International Journal of Industrial Engineering & Production Research (2018)

December 2018, Volume 29, Number 4
pp.483 - 496

http://IJIEPR.iust.ac.ir/

A Three-Stage Model for Location Problem Under Fuzzy Environments

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KEYWORDS

Fuzzy environment;
Non-linear mathematical programming;
Multiple objectives.

ABSTRACT

This study contains a three-level mathematical model with a number of suppliers in fixed locations, candidate distribution centers, and affected areas at certain points. A mixed integer nonlinear mathematical programming model is presented here for the open location problem, while a split delivery of demand is considered. In this study, a fuzzy environment is taken into account for our presented model to be in an uncertain environment. The objective is considered for cost minimization, minimization of the maximum travel time of vehicles, and minimization of demands. Finally, to this end, this study uses a fuzzy Multiple Optimal Linear Programming. To make the proposed model and solution approach applicable, numerical examples are provided.

1. Introduction

Unexpected events and natural disasters (floods, earthquakes, hurricanes, etc.) and their consequences require current societies to plan for assistance in such crisis. This plan is filled with challenges such as damage to infrastructure, trans- portation, limited time and resources, difficulties in coordination between different factors, and so on. Therefore, compared to conventional logistics, providing assistance in crisis and emergency logistics is complicated and challenging [24]. In the incidence of natural disasters at the time of critical condition, demand for logistic goods and services increases, and quick distribution of essential facilities can be effective in minimizing the damage and fatal accidents. Therefore, the affected areas shall be supported by various emergency items such as tents, water, etc., which are needed quickly in crisis. Emergency aid processes include the transfer of the needed goods from different suppliers (Red Crescent, airports, local suppliers, etc.) by local distribution centers to the damaged areas. Therefore, one of the important logistic strategies to improve performance and reduce latency is the location and establishing of distribution centers near the affected areas. If distribution centers are situated in appropriate locations from the network, which could cover demand in these conditions appropriately, it would be very important in the successful rescue operation. In all the cases listed, poor selection of suitable locations will increase the probability of capital loss and ultimately will lead to many human losses. Of other logistic activities that are

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Received 6 August 2018; revised 3 December 2018; accepted 19 December 2018

of great importance and affect the optimal distribution network is the plan to transport essential items and required goods to the affected areas. Therefore, deciding on the number of vehicles allocated to each distribution center, each transportation route for the delivery of goods to critical areas, as well as the allocation of critical areas to created distribution centers can affect the decision to choose distribution centers.
Dealing with location problems using mathematical optimization is now of great importance. The authors [17] proposed an Emergency Medical Service (EMS) station location and sizing problem using distributionally robust optimization. Their paper [35] proposed a particle swarm optimization algorithm to solve the Capacitated Location-Routing Problem (CLRP). Other researchers [?], in their paper, introduced the Robust Connected Facility Location (ConFL) problem, while the robust discrete optimization framework is considered. Fuzzy environments as well as multi-optimization problem are widely used for different applications [18], [14], and [11].
Aid distribution features after crises are crucial for decision-making. One of the features that can be considered for vehicle routing problems in crisis, which brings the problem closer to a real emergency situation, is that vehicles do not return to distribution center after serving the last part of the route. In other words, the path is open for vehicles, because, in the real world, vehicles that distribute aid to affected areas mostly belong to volunteer forces or they are rented from transportation companies and do not need to come back to distribution centers after the completion of the work. The open location-routing problem is a new issue in the literature, which was first appeared in the referenced paper [12]. Despite high demand for assistance in affected areas after the crisis, another problem is that when demand is greater than the capacity of the server vehicle, the critical area can receive more than one service. In the literature, this is called split delivery. Allowing split delivery leads to substantial savings in costs that were shown experimentally in the research by [1]. Thirdly, the dynamic and complex nature of disaster aid chain imposes a high degree of uncertainty on aid logistics planning decisions and highly affects the performance of the chain. As a result, taking into account the uncertainty of key parameters helps the quality of the decisions made at the strategic, tactical, and operational levels of the aid chain [8].
According to the considered issues in this study, attempt has been made to propose a multi-objective, multi-product model for three-level aid chain under uncertainty to transport aid supplies from suppliers (Red Crescent, airports, and local suppliers) to created distribution centers, to allocate critical areas and vehicles to distribution centers, and to design directions from distribution centers to critical areas by considering split delivery. Moreover, the study considers all routes for vehicles as open routes. Objectives considered in the model include (1) minimizing the cost of the entire system, (2) minimizing the maximum travel time on the track, and (3) minimizing unmet demand. To get the model closer to reality, using fuzzy possibilistic programming, the model expands in the non-deterministic state. In addition, in order to solve the proposed model, fuzzy multi-objective programming is used.
The rest of the article is as follows: Section 2 presents a brief review of the literature that discusses the logistics of aid. Section 3 includes the statement of the problem and the proposed model. The suggested solution is provided in Section 4. Computational results are expressed to validate the model in Section 5. Finally, in Section 6, conclusions and recommendations for future studies are offered.

