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A Location-Routing Model for Assessment of the Injured People and Relief Distribution under Uncertainty

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

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

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ABSTRACT

Throughout history, nature has exposed humans to destructive phenomena such as earthquakes, floods, droughts, tornadoes, volcanic eruptions, and tropical and marine storms. The large scale of damages and casualties caused by natural disasters around the world has led to extensive applied research in the field of preparation and development of a comprehensive system for disaster management to minimize the resulting casualties and financial damages. Based on this motivation and challenges to the field, this research designs an integrated relief chain to optimize simultaneously the preparedness and response phases of disaster management. Decisions to improve the supply chain include locating distribution centers of relief supplies; the amount of inventory stored in facilities in pre-disaster phase, locating temporary care centers and transportation points of the injured, how to allocate relief services to the affected areas, and routing of the vehicles used to distribute relief supplies and evacuate the injured. The results show that decreasing the capacity of distribution centers increases the amount of shortage of supplies and increasing the capacity of these centers reduces the amount of shortage of supplies.

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1. INTRODUCTION

In today's world, because natural disasters such as earthquakes, floods, droughts, storms, volcanic eruptions and so on are sweeping the globe, the importance of disaster management and strategies to accelerate supply and response to demand created at the time of disaster is felt more than before [1]. In fact, the unpredictable nature and devastating effects of such events force communities to foresee and develop appropriate plans to minimize disaster damage and casualties. Disaster management is a continuous process involving operations to prepare for a disaster, respond to it as soon as it occurs, and support and rebuild damaged infrastructure after a disaster [2]. Disaster management activities are usually categorized into four phases of preparedness, response, recovery, mitigation, and proper planning for each phase can lead to better preparation, less vulnerability or future disaster prevention. After the occurrence of a disaster, we face major problems, such as a shortage of inventory to supply and transport many of the critical supplies including food, clothing, medicine, equipment, and personnel to the affected areas [3]. Emergency relief efforts should also focus on finding and rescuing survivors. Logistics and rescue personnel must therefore be transported quickly and efficiently to maximize the rescue rate of affected people and minimize the cost of operations [4]. However, as the transportation of logistics to the affected areas is carried out under uncertainty and as the relevant logistics information changes during disaster response, planning for the disaster will face significant complexities [5]. Therefore, the rules and strategies of relief organizations should be dynamic and flexible due to the sudden and unexpected changes and an information support system can bring this dynamism and adapt plans to the new information obtained [6, 7]. In relief logistics problems, finding the location of critical supplies before the occurrence of a disaster is one of the most important logistics strategies to reduce delivery times and operating costs, prior to the accident [8–10]. Pre-location of the

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

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facilities not only enables faster response but also creates a better preparation plan and improves distribution costs. Also, a good logistics support operation requires tactical level decisions to transport logistics to the affected areas and the affected people to hospitals and care centers [10–15]. Therefore, efficient transportation systems along the relief supply chain are of the utmost importance in order to respond appropriately to the critical conditions occurred.

Based on recent advances in this research area, the location-routing problem has been one of the most important location problems from the viewpoint of integrated logistics systems analysts [15–19]. This problem gives analysts a stronger perspective on the mutual relationships between facility locations and vehicle routes; allows for a centralized operational plan where delays are eliminated and limited resources are allocated as best as possible. In fact, the fundamental difference between this comprehensive and integrated approach and classic location problems is that in the location-routing method, after determining the location of the facilities, the routes between the facilities and the customers are examined as a tour, while in the traditional method; it is assumed that there are direct routes between the customer and the facilities. Having a conclusion about aforementioned contributions, the main novelty of this paper is to develop a new location-routing model for the assessment of injured people and relief distribution under uncertainty.

The rest of this research will be as follows: In section 2, we will review the literature on this subject. In section 3, the problem statement will be mentioned and in section 4, we will introduce the parameters of the problem and the mathematical model. Section 5 will outline the solution approach. Section 6 will describe the case study and present the computational results. Finally, section 7 will present conclusion, managerial insights and future research proposals.

2. LITERATURE REVIEW

The literature is rich in using the application location-routing models for different supply chain concepts [16–22]. To close to nature of real-world application, uncertainty modeling is an active keyword for logistics network from recently-published papers [23–32]. Here, we review some recent and most relevant works related to our scope of research. For example, in 2019, Paul and Zhang [1] presented a multi-objective hybrid optimization model for the routing-location problem of mobile units of medical services. They presented three heuristic and metaheuristic algorithms to solve the model and applied real data to validate these algorithms. Paul and Wang [2] formulated the location and distribution of relief supplies during the occurrence of a flood under different probabilistic scenarios using two-stage stochastic programming. The model assumed that there are several types of relief centers, such as: regional relief centers, local relief centers, etc. that support each other and demand points if necessary. The objective was to minimize costs and a heuristic method was used to solve it.

In another recent paper, Nagurney et al., [12] proposed a two-stage multi-criteria uncertain programming model for locating pre-disaster emergency response and distribution centers for efficient emergency logistics in times of a disaster. They also presented a goal programming that in the first stage, determined the location, capacity of the facilities and the quantity of supplies stored in each facility; and in the second stage, a transportation problem was solved with two main assumptions: the capacity of the routes was infinite, but it was possible that in a scenario this route would not be possible and nodes were as storages for supplies. Fathollahi-Fard et al., [18] developed a two-stage stochastic programming model to develop a closed-loop logistics network design for the application of water distribution network. They developed an adaptive Lagrangian relaxation to solve a case study in the west Azerbaijan province of Iran. Another closed-loop logistics under uncertainty was developed by Abdi et al., [16]. They considered the demand, returned productions and prices as the uncertain parameters and applied a financial risk model to evaluate the application fruit industry in Iran. Another contribution was a comparison with whale optimization algorithm as a recent meta-heuristic with genetic algorithm, simulated annealing and particle swarm optimization based on the assessment metrics of Pareto fronts.

