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A multi-objective relief logistics model under uncertainty with robust optimization method, case Study: flood in Mazandaran

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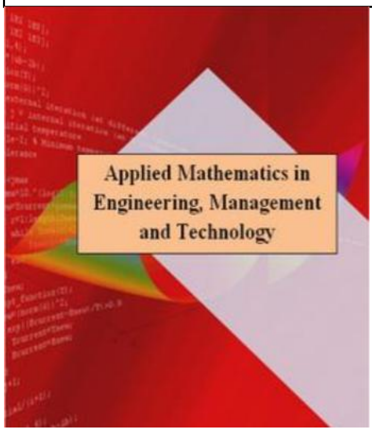


Abstract

For the last two decades, many of people have been affected by different kind of disasters which have disrupted the social and economic development of societies and caused losses over hundreds of millions of dollars. Therefore, under these circumstances, the issue of relief logistics, which is a major activity in disaster management problems, is –very important. This research proposes a three-objective mathematical planning model with multi-commodity, transportation vehicles, and considering different damages under uncertainty. The proposed model aims to apply maximum covering in transferring the injured people to medical centers, applying maximum covering in moving commodity to affected areas, and minimize existing costs. Accordingly, the weighted fuzzy goal programming method is used to solve this multi-objective model. some parameter are considered uncertain Due to the unpredictability of natural disasters and the uncertainty of their intensity, some, including the demand for relief commodity, the number of injured people, providing medical and non-medical service. The scenario-based robust optimization method is used to solve the model in an uncertain environment. The efficiency of the proposed model is evaluated by a case study and necessary sensitivity analysis is performed for important parameters of model.

Keywords:Relief logistics, multi-object programming, uncertainty, robust optimization, fuzzy goal programming

1. Introduction

Each year, natural disasters, including floods, earthquakes, storms, droughts, affect the lives of many people in different regions of the world and Due to their unpredictability, inflict heavy and irreversible damages to nations. These natural disasters mostly cause many fatal and financial damages. The large extent of the damages and fatalities of these disasters in different cities of the worlds has recently attracted for relief missions to damaged regions and reducing the impacts of these disasters. Therefore, relief chains are responsible for supplying basic needs and aiding the injured people at appropriate locations in the fastest time. Support and relief logistics play a determinant role as one of the main pillars of disaster management. In case of any disruption in this role, the whole disaster management process is disturbed. Relief logistics includes all processes for estimating, preparing, planning, predicting, and preventing, supply, transportation, maintenance and distribution of commodities, equipment and services for the injured people, and rescue teams. Therefore, if disaster management logistics possesses a comprehensive and scientific system, it can succeed in managing the crisis to a large extent. On the other hand, natural disasters inherently require a response in a short amount of time. Under such emergent and intricate conditions, decision makers should rapidly and effectively respond to logistics issues and transfer the injured from affected areas to deployed centers. In order to achieve these goals, logistics is a scope, which improvement can provide effective results. In fact, the major part of disaster management is logistics management [1]. Moreover, logistics enables more coordination in delivering commodity, communications, and increasing the delivery speed and response [2].
Generally, the issues mostly considered in relief logistics research include:

a. Servicing the injured people
b. Models with cost minimization goals
c. Facility location
d. Inventory management
e. Transportation models
f. proper distribution of relief commodities

And models, which are a combination of the above that review some of them.

Ray (1987) developed a single-commodity, limited capacity model with multiple transportation models in a network and a multi-period planning, which minimizes the sum of the transportation costs and food storage costs [3].

Gehbouer et al. (2000) discussed the fatalities and calculated them after earthquake disaster. They propose a model to minimize these fatalities [4]. Brotcorne et al. (2003) categorized location and relocation models and divided existing models to three categories: deterministic models, probabilistic queue models and dynamic models [5].

Barbarosoglu and Arda (2004) proposed a two-stage stocastic planning model for transportation planning in response to incident. They consider uncertainty in distribution, capacity of routes, and demands. They designed eight earthquake scenarios to adapt their approach to real world cases. Their planning model does not cover important details, which may be required at strategic and operational levels and does not solve the facility location and transportation routing problems [6].

Amiri (2006) studied the distribution network problem and used multiple capacity levels for warehouses and plants [7]. Mete and Zabinsky (2010) proposed a stochastic optimization model for warehouse planning and distributing medical items in emergency situations [8].

Ukkusuri and Yushimito (2008) proposed a model to select the optimal location to store items prior to a crisis. Their model maximizes the probability that uncertain transportation network points can be supplied from a facility [9].

Rawls and Turnquist (2011) proposed a probabilistic planning for the phase before the actual crisis, which aimed to minimize costs [10]. Doyen et al. (2012) proposed a multi-level probabilistic planning during a disaster, which aimed to minimize costs [11].

ROH et al. (2013) practically considered key factors, which are introduced to select the location of a humanitarian relief warehouse, as a measure in the analysis hierarchical process (AHP) [12]. Eshghi and Najafi (2013) proposed a mathematical model for logistics planning with the goal of improving the results of logistics operations in response to earthquakes and thus, taking necessary measures to transport the injured and commodities. Objective functions are selected to minimize the sum of unsatisfied commodity requirements and unattended injuries [13].

Fu-sheng Chang et al. (2014) proposed an algorithm, which could adjust the distribution of existing resources and automatically generated a number of temporal plans for emergency and executable supplies for decision makers [14].

Hadiguna et al. (2014) explained the required processes to create an effective and reliable decision support system to evaluate the availability of public facilities during the evacuation operations after an incident [15].

Mohammad Rezaei-Malek et al. (2015) developed an interactive approach in robust relief logistics networks with perishable commodities, which aimed to minimize the average time of the response phase, total operational costs, and the penalty for unsatisfied demands. Moreover, they also used the reservation level Tchebycheff procedure [16].

Tofighi et al. (2015) proposed a humanitarian logistics model under complex uncertainty, which used a scenario-based two-stage stochastic-contingency planning approach. Its goal was to minimize the total distribution time, overall costs, and the penalty for unsatisfied demands [17].

Alfredo Morenoa et al. (2015) employed heuristic approaches in relief logistics for a multi-period transportation-location problem by reusing transportation vehicles. The proposed model was multi- commodity and multi-period, which considers uncertainty, eventually reduces total costs, and improves performance [18].

