IJE TRANSACTIONS B: Applications Vol. 33, No. 5, (May 2020) 814-824

International Journal of Engineering

Journal Homepage: www.ije.ir

Multi-objective Optimization of Multi-vehicle Relief Logistics Considering Satisfaction Levels under Uncertainty

H. Beiki[a], S. M. Seyedhosseini*[b], V. R. Ghezavati[a], S. M. Seyedaliakbar[a]

[a] *School of Industrial Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran*
[b] *Department of Industrial Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran*

PAPER INFO

Paper history:
Received 03 February 2020
Received in revised form 18 February 2020
Accepted 06 March 2020

Keywords:
Disaster Relief
Location-Routing Problem
Multi-objective Optimization
Response Phase
Reverse Logistics

ABSTRACT

Today, there is a high number of injuries and various wastes and debris produced during natural and unnatural events. This study aims to investigate the reverse logistics planning problem in the response and reaction phases as well as improvement and reconstruction in earthquake conditions by using a real case study. Regarding the high complexity of this type of optimization problem, a multi-objective model as a multi-vehicle relief logistic problem considering satisfaction levels, is developed concerning the environmental conditions paying attention to uncertainty. To address the problem, an exact solver by using epsilon constraint method is conducted to validate the model. To solve the model optimality, a well-established non-dominated sorting genetic algorithm is tuned and compared with multi-objective particle swarm optimization algorithm to solve the model. Having a conclusion about the main finding of this research, the use of the reverse logistics in the response and the recovery phases has been approved by the results of this paper. Most broadly, the application of the proposed model is validated by using a real case in Tehran, Iran to show the managerial insights of this research.

doi: *10.5829/ije.2020.33.05b.13*

1. INTRODUCTION AND LITERATURE REVIEW

Today, the natural disaster (crisis) has been dramatically increased. According to recent statistics, approximately 70,000 people were killed and 200 million injured per year [1–3]. The main logistics role in the Indian Ocean tsunami in 2004 attracted the attention of researchers [4–7]. According to Özdamar and Demir [8], "Logistics is part of any crisis-saving operation that means the difference between success and failure in operations." Given a high number of injuries and various wastes and debris produced during natural and unnatural events, the needs and benefits of an effective planning and action is highly suggested to collect and to transfer the injured individuals to treatment centers during the reaction phase [9, 10]. Additionally, in the recovery and reconstruction phase, since large volume of hazardous and non-hazardous wastes are produced during catastrophes, effective measures should be taken to collect and to recycle them if necessary. These activities are the main parts of the reverse or the closed-loop options for supply chin and logistic networks [11–14]. In accordance with the global statistics released in the past 7-8 years, the Islamic Republic of Iran is ranked as seventh among the ten countries with the highest rate of disasters in the world. Hence, it is considered to be a high-risk country with several natural events such as earthquake and flood [11–13]. Based on the reports published during the last two decades, nearly 10% of the whole population of Iran has been killed, suffered losses, or injured in some way due to natural disasters, which is a significant figure [14, 15]. This motivates several studies about relief logistics to address this grand challenge in Iran [16–18].

To assess the literature of relief logistics, no doubt that location and routing decisions are among the problems that have been well-studied in the disaster context [19–22]. Combining of these two problems generates a combinatorial optimization problem which is difficult to solve and NP-hard [21–25]. Since there are many objectives to be minimized and maximized for

*Corresponding Author Email: *seyedhosseini@iust.ac.ir* (S. M. Seyedhosseini)

Please cite this article as: H. Beiki, S. M. Seyedhosseini, V. R. Ghezavati, S. M. Seyedaliakbar, Multi-objective Optimization of Multi-vehicle Relief Logistics Considering Satisfaction Levels under Uncertainty, International Journal of Engineering (IJE), IJE TRANSACTIONS B: Applications Vol. 33, No. 5, (May 2020) 814-824

relief items, the literature is rich in using optimization models and algorithms [26–34]. Here, a brief literature about the studies during the last decade is provided.

As one of well-cited papers, Fetter and Rakes [19] carried out a study on recycling of the post-event waste and declared that a large volume of waste is produced after the disaster, and presented a model to optimize the waste recycling and disposal sites. In 2011, Brown et al. [5] addressed the waste management issues in a review study by discussing various aspects including temporary storage, recycling, and disposal sites, as well as social health and economic issues. In another study in 2012, Özdamar and Demir [8] proposed a model to transfer the relief materials to the damaged areas, in addition to discharging the injured individuals and taking them to hospitals. Next in 2014, Rath and Gutjahr [31] presented a three-objective optimization problem with a mid-term economic section and a short-term economic section as well as a disaster objective function. Then, they designed a heuristic method to solve this problem in addition to developing a metaheuristic approach based on the genetic algorithm. In 2017, Zhou et al. [35] developed a decision-making problem used by rescue agencies to plan for more emergency logistics preparedness during floods in a multi-vehicle mode. In this study, the flood emergency logistics problem was modeled as random planning. To do this, four types of support activities were considered and all points in the network were divided into five groups. Li et al. [26] analyzed the transport of large volumes of goods in an efficient approach to minimize the loss of life with several types of vehicles (multi-vehicle mode) for rescue operations. By using a case study in Shanghai, China, they examined and located intermediate warehouses to minimize transportation costs. Ultimately, they investigated the disaster rescue route with routing approaches and provided the practical solutions.

Recently in 2018, Noyan et al. [30] presented a probabilistic mathematical model for the location and allocation of distribution centers to relief resources in the post-crisis conditions. Considering justice in disaster relief, budget constraints, and resource availability in a multilevel supply chain were among the innovations of this study. The branch-and-cut algorithm was employed to solve the proposed problem, besides, the validity of the proposed model was tested for 2011 earthquake in Turkey. Habibi-Kouchaksaraei et al. [22] presented a robust multi-objective model to locate blood centers and hospitals in disaster times. The main objective in this study was to specify the optimal number of facilities and their allocation strategies under different scenarios. The proposed model was solved by the ideal planning and Ghaemshahr City, Iran, was chosen as a case study to present the accuracy of the model performance. In 2018, Maharjan and Hanoaka [28] suggested a multi-objective mathematical model for locating temporary hubs in the earthquake conditions. This study was performed aiming to minimize costs and unsatisfied demands for the injured people. A fuzzy weighting strategy was employed to solve this two-objective model. The case study considered was 2015 Nepal earthquake. The results indicated the accurate performance of the proposed model.