In another different research, Davoodi et al. [6] developed a deterministic and static location-routing approach for deploying pre-disaster establishment of suppliers in such a way as to maximize the probability of supplying the demand of affected points through supplier facilitation considering the transportation network failures. With regards to order allocation and the selection of suppliers, Safaeian et al., [21] developed a Zemin's fuzzy model to consider the uncertain parameters of this problem. Their significant contribution was to apply a non-dominated sorting genetic algorithm to find an interaction between the total cost, quality of products, prices and satisfactions of customers as the objective functions. As another supplier selection assessment, Feng et al., [28] developed a new hybrid fuzzy grey TOPSIS method to provide a comprehensive analysis for a case study in China.

Fathollahi-Fard et al., [24] developed a bi-objective logistics network for the application home healthcare organizations. Their model as a variant of location-routing model optimizes the total cost and the environmental pollution simultaneously. They also provided a comparison with new and state of the art modified simulated annealing algorithms. In another multi-objective model, Torabi et al. [10] presented a multi-objective approach for the location of emergency shelters as well as determination of evacuation routes during the preparedness and response phases. Since a route or a shelter may be unusable due to a fire, the backup route or shelter is provided for each building.

As another logistics network under uncertainty, Noham and Tzur [7] integrated the problem of pre-disaster facility location, inventory, and routing by presenting a two-stage probabilistic planning model. The objective was to determine the location and number of local distribution centers and their inventory levels to ensure rapid and efficient response in times of a disaster. In the first stage, the design variables were determined based on the available information and in the second stage, these variables were estimated with the objective of optimizing the total demand met and the total transportation costs based on the existing information. In addition, Loree and Aros-Vera [3] presented an integrated supply chain logistics model for controlling the flow of multiple relief supplies in the response network. The model considered the optimal locations for several layers of temporary facilities, as well as the optimal routes for delivering and loading relief supplies. Based on a collaborative closed-loop logistics for water supply chain, Torabi et al. [33] proposed a stochastic programming and applied Lagrangian relaxation to address it.

In 2019, Liu et al. [13] proposed a multiple optimization algorithm for the capacitated location-routing problem. In this study, the capacitated location-routing problem was divided into two facility location problem and the vehicle routing problem with multiple warehouses, so that the second problem was a sub-problem of the first problem. Mehranfar et al., [34] proposed a production-distribution logistics network considering carbon tax under uncertainty. A novel hybrid whale optimization algorithm was developed to address their problem.

As the last example of multi-objective optimization in this literature, Li et al. [25] presented a three-objective transportation location model for the disaster response phase. The objectives of this model included reducing the transportation time of relief supplies, reducing the number of rescuers needed to open and operate the established distribution centers, and reducing the number of unmet demand. Finally, the epsilon constraint exact approach was proposed to solve the model. At last but not least, Haghi et al., [8] proposed a three-level stochastic programming model for the disaster response phase. This model aimed to maximize effectiveness and fairness in relief distribution by locating facilities, allocating resources, and last-mile distribution of relief supplies. In this problem, demand, the number of transportation vehicles and accessibility of uncertain communication infrastructure were considered.

Based on the aforementioned works and to keep this research area active, the following contributions can fill the research gaps in this research area:

- Designing an integrated four-level relief chains including suppliers, distributors, affected areas and a variety of care centers with the aim of minimizing unmet demand and uncared people.
- Simultaneous consideration of strategic and operational decisions related to disaster preparedness and response phases.
- Simultaneous optimization of facility location, resource allocation, relief distribution and evacuation of the injured problems assuming demand uncertainty and facility availability and so on.
- Using the data and results of earthquake damage estimation in district one of Tehran city to validate the model under real conditions.

3. PROBLEM STATEMENT

As noted before, as human health suffers most damages in disaster situations, medical service planning and management in emergency situations are of utmost importance. This is especially important in the early hours after the occurrence of a disaster because the efficient planning and management of medical and pharmaceutical supplies can save the injured.

Further, any kind of planning in disaster situations without considering the inseparable features of these situations, is not efficient. These features include issues such as uncertainty. In the event of a disaster, potential damage, the location of temporary centers and consequently the amount of demand in the affected areas is highly uncertain. Therefore, the location should be done such that it can effectively cover the demand points. In the real world, we often face uncertain supply, demand and costs during disaster response. Considering the uncertainties arising from disaster situations in the design and analysis of the model presents many challenges.

Our objective in this study is to present a mathematical model for integrating location and routing decisions in uncertain and changeable situations arising from the occurrence of a disaster. In fact, we formulate the disaster relief logistics location-routing problem as a linear integer scenario-based multi-objective model. In this study, a multi-objective model is presented to coordinate the distribution of emergency medical supplies and emergency evacuation activities of the injured. In order to have an effective relief distribution, the proposed model also seeks to locate a number of temporary relief centers near the affected areas. In this model, the major source of uncertainty, which is an inherent characteristic of emergency situations, is considered. This source of uncertainty includes the unpredictability of the time and location of the disaster, the amount of demand and potential damage to the infrastructure which is discussed in this paper through scenario-based planning considering different scenarios for the disaster. Based on the explanations given, this paper attempts to optimize the necessary strategic decisions in disaster situations by presenting a multi-period multi-objective mathematical model.