2. Literature Review

In recent years, emergency logistical problems have attracted the attention of many researchers. Below are the published studies on the topic briefly studied. Fiedrich et al. (2000) investigated casualties following a disaster and calculated the casualties and related losses and tried to provide a model to minimize such losses. As mentioned, this study only examines the transport of the injured, and there has been no discussion about relief supplies. They used Tabu search and simulated annealing to solve their models. Saydam et al. (2006) proposed a multiple-period location-covering method for dispatching ambulances. The model was designed to improve the performance of emergency medical services System, especially to re- spond to demands in events and disasters. However, routing vehicles have not been considered. Tzeng et al. (2007) provided a definitive multi-criteria model for the distribution of emergency goods to the affected areas considering the cost, response time, and customer satisfaction, and they solved it by fuzzy multi-objective programming. In addition, Sheu (2007) investigated a combined fuzzy clustering approach to optimize multi-objective dynamic programming. The weighting method for converting the distribution to one objective is applied to achieve cost minimization and maximization of demand coverage rate.

Ozdamar and Yi (2007) provided an integrated location-distribution model to coordinate logistical operation and unloading in disaster conditions. The purpose of the model was to maximize service levels through immediate access to the affected areas and location of temporary emergency units in appropriate points. The sub-problem of location included the facilitation of limited medical resources and access to balance in the rate of service, among medical centers. Medical staff can move between distribution centers; however, the total number of these people remain fixed over time.

The coverage radius for relief items in locating the humanitarian relief facilities is done in a study conducted by Black and Beamon (2008). One of the main features of the provided model is to consider and apply the budget constraints before and after the disaster. In addition, upper and lower limits were considered for the time of response to the demand by any supply center, and it is suggested that the relief time cannot exceed this limit. Maximizing the total demand covered by constructed distribution centers is the only objective function of the model.

Yi and Kumar (2007) provided ant colony optimization algorithm to solve logistic problems in disaster relief activities in the responding phase. In this study, sending goods to distribution centers deployed in the affected areas and transferring of victims to relief centers have been considered simultaneously. The objective function is to minimize the weighted sum of unmet demand for total goods. In their model, vehicle routes are determined; however, locating distribution centers is not considered. Vitoriano et al. (2011) provided a multi-criterion optimization model based on cost, time, and priority for the distribution of humanitarian relief. This model helps select vehicles and design the routes; however, locating distribution centers is not considered. Lin et al. (2011) provided a multi-period, multi-product and multi-vehicle logistic model for logistical planning of major commodities with priority in disaster response phase. The model has two objectives: the first objective minimizes the unmet demand, and the second one minimizes travel time. Berkoune et al. (2012) presented a mathematical model for planning transportation of goods in the response phase where he tried to minimize the travel time of vehicles carrying goods. Eshghi and Najafi (2013) proposed a multi-objective, multi-product, multi-period, and randomized model to achieve logistical management of relief items and injured people.

Disaster network explained in their research included affected centers, hospitals, and transfer centers of relief items. Objectives of the model include minimization of the total number of non-serviced people, the total number of unmet demands, and the total number of transportation vehicles required. Their investigation took into consideration uncertainty in the sent items, the number of affected persons, and the capacity of suppliers and hospitals. For this purpose, a robust approach was developed in the model to face uncertainty, and a solution was proposed based on hierarchical objective functions.

Bozorgi-Amiri et al. (2013) developed a multi-objective robust stochastic programming model for relief logistic in the conditions of uncertainty. In this research, not only demand was considered, but also supply and purchase and transportation costs were considered as uncertain parameters. Their model includes two stages. The first stage is concerned with determining the distribution center locations and required an inventory of any relief items under storage, and the second stage is concerned with determining the level of goods transferred from relief distribution centers to affected areas. Their model is based on the assumption that disaster information does not depend on time and routing the vehicles.

Wang et al. (2014) provided a multi-objective model for open locating-routing problem for distribution after the earthquake. The considered disaster network in their study included distribution centers and affected areas. In the presented model, emergency repair of roads and damaged communication channels were not considered. They used a non-dominated sorting genetic algorithm (NSGA-II) to solve the model. Zhan et al. (2014) provided the vehicle allocation problem in relief logistic to ensure efficiency and equity in the decision-making process about issues such as vehicle routing and allocation of relief. The considered network is a two-echelon supply chain including relief supplies and disaster areas. The decisions concerning facility development are made such that the number of vehicles and relief goods is programmed for suppliers of relief before the disaster, while routing of vehicles and allocation of relievers are programmed for after the disaster.

Martnez-Salazar et al. (2014) provided a single-period, two-objective model for transportation and location routing regarding a three-level supply chain and used two algorithms, including multi-objective genetic algorithm using non-dominated sorting and scatter multi-objective search algorithm, for solving the problem. Their problem objectives include minimization of the total cost and production of a balanced set of routes for vehicles.