More recently in 2019, Rajendran and Ravindran [32] proposed a stochastic integer programming model under demand uncertainty to determine ordering policies along the blood supply chain. Regarding the complexity of the proposed problem, a variant of the genetic algorithm, called Modified Stochastic Genetic Algorithm (MSGA), is proposed for large-sized problems. In another study, Hamdan and Diabat [23] presented a two-stage stochastic model to formulate the blood supply chain based on the red blood cells products. In the first stage, the problem determines the number of mobile blood collection facilities to deploy, while the second stage determines inventory and production decisions. The model contributes to three objectives including the total cost, the number of outdated units and blood delivery time, simultaneously. They utilized the exact method to solve the proposed problem. Furthermore, Dutta and Nagurney [10] presented a multi-tiered competitive supply chain network model for the blood banking industry, with a focus on the United States. They modeled the behavior of each category of stakeholder and used the theory of variation inequalities to derive the equilibrium conditions for the entire supply chain. In another study, Rajendran and Srinivas [33] proposed two new variants of review policies which are compared against two well-performing ordering policies in the literature, for real-life hospital settings by considering unique characteristics such as weekday/weekend demand fluctuation and varying shelf-life of platelet units received. At last but not least, Safaeian et al. [34] proposed a supplier section and order allocation considering the customers' satisfaction and quality of the products with incremental discount within the possibility of the case of disaster. They applied a classical fuzzy approach to handle the uncertainty of their problem. Also, a non-dominated sorting genetic algorithm is considered to solve the large sizes.

Reviewing the studies performed, the following research gaps have been identified:

- There is a great deal of interest in employing uncertainty models regarding the lack of knowledge about environment, data, information, and available resources. However, few studies have addressed the issue of uncertainty with fuzzy model. This paper proposes a multi-objective fuzzy model to formulate the proposed location-routing problem for a multi-vehicle relief logistics.
- Based on the application of relief logistics, using case studies and real data are highly recommended. Since applying real problems are a good measurement criterion

to show the model performance and practical solutions, a case study in Tehran, Iran, is done in the study that can significantly help the research process.

- As the location-routing problems are NP-hard, another point is the development and application of heuristic and metaheuristic methods. This study uses a well-established evolutionary metaheuristic for multi-objective optimization called non-dominated sorting genetic algorithm as well as a well-known established swarm algorithm called the multi-objective of particle swarm optimization algorithm.

The rest of this paper is organized as follows. The proposed problem and optimization model have been illustrated in Section 2. Our real example is addressed in Section 3. The solution algorithms are conducted in Section 4. Our computational analyses, validation, comparison of the algorithms and sensitivities are given in Section 5. Finally, the conclusion, main findings and managerial insights as well as future works are recommended in Section 6.

2. PROBLEM DESCRIPTION

The present study proposes an integrated model in two phases of preparedness and response for the location, allocation, and routing in the disaster rescue logistics. The occurrence of a disaster is one of the reasons that requires the model uncertainty to be examined. The uncertainty considered in this study is a scenario and has been optimized on the basis of different scenarios. These scenarios can differ depending on the time of the earthquake or its severity. In this study, the reverse logistics planning problem in the response and reaction phases as well as the recovery and reconstruction in the earthquake circumstances will be investigated. Given the nature of the problem, it is predicted to encounter a multi-objective problem, in addition, the environmental conditions governing the problem require considering uncertainty; in this case, the problem can be discussed in both the information uncertainty and certainty states. Given the issues discussed above, the problem of reverse logistics in the response phase and the recovery phase has been examined in the present study. The innovations of the present study are as follows:

✓ It has been attempted in this study to incorporate the various parts of the rescue logistics network involved in the disaster rescue operations; so that the model presented includes the disaster-affected areas, distribution centers, shelters, burial centers, and hospitals. Considering more levels in the rescue chain helps to its higher integrity and makes the model closer to the real world and more applicable.

✓ In the real world, the problem parameters are time-dependent and dynamic; however, in many studies, the planning horizons have been considered as single-period rather than multi-period. In this study, the model was considered to be as multi-period.

✓ In a large number of studies, the problem has been formulated on a single-good basis; however, several essential goods are required to be distributed in the disaster conditions, including potable water, food, drug, clothing, relief tents, etc. In some cases, these commodities need to be distributed simultaneously, so the model must be formulated on the basis of multiple goods. Various rescue goods have been considered in the present study.

✓ A large number of studies have considered one type of vehicle and one mode of transportation. However, several modes of transportation (multi-vehicle) have been considered with different types of vehicles in this study.

✓ In this study, a model was considered with various sources of uncertainty as integrated including supply and demand, which is a very important issue, since the interaction between these sources of uncertainty makes the decision making difficult.

✓ In this study, several capacity options were considered for the distribution centres and the capacity of the shelters was a model output determined by the model.

✓ In most studies, the presented models are single-objective with the goal of minimizing total cost or minimizing total time. In fact, the objective in most studies is either minimizing costs or humanitarian purposes. The proposed model is a multi-objective and the cost minimization and humanitarian objectives are considered simultaneously.

✓ In this model, some objective functions are considered to minimize a maximum value, indicating justice in service distribution. For simplicity, these goals are changed into the service-level and satisfaction-level constraints.

✓ Distribution of perishable goods should also be taken into account in the studies, because goods such as potable water, food, and medicines that are essential items for distribution are considered among the perishable goods.

✓ Applying the model to a real-world case study is done.

Here, we define our optimization model to formulate the proposed location-routing problem considering multi-vehicle for relief logistics. The model characteristics and assumptions are listed as follows:

1. The number and location of hospitals, waste collection centers, and the disaster-affected areas are fixed and specified.
2. The weight and volume capacity of each vehicle for carrying goods or individuals is specified.
3. Several capacity options are regarded for the construction of the distribution centers.
4. There are potential locations specified for the construction of shelters and distribution centers.
5. Every vehicle is allowed to carry a specified load.

6. Justice considerations in the distribution of services such as distribution of goods, evacuation of the injured people, and dispatch of the relief personnel are regarded in the model and constraints regarding the satisfaction levels are expressed. This leads to covering the demand of certain areas to a certain level.