4. MATHEMATICLA FORMULATION

This section provides the assumptions, notations and mathematical model.

4. 1. Assumptions

- The number and location of suppliers, affected areas and existing care centers are fixed and determined.
- Potential locations for the establishment of relief distribution centers and the injured transportation points are identified.
- The capacity of relief centers is constrained and varies based on their size (small, medium, large).
- Each distribution center is only able to serve the area in which it is located.
- The capacity of vehicles to carry different kinds of supplies and the injured is constrained and determined.
- Each vehicle can start and end its route from different locations.

4. 2. Notations

- **Sets**

N: Set of network nodes (o,p$\in N$) (I$\cup J \cup K \cup L \subset N$)
I: Set of suppliers
J: Set of candidate distribution points
K: Set of affected areas
M: Set of temporary care centers
H: Set of hospitals
C: Set of supplies
W: Set of the injured
S: Set of possible scenarios
L: Set of the size of distribution centers
V: Set of vehicles

- **Parameters:**

p_s: Probability of occurrence of scenario s
ω_c: Priority of meeting the demand for supply c
ω'_w: Priority of serving the injured person w
P: The number of temporary care centers to be established
v_c: Volume of each unit of supply c
w''_c: Weight of each unit of supply c
cap_l: Capacity of distribution center size l
$capm_w$: Capacity of a temporary care center for the injured type w
$capv_v$: Volume capacity of vehicle v for transporting supplies (in cubic meters)
$capw_v$: Weight capacity of vehicle v for transporting supplies (in kilograms)
$Capl_v$: Capacity of vehicle v to carry the injured
$Caps_{oc}$: The amount of supply c that can be supplied from the supplier node o∈I
av_{vs}: Number of vehicles type v available in scenario s
dc_{ocs}: Demand for supply c in affected node o∈kin scenario s
dw_{ows}: Number of affected people type w in affected node o∈kin scenario s
ρ_{os}: Percentage of accessibility of facilities including suppliers, distributors and care centers located in node o in scenario s
sb_{wo}: Number of beds available at node o∈H for the injured type w
δ_{opvs}: 1, If the vehicle v can travel the axis of o to pin scenario s; otherwise it is zero.
ac_{cv}: 1. If vehicle v is capable of carrying supply c; otherwise it is zero.
aw_{wv}: 1, If vehicle v is capable of carrying the injured type w; otherwise it is zero.
ab_{ops}: 1, If the facility at the location o∈Jis able to serve the facility located in p∈kin scenario s; otherwise it is zero.

- **Decision variables:**

Q_{opc}: The quantity of supply c supplied by the supply node o and stored in the node p
x^v_{opcs}: The quantity of supply c transported from supply node o to p by vehicle v in scenario s
y^v_{opws}: Number of the injured type w transported from node o∈k to node p∈H by vehicle v in scenario s
y'^s_{opw}: Number of the injured type w transported from node o∈k to node p∈Min scenario s
N_{opvs}: The number of vehicles type v passing the route (o,p)in scenario s
Ux_{ocs}: The amount of shortage for supply c in affected node $o \in k$in scenario s
Uy_{ows}: Number of the injured type w that are not served yet in affected node $o \in k$in scenario s.
z_{ol}: 1, If the distribution center size l is established in the node o∈J; otherwise it is zero.
z'_{os}: 1, If a temporary care center is established in scenario s in location o∈M; otherwise it is zero.

4. 3. Mathematical Model

$$MinZ_1 = \sum_w \sum_{o\in k} \sum_s \omega'_w . Uy_{ows} \quad (1)$$

$$MinZ_2 = \sum_c \sum_{o\in k} \sum_s \omega_C . Ux_{ocs} \quad (2)$$

$$\sum_{o\in I} \rho_{os} . Q_{opc} + \sum_{o\in I} \sum_v x^v_{opcs} - \sum_{o\in K} ab_{pos} . \sum_v x^v_{pocs} \geq 0 \qquad \forall p \in j, c, s \quad (3)$$

$\sum_{p\in j}\sum_{v} ab_{pos}\,.\,x^{v}_{pocs} + Ux_{ocs} \geq dc_{ocs}$ $\forall o \in k, c, s$ (4)

$\sum_{p\in H}\sum_{v} y^{v}_{opws} + \sum_{p\in M} y'^{s}_{opw} + Uy_{ows} = dw_{ows}$ $\forall o \in k, w, s$ (5)

$\sum_{o\in N} x^{v}_{opcs} \leq M.\sum_{l} Z_{pl}$ $\forall p \in j, c, s$ (6)

$\sum_{p\in N} x^{v}_{opcs} \leq M.\sum_{l} Z_{ol}$ $\forall o \in j, c, s$ (7)

$\sum_{w}\sum_{o\in K} y'^{s}_{opw} \leq M.\sum_{o\in K} z'_{os}$ $\forall p \in M, s$ (8)

$\sum_{o\in N}\sum_{p\in N} x^{v}_{opcs} \leq M.\,ac_{cv}$ $\forall v, c, s$ (9)

