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Research Article

A New Multiechelon Mathematical Modeling for Pre- and Postdisaster Blood Supply Chain: Robust Optimization Approach

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Disaster management is one of the most important actions to protect the property and lives of the victims. Failure to pay attention to logistical decisions of disaster can have irreversible consequences. Therefore, a multiechelon mathematical model for blood supply chain management in disaster situations is proposed in this research. The proposed supply chain includes supplier, central warehouse, reliable distributor, unreliable distributor, distributor, and affected areas. How the proposed model performs is explained as follows: blood is sent from the supplier to warehouses and distribution centers. Also, the capacity of suppliers is limited. The main objective of the mathematical model is to minimize supply chain costs while maximizing the level of satisfaction in order to meet the demand of the affected area. Hence, this research seeks to decide whether or not to establish a reliable distributor, unreliable distributor, and central warehouse. The amount of blood sent to the centers will also be calculated. One of the contributions of the proposed model is to consider the pre- and postdisaster modes simultaneously. Locating and investigating the flow between centers are also the other contributions of this study. Solving the proposed model using a robust optimization approach is another innovation taken into account in this research. The proposed model is solved using robust optimization, and finally, the results indicate the proper performance of the proposed model.

1. Introduction

One unit of blood can be used once for a patient or several times. In addition to urgent cases, blood therapeutically supports (not for treatment) diseases such as hemoglobin, coagulation, and bone marrow disorders. Having a stable blood supply system requires good services at the level of the blood transfusion organization, a suitable platform such as volunteer donors (donating blood without receiving money and altruistically), rigorous testing systems, a desirable quality system, and a proper monitoring process. Having such a system requires the commitment and support of national health officials and the use of appropriate human, financial, and technological resources [1, 2].

The most important challenge after a major event such as an earthquake is locating relief distribution centers and sending essential goods to the affected areas in order to meet the basic needs of the affected [3]. Disaster relief logistics is one of the main activities in disaster management. What is important in relief logistics is the value of time and delivering the necessary goods and services to the affected in the shortest possible time [4]. One of the important logistic strategies to improve performance and reduce latency is to locate and establish relief distribution centers near these vulnerable areas [5–7]. Thus, the existence of distribution centers in suitable locations of the network, which can properly cover the demand created in these conditions, is of great importance in the successful implementation of relief and rescue operations, and in all cases, the weakness in choosing the right location will increase the likelihood of wasting capital and will ultimately lead to many casualties [8, 9]. The goals pursued in the issue of locating relief distribution centers are to get the location of relief distribution centers closer to the affected areas and reduce the distance (objective minimization function) to deliver services as fast as possible, increase the level of services, and attempt to balance the distance between distribution centers and demand areas (affected people).

The golden time to rescue the injured in an earthquake is only 72 hours [10]. As it is clear, not paying attention to logistical decisions can have harmful financial and human consequences. Thus, minimizing relief time is one of the most important goals of logistics measures. Also, uncertainties in disaster situations make the issue of relief more complicated. Therefore, in this research, a multiechelon mathematical model for blood supply chain management in disaster situations is proposed. The proposed supply chain includes supplier, central warehouse, reliable distributor, unreliable distributor, distributor, and affected areas. How the proposed model performs is explained as follows: blood is sent from the supplier to warehouses and distribution centers. Also, the capacity of suppliers is limited. The main objective of the mathematical model is to minimize supply chain costs while maximizing the level of satisfaction in order to meet the demand of the affected area. Hence, this research seeks to decide whether or not to establish a reliable distributor, unreliable distributor, and central warehouse. The amount of blood sent to the centers will also be calculated. The amount of blood sent to the centers will also be calculated.

The main contributions of the study are as follows:

(i) Considering the pre- and postdisaster modes simultaneously.
(ii) Locating and investigating the flow between centers.
(iii) Solving the proposed model using robust optimization approach.

2. Literature Review

Shaw et al. [11] provide a mathematical model for location and resource allocation in disaster condition. The uncertainty of the model was fuzzy and was solved using chance-constrained approaches. Minimizing total delivery time and maximizing total affected coverage are the most important goals of their model. Considering loading and unloading times is one of the innovations of this research. The results indicate the proper performance of the proposed model.