All notations including indices, parameters and decision variables are given as follows:

Indices:

$t, \acute{t}$	Time periods along the programming horizon, $t, \acute{t} = 1,2,\ldots,T$
f	Potential nodes for the construction of a shelter, $f = 1,2,\ldots,F$
g	Nodes of waste collection centers , $g = 1,2,\ldots,G$
r	Particular types of medical and rescue personnel, $r = 1,2,\ldots,R$
j	Specific capacity option for the distribution centers $j = 1,2,\ldots,J$
y	Particular routes, $y = 1,2,\ldots,Y$
d	Nodes of the earthquake − affected areas, $d = 1,2,\ldots,D$
l	Potential nodes for the construction of the distribution centers, $l = 1,2,\ldots,L$
q	Hospital nodes, $q = 1,2,\ldots,Q$
o, p	Potential nodes for the construction of the distribution centers and shelters, $o, p = 1,2,\ldots,N$
c	Particular goods associated with the distribution centers, $c = 1,2,\ldots,C$
v	Particular vehicles, $v = 1,2,\ldots,V$
h	Types of injury, $h = 1,2,\ldots,H$
s	Set of scenarios, $s = 1,2,\ldots,S$

Parameters:

pl_f	Fixed cost of construction of a shelter at site *f*
vl	Variable cost of shelter for unit capacity per individual
f'_{lj}	Cost of construction of a distribution center at site *l* with the capacity option *j*
Fk_v	Fixed cost of launching vehicle *v*
vrc_v	Variable cost of moving vehicle type *v* per unit distance
d'_{rds}	Number of type *r* rescue personnel required in the affected area *d* at the beginning of the earthquake event and in scenario *s*
d''_{hds}	Number of the individuals with type *h* injuries needing service in the affected area *d* at the beginning of the earthquake event and in scenario *s*
pp_{ds}	Healthy earthquake-hit population and the individuals with outpatient injuries requiring discharge in the affected area *d* in scenario *s*
cr_{ds}	Number of corpses needed to be discharged in the affected area *d* in scenario *s*
cw^v	Weight capacity of vehicle type *v* to carry goods
cv^v	Volume capacity of vehicle type *v* to carry goods
cm^v	Capacity of a number of type *v* vehicles to carry rescue personnel
cph^v	Capacity of a number of type *v* vehicles to carry the injury
ss_{rqs}	Number of medical staff and relief type *r* provided in hospital *q* in scenario *s*
bd_{hqs}	Capacity of hospital *q* to admit the individuals with type *h* injuries in scenario *s*
cpp^v	Capacity of a number of type *v* vehicles to carry earthquake-hit individuals and the individuals with outpatient injuries
cpc^v	Capacity of a number of type *v* vehicles to carry the corpses
cy_j	Capacity of the capacity option *j* for the distribution centers
q_{qd}	Distance between hospital *q* and affected area *d*
q'_{op}	Distance between nodes *o* and *p*
q''_{dq}	Distance between affected area *d* and hospital *q*
q'''_{dg}	Distance between affected area *d* and waste collection center *g*
lng^{y}_{df}	Length of the route *y* from the affected area *d* to shelter *f*
M_{Big}	A large positive number
wt_c	Weight of a unit of good type *c*
vlm_c	Volume of a unit of good type *c*
po_s	Probability of occurrence of scenario *s*
co_c	A fraction of the capacity of the distribution center considered to store good *c*
pb^{y}_{dfs}	Probability of successful passing in the route *y* from the affected area *d* to the shelter *f* in scenario *s*
vrh_{ct}	Amount of good type *c* at time *t* consumed per the injured individual
alw_{dg}	$\begin{cases} 1 & \text{If the corpses in the affected area } d \text{ are allowe to be transported to collection center } g \\ 0 & \text{Otherwise} \end{cases}$

Variables:

lo_f	$\begin{cases} 1 & \text{If the shlter is built at site } f \\ 0 & \text{Otherwise} \end{cases}$
lo'_{lj}	$\begin{cases} 1 & \text{If the distribution center with capacity option } j \text{ is built at site } l \\ 0 & \text{Otherwise} \end{cases}$
ru^{y}_{dfs}	$\begin{cases} 1 & \text{If distance } y \text{ is selected from } d \text{ to } f \text{ inscenario } s \\ 0 & \text{Otherwise} \end{cases}$
lb^{t}_{cops}	Amount of good type *c* transported from node *o* to node *p* at time *t* in scenario *s*
gc_{rqds}	Number of *r*-type rescue personnel transferred from hospital *q* to affected area *d* in scenario *s*
kn_{hdqs}	Number of individuals with *h*-type injuries transferred from affected area *d* to hospital *q*in scenario *s*
Bc_{dfs}	Number of earthquake-hit individuals or individuals with the outpatient injuries transferred from affected area *d* to shelter *f* in scenario *s*
pd_{dgs}	Number of corpses transferred from affected area *d* to waste collection center *g* in scenario *s*
vn^{v}_{dfs}	Number of vehicles *v* traveling from affected area *d* to shelter *f* in scenario *s*
vn'^{v}_{dgs}	Number of vehicles *v* traveling from affected area *d* to waste collection center *g* in scenario *s*
vn''^{v}_{dqs}	Number of vehicles *v* traveling from affected area *d* to hospital *q* in scenario *s*
vn'''^{v}_{qds}	Number of vehicles *v* traveling from hospital *q* to affected area *d* in scenario *s*
vc^{vt}_{ops}	Number of vehicles *v* traveling from node *o* to node *p*in scenario *s*
Bs_{cfts}	Amount of unsatisfied demand for good type *c* in shelter *f* node at time *t* in scenario *s*

Bm_{rds} Unsatisfied demand for medical personnel and relief type *r* in affected area *d* at the time of the earthquake event in scenario *s*
Bw_{hds} Number of unserved individuals with type *h* injury in affected area *d* at the time of the earthquake event in scenario *s*
sf_{cfts} Amount of excess good type *c* in shelter *f* at time *t* in scenario *s*
sd_{rds} Number of excess personnel type *r* in affected area *d* in scenario *s*
k'_{cfts} Amount of required good type *c*at shelter *f* node at time *t* in scenario *s*
ch_f Capacity of shelter built at site *f*

Regarding the proposed optimization model, it briefly includes location, allocation, and routing in the disaster circumstances and is a multi-good, multi-period, and multi-vehicle model.

$$min\ f_1 = \sum_{s=1}^{S} Po_s \sum_{h=1}^{H} \max_d\{Bw_{hds}\} \quad (1)$$

$$minf_2 = \sum_{f=1}^{F} pl_f . lo_f + \sum_{f=1}^{F} vl . ch_f + \sum_{l=1}^{L}\sum_{j=1}^{J} f'_{lj} . lo'_{lj} + \sum_{s=1}^{S}\sum_{v=1}^{V} \mathrm{vrc_v} . \mathrm{po_s}[\sum_{d=1}^{D}\sum_{q=1}^{Q} q''_{dq} . vn''^{v}_{dqs} + \sum_{d=1}^{D}\sum_{f=1}^{F}\sum_{y=1}^{Y} lng^{y}_{df} . vn^{v}_{dfs} + \sum_{d=1}^{D}\sum_{g=1}^{G} q'''_{dg} . vn'^{v}_{dgs} + \sum_{q=1}^{Q}\sum_{d=1}^{D} q_{qd} . vn'''^{v}_{qds} + \sum_{o=1}^{O}\sum_{p=1}^{P}\sum_{t=1}^{T} q'_{op} . vc^{vt}_{ops}] + \sum_{s=1}^{S}\sum_{v=1}^{V} \mathrm{fk_v} . \mathrm{po_s}\ [\sum_{d=1}^{D}\sum_{q=1}^{Q} vn''^{v}_{dqs} + \sum_{d=1}^{D}\sum_{f=1}^{F} vn^{v}_{dfs} + \sum_{d=1}^{D}\sum_{g=1}^{G} vn'^{v}_{dgs} + \sum_{q=1}^{Q}\sum_{d=1}^{D} vn'''^{v}_{qds} + \sum_{o=1}^{O}\sum_{p=1}^{P}\sum_{t=1}^{T} vc^{vt}_{ops}] \quad (2)$$