Talarico et al. (2015) considered a routing problem for ambulances in the sce- nario of response to natural disasters. The ambulances are used for carrying med- ical personnel and patients. They considered two groups of patients: people with insignificant injury that can receive relief; those who are severely injured and should be taken to the hospital. Since ambulances indicate a source-scarce setting in critical conditions, their efficient use is important. Two mathematical formulas have been provided to obtain the route programs that take the least relief-delivery total time. Bozorgi Amiri and Khorsi (2015) provided a multi-objective dynamic location-routing model for mid-planning and short-term regarding relief with uncertain conditions in demand, travel time, and cost parameters. Their model objectives include the process of minimizing the maximum deficit among the affected areas in all periods, travel time, and total cost. The proposed model was solved by using the constraint method. In their model, the intended route was considered close, and split delivery of demand was not considered.

Tofighi et al. (2016) introduced a two-stage possibilistic-stochastic approach based on the scenario to design a relief logistic network in Tehran. In the first stage, central warehouse and local distribution centers with a predetermined amount of relief supplies are determined. In the second stage, a relief distribution program for different disaster scenarios is presented. In addition, this study extended a meta-heuristic algorithm for obtaining a practical and convenient solution in the appropriate time for the Tehran case. Zokaee et al. (2016) presented a robust scheduling model for a three-level relief chain consisting of suppliers, relief distribution center, and damaged areas in the uncertainty conditions. The goals of their model were to minimize the total cost of relief operation costs, while it maximized the satisfaction of victimized people simultaneously by minimizing the shortage of relief goods. For model efficiency, they conducted a case study in Alborz area, Iran. The proposed model in this study is consistent with characteristics that are rarely considered in previous studies. In this study, a nonlinear integer multi-objective open transportation location routing model is presented for three levels of relief chain. The distribution of aid to the affected areas takes place along with split delivery of demand. In addition, an important point that must be considered in planning the logistical response to the crisis is dynamic and uncertain nature of the information which is not considered in many studies. Such cases have led to their reduced efficiency of implementation. Therefore, to evaluate uncertainty, this study is based on fuzzy possibilistic programming, and fuzzy multi-objective programming provided by Torabi and Hassini (2008) is used to solve the model.

3. Definition of the Problem and Mathematical Model

In the aftermath of natural disasters, emergency response to victims and provid- ing services to the injured people is essential. In this study, a network of relief after a disaster is considered. For this purpose, a nonlinear mixed integer programming model is presented for multi-commodity and multi-objective open transportation location routing problem in a three-level relief chain. This chain consists of suppliers (the gathering centers of relief goods) in fixed locations, some candidate distribution centers, and a set of affected areas with different demands of each type of goods. Relief goods are transferred from suppliers to distribution centers in affected areas. Thus, the location of distribution centers in appropriate places in the network that can cover the affected areas appropriately is important to carry out a successful rescue operation. In the proposed problem, the process of providing relief is such that the first subsets of the distribution centers are specified for reopening. The suppliers transfer their aid on a large scale through different transportation networks to created distribution centers, and in a later stage of distribution, vehicles and critical areas will be allocated to distribution centers, and tracking vehicles from distribution centers to critical areas is designed for rapid distribution of the emergency aid. Split delivery of demand required as demand in the critical area is larger than the capacity of the vehicle, and each critical area can be served more than once and by different vehicles. Heterogeneous vehicles are considered at different speeds and capacities. It should be noted that any vehicle is allowed to transport multiple types of assistance to each allocation, and various types of aid are allowed at the same time in one vehicle load. In addition, after the completion of operation when the vehicles serve the last node of the route, they do not need to return to their origin. Therefore, the route for the vehicles is considered open. Intended objectives in the problem include the minimization of the total cost including fixed cost of creating distribution centers, travel cost of the vehicle, and costs of goods transported from suppliers to distribution centers. The second objective is the minimization of maximum travel time on the route (maximum travel time means the latest completion time of the service among all critical areas), and the third objective is to minimize unmet demand.

Tab. 1. Sets and indices

H	Set of suppliers 1,…,h
N	Set of disaster areas 1, . . . , n
M	Set of candidate DCs n+ 1,…,n+ m V Set
of node 1,…,n+ m	
K	Set of vehicles 1,…,k
L	Set of relief 1,….,l
E	Set of available traffic links (i,j), i,j v, i = j i, j
	Indices of nodes i,j v
l	Indices of relief
k	Indices of vehicles

Tab. 2. Parameters

$\tilde{f}_i$	Fixed cost of establishing DC i, ∀i ∈ M
e_{ij}	Distance of link (i, j), ∀(i, j) ∈E
S_{hil}	Transportation cost per unit of relief l from supplier h to distribution i $\tilde{D}_{il}$
	Quantity of relief l demanded by disaster area i
sv_l	Unit volume of relief l, ∀l ∈ L
O_{hl}	Amount of relief l available in supplier h
$\tilde{Q}_{il}$	Maximum capacity of the distribution center i from relief l $\tilde{c}_k$
	Transportation cost per kilometer of vehicle k
v_k	Normal speed of terrestrial vehicle k
CA_k	Loading capacity of terrestrial vehicle k

Tab. 3. Decision variables

y_i	1, if candidate DC i is opened, 0, else, ∀i ∈M
x_{ijk}	1, if i precedes j in route of vehicle k, 0, else
R_{ijk}	1, if i is on route of vehicle k, 0, else
P_{ik}	1, if the last demand point serviced by vehicle k is node i ∈ N ; 0,else W_{hil}
	Quantity of relief l transported from supplier h to distribution center i dev_{il}
	Amount of unsatisfied demand relief type l at node i at the end of the
operation	
q_{jlk}	Quantity of relief l distributed by k to demand point i