Garridoa et al. (2015) proposed a stochastic planning approach in flood situations for relief logistics. The proposed model emphasized on optimizing existing levels and transportation availability for allocating better commodities [19].

In the domain of robust optimization, in a paper called “a robust optimization model for the multi-site production planning problem under uncertainty”, Leung et al. (2007) discussed robust optimization in a supply chain in the domain of production planning [20].

In a paper called “allocating semi-conductor shipments using robust optimization”, Ng et al. (2010) considered the allocation problem of a set of production groups to respond to customer orders [21].

Torabi et al. (2012) designed a socially accountable supply chain network under uncertainty and proposed a mathematical planning model, whose objective functions included reducing total cost and maximizing the accountability of the social supply chain. Subsequently, in order to deal with effective uncertainty with parameters, they proposed a contingency planning called robust contingency planning [22].

Armin Jabbarzadeh et al. (2014) proposed a robust model to design dynamic supply chain networks with real world applications to supply blood during natural disasters [23].

According to the existing research, there has been no research to propose a model in relief logistics using scenario-based robust optimization with goals of increasing the satisfaction of the injured, who are transferred to medical centers, and increasing the satisfaction of affected areas by maximizing commodity coverage, at the same time minimizing costs, pre-location for inventory management, organizing transportation vehicles to transfer commodities.

2. Problem

According to figure 1, the network, which is considered for the relief logistics model under uncertainty, consists of four levels to respond to commodity demands of affected areas and two medical centers (hospital and emergency medical center) to transfer the injured. Supply centers include factories or companies that manufacture the required commodities. Distribution centers consist of large relief institutions with inventory. Temporary warehousing centers include relief center of some cities, which close to affected areas and their sizes are smaller than distribution centers. Also affected areas consist of regions affected by the disaster.

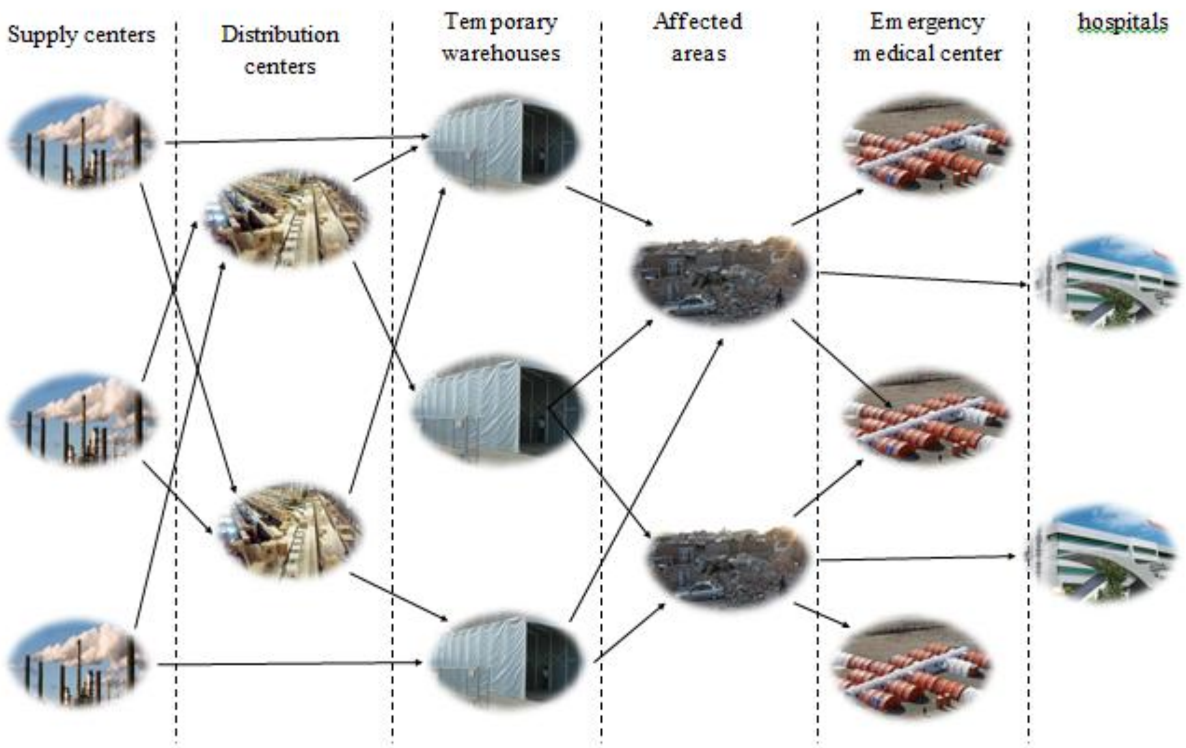


Figure1. Relief logistics network

2.1. Model assumption

a. The number of injured people and relief commodity demand and services are uncertain.
b. Several kinds of commodity with the size, weight, buy cost and transportation cost are considered certain.
c. Relief commodities are sent from supply centers to distribution centers and temporary warehouses and they are sent from temporary warehouses to affected area.
d. Injured people are transferred from affected areas to hospitals and emergency medical centers, according to the type of injury.
e. Several types of vehicles with volume capacity and weight capacity are assumed.
f. Distribution centers could be setting up with different sizes.
g. Distribution centers have inventory of some commodity.
h. Distribution centers, temporary warehouses, hospitals and emergency medical centers have capacity.

i. The modeling scenario is assumed disaster intensity.
j. Supply centers have production capacity and sales capacity.