$$\sum_{d=1}^{D} \mathrm{gc_{rqds}} \le ss_{rqs} \quad \forall \mathrm{r}, q, \mathrm{s} \quad (3)$$

$$\sum_{j=1}^{J} \mathrm{lo'_{lj}} \le 1 \quad \forall l \quad (4)$$

$$\sum_{d=1}^{D}\sum_{v=1}^{V} Bc_{\mathrm{dfs}} \le ch_f \quad \forall \mathrm{f}, s \quad (5)$$

$$\sum_{p=1}^{P} \mathrm{lb^{t}_{clps}} \le \sum_{j=1}^{J} \mathrm{cy_j} . lo'_{lj} . co_c \quad \forall \mathrm{c, l, t, s} \quad (6)$$

$$\sum_{y=1}^{Y} ru^{y}_{dfs} \le 1 \quad \forall \mathrm{d, f, s} \quad (7)$$

$$Bc_{\mathrm{dfs}} \le M_{Big} . \sum_{y=1}^{Y} \mathrm{ru^{y}_{dfs}} . \mathrm{pb^{y}_{dfs}} \quad \forall \mathrm{d, f}, s \quad (8)$$

$$\sum_{y=1}^{Y} \mathrm{ru^{y}_{dfs}} \le \mathrm{lo_f} \quad \forall \mathrm{d, f, s} \quad (9)$$

$$\sum_{d=1}^{D} Bc_{\mathrm{dfs}} . vrh_{ct} = k'_{cfts} \quad \forall \mathrm{f, t, c, s} \quad (10)$$

$$\sum_{\acute{t}=1}^{t}\sum_{o=1}^{O} \mathrm{lb^{\acute{t}}_{cofs}} - \sum_{\acute{t}=1}^{t}\sum_{p=1}^{P} \mathrm{lb^{\acute{t}}_{cfps}} - \sum_{\acute{t}=1}^{t} k'_{cf\acute{t}s} = sf_{cfts} - Bs_{\mathrm{cfts}} \quad \forall \mathrm{f, c}, t, s \quad (11)$$

$$\sum_{q=1}^{Q} \mathrm{gc_{rqds}} - d'_{rds} = sd_{rds} - Bm_{\mathrm{rds}} \quad \forall \mathrm{d, r}, s \quad (12)$$

$$\sum_{q=1}^{Q} \mathrm{Kn_{hdqs}} + Bw_{\mathrm{hds}} = d''_{hds} \quad \forall \mathrm{d, h}, s \quad (13)$$

$$ch_{\mathrm{f}} \le \mathrm{M_{Big}} . lo_f \quad \forall f \quad (14)$$

$$\sum_{f=1}^{F} Bc_{\mathrm{dfs}} = pp_{ds} \ \forall \mathrm{d, s} \quad (15)$$

$$\sum_{g=1}^{G} pd_{\mathrm{dgs}} = \mathrm{cr_{ds}} \quad \forall \mathrm{d, s} \quad (16)$$

$$\sum_{c=1}^{C} \mathrm{lb^{t}_{cops}} . wt_c \le \sum_{v=1}^{V} vc^{vt}_{ops} . cw^{v} \quad \forall \mathrm{o}, p, t, s \quad (17)$$

$$\sum_{r=1}^{R} \mathrm{gc_{rqds}} \le \sum_{v=1}^{V} vn'''^{v}_{qds} . cm^{v} \quad \forall \mathrm{q}, d, s \quad (18)$$

$$\sum_{h=1}^{H} \mathrm{kn_{hdqs}} \le \sum_{v=1}^{V} vn''^{v}_{dqs} . cph^{v} \quad \forall\ d, q, s \quad (19)$$

$$Bc_{\mathrm{dfs}} \le \sum_{v=1}^{V} vn^{v}_{dfs} . cpp^{v} \quad \forall \mathrm{d}, f, s \quad (20)$$

$$\sum_{c=1}^{C} \mathrm{lb^{t}_{cops}} . \mathrm{vlm_c} \le \sum_{v=1}^{V} vc^{vt}_{ops} . cv^{v} \quad \forall \mathrm{o}, p, t, s \quad (21)$$

$$pd_{\mathrm{dgs}} \le \sum_{v=1}^{V} vn'^{v}_{dgs} . cpc^{v} \quad \forall \mathrm{d, g, s} \quad (22)$$

$$\sum_{d=1}^{D} \mathrm{kn_{hdqs}} \le bd_{\mathrm{hqs}} \quad \forall \mathrm{h, q, s} \quad (23)$$

$$pd_{\mathrm{dgs}} \le M_{Big} alw_{dg} \quad \forall \mathrm{d, g, s}$$

$$k'_{\mathrm{cfts}}, Bs_{\mathrm{cfts}}, Bm_{\mathrm{rds}}, Bw_{hds}, Sf_{\mathrm{cfts}}, sd_{rds}, vn^{v}_{dfs}, vn'^{v}_{dgs}, vn''^{v}_{dqs}, vn'''^{v}_{qds}, vc^{vt}_{ops}, \mathrm{lb^{t}_{cops}}, \quad (24)$$

$$\mathrm{gc_{rqds}}, kn_{\mathrm{hdqs}}, Bc_{\mathrm{dfs}}, pd_{\mathrm{dgs}}, ch_f \ge 0\ \&\ Integer\ ;\ lo_f, lo'c_{\mathrm{lj}}, \mathrm{ru^{y}_{dfs}} \in \{0,1\} \quad (25)$$

Objective Function (1) is associated with the satisfaction levels. This equation is used to minimize the maximum number of the unserved injured people in the affected areas (taking into account justice). Objective Function (2) is used to minimize the sum of costs.