3-1. Mathematical model

$$z_{\partial} = Min \quad \sum_{i \in M} \tilde{f}_i y_i + \sum_{k \in K} \sum_{(i,j) \in E} \tilde{c}_k d_{ij} x_{ijk} + \sum_{h \in H} \sum_{i \in M} \sum_{l \in L} \tilde{S}_{hil} Whil \tag{1}$$

$$z_2 = \min \max \left\{ \sum_{(i,j) \in E} \frac{e_{ij} x_{ijk}}{v_k}, k \in K \right\} \tag{2}$$

$$z_3 = \min \sum_{jx_{ijk} N} \sum_{lx_{ijk} L} \sum_{kx_{ijk} K} (\tilde{D}_{il} - q_{jlk}) R_{jk} \quad (3)$$

$$y_j \geq x_{ijk}, \quad \forall i \in M, (i,j) \in E, k \in K, i \neq j \quad (4)$$

$$y_i \geq R_{ik}, \quad \forall i \in V, (i,j) \in E, k \in K \quad (5)$$

$$R_{ik} \geq x_{ijk}, \quad \forall i \in V, (i,j) \in E, k \in K : i \neq j \quad (6)$$

$$R_{ik} \geq P_{ik}, \quad \forall i \in V, k \in K \quad (7)$$

$$\sum_{i \in V} P_{ik} = 1, \quad \forall k \in K \quad (8)$$

$$\sum_{i \in K} x_{ijk} \leq 1, \quad \forall (i,j) \in E : i \neq j \quad (9)$$

$$\sum_{i \in K} x_{ijk} \leq 1, \quad \forall i \in N : \mathrm{k} \in K : i \neq j \quad (10)$$

$$\sum_{i \in M} \sum_{j \in N} x_{ijk} \leq 1, \quad \forall k \in K \quad (11)$$

$$\sum_{i \in M} W_{hil} \leq \tilde{Q}_{hl} \quad \forall i \in M, l \in L \quad (12)$$

$$\sum_{i \in H} W_{hil} \leq \tilde{Q}_{il} \, \mathrm{y}_{\mathrm{i}}, \quad \forall i \in M, l \in L \quad (13)$$

$$\sum_{i \in M} \sum_{k \in K} q_{jlk} R_{ik} \leq \tilde{Q}_{il}, \quad \forall i \in M, l \in L \quad (14)$$

$$dev_{jl} = \tilde{D}_{il} - (\sum_{k \in K} q_{jlk}) \geq 0 \quad \forall j \in N, l \in L \quad (15)$$

$$\sum_{h \in H} \sum_{i \in M} W_{hil} \geq \sum_{j \in N} \tilde{D}_{jl}, \quad \forall l \in L \quad (16)$$

$$\sum_{j \in N} \sum_{l \in L} sv_l q_{jlk} \leq CA_{\mathrm{k}}, \quad \forall k \in K \quad (17)$$

$$\sum_{i \in v} \sum_{k \in K} x_{ijk} \geq 1, \quad \forall j \in N \quad (18)$$

$$(\sum_{j/(i,j) \in E} x_{jik} - \sum_{j/(i,j) \in E} x_{ijk}).p_{ik} = p_{ik}, \quad \forall i \in N, k \in K \quad (19)$$

$$(\sum_{j/(i,j) \in E} x_{jik} - \sum_{j/(i,j) \in E} x_{ijk}).\mathrm{R}_{ik} = -R_{ik}, \quad \forall i \in M, k \in K \quad (20)$$

$$(\sum_{j/(i,j) \in E} x_{jik} - \sum_{j/(i,j) \in E} x_{ijk}).\mathrm{P}_{ik} = 0, \quad \forall i \in N, k \in K \quad (21)$$

$$(\sum_{j/(i,j) \in E} x_{jik} - \sum_{j/(i,j) \in E} x_{ijk}).\mathrm{R}_{ik} = 0, \quad \forall i \in M, k \in K \quad (22)$$

$$(\sum_{j/(i,j) \in E} x_{jik} - \sum_{j/(i,j) \in E} x_{ijk}).(1 - p_{ik}) = p_{ik}(1 - p_{ik}), \ \forall i \in N, k \in K \quad (23)$$

$$(\sum_{j/(i,j) \in E} x_{jik} - \sum_{j/(i,j) \in E} x_{ijk}).(1 - R_{ik}) = R_{ik}(1 - R_{ik}), \ \forall i \in M, k \in K \quad (24)$$

$$\sum_{i \in M} M x_{ijk} = 0 \quad \forall j \in M .k \in K, t \in T \quad (25)$$

$$-u_{jk} + n \times x_{jik} \leq n - 1, \quad \forall (i,j) \in N .k \in K, \mathrm{i} \neq j \quad (26)$$

$$q_{ilk} \geq 0, \quad \forall i \in M, \mathrm{l} \in L, \mathrm{h} \in H \quad (27)$$