$\sum_{o\in N}\sum_{p\in N} y^{v}_{opws} \leq M.\,aw_{wv}$ $\forall v, w, s$ (10)

$\sum_{o,c} \upsilon_{c}.\,Q_{opc} \leq \sum_{l} Cap_{l}.\,Z_{pl}$ $\forall p \in j$ (11)

$\sum_{p\in j} Q_{opc} \leq caps_{oc}$ $\forall o \in I, c$ (12)

$\sum_{V}\sum_{p\in j} x^{v}_{opcs} \leq \rho_{os}.\,caps_{oc}$ $\forall o \in I, c, s$ (13)

$\sum_{V}\sum_{o\in k} y^{v}_{opws} \leq \sum_{o\in k} \rho_{os}.\,sb_{wp}$ $\forall p \in H, w, s$ (14)

$\sum_{V}\sum_{o\in k} y'^{s}_{opw} \leq \sum_{o\in k} capm_{w}.\,z'_{os}$ $\forall p \in M, w, s$ (15)

$\sum_{v}\sum_{c} v_{c}.\,x^{v}_{opcs} \leq \sum_{v} Capv_{v}.\,N_{opvs}$ $\forall o \in N, p \in N, s$ (16)

$\sum_{v}\sum_{c} w''_{c}.\,x^{v}_{opcs} \leq \sum_{v} capw_{v}.\,N_{opvs}$ $\forall o \in N, p \in N, s$ (17)

$\sum_{v}\sum_{w} y^{v}_{opws} \leq \sum_{v} Capl_{v}.\,N_{opvs}$ $\forall o \in N, p \in N, s$ (18)

$\sum_{(o,p)\in N} N_{opvs} \leq av_{vs}$ $\forall v, s$ (19)

$N_{opvs} \leq M.\,\delta_{opvs}$ $\forall o \in N, p \in N, s, v$ (20)

$\sum_{l} Z_{ol} \leq 1$ $\forall o \in J$ (21)

$\sum_{o\in M} z'_{os} = p$ $\forall s$ (22)

$z'_{os}, z_{ol} \in \{0,1\}, Ux_{ocs}, Uy_{ows}, N_{opvs}, y'^{s}_{opw}, x^{v}_{opcs}, y^{v}_{opws}, Qopc \geq 0$ (23)

Contrary to previous works, the first objective function does not seek to minimize the number of the injured served; in fact it seeks to increase the level of service to the injured. The second objective function also seeks to minimize the shortage of relief supplies in the affected areas. It should be noted that these objective functions do not have the same priority and are optimized hierarchically.

Constraint (3) relates to the flow of relief supplies in distribution centers and ensures that the quantity of supplies delivered by each distribution center to the affected areas should be less than the inventory available at those centers. Constraint (4) shows the flow of relief supplies in the affected areas and indicates the amount of shortage in each affected area. Constraint (5) relates to the flow of the injured in the affected areas and also determines the number of the injured waiting in each affected area to be served. Constraints (6) and (7) ensure that the inflow and outflow of supplies in distribution centers is only possible if these centers are established. Constraint (8) also guarantees that the transportation of the injured to temporary care centers is only possible if these centers are established.

Constraints (9) and (10), respectively, indicate the ability of vehicles to carry different kinds of relief supplies and to carry different kinds of the injured. Constraint (11) guarantees that it is possible to store all kinds of relief supplies in distribution centers only if these centers are established and that the amount of these supplies is less than the capacity of the distribution centers. Constraint (12) indicates the capacity of suppliers to deliver relief supplies to distribution centers before the occurrence of a disaster. Constraint (13) guarantees that suppliers are able to deliver relief supplies after the occurrence of a disaster. Constraints (14) and (15) also ensure the consideration of the capacity of existing care centers and temporary care centers after the occurrence of a disaster. Constraints (16) and (17) guarantee the consideration of the volume and weight capacity of vehicles to carry different kinds of relief supplies. Constraint (18) ensures the consideration of the capacity of vehicles to carry different kinds of the injured. Constraint 19 indicates that the number of vehicles available in each scenario is constrained. Constraint 20 also guarantees that vehicles can only move on the network arcs if they are available after the occurrence of a disaster. Constraint 21 indicates that only one of the sizes of distribution centers can be established at each point. Constraint 22 guarantees that a determined number of temporary care centers will be established. Constraint 23 specifies the type of decision variables.

5. SOLUTION APPROACH

Given that the proposed model is presented in the humanitarian space, their objective functions cannot be compared with each other in terms of priority. For example, the objective functions related to evacuation and rescue of the injured have a higher priority than the distribution of relief supplies. Also, time-related objective functions are more important than cost functions. Therefore, since the objective functions of the proposed model are hierarchically prioritized, one of the multi-objective optimization methods called lexicographic approach has been used to solve the problem. Based on this approach, the first objective function is assumed without considering the other objective functions. Then, this objective function is optimized based on the optimal value obtained from solving the model, the constant f_1. Therefore, the initial objective function is added to the model as an additional constraint $\sum_w \sum_{o\in k} \sum_s \omega_w . Uy_{ows} \leq f_1$. Then, the initial model is solved by assuming that a constraint is added to the problem in order to minimize the second objective function.

6. CASE STUDY AND RESULTS

Tehran is one of Asia's most densely populated and earthquake-prone cities. Evidence shows that severe earthquakes could result severe damages if they happen in this city. District one of Tehran city is one of the busiest and most sensitive parts of Tehran, surrounded by two Mosha and Ray faults. According to statistical data, this area is 200 square kilometers with a population of 620000 people. In this section, the performance of the proposed model in this area is investigated. Figure 1 shows Tehran's earthquake-prone zones along with the map of the case study.