Regarding the limitations of our model, Constraint (3) indicates that the number of the r-type rescue personnel sent from hospital q should not exceed the number of the personnel available in that hospital. Constraint (4) guarantees that a maximum of one distribution center is constructed with a specified capacity option in each location. Given Constraint (5), the number of the earthquake-hit individuals transferred to shelter f from different incident areas shall not exceed its maximum allowable capacity. Constraint (6) guarantees that the number of the goods type *c* sent from distributor *l* should not exceed its supplied amount. In accordance with Constraint (7), it is guaranteed that at most one route is selected from each affected area to each shelter. Constraint (8) indicates that the earthquake-hit individuals are transported from disaster area *d* to shelter f if a route is selected between them and that route is available. Constraint (9) states that a route is selected from affected area d to shelter in case a shelter is constructed at site *f*. Constraint (10) determines the demand for a good in each shelter. Constraint (11) expresses the unsatisfied demand or excess goods in each shelter. Constraint (12) defines the unsatisfied demand and surplus rescue personnel for each disaster area. Constraint (13) defines the unserved injured people for each type of injury in each disaster area. Constraint (14) indicates that a capacity is allocated to the shelter of the region f provided that a shelter is constructed in. Constraint (15) states that all healthy earthquake-affected individuals and the outpatient injured people should be discharged from the affected areas. Constraint (16) ensures that all corpses are discharged from the affected area. Constraint (17) indicates the weight capacity limitation of vehicles to carry goods. Constraint (18) expresses the vehicle capacity limitation to carry rescue personnel. Constraint (19) states the limitation of the capacity of vehicles to carry the injured. Constraint (20) indicates the capacity limitation of the vehicles to carry the earthquake-hit people. Constraint (21) shows the volume capacity limitation for vehicles to carry goods. Constraint (22) states the vehicles' capacity limitation to carry corpses. Constraint (23) guarantees that the number of the h-type injured individuals in each hospital does not exceed the capacity of that hospital to admit the individuals with h-type injuries. Constraint (24) announces that the corpses in the incident area d are carried to the waste collection center g on the condition that the transfer of the corpses from this area to the waste collection center g is allowed. Constraint (25) states that the variables are of type integer and zero and one.

3. REAL EXAMPLE OF THE MODEL

Taking into account the importance of the problem, studying the earthquake event in Tehran, Iran as a real example of the model seems highly necessary. Therefore, the model presented in this study was applied to the Tehran case study. For preparation for disasters, sheds should be built in different areas to accommodate the earthquake-affected individuals in times of disaster. As given in Table 1, Ayatollah Taleghani, Azadeghan, Behesht-e Madaran, and Beihaghiparks were considered for this purpose which are located in an appropriate distance from the affected areas, so that in addition to faster discharge of the earthquake-hit individuals, should be safe enough in the event of aftershocks. Furthermore, warehouses and distribution centers must also be constructed in these shelters to supply the needs of individuals. For this purpose, three candidate parks of Andisheh Park, SaeiPark,and ShafaqGhanbari Park were considered. The people injured due to the earthquake should be carried to the suitable hospitals and medical centers. Four hospitals of Imam Hossein, 15 Khordad, Dr. Shariati, and Imam Khomeini were considered due to the proximity to the affected areas and providing proper general and specialized services. Center 1 was the only recycling center in this study to where the corpses should be transported. Demand areas, shelter sheds, sheds of distribution centers, hospitals, and recycling centers are given in Table 1.

In this study, three categories of relief personnel including doctors, nurses, and rescuers were considered who were sent from the hospitals available in the desired area. In the present study, each medical team was assumed to include one doctor, two nurses, and four rescuers. Each hospital has a limited potential to send the personnel of any category. The number of the relief personnel required in each area who must be sent from hospitals and Red Crescent centers to the area was calculated as a percentage of the area's population and the severity of the incident. The number of the relief personnel of any category required in each incident area and the dispatch capacity of each hospital for each category of the relief personnel are presented in Tables 2 and 3.

The golden time in relief operations considered in this study was the first 72 hours after the incident, during which some key operations such as triage operations,

TABLE 1. Demand areas, shelter sheds, sheds of distribution centers, hospitals, and recycling centers in the case study

Demand areas	Shelter sheds	Distribution sheds	Hospitals	Recycling centers
Area 1 (District 3)	Beihaghi Park	Saei Park	Dr. Shariati Hospital	Center 1
Area 2 (District 6)	Azadeghan Park	Andisheh Park	15 Khordad Hospital	
Area 3 (District 7)	Behesht-e Madaran	Shafagh Ghanbari Park	Imam Hossein Hospital	
	Taleghani Park		Imam Khomeini Hospital	

TABLE 2. Relief personnel dispatch capacity in each hospital

Hospital	Relief personnel dispatch capacity					
	First scenario			Second scenario		
	Physician	Nurse	Rescuer	Physician	Nurse	Rescuer
Dr. Shariati	48	96	192	40	80	160
Imam Hossein	55	110	220	50	100	200
Imam Khomeini	55	110	220	50	100	200
15 Khordad	20	40	80	10	20	40

TABLE 3. Number of rescue personnel required in each incident area

Incident area	Number of rescue personnel needed					
	First scenario			Second scenario		
	Physician	Nurse	Rescuer	Physician	Nurse	Rescuer
1	25	50	100	25	50	100
2	44	88	176	46	92	184
3	74	148	296	75	150	300

discharge of earthquake victims, and carrying of the injured individuals should be performed [2, 20].

4. SOLUTION METHODS

This paper applies the epsilon constraint method by using an exact solver in GAMS software as well as two strong multi-objective metaheuristics, i.e., NSGA-II and MOPSO to address the proposed model.

4. 1. Epsilon Constraint Method The epsilon constraint method is adopted here to solve the proposed bi-objective optimization model. This well-established algorithm firstly proposed by Fathollahi-Fard et al. [14, 15]. This algorithm is based on the one objective function to be optimized and to consider the other objectives as the constraints with allowable bounds. Therefore, the following model has been solved by the epsilon constraint method.

$$\begin{aligned} &\min f_1 \\ &s.t. \\ &\qquad Eq.(3)-(25) \\ &\qquad f_2 \leq \varepsilon \end{aligned} \tag{26}$$

By updating the bound (ε), some solutions will be generated. In this case, the best solutions as the non-dominated ones should be selected among all generated ones. A solution can dominate another when all its objectives are not worse than that solution [1–3, 12].

4. 2. NSGA-II As mentioned earlier, NSGA-II is applied in this study to solve the model. In general, in the main loop of the employed NSGA-II algorithm, random solutions are initially generated as the number of the population [25–28]. Then, the values of the objective functions are calculated for each solution [32, 33]. In the next step, the solutions are ranked. Some parents are selected from the ranked solutions based on a mechanism for crossover and mutation operations, and after checking the constraints, the values of the objective functions are calculated for each of the solutions generated [34]. Next, the new solutions lay beside the initial solutions and the solutions are ranked again.

