., Semet, F., & Doerner, K. F. (2011). Risk approaches for delivering disaster relief supplies. *OR Spectrum, 33*(3), 543-569.

Ozdamar, L. (2011). Planning helicopter logistics in disaster relief. *OR spectrum, 33*(3), 655-672.

Özdamar, L., & Demir, O. (2012). A hierarchical clustering and routing procedure for large scale disaster relief logistics planning. *Transportation Research Part E: Logistics and Transportation Review, 48*(3), 591-602.

Özdamar, L., Ekinci, E., & Küçükyazici, B. (2004). Emergency logistics planning in natural disasters. *Annals of Operations Research, 129*(1-4), 217-245.

Sheu, J. B. (2007). An emergency logistics distribution approach for quick response to urgent relief demand in disasters. *Transportation Research Part E: Logistics and Transportation Review, 43*(6), 687-709.

Sheu, J. B. (2010). Dynamic relief-demand management for emergency logistics operations under large-scale disasters. *Transportation Research Part E: Logistics and Transportation Review, 46*(1), 1-17.

Tzeng, G. H., Cheng, H. J., & Huang, T. D. (2007). Multi-objective optimal planning for designing relief delivery systems. *Transportation Research Part E: Logistics and Transportation Review, 43*(6), 673-686.

Yi, W., & Kumar, A. (2007). Ant colony optimization for disaster relief operations. *Transportation Research Part E: Logistics and Transportation Review, 43*(6), 660-672.

Yi, W., & Özdamar, L. (2007). A dynamic logistics coordination model for evacuation and support in disaster response activities. *European Journal of Operational Research, 179*(3), 1177-1193.

Zhan, S. L., & Liu, N. (2011, April). A multi-objective stochastic programming model for emergency logistics based on goal programming. *In Computational Sciences and Optimization (CSO), 2011 Fourth International Joint Conference on (pp. 640-644). IEEE.*