2.2. Sets:

A: set of affected nodes $a \in A$
D: set of relief commodity distribution centers $d \in D$
S: Set of relief commodity supply centers $s \in S$
H: Set of hospital centers $h \in H$
EH: set of emergency hospital centers $e \in EH$
G: set of temporary warehouses $g \in G$
C: Set of commodity type $c \in C$
W: Set of intensity of injured type $w \in W$
V: set of vehicle type $v \in V$
M: Set of size of distribution centers $m \in M$
T: Set of scenario type $t \in T$

2.3. Parameters:

CO_{ca}^{t} : commodity type c is needed in affected area a in scenario t
IP_{wa}^{t} : number of injured people, type w in affected area a, in scenario t
CSu_{cs} : number of commodity, type c at supply center s
$IVTR_{dc}$: inventory of commodity c in distribution center d
WCa_{v} : weight capacity of vehicle type v
VCa_{v} : volume capacity of vehicle type v
We_{c} : unit weight of commodity type c
Vo_{c} : unit volume of commodity type c
HCa_{hw} : hospital capacity for injured people type w in hospital h
DCa_{dmc}^{t}: distribution center capacity for commodity type c in distribution center d with size m in scenario t
GCa_{gc}^{t} : temporary warehouse capacity for commodity type c in temporary warehouse g in scenario t
ECa_{ew}^{t}: emergency medical center capacity for injured people type w in emergency medical center e in scenario t
IND_{dm}: setup cost of distribution center d with size m
ING_{g} : setup cost of temporary warehouse g
INE_{e} : setup cost of emergency medical center e
$DisSD_{sd}$: distance from supply center s to distribution center d
$DisSG_{sg}$: distance from supply center s to temporary warehouse g
$DisGA_{ga}$: distance from temporary warehouse g to affected area a
$DisDG_{dg}$: distance from distribution center d to temporary warehouse g
TC_{cv}: transportation cost of commodity c by vehicle v
TH_{wah}: transportation cost of injured people type w is transferred from affected area a to hospital h
TE_{ae} :transportation cost of injured people type w is transferred from affected area a to medical center e
CCo_{cs} : buying cost of commodity type c from supply center s
NV_{vs}: number of available vehicle type v in supply center s
NV_{vd} : number of available vehicle type v in distribution center d
NV_{vg}: number of available vehicle type v in temporary warehouse g
NA_{a} : number of available vehicle type v in affected area a
AmCa : ambulance capacity for injured people
PH_{dc}^{t}: transferred public donation type c in distribution center d in scenario t
F_{w} : weighted factor for priority service to injured people type w
U : great number

2.4. Variables:

YE_{wae}^{t} : number of transferred injured people type w from affected area a to emergency medical center e in scenario t
YH_{wah}^{t} : number of transferred injured people type w from affected area a to hospital h in scenario t
XSD_{sdcv}^{t} : number of transferred commodity type c from supply center s to distribution center d by vehicle v in scenario t
XSG_{sgcv}^{t}: number of transferred commodity type c from supply center s to temporary warehouse g by vehicle v in scenario t
XDG_{dgcv}^{t} :number of transferred commodity type c distribution center d to temporary warehouse g by vehicle v in scenario t
XGA_{gacv}^{t} :number of transferred commodity type c temporary warehouse g to affected area a by vehicle v in scenario t
PD_{dm} : if distribution center d with size m set up 1 other wise 0.
PE_{e} : if emergency medical center e set up 1 other wise 0.
PG_{g}: if temporary warehouse g set up 1 other wise 0.

2.5. Objective function:

1- The first objective function maximizes the satisfaction of the injured by maximizing minimum ratio of injured transfer to all injured to medical centers.

$$Max \quad Z_1 = \sum_{w} min_a \left[\frac{F_w * \sum_{e}\sum_{h}\left(YH_{wah}^{t} + YE_{wae}^{t}\right)}{IP_{wa}^{t}} \right] \tag{1}$$

2- The second objective function maximizes the satisfaction of the affected areas by maximizing minimum ratio of commodity distribution to all demands to affected areas.

$$Max \quad Z_2 = \sum_{c} min_a \left[\frac{\sum_{g}\sum_{v} XGA_{gacv}^{t}}{CO_{ca}^{t}} \right] \tag{2}$$

3- The third objective function minimizes total cost, which consist of set up cost, buy cost, and transportation costs.

$$Min\ \xi_{3t} = \sum_t \sum_d \sum_m IND_{dm} * PD_{dm} + \sum_t \sum_g ING_g * PG_g + \sum_t \sum_t INE_e * PE_e$$
$$+\sum_t \sum_s \sum_d \sum_c \sum_v TC_{cv} * DisSD_{sd} * XSD^t_{sdcv} + \sum_t \sum_s \sum_g \sum_c \sum_v TC_{cv} * DisSG_{sg} * XSG^t_{sgcv}$$
$$+\sum_t \sum_d \sum_g \sum_c \sum_v TC_{cv} * DisDG_{dg} * XDG^t_{dgcv} + \sum_t \sum_g \sum_a \sum_c \sum_v TC_{cv} * DisGA_{ga} * XGA^t_{gacv}$$
$$+\sum_t \sum_w \sum_a \sum_e TE_{ae} * YE^t_{wae} + \sum_t \sum_w \sum_a \sum_e TH_{ah} * YH^t_{wah}$$
$$+\sum_t \sum_s \sum_d \sum_c \sum_v CCo_{cs} * XSD^t_{sdcv} + \sum_t \sum_s \sum_g \sum_c \sum_v CCo_{cs} * XSG^t_{sgcv} \quad (3)$$

2.6. Linearize of first and second objective function

Before introducing constraints and entering the robust issue, first and second objective function become linear in the following way:

- First objective function

$$Max\ \ \xi_{1t} = \sum_w F_w B_{wt} \quad (4)$$

Subject to:

$$B_{wt} \le \left[\frac{F_w * \sum_e \sum_h \left(YH^t_{wah} + YE^t_{wae} \right)}{IP^t_{wa}} \right] \qquad \forall w \in W, a \in A, t \in T \quad (5)$$

- Second objective function

$$Max\ \ \xi_{2t} = \sum_c Q_{ct} \quad (6)$$

Subject to:

$$Q_{ct} \le \left[\frac{\sum_g \sum_v XGA^t_{gacv}}{CO^t_{ca}} \right] \qquad \forall c \in C, a \in A, t \in T \quad (7)$$

2.7. Constraints:

Constraints of this model include equation 6, 7 and the following:

$$\sum_d \sum_v XSD^t_{sdcv} + \sum_g \sum_v XSG^t_{sgcv} \le CSu_{cs} \qquad \forall s \in S, c \in C, t \in T \quad (8)$$

$$\sum_s \sum_v XSD^t_{sdcv} \le DCa^t_{dmc} \qquad \forall d \in D, m \in M, c \in C, t \in T \quad (9)$$

$$\sum_s \sum_v XSD^t_{sdcv} + IVTR_{dc} + PH^t_{dc} \ge \sum_g \sum_v XDG^t_{dgcv} \qquad \forall d \in D, c \in C, t \in T \quad (10)$$

$$\sum_s \sum_v XSG^t_{sgcv} + \sum_d \sum_v XDG^t_{dgcv} \ge \sum_a \sum_v XGA^t_{gacv} \qquad \forall g \in G, c \in C, t \in T \quad (11)$$

$$\sum_{d}\sum_{v} XDG_{dgcv}^{t} + \sum_{s}\sum_{v} XSG_{sgcv}^{t} \le GCa_{gc}^{t} \qquad \forall g \in G, c \in C, t \in T \qquad (12)$$