$$y_i \in (0,1), \quad \forall i \in M \quad (28)$$

$$x_{ijk} \in (0,1), \quad \forall i \in V, k \in K \quad (29)$$

$$R_{ik} \in (0,1), \quad \forall i \in V, k \in K \quad (30)$$

$$p_{ik} \in (0,1), \quad \forall i \in N, k \in K \quad (31)$$

$$u_{ik} \in (0,1), \quad \forall i \in N, k \in K \quad (32)$$

Equation (1) is the first objective function that minimizes the distribution costs including the fixed costs of creating distribution centers, travel expenses of the vehicles, and the cost of transporting goods from suppliers to distribution centers.
Equation (2) as the second objective function minimizes the maximum travel time of the vehicles. The objective function (3) minimizes the total unmet demand.
Constraints (4) and (5) specify that only established distribution centers can obtain service. Constraint (6) ensures that every vehicle can travel through connection (i, j), if and only if node i is on the route of each vehicle. Constraint (7) specifies that the nodes at the end of the route of each vehicle must be serviced by the same vehicle. Equation (8) ensures that every vehicle must ultimately remain in a disaster area or distribution center. Constraint (9) shows that only one vehicle is selected for each route. Constraint (10) ensures that any vehicle serves once at most in any critical area. Constraint (11) ensures that any vehicle is sent from one distribution center at most. Constraint (12) ensures that the amount of aid transferred by any supplier of any goods to all distribution centers does not exceed the maximum amount. Constraints (13) and (14) are capacity constraints of distribution centers. Constraint (15) shows that the amount of relief distributed to each node does not exceed the amount demanded by that node. Constraint (16) ensures that there will be no shortage of goods. Constraint (17) ensures that the amount of all the relief distributed to disaster areas by a vehicle does not exceed their capacity. Constraint (18) ensures that every disaster area can be visited at least once. The assumption of split delivery in this constraint has been well illustrated. Constraints (19) - (24) are the limits of maintaining the flow, which also ensures the openness assumption of the routes (ensuring that each vehicle at any point is dispatched from that point, and the last node of the route does not return to the distribution center). Constraint (25) ensures that distribution centers are not related to each other. It means that goods are not exchanged between distribution centers. Constraint (26) is the constraint of elimination sub-tours. Constraints (27)-(32) correspond to non-negative integer values and numbers of zero, and one for decision variables. The model was presented given the certainty of parameters in Sections 3-5. In the real world, there is uncertainty in many of these parameters. To bring the model closer to real conditions in the future, the model has also been expanded in non-deterministic conditions. To develop the model, a robust optimization approach is used.

3-2. Uncertainty approach.

With respect to the above-mentioned consideration, a mixed integer programming model with fuzzy parameters is proposed. Next, the proposed model, by virtue of a new technique based on the possibilistic method [13, 21, 27], is converted to its commensurate deterministic version.
The commensurate adjuvant crisp model:
Suppose that $\tilde{c}$ is a triangular fuzzy number (TFN); Eq. (33) is the membership function of $\tilde{c}$:

$$\mu_c(X) = \begin{cases} f_c(X) = \dfrac{x - c^P}{c^m - c^P} & if \quad c^p \le x \le c^m \\ 1 \quad if \quad x = c^m \\ g_c(X) = \dfrac{c^0 - c}{c^o - c^m} & if \quad c^m \le x \le c^p \\ 0 \quad if \quad c^p \ge x \quad or \quad x \ge c^p \end{cases} \quad (33)$$

In the following FMP model, all parameters are defined as TFNs. The commensurate crisp-parametric problem can be written as follows (Jimenez et al., 2007). Thus, by considering these issues, the model will be presented as follows:

$$EV(c) = \frac{c^p + 2c^m + c^o}{4}, E_1^a = \frac{a}{2}(a^p + a^m), E_2^a = \frac{a}{2}(a^m + a^o)$$
$$E_1^b = \frac{b}{2}(b^p + b^m), E_2^b = \frac{b}{2}(b^m + b^o)$$
$$\tilde{f}_i = \frac{f_i^p + 2f_i^m + f_i^o}{4} \tag{34}$$
$$\tilde{s}_{hil} = \frac{s_{hili}^p + 2s_{hili}^m + s_{hil}^o}{4}$$
$$\tilde{D}_{il} = \frac{D_{il}^p + 2D_{il}^m + D_{il}^o}{4}$$

4. The Proposed Solution Approach

In this study, to solve the proposed model, a hybrid solution approach is presented, composed of the techniques presented in the previous section and the fuzzy solution approach derived from the method of Torabi and Hosseini (2008):

The steps involved in the proposed hybrid solution approach are summarized as follows:

Step 1: determine the parameters and variables of uncertainty and consider the distribution functions required for the model.

Step 2: formulate the proposed model with the parameters defined in the previ- ous step.

Step 3: convert the constraints of mixed-integer programming model to con- straints of the certain counterpart by applying the approach outlined in the previous section.