Here, we solve this case study in Tehran. In this regard, Table 1 shows the probability of occurrence of each scenario in the case study.

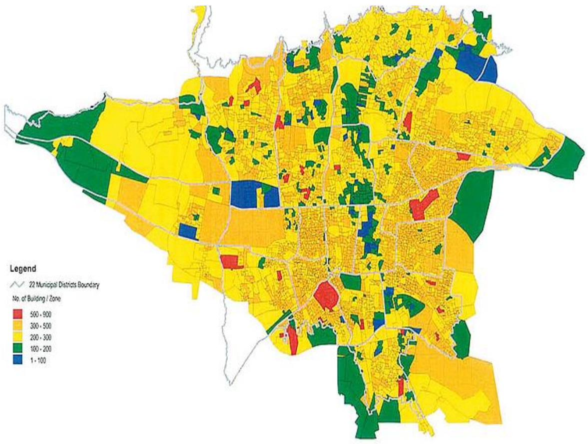

Figure 1. The map of the case study

TABLE 1. The probability of occurrence of each scenario

Scenario	Mosha fault		Ray fault	
Time of occurrence	night	day	night	day
Probability of occurrence	0.0614	0.2036	0.0305	0.0465
Severity of occurrence	6.8		6.2	

Table 2 shows the set of candidate points for the establishment of distribution centers. These centers can be established in three sizes: small, medium and large, each with different establishment costs.

Table 3 shows the bases of suppliers in District 1 of Tehran city. In this study, we have assumed that the affected areas include damaged and old areas of the city. These areas are listed in Table 4. The set of available care centers in the district is shown in Table 5.

TABLE 2. Candidate points for the establishment of distribution centers

No.	Distribution center
1	Niavaran base
2	Jamaran Base
3	Dezashib base
4	Tajrish base
5	Elahieh base
6	Chizar base
7	Velenjak base
8	Aqdasieh base

TABLE 3. Supplier bases

No.	Supplier base
1	Hekmat base
2	Farmanieh base
3	Evin base
4	Zafaranieh base

TABLE 4. Affected areas

No.	Affected area	No	Affected area
1	Kamranieh	6	Pasdaran
2	Sa'dabad	7	Aqdasieh
3	Darakeh	8	Dezashib
4	Jamshidieh	9	Andarzgu
5	Darband	10	Kashanak

TABLE 5. Care centers

No.	Hospital	Reception capacity	No	Hospital	Reception capacity
1	Sasan	1500	6	Mahak	5000
2	Chamran	5000	7	Jamaran	10000
3	Nikan	8000	8	505 Artesh	12000
4	ShohadaTajrish	4800	9	Nurafshar	10000
5	Farhangian	6000	10	Ramtin	4000

Three types of relief supplies including tents, water and food are considered in this study. To calculate the demand for these supplies during the occurrence of an earthquake, it is assumed that during the first 100 hours (golden time) of the disaster response, one tent will be delivered to each affected family and two quotas of water and food will be delivered to each person per day. The percentages of availability of facilities in each of these areas were calculated using the percentage of destruction of buildings and are presented in Table 6.

Table 7 shows the parameters needed for relief supplies including their weight, volume and cost. Table 7 shows information on priority of meeting demand, supply costs, etc. for each type of relief supplies. It is also assumed that the cost of maintaining inventory and the cost of providing each supply for the post-disaster phase is similar to the pre- disaster phase.

Table 8 shows the information and parameters related to the injured. Table 9 shows the capacity of suppliers for relief supplies.

TABLE 6. Percentage of facility availability

Affected area	Percentage of facility availability	Affected area	Percentage of facility availability
1	25	6	75
2	40	7	19
3	58	8	60
4	25	9	65
5	48	10	80

TABLE 7. Parameters required for relief supplies

Commodities	Volume (m^3)	Weight (kg)	Supply cost (10^3\$)
Water	0.0038	1.5	0.003
Tent	0.18	3	0.05

TABLE 8. Parameters needed to serve the injured

Injured type	Priority
Mild	0.15
medium	0.45
Dire	0.65

TABLE 9. Capacity of suppliers

No.	Supplier base	Water	Food	Tent
1	Hekmat base	600000	500000	40000
2	Farmanieh base	550000	450000	40000
3	Evin base	750000	800000	40000
4	Zafaranieh base	850000	70000	50000

Table 10 shows the capacity of distribution centers. The results of this exact solution are as follows: 36 people are not served and there are 420 units of supply shortage in various affected areas. Table 11 shows the distribution centers established at each of the potential locations with their optimal capacity.

Table 12 shows the quantities of supplies transported from suppliers to distribution centers after the occurrence of a disaster in a defined scenario. Table 13 shows the number of the injured transported from affected areas to existing hospitals in the district.

After solving our model, we examine the model's sensitivity to the parameters of facility capacity, the number of established temporary care centers, and the number of established distribution centers. Decreasing the capacity of distribution centers increases the amount of shortage of supplies and increasing the capacity of these centers reduces the amount of shortage of supplies (Figure 2). As can be seen, due to the 30 percent increase, the objective function has decreased to 980, and by 35 percent decrease, the objective function increases to 3500.