Equation (8) specifies the amount of sent commodities from supply centers cannot exceed its total capacity. Equation (9) states the sum of sent commodities to distribution centers should be less than its capacity. Equation (10) indicates the amount of existing commodities and the sent commodities (inventory and public aid) to distribution centers is larger than sent commodities to temporary warehouses from the distribution centers. Equation (11) specifies the amount of sent commodities to temporary warehouses is less than its capacity. Equation (12) states the amount of sent commodities to temporary warehouses is larger than the output commodities from these warehouses.

$$\sum_{d} XSD_{sdcv}^{t} * \mathrm{We}_c \le WCa_v * \mathrm{NV}_{vs} \qquad \forall \mathrm{s} \in S, \mathrm{v} \in V, c \in C, t \in T \qquad (13)$$

$$\sum_{g} XSG_{sgcv}^{t} * \mathrm{We}_c \le WCa_v * \mathrm{NV}_{vs} \qquad \forall \mathrm{s} \in S, \mathrm{v} \in V, c \in C, t \in T \qquad (14)$$

$$\sum_{g} XDG_{dgcv}^{t} * \mathrm{We}_c \le WCa_v * \mathrm{NV}_{vd} \qquad \forall \mathrm{s} \in S, \mathrm{v} \in V, c \in C, t \in T \qquad (15)$$

$$\sum_{a} XGA_{gacv}^{t} * \mathrm{We}_c \le WCa_v * \mathrm{NV}_{vg} \qquad \forall \mathrm{s} \in S, \mathrm{v} \in V, c \in C, t \in T \qquad (16)$$

$$\sum_{d} XSD_{sdcv}^{t} * \mathrm{Vo}_c \le VCa_v * \mathrm{NV}_{vs} \qquad \forall \mathrm{s} \in S, \mathrm{v} \in V, c \in C, t \in T \qquad (17)$$

$$\sum_{g} XSG_{sgcv}^{t} * \mathrm{Vo}_c \le VCa_v * \mathrm{NV}_{vs} \qquad \forall \mathrm{s} \in S, \mathrm{v} \in V, c \in C, t \in T \qquad (18)$$

$$\sum_{g} XDG_{dgcv}^{t} * \mathrm{Vo}_c \le VCa_v * \mathrm{NV}_{vd} \qquad \forall \mathrm{s} \in S, \mathrm{v} \in V, c \in C, t \in T \qquad (19)$$

$$\sum_{a} XGA_{gacv}^{t} * \mathrm{Vo}_c \le VCa_v * \mathrm{NV}_{vg} \qquad \forall \mathrm{s} \in S, \mathrm{v} \in V, c \in C, t \in T \qquad (20)$$

Equations (13) to (20) indicate the weight limitation and volume limitation for sent commodities considering the number of transportation vehicles.

$$\sum_{w}\sum_{h} \mathrm{YH}_{wah}^{t} \le \mathrm{NA}_a * \mathrm{AmCa} \qquad \forall \mathrm{a} \in A, t \in T \qquad (21)$$

$$\sum_{e} \mathrm{Y}E_{wae}^{t} \le \mathrm{NA}_a * \mathrm{AmCa} \qquad \forall \mathrm{a} \in A, t \in T \qquad (22)$$

Equations (21) and (22) limit the number of transferred injured people by the overall capacity of existing ambulances.

$$XGA_{gacv}^{t} \le U * PG_g \qquad \forall g \in G, \mathrm{a} \in A, c \in C, v \in V, t \in T \qquad (23)$$

$$XDG_{dgcv}^{t} \le U * PG_g \qquad \forall d \in D, g \in G, c \in C, v \in V, t \in T \qquad (24)$$

$$XDG_{dgcv}^{t} \le U * PD_{dm} \qquad \forall d \in D, g \in G, c \in C, v \in V, m \in M, t \in T \qquad (25)$$

$$XSD_{sdcv}^{t} \le U * PD_{dm} \qquad \forall s \in S, d \in D, c \in C, v \in V, m \in M, t \in T \qquad (26)$$

$$XSG_{sgcv}^{t} \le U * PG_g \qquad \forall s \in S, \mathrm{g} \in G, c \in C, v \in V, t \in T \qquad (27)$$

$$YE_{wae}^{t} \leq U * PE_{e} \qquad \forall w \in W, a \in A, e \in E, t \in T \qquad (28)$$

Equations (23) to (28) show commodities are transferred after set up distribution centers, temporary warehouses, and emergency medical centers.

$$\sum_{a} YH_{wah}^{t} \leq HCa_{hw} \qquad \forall w \in W, h \in H, t \in T \qquad (29)$$

$$\sum_{a} YE_{wae}^{t} \leq ECa_{e}^{t} \qquad \forall w \in W, e \in E, t \in T \qquad (30)$$

$$\sum_{e}\sum_{h}\left(YH_{wah}^{t} + YE_{wae}^{t}\right) \leq IP_{wa}^{t} \qquad \forall w \in W, a \in A, t \in T \qquad (31)$$

$$\sum_{g}\sum_{v} XGA_{gacv}^{t} \leq CO_{ca}^{t} \qquad \forall a \in A, c \in C, t \in T \qquad (32)$$

$$XGA_{gacv}^{t}, XSD_{sdcv}^{t}, XSG_{sgcv}^{t}, XDG_{dgcv}^{t}, YE_{wae}^{t}, YH_{wah}^{t} \geq 0, \text{integer} \qquad (33)$$

$$PD_{dm}, PE_{e}, PG_{g} \in \{0,1\} \qquad (34)$$

Equations (29) and (30) state the injured people can be transferred to hospitals and emergency medical centers only as many as their capacities. Equations (31) and (32) limit the services to the commodities and medical demands. Equations (33) and (34) indicate variables are not negative and they are integers and binary.