Step 4: determine the positive and negative ideal solutions to every objective function. To calculate the positive and negative ideal solutions, i.e.,

$$(W_1^{PIS}, x_1^{PIS}), (W_2^{PIS}, x_2^{PIS}) \tag{35}$$

each problem is separately solved for each of the objective functions, and the positive ideal solution

is obtained; then, the negative ideal solution is estimated as follows:

$$W_1^{NIS} = W_1^{NIS}(x_2^{PIS}), W_2^{NIS} = W_2^{NIS}(x_1^{PIS}), \tag{36}$$

Step 5: determine a linear membership function for each objective function as follows:

$$\mu_1(X) = \begin{cases} 1 & if \quad W_1 < W_1^{PIS} \\ \dfrac{W_1^{NIS} - W_1}{W_1^{NIS} - W_1^{PIS}} & if \quad W_1^{PIS} \le W_1 \le W_1^{NIS} \\ 0 & if \quad W_1 \ge W_1^{NIS} \end{cases}$$
$$\mu_2(X) = \begin{cases} 1 & if \quad W_2 < W_2^{PIS} \\ \dfrac{W_2^{NIS} - W_2}{W_2^{NIS} - W_2^{PIS}} & if \quad W_2^{PIS} \le W_2 \le W_2^{NIS} \\ 0 & if \quad W_2 \ge w_2^{NIS} \end{cases} \tag{37}$$

In fact, $\mu_h(x)$ represents the satisfaction degree of the h^{th} objective function. It should be noted that $\mu_1(x)$ is used for minimization objective functions and $\mu_2(x)$ for maximization objective function.

Step 6: Convert the certainty mixed integer programming model to a certainty single-objective mixed integer programming model using the integrated function calculated as follows:

Step 8: determine parameters θ_h, ρ, and ψ and solve single-objective models created in the previous step. If the answer is satisfactory for decision-makers, it stops; otherwise, in order to achieve new answers, change the values of parameters ψ and ρ; if needed, change the value of θ_h.

5. Computational Results

The computational results of the model are presented in this section. To demon- strate the validity and usefulness of the model and the solution approach, several numerical tests are run, and the results are presented in this section. To this end, four different problems with different aspects were considered. The information related to the dimensions is shown in Table 1, and the information about the pa- rameters of the model is shown in Table 2. It should be noted that to generate the triangular fuzzy parameters according to Lai and Hwang (1992), three prominent points are obtained for each imprecise parameter. The most likely (C^m) value of each parameter is first provided randomly by utilizing the uniform distributions specified in Table 2. Thus, without loss of generality, two random numbers (r_1, r_2) are generated between 0.2 and 0.8 by applying uniform distribution. All problems considered in both deterministic and non-deterministic conditions were solved by software GAMS version 23.6 and Baron Solver.

Tab. 4. Dimensions of the Problem

Test problems	(h)	(M)	(N)	(K)	(L)
1	2	3	11	3	2
2	3	4	10	4	2
3	2	2	8	3	2
4	2	3	6	3	2

Tab. 5. Model Parameters

Parameters	Values
f_i	~uniform(10000,30000)
e_{ij}	~uniform(60,250)
O_{hl}	~uniform(14000,24000)
Q_{il}	~uniform(9000,12000)
D_{jl}	~uniform(800,2500)
V_k	~uniform(70,90)
CA_k	~uniform(23,39)
uv_l	~uniform(0.0123, 0.028)
c_k	uniform(3,5)
s_{hil}	uniform(8,10)

As is clear, to solve the problem in deterministic condition, distribution centers (1) and (2) are opened, to which the supplies of collected aid are sent, and vehicles tailored to the track status and demands of critical areas are assigned to distribution centers. As observed, the route is open for all vehicles, and they do not return to the distribution center. In addition, due to high-demand critical areas (7) and (8) that are larger than the remaining capacity of Vehicle 3 in the first stage of service, some of the remaining demand in Area 8 is met by Vehicle 1 in the next stage. Area 7 will meet again by vehicle 2. With careful consideration of non-deterministic condition, centers (1) and (3) have been opened for providing aid, and the critical area (3) due to high demand has been met in three stages by various vehicles.

The computational results are summarized in Tables 3 and 4 in both determin- istic and non-deterministic conditions based on three levels of (0.1, 0.3, and 0.5) and various degrees of importance for the objective functions. The value for levels of uncertainty for all model parameters in each stage of the implementation is considered constant, and this value is ρ = 0 for certain models. In addition to the impact of penalty coefficient (ϕ) on objective functions in both deterministic and non-deterministic conditions, sensitivity analysis was conducted; because of the required time for this analysis, it was conducted only on two problems, the results of which are shown in Table 5.