Alizadeh et al. [12] provided a multiperiod model for locating relief facilities in natural disaster situations. The main objective of their research is to maximize the coverage of hospitals and distribution centers. The Lagrangian approach is used to solve the proposed model. The results of the case study indicate that an increasing demand reduces the level of coverage of the areas. Alinaghian et al. [13] addressed locating and allocating disaster relief centers in the pre- and post-earthquake conditions. Consideration of temporary relief centers to prevent crowding of the injured is one of the innovations of this research. In order to solve the proposed model, the harmonic algorithm and the forbidden search along with the neighborhood search are used. Numerous numerical examples solved with robust optimization indicate the proper performance of the proposed model. Manopiniwes and Irohara [14] proposed a mathematical model for locating temporary relief centers in flood conditions. The main objective of the research is to minimize supply chain costs such as location and transportation. Therefore, the proposed model is considered as a multiperiod model, as investigated in different periods of demand. One of the considered innovations is the consideration of several modes of transportation. The results of solving the case study indicate the proper performance of the proposed model. Dunn and Gonzalez [15] proposed the development of an adaptive algorithm to increase resilience and the location and allocation of relief bases in flood conditions. Considering possible uncertainty and reliability for the centers are among the innovations considered. ArcGIS software is used to locate the centers. The main objective of the research is to minimize the costs of the whole system, including location costs. The proposed system is solved for various examples and its performance results are satisfactory. Cavdur et al. [16] proposed new strategies for distributing relief goods and human resources in times of disaster. Therefore, a possible two-level model for locating and allocating temporary relief centers is provided. The first level is the predisaster phase and the second level is the postdisaster phase. Minimizing chain costs is done in the first phase and allocating resources to centers is done in the second phase. The results of the sensitivity analysis of the case study indicate that with increasing demand, allocation costs increase sharply. Zhou et al. [17] proposed a mathematical model for blood supply chain management in conditions of uncertainty. The proposed model is implemented using two scenarios of LIFO and FIFO. Considering fairness and minimizing shortage are among the objectives of this research. One of the contributions of the proposed model is demand estimation using discrete event system simulation. Finally, the proposed model is solved using the estimated withdrawal and aging approach. Arani et al. [18] proposed a mixed-integer programming mathematical model for managing blood databases. The considered innovation includes sustainable lateral resupply. Considering inventory-routing decisions is one of the approaches of this research. The proposed model is solved using the multichoice goal programming approach. Shokouhifar et al. [19] proposed a fuzzy mathematical model for blood inventory management. Considering the short lifetime of blood platelets and the cost of corruption is one of the contributions considered. Minimizing the costs of shortages and wastage costs in the supply chain is one of the objectives of the research. The results show that lateral transshipment reduced costs by 3.4%. Shirazi et al. [2] proposed a mathematical model for blood chain management in the Covid-19 outbreak. They first estimated the blood demand using discrete simulation and then the value of this parameter was entered into the mathematical model. The proposed model is solved by the approaches of strength pareto evolutionary algorithm 2 (SPEA-II) and multi-objective gray wolf optimizer (MOGWO). The results show that with increasing demand, the number of established relief bases increases sharply. Khalili-Damghani et al. [20] proposed a mathematical model for cascade disaster management under uncertainty conditions. The considered innovation includes location using the GIS approach. The main objective of the research is to maximize the coverage level. The proposed model is solved using the invasive weed optimization algorithm approach. Table 1 lists the summary of literature review.

One of the research gaps is the lack of attention to the pre- and postdisaster situations simultaneously. Also, locating and examining the flow between the centers are among the research gaps considered. Lack of attention to solving the proposed model using a sustainable approach is another research gap in this research.

3. Problem Statement

This section presents problem assumptions and mathematical modeling as follows:

3.1. Problem Assumptions

(i) Costs related to the shortage of relief items in postdisaster are considered.

(ii) Transportation costs depend on items and scenario.

(iii) Doing transactions between LDCs is allowed. Relief items can be sent from reliable LDCs to unreliable items in case of shortage (ancillary transportation).

(iv) Distribution of relief items in the response phase is assumed for several periods.

(v) Suppliers can procure postdisaster relief items and distribute them in LDC.

In this section, we will model the designed network and describe sets, then parameters, and then variables, and the problem indices are as follows:

(i) I: Supplier

J: Central warehouse

K: Reliable distributor

L: Unreliable distributor

M: Distributor

D: Affected areas

T: Period

c: Product

Now, we have described the problem indices, and we will examine the problem parameters as follows:

g_j: Fixed cost of building a warehouse j

fr_k: Fixed cost of building a reliable distributor k

fu_l: Fixed cost of building an unreliable distributor l

aq_c: Cost of maintenance of relief good c

pc_{ic}: Cost of supplying relief product c before the disaster by supplier i

pc_{cit}: Cost of supply of relief product c by supplier i after the disaster in period t

tc_{ij}: Cost of transportation from supplier i to distributor j

tc_{jm}: Cost of transportation from warehouse j to central distributor m

tc_{md}: Cost of transferring from the central distributor m to the affected area d

tc_{kl}: Cost of transferring the product from a reliable distributor k to an unreliable distributor l