3. Scenario-Based Robust Optimization Method

Mulvey et al. propose two important definitions in the field of robust model. They are robust solution and robust model [24]. A robust solution for the optimization model remains optimal for all scenarios of input data. A robust model is valid for almost all scenarios of input data.

Yu and Li (2000) state the proposed model by Mulvey et al. require high computations due to being quadratic. Instead, they present the following equation [25].

$$Min \quad Z = \sum_{s \in S} P_s \xi_t + \lambda \sum_{s \in S} P_s \left[\left(\xi_t - \sum_{s' \in S} P_{s'} \xi_{s'}\right) + 2\theta_s\right] \qquad (35)$$

$$\xi_s - \sum_{s' \in S} P_{s'} \xi_{s'} + \theta_s \geq 0 \qquad (36)$$

$$\theta_s \geq 0 \qquad (37)$$

Where, p_s is the probability that scenario s occurs. This equation includes the mean of the scenario dependent objective functions, as well as a constant value, λ, multiplied by the variance of those functions. Moreover, θ_s is the linearization variable and equations (37) and (38) are used to linearize the variance expression. λ is also called the infeasible coefficient of the model.

3.1. Objective function reformulation based on robust planning

According to equations (35), (36) and (37), objective functions are reformulated as follows.

A - First objective function:

$$\max \quad \xi_{1t}' = \sum_{w}\sum_{t \in T} P_t B_{wt} - \lambda_1 \sum_{t,T} P_t \left[\left(\sum_{w} B_{wt} - \sum_{w}\sum_{t' \in T} P_{t'} B_{wt'}\right) + 2\theta_{1t}\right] \qquad (38)$$

With a linearization constraint:

$$\sum_{w} B_{wt} - \sum_{w}\sum_{t'\in T} P_{t'} B_{wt} + \theta_{1t} \geq 0 \qquad \forall t \in T \tag{39}$$

B - Second objective function:

$$\max \quad \xi_{2t}{}' = \sum_{c}\sum_{t\in T} P_t Q_{ct} - \lambda_2 \sum_{t,T} P_t \left[\left(\sum_{c} Q_{ct} - \sum_{c}\sum_{t'\in T} P_{t'} Q_{ct'} \right) + 2\theta_{2t} \right] \tag{40}$$

With a linearization constraint:

$$\sum_{c} Q_{ct} - \sum_{c}\sum_{t'\in T} P_t Q_{ct} + \theta_{2t} \geq 0 \qquad \forall t \in T \tag{41}$$

C - Third objective function:

$$Min \quad \xi_{3t}{}' = \sum_{t\in T} P_t \xi_{3t} + \lambda_3 \sum_{t,T} P_t \left[\left(\xi_{3t} - \sum_{t'\in T} P_{t'} \xi_{3t'} \right) + 2\theta_{3t} \right] \tag{42}$$

With a linearization constraint:

$$\xi_{3t} - \sum_{t'\in T} P_t \xi_{3t} + \theta_{3t} \geq 0 \qquad \forall t \in T \tag{43}$$

4. Weighted fuzzy goal programming:

Weighted fuzzy goal programming method is used for solving multi-objective robust model in this paper. The model is reformulated as follows: [26]

$$Max\ Weighted\ FGP = \sum_{k} w_k \varphi_k \tag{44}$$

Subject to:

$$\varphi_1 \leq 1 - \frac{u_1 - \xi_{1t}{}'}{u_1 - l_1} \tag{45}$$

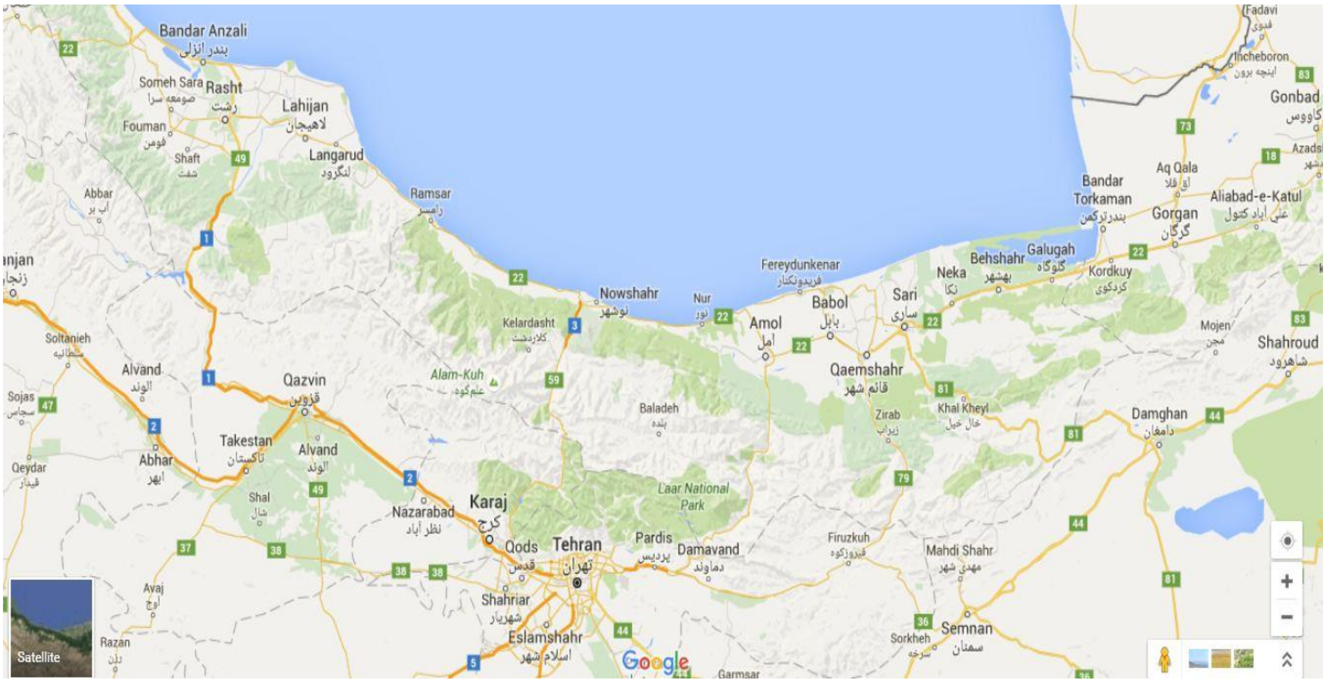
$$\varphi_2 \leq 1 - \frac{u_2 - \xi_{2t}{}'}{u_2 - l_2} \tag{46}$$

$$\varphi_3 \leq 1 - \frac{\xi_{3t}{}' - l_3}{u_3 - l_3} \tag{47}$$

And constraints (5) ، (7) ، (8) تا (34) ، (39) ، (41) و (43)

That equation (44), the objective function to maximize the satisfaction of decision maker and W_k is the weight of each objective and in equations (46) to (48) l and u are the minimum and maximum values of objective functions separately.