Tab. 6. Results of sensitivity analysis for problems based on ϕ = 0.4 and α = 0.3

Test problem	Deterministic			
	(z_1, μ_1)	(z_2, μ_2)	(z_3, μ_3)	α
				0.1
1	(346923 ,0.94)	(12.70 ,0.77)	(3404.43, 0.73)	0.3
				0.5
				0.1
2	(512639.7,0.79)	(8.74,0.86)	(2142.3, 0.85)	0.3
				0.5
				0.1
3	(287040, 0.82)	(6.82, 0.91)	(3392.6, 0.76)	0.3
				0.5
				0.1
4	(183124.7, 0.93)	(3.56, 0.85)	(3097.14, 0.87)	0.3
				0.5

Tab. 7. Results of sensitivity analysis for problems based on ϕ = 0.4 and α = 0.3

Test problem	Fuzzy possibilistic			
	α	(z_1, μ_1)	(z_2, μ_2)	(z_3, μ_3)
	0.1	(375467.5, 0.81)	(12.92, 0.75)	(3657.4, 0.67)
1	0.3	(426795.16, 0.90)	(13.24, 0.71)	(4290.02, 0.68)
	0.5	(485078.04, 0.89)	(16.05 , 0.63)	(4718 , 0.62)
	0.1	(568331.37, 0.64)	(9.74, 0.66)	(2142.72,0.89)
2	0.3	(621713.4, 0.58)	(10.34, 0.49)	(2891.8,0.75)
	0.5	(692864.83,0.71)	(13.41,0.78)	(3273.54,0.69)
	0.1	(314287.14,0.75)	(6.96 , 0.85)	(3489.2 , 0.70)
3	0.3	(355284.65, 0.72)	(7.87, 0.69)	(3941.5, 0.78)
	0.5	(395017.89, 0.68)	(8.74, 0.61)	(4413.17,0.69)
	0.1	(198211.09, 0.76)	(3.96 , 0.64)	(3285.5, 0.83)
4	0.3	(235017.5 , 0.82)	(4.37 , 0.70)	(3889.2, 0.81)
	0.5	(295088.27, 0.89)	(5.10 , 0.62)	(4185.12, 0.78)

Tab. 8. Sensitivity analysis of (α) based on ϕ= 0.4

Test problem		Deterministic		
	$(\theta_1, \theta_2, \theta_3)$	(z_1, μ_1)	(z_2, μ_2)	(z_3, μ_3)
	(0.3,0.3,0.4)	(346923 , 0.94)	(12.70, 0.77)	(3404.7,0.78)
1	(0.3,0.4,0.3)	(399438.3, 0.86)	(11. 8, 0.89)	(3779.2,0.74)
	(0.4,0.3,0.3)	(318152.07,0.96)	(13 , 0.78)	(4081 , 0.72)
	(0.2,0.4,0.4)	(409871.6, 0.68)	(11.5 , 0.85)	(513549.4, 0.69)
	(0.3,0.3,0.4)	(512639.7, 0.79)	(8.74 , 0.86)	(2142.38,0.85)
2	(0.3,0.4,0.3)	(542047.2 , 0.84)	(7.67, 0.83)	(2527.61,0.74)
	(0.4,0.3,0.3)	(471947.8 , 0.87)	(8.91 , 0.70)	(2876.41,0.64)
	(0.2,0.4,0.4)	(592096.5 , 0.82)	(7.25 , 0.82)	(2123.74,0.71)
	(0.3,0.3,0.4)	(287040.4, 0.82)	(6.82 , 0.91)	(3392.63,0.76)
3	(0.3,0.4,0.3)	(317538.31,0.81)	(5.28 , 0.85)	(3617.2 , 0.92)
	(0.4,0.3,0.3)	(263669.8, 0.92)	(6.96, 0.70)	(3941.61,0.84)
	(0.2,0.4,0.4)	(394164.15,0.54)	(5.013,0.76)	(3295.42,0.92)
	(0.3,0.3,0.4)	(183124.7, 0.93)	(3.56 , 0.85)	(3097.14,0.87)
4	(0.3,0.4,0.3)	(203322.3, 0.78)	(2.75 , 0.87)	(3485.11,0.74)
	(0.4,0.3,0.3)	(162761.3, 0.72)	(3.94 , 0.78)	(3890.81,0.87)
	(0.2,0.4,0.4)	(243633.9, 0.58)	(2.217,0.77)	(2975.8 , 0.91)

Tab. 9. Sensitivity analysis of (α) based on ϕ= 0.4

Test problem	Fuzzy possibilistic			
	$(\theta_1, \theta_2, \theta_3)$	(z_1, μ_1)	(z_2, μ_2)	(z_3, μ_3)
1	(0.3,0.3,0.4)	(426795.16,0.90)	(13.24, 0.71)	(4290.26, 0.88)
	(0.3,0.4,0.3)	(454297.23,0.74)	(13.10, 0.72)	(4480.21, 0.66)
	(0.4,0.3,0.3)	(384616.9, 0.92)	(14.96, 0.48)	(4623.10, 0.69)
	(0.2,0.4,0.4)	(12.9 , 0.72)	(3397.4, 0.81)	(4099.8 , 0.72)
2	(0.3,0.3,0.4)	(621713.4, 0.58)	(10.34, 0.49)	(2891.8 , 0.80)
	(0.3,0.4,0.3)	(681282.9, 0.36)	(8.53 , 0.73)	(3341.51 , 0.72)
	(0.4,0.3,0.3)	(594781.7, 0.73)	(10.79, 0.64)	(3762.11, 0.58)
	(0.2,0.4,0.4)	(719156.2, 0.60)	(8.02 , 0.77)	(2678.05, 0.67)
3	(0.3,0.3,0.4)	(355884.65,0.72)	(7.87 , 0.69)	(3941.5, 0.71)
	(0.3,0.4,0.3)	(384946.50,0.56)	(6.51 , 0.74)	(4185.41,0.83)
	(0.4,0.3,0.3)	(323858.53,0.65)	(8.04 , 0.65)	(4518.2, 0.75)
	(0.2,0.4,0.4)	(465421.41,0.34)	(5.98, 0.70)	(3890.27,0.78)
4	(0.3,0.3,0.4)	(235017.5, 0.82)	(4.37, 0.70)	(3889.2, 0.81)
	(0.3,0.4,0.3)	(268916.31,0.58)	(3.56 , 0.86)	(4075.21, 0.75)
	(0.4,0.3,0.3)	(203864.19,0.64)	(5.29 , 0.64)	(4316.81, 0.70)
	(0.2,0.4,0.4)	(315261.75,0.45)	(3.15, 0.75)	(3463.85, 0.85)