4. 3. Definitions of Choromosomes and Operators of NSGA-II To handle the constraints of the model, an encoding plan for chromosomes and operators of the algorithm is needed [35, 36]. The defined chromosome had a multi-part structure, in which the variables associated with the routing of the goods and the survivors were considered as one part [33–35]. In addition, the variables related to the demand of transfer of the survivors and the demand for goods in the emergency relief centers were also defined in another part. Each part of the chromosome was defined as a matrix with the dimensions varying based on the number of indices. For example, the chromosome corresponding to the variable $\boldsymbol{k'}_{\mathbf{cfts}}$ is shown in Figure 1 as follows:

Based on the operators of NSGA-II, Figure 2 demonstrates the crossover operator. As shown in this figure, a double-point crossover is used in this operator. At last, Figure 3 illustrates the mutation operator. For this purpose, a row is selected arbitrarily and inverted to a new solution.

4. 4. MOPSO The Particle Swarm Optimization (PSO) is another well-known metaheuristic as the basis

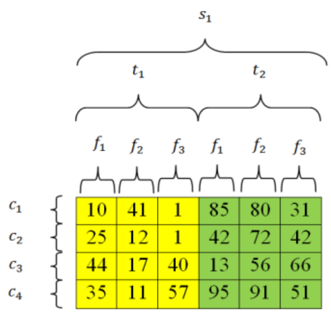

Figure 1. Chromosome representation

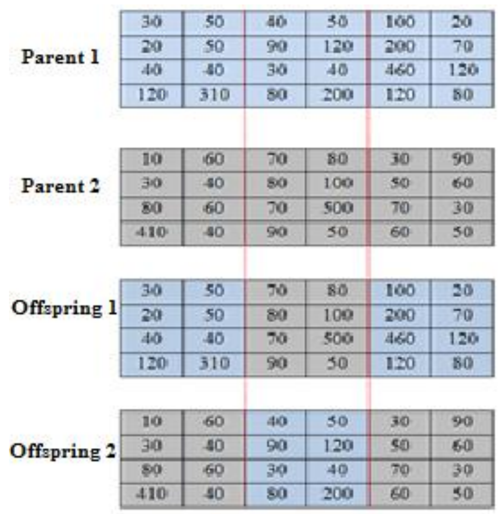

Figure 2. Double-point crossover operator

Parent

80	50	40	60	70	40
60	60	20	90	400	100
40	40	50	400	460	70
100	320	30	60	120	90

Child

80	50	40	60	70	47
100	400	90	20	60	60
40	40	50	400	460	70
100	320	30	60	120	90

Figure 3. Inversionmutation operator

of swarm intelligence. The swarm algorithms motivated by a collective intelligence. The PSO is inspired by the social behaviour of fish schooling or bird flocking [23–25]. This paper employs a multi-objective version of PSO called as MOPSO as employed by several studies [1, 25].

5. COMPUTATIONAL RESULTS

To tune the parameters of NSGA-II and MOPSO, the response surface method (RSM) introduced by Box and Wilson is utilized [19]. The RSM consider each parameter as a factor with allowable bounds. A regression model is applied to do a set of experiments for each factor, and a mea desirability based on the deviations for each random point in the bounds, is computed. The factors, their levels, and the number of experiments are shown in Table 4. Consequently, the tuned values for parameters, and desirability (*D*) of each algorithm, are estimated as given in Table 5.

Based on this calibration, we firstly check the metaheuristics with the epsilon constraint. Table 6 reveals the Pareto optimal solutions in our case problem for both exact and metaheuristic algorithms. To make the comparison easier, the algorithms' solutions are sorted in the provided table. Regarding the Pareto frontier of the epsilon constraint, the solutions of metaheuristic approaches are checked. Accordingly, the non-dominated solutions of each metaheuristic by considering the non-dominated solutions of the epsilon constraint are highlighted. Consequently, for the rest of test problems,

TABLE 4. Factors, levels, and number of experiments of the two proposed algorithms

Algorithm	Factors and their levels				N. of experiments; Total Number=(n_f, n_{ax}, n_{cp})
MOPSO	nPop	W	C1	C2	30=(2^4, 8, 6)
	(100, 200)	(0.65, 0.9)	(1.2, 2)	(1.2, 2)	
NSGA-II	nPop	P_C	P_M		
	(100, 200)	(0.5, 0.8)	(0.02, 0.1)		20=(2^3, 6, 6)

nPop=number of populations, W=inertia weight, C1=acceleration coefficient of local optimum, C2=acceleration coefficient of global optimum , P_C=probability of crossover, P_M=probability of mutation

TABLE 5. Optimized values of algorithms parameters and Desirability (D)

Algorithm	Tuned parameters	D
MOPSO	nPop=133, W=0.73, C1=1.46, C2=1.46	0.6823
NSGA-II	nPop=168; P_C=0.75; P_M=0.05	0.6523

the performance of Pareto frontier of the algorithms would be analyzed. It can be concluded that the solutions of metaheuristics are highly acceptable in comparison with the exact solver. The results also have been depicted in Figure 4.

To compare the efficiency of the applied algorithms, different criteria including the assessment metrics, i.e., diversification metric (DM) [1], spread of non-dominance solution (SNS) [14], data envelopment analysis (DEA) [15] and percentage of domination (POD) [1] as well as the computational time (CPU). For the assessment metrics, a higher value brings a better capability of the Pareto fronts. As such, a lower value of the process time brings a better performance. The outputs are given in Table 7. As a result, the best results are highlighted and the results of NSGA-II is highly better than MOPSO.

TABLE 6. Algorithms' Pareto solutions

Number	Epsilon constraint		NSGA-II		MOPSO	
	f_1	f_2	f_1	f_2	f_1	f_2
1	**1000100000**	2695000000	**1032000000**	2698000000	**1086000000**	2678000000
2	1143200000	2552000000	1052600000	2647000000	1095400000	2612000000
3	1297000000	**2509000000**	1078500000	2591000000	1103700000	2603000000
4	-	-	1092100000	2566000000	1125800000	2589000000
5	-	-	1103500000	2528000000	1131700000	2575000000
6	-	-	1126800000	**2509000000**	1159200000	2546000000
7	-	-	-	-	1186100000	**2530000000**

TABLE 7. Comparison of metaheuristics

Problem	DM		SNS		DEA		POD		CPU	
	NSGA-II	MOPSO	NSGA-II	MOPSO	NSGA-II	MOPSO	NSGA-II	MOPSO	NSGA-II	MOPSO
Tehran example	**41957**	38456	2671	**3166**	**0.52**	0.12	**0.24**	0.17	**24.56**	26.84