Figure2. Map of affected cities position



5. Case study

Since the northern regions of Iran are prone to floods, particularly Mazandaran, due to the excessive harvesting of natural resources, invading the river beds, constructing non-standard roads and bridges, and the vulnerability of this region against such disasters, three cities, Behshahr, Nowshahr, and Tonekabon, were selected as the vulnerable areas to floods. The three cities, Isfahan, Tehran, and Sari, were also considered as supply centers, which sell the necessary relief commodities. Supply capacity of these centers including 11000 tents, 30000 food packages, and 20000 sanitary packages. In this example, relief commodities include tents, food packages, and sanitary packages. Every Food packages for four individuals include 10k of rice, 16 food conserves, 3 cans of vegetable oil, 20 bottles of water. Sanitary packages for each four individuals consist of 6 bars of soap, 2 cans of washing powder, 8 gallons of water. The three states, Tehran, Semnan, and Gilan are the covering[1] states of Mazandaran. It means that distribution centers of the aforementioned states will send relief commodities to Mazandaran. Therefore, the four cities, Sari, Tehran, Semnan, and Gilan are considered the relief commodity distribution centers. Inventory of these centers contain some commodities and the rest are purchased. The hospitals considered in the problem include Omidi hospitals, Imam Khomeini Behshahr, Shahid Beheshti Nowshahr, Taleghani Chaloos, Rajaie Tonekabon, and Imam Sajjad Ramsar hospital. We must note that considering the low distance between cities of Nowshahr and Chaloos, as well as Tonekabon and Ramsar, the capacities of these hospitals are combined in the presented example. Emergency medical center of each city are deployed at the nearest location to that city. In sum, three hospitals and three Emergency medical centers are used as medical services. Moreover, hospitals and Emergency medical centers use ambulances with capacities of four individuals (two-way transportation for two individuals) to transfer the injured from the damaged regions. The cost of deploying centers is considered between one to four million Rials. Hospital capacity for first and second type injuries is respectively 100 to 200 and 80 to 120. Moreover, capacity of Emergency medical centers for first and second type injuries is respectively 30 to 40 and 20 to 30.

The problem scenario is the probability of the flood intensity. The probabilities of a low, average, and high intensity floods are respectively 0.20, 0.50, and 0.30. Different weights are considered to prioritize the transfer of the injured people depending on their injury type. More specifically, second type injuries are assumed more severe and have a larger weight (0.6) in comparison to that of first type injuries (0.4). Other necessary information is presented in the following tables.

Table1. Relief commodity demand

[1] Covering states are the states that support each other in case of a disaster.

Flood Intensity / Commodity-affected area	low	medium	high
Tent – Behshahr	3000	2000	1000
Tent – Noeshahr	3500	2500	1500
Tent – Tonekabon	4000	3000	2000
Food package – Behshahr	4800	3800	2800
Food package – Nowshahr	5500	4500	3500
Food package – Tonekabon	4500	3500	2500
Sanitary package – Behshahr	4000	3000	2000
Sanitary package – Nowshahr	5500	4500	3500
Sanitary package – Tonekabon	5200	4200	3200

Table2. Number of injured people

Flood Intensity / Injured type-affected area	low	medium	high
First type injured – Behshahr	110	80	50
First type injured – Noeshahr	100	70	40
First type injured – Tonekabon	120	90	60
Second type injured - Behshahr	90	60	30
Second type injured - Noeshahr	115	85	55
Second type injured – Tonekabon	105	75	45

Table3. Vehicle capacity

Vehicle type	Weight capacity(kg)	Volume capacity(m^3)
Pick up	2800	9
three-axle truck	10000	50
Four-axle truck	17000	90

Table4. Weight and volume of commodity

Commodity	Weight (kg)	Volume (m^3)
Tent	50	2
Food package	70	1
Sanitary package	42	1.5

Table5. Public aid to distribution centers

Distribution center	Sanitary package	Food package	tent
Sari	8000	10000	0
Tehran	10000	30000	0
Semnan	0	20000	0
Rasht	5000	15000	0

Table6. Inventory in distribution centers

Distribution center	Sanitary package	Food package	tent
Sari	0	10000	300
Tehran	1000	20000	500
Semnan	2000	30000	0
Rasht	0	5000	0

Table7. Capacity of distribution center

Size / Commodity- distribution center	low	medium	high
Tent - sari	200000	150000	100000
Food package - sari	400000	300000	200000
Sanitary package - sari	250000	200000	150000
Tent - Tehran	90000	80000	70000
Food package - Tehran	450000	350000	250000
Sanitary package - Tehran	500000	400000	300000
Tent - Semnan	160000	150000	140000
Food package - Semnan	440000	340000	240000
Sanitary package - Semnan	460000	360000	260000
Tent - Rasht	110000	100000	90000
Food package - Rasht	380000	280000	180000
Sanitary package - Rasht	200000	150000	100000

Table8. Capacity of temporary warehouses

commodity / Affected area	Sanitary package	Food package	tent
Behshahr	30000	30000	10000
Nowshahr	20000	20000	9000
Tonekabon	40000	40000	12000

Table9. Transportation cost of unit commodity per kilometers by different vehicle (Rial)

vehicle / commodity	Four-axle truck	three-axle truck	Pick up
tent	222	255	354
Food package	111	127	177
Sanitary package	166	190	256

Table10. Number of available vehicles in centers

	Ambulance	Four-axle truck	three-axle truck	Pick up
Behshahr	20	10	45	50
Nowshahr	16	15	65	70
Tonekabon	22	12	55	60
Distribution center Sari	-	30	40	50
Distribution center Tehran	-	10	20	30
Distribution center Semnan	-	20	30	45
Distribution center Rasht	-	15	25	35
Supply center Sari		20	30	40
Supply center Tehran		30	40	50
Supply center Esfahan	-	25	35	45

5.1. Solving result

This model is solved using GAMS 24.4.1 software with CPLEX solver on a computer with 4 GB of RAM, core™ i5, under win 7.
The propose model should be solved separately with fuzzy goal programming method. Thus three models solved. One model solved with goal of injured people satisfaction that equal to 0.891. The goal of commodity coverage equal to .0721 and the goal of minimum cost equal to 13,100,900,000.
Therefore, according to different decision under different conditions, the following results present sensitivity analysis for weight of objective functions.