According to the computational results presented in Tables 3 and 4, it can be seen that all uncertain problems have answers worse than certain problems. In addition, it can be concluded based on the results in Table 4 that TH method acquires unique solutions for every different degree of importance for the objective functions. In general, it can be said that TH is a good and eligible method for planning multi-objective problems, because it can achieve effective and efficient solutions.

Tab. 10. Results of sensitivity analysis on ϕ-value for problems based on α = 0.3 and θ = (0.3, 0.3, 0.4)

Test problem	Deterministic			
	ϕ	(z_1, μ_1)	(z_2, μ_2)	(z_3, μ_3)
1	0.1	(325031.5,0.95)	(9.42, 0.82)	(3586.90,0.68)
	0.2-0.4	(346923.2 ,0.94)	(12.70,0.77)	(3404.43,0.73)
	0.5-0.7	(377635.1,0.87)	(13.61,0.69)	(3249.68,0.86)
	0.8,0.9	(418583.5,0.75)	(14.27,0.62)	(3186.16,0.92)
2	0.1-0.3	(499309.2,0.85)	(6.07,0.94)	(2270.9,0.79)
	0.4-0.6	(512639.7,0.79)	(2142.38,0.85)	(8.74,0.86)
	0.5-0.8	(547687.5,0.72)	(9.80,0.75)	(1931.74,0.89)
	0.9	(590369.2,0.64)	(11.26,0.62)	(1845.31,0.95)

Tab. 11. Results of sensitivity analysis on ϕ-value for problems based on α = 0.3 and θ = (0.3, 0.3, 0.4)

Test problem	Fuzzy possibilistic			
	ϕ	(z_1, μ_1)	(z_2, μ_2)	(z_3, μ_3)
1	0.1	(402687.5,0.93)	(10.92,0.79)	(4383.7,0.62)
	0.2-0.4	(426795.2,0.90)	(13.24,0.71)	(4290.2,0.68)
	0.5-0.7	(459456.7,0.82)	(14.58,0.64)	(4133.6,0.79)
	0.8,0.9	(499614.7,0.71)	(15.03,0.55)	(4058.6,0.84)
2	0.1-0.3	(589369.3,0.63)	(8.64, 0.56)	(2974.2,0.69)
	0.4-0.6	(621713.4,0.58)	(10.34,0.49)	(2891.8,0.75)
	0.5-0.8	(653091.8,0.51)	(11.50,0.43)	(2704.5,0.82)
	0.9	(689769.9,0.46)	(12.44,0.38)	(2517.6,0.90)

6. Conclusions

In this study, for the first time, multi-objective open transportation location rout- ing problem was modeled by considering split delivery of the demand for assistance distribution after the crisis in the three-level emergency chain as nonlinear integer programming. Few studies have focused on the open location-routing problem in emergency logistics; however, in reality, vehicles that are responsible for distributing aid to affected areas often work voluntarily by people or are rented from companies; therefore, this means that they do not return to distribution centers after the completion of operations. Therefore, in this study, the routes for all vehicles were considered open. Furthermore, when providing relief to the affected areas, the demand may not be met in one travel. As a result, in this study, split delivery of demand was raised aiming to get closer to the real-world situations and meet maximum demand and savings in costs. The model objectives include the minimization of logistics costs, the maximum travel time of the vehicles, and unmet demand. Since information is not definite while in crisis, in order to deal with uncertainty in the model, a possibilistic programming approach was used. Furthermore, the model as a multi-objective, fuzzy multi-objective programming approach was used to solve the model. According to the computational results, it is believed that the model and the solution can offer an effective and credible methodology for the management of relief distribution in an uncertain environment. Of note, the obtained results show entirely the uncertain environment, meaning that all uncertain problems have answers worse than certain problems. In addition, it can be concluded that the TH method acquires unique solutions for every different degree of importance for the objective functions. Generally, this is a good and eligible method for planning multi-objective problems as it can achieve effective and efficient solutions. Items that can be considered for future research: Integrated emergency chain network design considering tactical purposes such as in- ventory management during the response. In addition, while in crisis, many roads and communication routes in affected areas are destructed and blocked. To expedite relief, the repair of damaged roads can be taken into account. In addition to ground transportation network to provide relief to remote areas, air transport network can be considered, too. Development of meta-heuristic algorithms can be considered to solve the above model on a large scale.

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