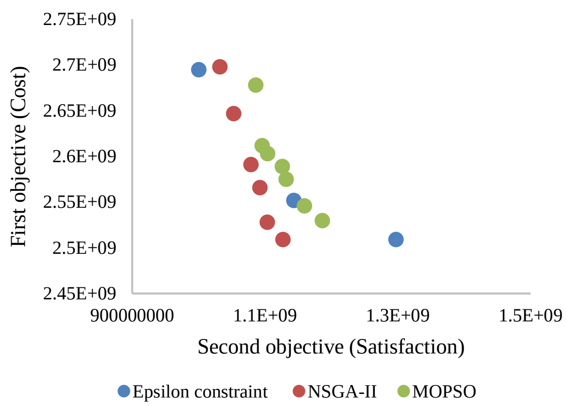

Figure 4. Pareto solutions

6. CONCLUSION

The mathematical model proposed in this study addressed the post-disaster issues and considered the issues associated with the location of the relief facilities, allocation of resources, distribution of the relief goods, and transfer of the survivors to the treatment centers given the problem objectives (reducing costs and increasing satisfaction) over several planning periods simultaneously. Regarding the random nature of the problem, determining the parameters of the problem is one of the critical issues for this purpose, using the available information on the case study and interviewing experts, statistical distribution was determined for the key parameters of the problem. To further explain the model and the results, the model solution outputs and general analyses of the problem were presented using the available data on the different areas of Tehran. To solve the problem, the epsilon constraint method using the exact solver in GAMS software as well as two well-known multi-objective metaheuristics, namely, NSGA-II and MOPSO were addressed the model. Firstly, they were tuned; then validated by the Pareto solutions of the epsilon constraint and finally, compared with the assessment metrics.

For future studies, the following remarks are recommended:

1. In this study, it was assumed that the demand and supply information was specified at the beginning of the planning period, but this information is dynamically changing in real conditions, so providing a dynamic logistics model can greatly enhance the planning efficiency.
2. Modelling the problem uncertainties using the robust approach can be compared with the fuzzy approach.
3. There are many recent techniques for solving multi-objective optimization models such as multi-objective of social engineering optimizer and red deer algorithm [11, 16, 17, 36].
4. Considering the terrific constraints for the routing decisions makes the model more difficult.

7. REFERENCES

1. Abdi, A., Abdi, A., Fathollahi-Fard, A.M. and Hajiaghaei-Keshteli, M., "A set of calibrated metaheuristics to address a closed-loop supply chain network design problem under uncertainty" ***International Journal of Systems Science: Operations & Logistics***, (2019), 1–18. https://doi.org/10.1080/23302674.2019.1610197
2. Sahebjamnia, N. and Fathollahi-Fard, A. M., "A Lagrangian Relaxation-based Algorithm to solve a Collaborative Water Supply Chain Network Design Problem", ***International Journal of Emerging Trends in Engineering Research***, Vol. 6, (2018), 40–45.
3. Bahadori-Chinibelagh, S., Fathollahi-Fard, A.M. and Hajiaghaei-Keshteli, M., "Two constructive algorithms to address a multi-depot home healthcare routing problem", ***IETE Journal of Research***, (2019), 1–7. https://doi.org/10.1080/03772063.2019.1642802
4. Fathollahi-Fard, A.M., Hajiaghaei-Keshteli, M. and Tavakkoli-Moghaddam, R., "A Lagrangian relaxation-based algorithm to solve a Home Health Care routing problem", ***International Journal of Engineering - Transaction B: Applications***, Vol. 31, No. 10, (2018), 1734–1740.
5. Brown, C., Milke, M. and Seville, E., "Disaster waste management: A review article", ***Waste Management***, Vol. 31, No. 6, (2011), 1085–1098.
6. Bhattacharya, S., Hyodo, M., Nikitas, G., Ismael, B., Suzuki, H., Lombardi, D., Egami, S., Watanabe, G. and Goda, K., "Geotechnical and infrastructural damage due to the 2016 Kumamoto earthquake sequence", ***Soil Dynamics and Earthquake Engineering***, Vol. 104, (2018), 390–394.
7. Burkart, C., Nolz, P.C. and Gutjahr, W. J., "Modelling beneficiaries' choice in disaster relief logistics", ***Annals of Operations Research***, Vol. 256, No. 1, (2017), 41–61.
8. Özdamar, L. and Demir, O., "A hierarchical clustering and routing procedure for large scale disaster relief logistics planning", ***Transportation Research Part E: Logistics and Transportation Review***, Vol. 48, No. 3, (2012), 591–602.
9. Cao, C., Li, C., Yang, Q., Liu, Y. and Qu, T., "A novel multi-objective programming model of relief distribution for sustainable disaster supply chain in large-scale natural disasters", ***Journal of Cleaner Production***, Vol. 174, (2018), 1422–1435.
10. Dutta, P. and Nagurney, A., "Multitiered blood supply chain network competition: Linking blood service organizations, hospitals, and payers", ***Operations Research for Health Care***, Vol. 23, (2019), 1–45.

11. Fathollahi-Fard, A.M., Hajiaghaei-Keshteli, M. and Tavakkoli-Moghaddam, R., "The social engineering optimizer (SEO)", ***Engineering Applications of Artificial Intelligence***, Vol. 72, (2018), 267–293.

12. Hajiaghaei-Keshteli, M., Abdallah, K.S. and Fathollahi-Fard, A. M., "A collaborative stochastic closed-loop supply chain network design for tire industry", ***International Journal of Engineering - Transaction B: Applications***, Vol. 31, No. 10, (2018), 1715–1722.

13. Fathollahi-Fard, A.M., Hajiaghaei-Keshteli, M. and Mirjalili, S., "A set of efficient heuristics for a home healthcare problem", ***Neural Computing and Applications***, Vol. 32, (2019), 6185–6205.

14. Mehranfar, N., Hajiaghaei-Keshteli, M. and Fathollahi-Fard, A. M., "A Novel Hybrid Whale Optimization Algorithm to Solve a Production-Distribution Network Problem Considering Carbon Emissions", ***International Journal of Engineering - Transaction C: Aspects***, Vol. 32, No. 12, (2019), 1781–1789.

15. Fathollahi-Fard, A.M., Govindan, K., Hajiaghaei-Keshteli, M. and Ahmadi, A., "A green home health care supply chain: New modified simulated annealing algorithms", ***Journal of Cleaner Production***, Vol. 240, (2019), 1–45.

16. Hajiaghaei-Keshteli, M. and Fathollahi Fard, A. M., "New Approaches in Metaheuristics to solve the truck scheduling problem in a cross-docking center", ***International Journal of Engineering - Transaction B: Applications***, Vol. 31, No. 8, (2018), 1258–1266.