Table11. Sensitivity analysis for weight of objective functions

Problem	Objective function	Weight of objective function	Available amount of function	Difference percentage between available and goal	Satisfaction of decision maker
1	Injured satisfaction	0.5	0.891	0	0.897
	Coverage of commodity distribution	0.3	0.631	12	
	Minimum cost	0.2	14,893,400,000	13	
2	Injured satisfaction	0.3	0.891	0	0.89
	Coverage of commodity distribution	0.6	0.715	0.8	
	Minimum cost	0.1	25,907,700,000	97	
3	Injured satisfaction	0.6	0.891	0	0.94
	Coverage of commodity distribution	0.1	0.537	25	
	Minimum cost	0.3	13,322,200,000	1.6	
4	Injured satisfaction	0.1	0.832	6.6	0.84
	Coverage of commodity distribution	0.3	0.608	15	
	Minimum cost	0.6	14,444,200,000	10	
5	Injured satisfaction	0.2	0.863	3.1	0.76
	Coverage of commodity distribution	0.6	0.672	6.7	
	Minimum cost	0.2	19,126,900,000	45	

Based on the sensitivity analysis in table 11, under different economic and social conditions, various decisions can be made regarding the weights. However, since this research discusses relief logistics in which social issues have a higher priority than economic issues, a method is selected that considers the importance of social issues. It means that the satisfaction of relief services is more important than the coverage of relief commodity distributions and costs. However, it does not mean that significant costs are expended to satisfy all demands. Therefore, a trade-off is made between different objective functions considering these priorities. Considering the

difference between efficient values of objective functions and goals, a method is selected, which maximizes the satisfaction of the decision maker and minimizes the different between all objective functions and goals.
In table 11 is seen, problem1, 2, and 3 result in the highest satisfaction of decision makers. However, in comparison to the first and second objective functions of problem 1, despite its highest satisfaction in transferring the injured and distributing commodities, the cost of weighted fuzzy goal problem 2 is 84% higher (i.e. 11014300000) to have 11% more coverage. Moreover, in problem 3, in order to reduce costs by 11.4% in comparison to problem 1, the decision maker should reduce commodity distribution coverage by 13% and settle for 54%, which is 25% less than the goal for commodity distribution satisfaction. Therefore, by selecting weighted fuzzy goal problem 1, a tradeoff is made between the goals and the following results are achieved by selecting the appropriate method:

5.2. Sensitivity Analysis for the Number of Ambulances

The number of available ambulances in the damaged areas can be considered as one of the main service elements in relief logistics. In the considered case study, the ambulance is the only means of transportation to transfer the injured.
Accordingly, considering the weighted fuzzy goal solution with weights 0.5, 0.3, and 0.2 for objective functions 1, 2, and 3, a sensitivity analysis is performed for the number of ambulances from a 50% reduction to a 50% increase. The following table and figure presents the results.

Table12. Sensitivity Analysis for the Number of Ambulances

Row	Variation of number of ambulance	Injured satisfaction	Cost function
1	Decrease 50%	0.494	14،523،200،000
2	Decrease 25%	0.682	14،655،100،000
3	0	0.891	14،893،400،000
4	increase 25%	0.967	15،235،900،000
5	increase 50%	0.967	15،235،900،000

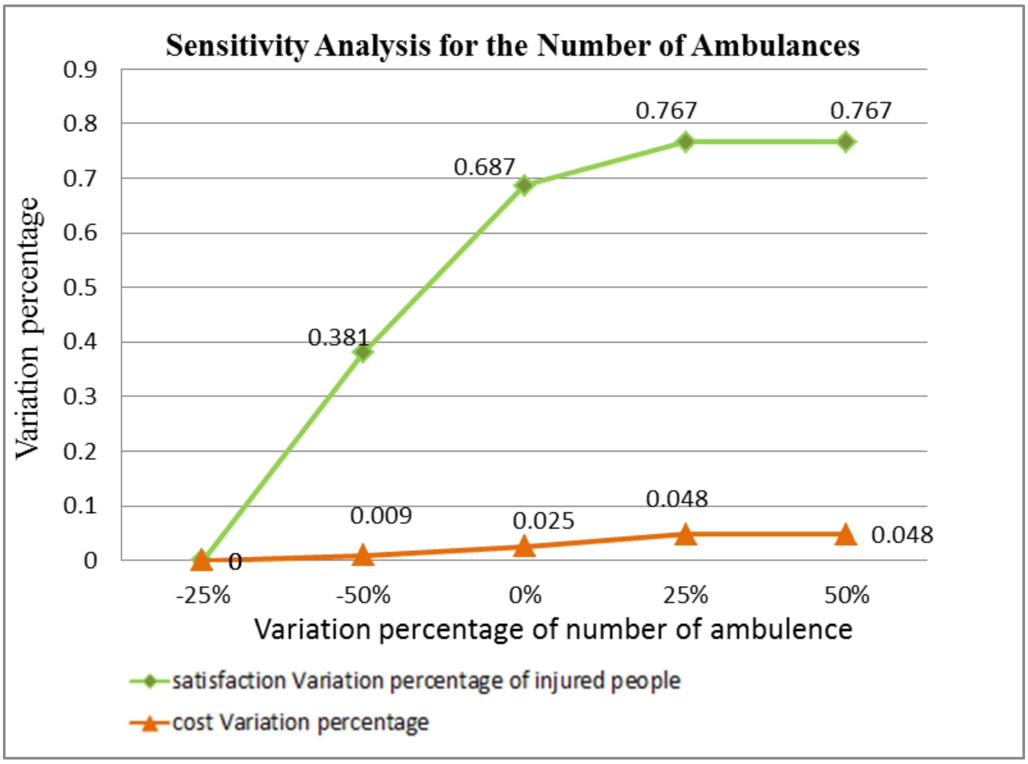
Figure3. 