Figure 3 shows the sensitivity analysis of both objective functions relative to the changes in the capacity of vehicles to carry different kinds of relief supplies and the injured. This figure shows that changes in the number and capacity of vehicles can increase or decrease the number of unserved injured in the network. Also, a part of the shortage of relief supplies is related to the weight and volume capacity of vehicles, so that as the capacity of vehicles increases, the amount of shortage of supplies will reach zero.

TABLE 10. Capacity of relief distribution centers

Scale	Capacity
Small	4000
Medium	6000
Large	8000

TABLE 11. Distribution centers established and the amount of their inventory

No.	Scale of distribution center	Amount of inventory in distribution centers		
		Tent	Water	Food
1	small	40771	131065	131065
2	medium	55972	386512	402568
3	large	46962	303987	820040
4	large	49856	294605	294625
5	medium	55802	401612	401612
6	medium	48887	280923	280923
7	large	70858	856006	70926
8	small	40460	130460	129565

TABLE 12. Quantity of relief supplies provided by suppliers in the post-disaster phase

Supplier	Commodities	Distribution center							
		1	2	3	4	5	6	7	8
1	Tent	6200	1200	650	0	450	230	0	0
	Water	0	0	1200	720	0	0	1500	1000
	Food	14200	0	0	1500	2000	100	0	1000
2	Tent	0	1000	0	550	1000	0	0	100
	Water	13500	600	0	780	4000	0	0	5000
	Food	1100	0	20000	120	1500	15000	0	8000
3	Tent	0	0	0	110	100	0	300	700
	Water	0	0	0	250	500	0	1500	230
	Food	0	2500	0	410	0	0	8000	1500

TABLE 13. Number of the injured sent to existing care centers

Affected area	Hospitals									
	1	2	3	4	5	6	7	8	9	10
1	-	350	-	-	230		600	75		-
2	-	-	760	-	-	400	-	-	100	460
3	210	-	-	-	-	-	130	35	-	-
4	-	-	-	800	-	150		-	-	-
5	-	810	-	-	-	-	120	-	200	-
6	-	-	-	560	530	-	-	-	-	460
7	-	360	-	-	-	80	-	100	-	-
8	-	-	-	650	-	-	-	-	300	410
9	400	-	-	-	-	630	200	-	-	-
10	-	-	160	-	100	-		100	-	150

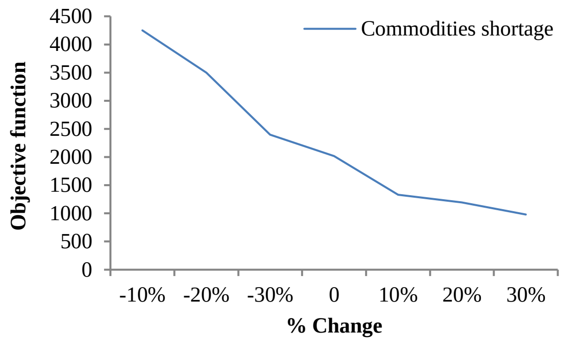

Figure 2. Sensitivity analysis of the objective function of the shortage of supplies relative to the capacity of the relief distribution centers

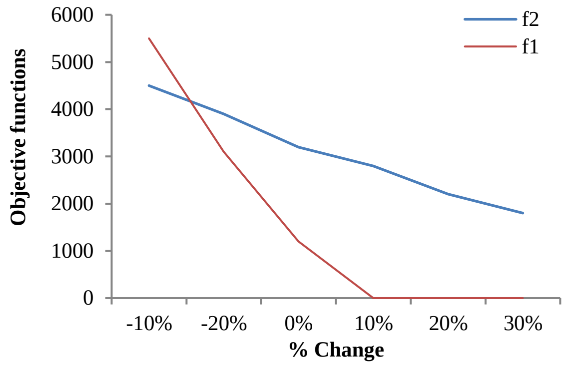

Figure 3. Changes of both objective functions relative to vehicle capacity changes

7. CONCLUSION, MANAGERIAL INSIGHTS AND FUTURE DIRECTIONS

In this study, it was attempted to design a comprehensive and integrated disaster relief model, so as to create a suitable model for disaster management programs. Also, the proposed relief chain structure for one of Tehran's districts was studied to evaluate its effectiveness in complex and flexible disaster situations, especially in an earthquake-prone metropolis such as Tehran with high population, low capacity of passages, unreliable construction and lack of relief facilities.

Finally, the results show that decreasing the capacity of distribution centers increases the amount of shortage of supplies and increasing the capacity of these centers reduces the amount of shortage of supplies. Objective functions also indicate that 36 people have been left unserved and that there are 420 units of shortage of supplies in different affected areas.

This research provides some practical implications from the model. First of all, the objective functions are not affected by each other and each of them individually improves the flow of the injured and relief supplies in the relief network. By optimizing the allocation and routing of different vehicles in the network to distribute relief supplies and evacuate the injured, this model reduces the amount of shortage of supplies and minimizes the number of the injured waiting to be served. Also, an increase in the number and capacity of vehicles can also have a significant impact on the values of the objective functions, but this managerial decision must be made considering system constraints.

The rest of managerial insights can be referred into the road restoration and relief distribution which has not been adequately addressed in past literature. The proposed relief model can provide reliable and fast communications to improve disaster rescue efficiency and road repair, as well as satisfy the victims' psychological needs. The integrated model provides an effective response decision with less total relief time, and higher rescue efficiency especially for large-scale disasters.