17. Fathollahi-Fard, A.M., Ranjbar-Bourani, M., Cheikhrouhou, N. and Hajiaghaei-Keshteli, M., "Novel modifications of social engineering optimizer to solve a truck scheduling problem in a cross-docking system", ***Computers & Industrial Engineering***, Vol. 137, (2019). https://doi.org/10.1016/j.cie.2019.106103

18. Fathollahi-Fard, A.M., Hajiaghaei-Keshteli, M., Tian, G. and Li, Z., "An adaptive Lagrangian relaxation-based algorithm for a coordinated water supply and wastewater collection network design problem", ***Information Sciences***, Vol. 512, (2020), 1335–1359.

19. Fetter, G. and Rakes, T., "Incorporating recycling into post-disaster debris disposal", ***Socio-Economic Planning Sciences***, Vol. 46, No. 1, (2012), 14–22.

20. Fu, Y., Tian, G., Fathollahi-Fard, A.M., Ahmadi, A. and Zhang, C., "Stochastic multi-objective modelling and optimization of an energy-conscious distributed permutation flow shop scheduling problem with the total tardiness constraint", ***Journal of Cleaner Production***, Vol. 226, (2019), 515–525.

21. Goretti, A., Hutt, C.M. and Hedelund, L., "Post-earthquake safety evaluation of buildings in Portoviejo, Manabí province, following the Mw7. 8 Ecuador earthquake of April 16, 2016", ***International Journal of Disaster Risk Reduction***, Vol. 24, (2017), 271–283.

22. Habibi-Kouchaksaraei, M., Paydar, M.M. and Asadi-Gangraj, E., "Designing a bi-objective multi-echelon robust blood supply chain in a disaster", ***Applied Mathematical Modelling***, Vol. 55, (2018), 583–599.

23. Hamdan, B. and Diabat, A., "A two-stage multi-echelon stochastic blood supply chain problem", ***Computers & Operations Research***, Vol. 101, (2019), 130–143.

24. Kackar, R. N., "Off-line quality control, parameter design, and the Taguchi method", ***Journal of Quality Technology***, Vol. 17, No. 4, (1985), 176–188.

25. Fazli, M., Fathollahi-Fard, A.M. and Tian, G., "Addressing a Coordinated Quay Crane Scheduling and Assignment Problem by Red Deer Algorithm", ***International Journal of Engineering - Transaction B: Applications***, Vol. 32, No. 8, (2019), 1186–1191.

26. Li, H., Zhao, L., Huang, R. and Hu, Q., "Hierarchical earthquake shelter planning in urban areas: A case for Shanghai in China", ***International Journal of Disaster Risk Reduction***, Vol. 22, (2017), 431–446.

27. Liu, X., Tian, G., Fathollahi-Fard, A.M. and Mojtahedi, M., "Evaluation of ship's green degree using a novel hybrid approach combining group fuzzy entropy and cloud technique for the order of preference by similarity to the ideal solution theory", ***Clean Technologies and Environmental Policy***, Vol. 22, No. 2, (2020), 493–512.

28. Maharjan, R. and Hanaoka, S., "A multi-actor multi-objective optimization approach for locating temporary logistics hubs during disaster response", ***Journal of Humanitarian Logistics and Supply Chain Management***, Vol. 8, (2018), 2–21.

29. Ni, W., Shu, J. and Song, M., "Location and emergency inventory pre-positioning for disaster response operations: Min-max robust model and a case study of Yushu earthquake", ***Production and Operations Management***, Vol. 27, No. 1, (2018), 160–183.

30. Noyan, N. and Kahvecioğlu, G., "Stochastic last mile relief network design with resource reallocation", ***OR Spectrum***, Vol. 40, No. 1, (2018), 187–231.

31. Rath, S. and Gutjahr, W. J., "A math-heuristic for the warehouse location–routing problem in disaster relief", ***Computers & Operations Research***, Vol. 42, (2014), 25–39.

32. Rajendran, S. and Ravindran, A. R., "Inventory management of platelets along blood supply chain to minimize wastage and shortage", ***Computers & Industrial Engineering***, Vol. 130, (2019), 714–730.

33. Rajendran, S. and Srinivas, S., "Hybrid ordering policies for platelet inventory management under demand uncertainty", ***IISE Transactions on Healthcare Systems Engineering***, (2019), 1–14. https://doi.org/10.1080/24725579.2019.1686718

34. Safaeian, M., Fathollahi-Fard, A.M., Tian, G., Li, Z. and Ke, H., "A multi-objective supplier selection and order allocation through incremental discount in a fuzzy environment", ***Journal of Intelligent & Fuzzy Systems***, Vol. 37, No. 1, (2019), 1435–1455.

35. Zhou, Y., Liu, J., Zhang, Y. and Gan, X., "A multi-objective evolutionary algorithm for multi-period dynamic emergency resource scheduling problems", ***Transportation Research Part E: Logistics and Transportation Review***, Vol. 99, (2017), 77–95.

36. Fathollahi-Fard, A.M., Hajiaghaei-Keshteli, M. and Tavakkoli-Moghaddam, R., "Red deer algorithm (RDA): a new nature-inspired meta-heuristic", ***Soft Computing***, (2020), 1–29. https://doi.org/10.1007/s00500-020-04812-z

Persian Abstract

چکیده

امروزه، تعداد زیادی صدمات، اتلافات مختلف و حوادث بر اساس سانحه‌های طبیعی و غیرطبیعی رخ می‌دهد. این مطالعه به دنبال بررسی برنامه‌ریزی لجستیک معکوس در هر دو فاز پاسخ و بازخورد و همچنین بهبود و ساختار مجدد شبکه بعد از شرایط زلزله با استفاده از یک مطالعه موردی واقعی می‌پردازد. با توجه به پیچیدگی بالا این نوع از مسائل بهینه‌سازی، یه مدل چندهدفه برای لجستیک منعطف چند وسیله نقلیه‌ای با سطوح رضایتمندی تسهیلات توسعه یافته که در محیط عدم قطعیت است. برای حل مساله، یک روش دقیق با استفاده از الگوریتم اپسیلون محدودیت برای اعتبارسنجی مدل به کار گرفته شده است. برای حل بهینه مدل در مساله اندازه بزرگ، یک الگوریتم مشهور نامغلوب مرتب شده ژنتیک تنظیم شده و با الگوریتم چندهدفه بهینه‌سازی ازدحام ذرات مقایسه شده است. با یک جمع‌بندی در مورد مهم‌ترین یافته این تحقیق، استفاده از لجستیک معکوس پیشنهادی در حالت پاسخ مورد تایید قرار گرفته است. به صورت بسیار گسترده‌تر، کاربرد مدل پیشنهادی با استفاده از یک مطالعه موردی در تهران مورد ارزیابی واقع شده است.