Chart of Sensitivity Analysis for the Number of Ambulances

According to table 12 and figure 3, although costs are insignificantly increased (0.9%), increasing the number of ambulances from 1 to 2 significantly increases the servicing satisfaction (38%). Moreover, by changing it from 2 to 3, a 30% increase in satisfaction is ensued by a 1.6% increase. Finally, increasing the number of ambulances from 4 to 5 makes no change in servicing satisfaction and costs.

5.3. Sensitivity Analysis for the Number of vehicle

The number of available vehicles in temporary warehouses is one of the main elements of commodity distribution in relief logistics.
Therefore, considering the weighted fuzzy goal solution with weights 0.5, 0.3, and 0.2 for objective functions 1, 2, and 3, sensitivity analysis was performed for the number of transportation vehicles for a 50% reduction to a 75% increase. The following table and figure present the results.

Table13. Sensitivity Analysis for the Number of vehicle

Row	Variation of number of vehicle	Commodity coverage	Cost function
1	Decrease 50%	0.343	10،223،500،000
2	Decrease 25%	0.51	12،356،200،000
3	0	0.631	14،893،400،000
4	increase 25%	0.824	27،562،100،000
5	increase 50%	0.921	39،245،200،000
6	increase 75%	1	45،399،800،000

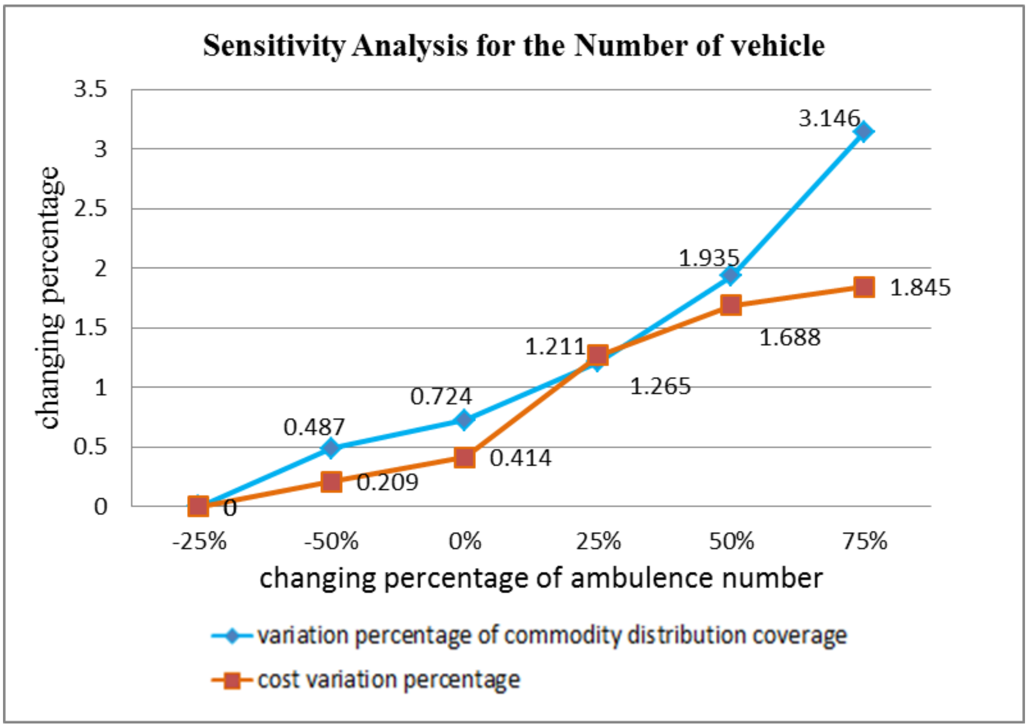


Figure4. Chart of Sensitivity Analysis for the Number of vehicle

According to table 13 and figure 4, it is clear that increasing the number of transportation vehicles from 1 to 2, costs are increased for 21% and commodity distribution coverage is significantly increased (49%). Moreover, increasing the number of transportation vehicles from 3 to 4 increases the costs by 80% and commodity distribution coverage by 50%.

We must note that it is clear in tables 12 and 13 and figures 3 and 4, that increasing equipment to a specific extent (which increases costs) can improve the satisfaction of the injured and commodity applicants and any further increase has no additional effect on satisfaction.

Therefore, according to the sensitivity analyses performed on the weights of objective functions, the number of transportation vehicles, and the number of ambulances, the corresponding model is solved and the following results are achieved considering the previous data.

table14. Percentage of injured satisfaction with injury type w in scenario t with more weight priority w_2

	t1	t2	t3
w1	0.700	0.694	0.691
w2	0.982	0.988	0.991

table15. Percentage of commodity coverage

	t1	t2	t3
c1	0.525	0.660	0.560
c2	0.591	0.593	0.692
c3	0.778	0.641	0.642

6. Results

This study first presented a general explanation of disaster and relief logistics. Relevant research and papers were then discussed regarding different relief logistics models in uncertain and certain environments.

Assumptions include four levels of relief commodity distribution and at the same, transferring the injured to medical centers (hospitals and emergency medical center), Intensity of disasters as model scenario and public aid, multi-objective relief logistics model, analyzes with multiple vehicles, multiple commodities, different types of injuries, and uncertain supply and demand. Finally, a scenario-based robust model was proposed. As it was mentioned, the first objective function maximizes the satisfaction of the injured regarding transfer to medical centers, the second objective function maximizes the satisfaction of the damaged regions regarding appropriate distribution of commodities, and the third objective function minimizes implementation, purchases, and transportation costs. Furthermore, the weighted fuzzy goal programming approach was used to solve the aforementioned multi-objective relief logistics model. Finally, a case study was used to prove the efficiency of the proposed model. Computational results of the sensitivity analyses regarding the weights of the fuzzy goal programming method indicate that the proposed model can be used in uncertainty and the event of disasters and to make different decisions under different conditions and priorities. The following issues are suggested to interest researchers to complement this research: considering inventory management of temporary warehouses and distribution centers for a multi-stage response phase, costs of purchasing ambulances and different transportation vehicles, multi-period response times, the objective to minimize the response time, comprehensive models which integrate multiple stages of disasters, issues of transportation vehicle scheduling and routing.

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