At last but not least, this study opens several new directions into this research area. Following suggestions are highly recommended for future studies.

- Choosing the most appropriate vehicle routing policy (such as vehicle routing with time windows), is one of potential directions of this paper.
- Adding more sustainability [35] and or resiliency [36] dimensions to the proposed model opens several new avenues for future works.
- Using heuristic and meta-heuristic solution methods to optimize the problem in a very large scale is highly recommended. We can especially suggest red deer algorithm [37] or social engineering optimizer [38] as two well-known and recent meta-heuristics [39].
- Considering the complete time of the disaster and dividing it into different periods to consider the dynamism of the disaster situation, is another good continuation of this work.

8. REFERENCES

1. Paul, J. A. and Zhang, M., "Supply location and transportation planning for hurricanes: A two-stage stochastic programming framework", ***European Journal of Operational Research***, Vol. 274, No. 1, (2019), 108–125. doi:10.1016/j.ejor.2018.09.042
2. Paul, J. A. and Wang, X. (Jocelyn), "Robust location-allocation network design for earthquake preparedness", ***Transportation Research Part B: Methodological***, Vol. 119, (2019), 139–155. doi:10.1016/j.trb.2018.11.009
3. Loree, N. and Aros-Vera, F., "Points of distribution location and inventory management model for Post-Disaster Humanitarian Logistics", ***Transportation Research Part E: Logistics and Transportation Review***, Vol. 116, (2018), 1–24. doi:10.1016/j.tre.2018.05.003
4. Fathalikhani, S., Hafezalkotob, A., and Soltani, R., "Government intervention on cooperation, competition, and coopetition of humanitarian supply chains", ***Socio-Economic Planning Sciences***, Vol. 69, (2020). doi:10.1016/j.seps.2019.05.006
5. 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. doi:10.1016/j.jclepro.2017.11.037
6. Davoodi, S. M. R. and Goli, A., "An integrated disaster relief model based on covering tour using hybrid Benders decomposition and variable neighborhood search: Application in the Iranian context", ***Computers and Industrial Engineering***, Vol. 130, (2019), 370–380. doi:10.1016/j.cie.2019.02.040
7. Noham, R. and Tzur, M., "Designing humanitarian supply chains by incorporating actual post-disaster decisions", ***European Journal of Operational Research***, Vol. 265, No. 3, (2018), 1064–1077. doi:10.1016/j.ejor.2017.08.042
8. Haghi, M., Fatemi Ghomi, S. M. T., and Jolai, F., "Developing a robust multi-objective model for pre/post disaster times under uncertainty in demand and resource", ***Journal of Cleaner Production***, Vol. 154, (2017), 188–202. doi:10.1016/j.jclepro.2017.03.102
9. Gu, J., Zhou, Y., Das, A., Moon, I.M., and Lee, G., "Medical relief shelter location problem with patient severity under a limited relief budget", ***Computers and Industrial Engineering***, Vol. 125, (2018), 720–728. doi:10.1016/j.cie.2018.03.027
10. Torabi, S. A., Shokr, I., Tofighi, S., and Heydari, J., "Integrated relief pre-positioning and procurement planning in humanitarian supply chains", ***Transportation Research Part E: Logistics and Transportation Review***, Vol. 113, (2018), 123–146. doi:10.1016/j.tre.2018.03.012
11. Hajiaghaei-Keshteli, M., Mohammadzadeha, H., and Fathollahi Fard, A. M., "New Approaches in Metaheuristics to Solve the Truck Scheduling Problem in a Cross-docking Center", ***International Journal of Engineering, Transactions B: Applications***, Vol. 31, No. 8, (2018), 1258–1266. doi:10.5829/ije.2018.31.08b.14
12. Nagurney, A., Salarpour, M., and Daniele, P., "An integrated financial and logistical game theory model for humanitarian organizations with purchasing costs, multiple freight service providers, and budget, capacity, and demand constraints", ***International Journal of Production Economics***, Vol. 212, (2019), 212–226. doi:10.1016/j.ijpe.2019.02.006
13. Liu, Y., Lei, H., Wu, Z., and Zhang, D., "A robust model predictive control approach for post-disaster relief distribution", ***Computers and Industrial Engineering***, Vol. 135, (2019), 1253–1270. doi:10.1016/j.cie.2018.09.005
14. 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, Transactions, A: Basics***, Vol. 31, No. 10, (2018), 1734–1740. doi:10.5829/ije.2018.31.10a.16
15. Abdalzaher, M. S. and Elsayed, H. A., "Employing data communication networks for managing safer evacuation during earthquake disaster", ***Simulation Modelling Practice and Theory***, Vol. 94, (2019), 379–394.

doi:10.1016/j.simpat.2019.03.010

16. 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 and Logistics***, (2019), 1–18. doi:10.1080/23302674.2019.1610197
17. 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. doi:10.1016/j.ins.2019.10.062
18. Fathalikhani, S., Hafezalkotob, A., and Soltani, R., "Cooperation and coopetition among humanitarian organizations: A game theory approach", ***Kybernetes***, Vol. 47, No. 8, (2018), 1642–1663. doi:10.1108/K-10-2017-0369
19. 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. doi:10.1016/j.jclepro.2019.04.046
20. Tavana, M., Abtahi, A.R., Di Caprio, D., Hashemi, R. and Yousefi-Zenouz, R., "An integrated location-inventory-routing humanitarian supply chain network with pre- and post-disaster management considerations", ***Socio-Economic Planning Sciences***, Vol. 64, (2018), 21–37. doi:10.1016/j.seps.2017.12.004
21. 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 and Fuzzy Systems***, Vol. 37, No. 1, (2019), 1435–1455. doi:10.3233/JIFS-182843
22. 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, No. 10, (2020), 6185–6205. doi:10.1007/s00521-019-04126-8
23. Noyan, N. and Kahvecioğlu, G., "Stochastic last mile relief network design with resource reallocation", ***OR Spectrum***, Vol. 40, No. 1, (2018), 187–231. doi:10.1007/s00291-017-0498-7
24. 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), 118200. doi:10.1016/j.jclepro.2019.118200
25. 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. doi:10.1016/j.ijdrr.2017.01.007
26. 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. doi:10.1080/03772063.2019.1642802
27. Khojasteh, S. B. and Macit, I., "A Stochastic Programming Model for Decision-Making Concerning Medical Supply Location and Allocation in Disaster Management", ***Disaster Medicine and Public Health Preparedness***, Vol. 11, No. 6, (2017), 747–755. doi:10.1017/dmp.2017.9
28. Feng, Y., Zhang, Z., Tian, G., Fathollahi-Fard, A.M., Hao, N., Li, Z., Wang, W. and Tan, J., "A Novel Hybrid Fuzzy Grey TOPSIS Method: Supplier Evaluation of a Collaborative Manufacturing Enterprise", ***Applied Sciences***, Vol. 9, No. 18, (2019), 3770. doi:10.3390/app9183770
29. Fathollahi-Fard, A. M., Niaz Azari, M., and Hajiaghaei-Keshteli, M., "An Improved Red Deer Algorithm to Address a Direct Current Brushless Motor Design Problem", ***Scientia Iranica***, (2019) doi:10.24200/sci.2019.51909.2419
30. Ghasemi, P., Khalili-Damghani, K., Hafezalkotob, A. and Raissi, S., "Stochastic optimization model for distribution and evacuation planning (A case study of Tehran earthquake)", ***Socio-Economic Planning Sciences***, Vol. 71, (2019) doi:10.1016/j.seps.2019.100745
31. 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 and Industrial Engineering***, Vol. 137, (2019). doi:10.1016/j.cie.2019.106103
32. Ghasemi, P., Khalili-Damghani, K., Hafezalkotob, A. and Raissi, S., "Uncertain multi-objective multi-commodity multi-period multi-vehicle location-allocation model for earthquake evacuation planning", ***Applied Mathematics and Computation***, Vol. 350, (2019), 105–132. doi:10.1016/j.amc.2018.12.061
33. Torabi, N., Tavakkoli-Moghaddam, R. and Najafi, E., "A Two-Stage Green Supply Chain Network with a Carbon Emission Price by a Multi-objective Interior Search Algorithm", ***International Journal of Engineering, Transactions C: Aspects***, Vol. 32, No. 6, (2019), 828–834. doi:10.5829/ije.2019.32.06c.05
34. 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, Transactions C: Aspects***, Vol. 32, No. 12, (2019), 1781–1789. doi:10.5829/ije.2019.32.12c.11
35. 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. doi:10.1007/s10098-019-01798-7
36. Safaei, A. S., Farsad, S., and Paydar, M. M., "Robust bi-level optimization of relief logistics operations", ***Applied Mathematical Modelling***, Vol. 56, (2018), 359–380. doi:10.1016/j.apm.2017.12.003
37. 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. doi:10.1016/j.engappai.2018.04.009
38. 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. doi:10.1007/s00500-020-04812-z
39. Fathollahi-Fard, A.M., Ahmadi, A., Goodarzian, F. and Cheikhrouhou, N.,, "A bi-objective home healthcare routing and scheduling problem considering patients' satisfaction in a fuzzy environment", ***Applied Soft Computing Journal***, Vol. 93, (2020). doi:10.1016/j.asoc.2020.106385

Persian Abstract

چکیده

در طول تاریخ، طبیعت بسیاری از بلایای طبیعی نظیر زلزله، سیل، خشکسالی، گردباد، طوفان‌های دریایی و سونامی را به بشر تحمیل کرده است. مقیاس گسترده خسارات و تلافات ناشی از بلایای طبیعی در سراسر جهان باعث شده است که تحقیقات گسترده‌ایی در زمینه تهیه‌ی یک سیستم جامع برای مدیریت بلایا انجام شود تا تلافات و خسارات مالی به حداقل برسد. بر اساس این انگیزه و چالش‌های موجود در این زمینه، این پژوهش یک زنجیره امداد یکپارچه را طراحی کرده است تا همزمان آمادگی و پاسخگویی برای مدیریت بحران بهینه کند. تصمیمات مربوط به بهینه‌سازی زنجیره تامین شامل استقرار مراکز توزیع منابع امدادی، میزان موجودی در تسهیلات در مرحله قبل از فاجعه، مکانیابی مراکز مراقبت موقت و نقاط حمل و نقل مصدومان، نحوه تخصیص خدمات امدادی، حمل و نقل مصدومان، مسیریابی وسائل نقلیه مورد استفاده برای توزیع منابع امدادی و تخلیه مصدومان هستند. نتایج نشان می‌دهد که کاهش ظرفیت مراکز توزیع باعث افزایش کمبود منابع می‌شود. و افزایش ظرفیت این مراکز می‌تواند راه‌حل مناسبی باشد.