π_{cdt}: Cost of fining a unit of relief product c in affected center d in period t

cap_{ic}: Supply capacity of relief product c by supplier i

w_{cm}: Capacity of distributor warehouse m for relief product c

v_{cj}: Central warehouse capacity j for relief goods c

v_c: Volume of relief product c

φ_m: Percentage of storage capacity that is likely to deteriorate

d_{cdt}: Demand for relief product c by affected area d in period t

Now, the problem parameters have been described, and we will examine the research variables as follows:

qc_{cij}: Transfer of product from supplier i to warehouse j

ql_{cim}: Transfer of product c from supplier i to distributor m before the disaster

q_{cimt}: Transfer of product c from supplier i to distributor m in period t after the disaster

y_{cjmt}: Transfer of product from warehouse j to distributor m in period t

x_{cmdt}: Transfer of product from distributor m to affected area d in period t

u_{cklt}: Transfer of product from a reliable center k to unreliable center l in period t

it_{cmt}: The amount of distributor m from relief product c in period t

b_{cdt}: Deficiency of product c in affected area d in period t

zr_k: Takes a value of 1 if center k is constructed and otherwise zero.

zu_l: Takes a value of 1 if center l is constructed.

δ_j: Takes a value of 1 if center j is constructed.

Now, the indices, parameters, and variables of the research have been described, and we will provide the mathematical model of the research as follows:

Table 1: Literature review.

No	Author	Number of objective functions (single/ multiobjective)	Level of satisfaction	Pre/ postdisaster decisions	Location	Flow	Multiechelon	Data type (deterministic/ uncertain)	Reliable and unreliable centers	Optimization method (deterministic/ stochastic/ robust/fuzzy optimization)
1	Alizadeh et al. [12]	SO		Po	*		*	U		Sto
2	Alinaghian et al. [13]	SO		Pr/po	*			U		Ro
3	Manopiniwes and irohara [14]	MO	*	Po	*		*	U		Sto
4	Dunn and gonzalez [15]	SO		Pr	*			U	*	Sto
5	Cavdur et al. [16]	SO		Po/Pr		*	*			Dto
6	Zhou et al. [17]	MO	*	Pr		*		U	*	Sto
7	Arani et al. [18]	MO	*	Po				U	*	Ro
8	Shokouhifar et al. [19]	MO	*	Pr		*		U	*	Fo
9	Shirazi et al. [2]	MO		Po	*	*	*	U		Sto
10	Khalili-damghani et al. [20]	SO	*	Po	*			U		Sto
11	This study	MO	*	Pr/po	*	*	*	U	*	Ro

Note. SO, single objective; MO, multiobjective; Po, postdisaster; Pr, predisaster; U, uncertain; Sto, stochastic optimization; Ro, robust optimization; Dto, deterministic optimization; F, fuzzy optimization.

$$
\begin{aligned}
minz = {} & \sum_j g_j \delta_j + \sum_l fu_l zu_l + \sum_k fr_k zr_k + \sum_i \sum_j \sum_c pc_{ic} qc_{cij} \\
& + \sum_i \sum_m \sum_c pc_{ict} ql_{cim} + \sum_i \sum_j \sum_c aq_c qc_{cij} + \sum_i \sum_m \sum_c aq_c ql_{cim} + \sum_j \sum_m \sum_c \sum_t tc_{jm} y_{cjmt} \\
& + \sum_m \sum_d \sum_c \sum_t tc_{md} x_{cmdt} + \sum_i \sum_m \sum_t \left(pc_{ict} + tc_{im} \right) q_{cimt} + \sum_k \sum_l \sum_c \sum_t tc_{kl} u_{cklt} + \sum_d \sum_c \sum_t \pi_{cdt} b_{cdt}.
\end{aligned}
\tag{1}
$$

The objective function (1) in the first part will minimize the cost of establishing a local collection center and charity center (consisting fixed cost of building a warehouse, fixed cost of building an unreliable distributor, and fixed cost of building a reliable distributor), and in other parts, it will minimize the cost of sending goods between different levels of the network (consisting supplying relief product c before the disaster by supplier, maintenance of relief good, transportation from supplier to distributor, and cost of fining relief product in affected center):

$$
\max z2 = \sum_m \sum_d \sum_c \sum_t \frac{x_{cmdt}}{d_{cdt}}. \tag{2}
$$

The second objective function of the problem will maximize the level of satisfaction in order to meet the demand of the affected area:

$$
\sum_i v_c qc_{cij} \leq v_{cj} \delta_j \quad \forall (j, c), \tag{3}
$$

$$
\sum_i v_c ql_{cim} \leq w_{cm} zr_k \quad \forall (k, m, c), \tag{4}
$$

$$
\sum_i v_c ql_{cim} \leq w_{cm} zu_l \quad \forall (l, m, c). \tag{5}
$$

Constraints (4) and (5) will address the issue that no relief goods will be sent until the warehouse and distribution center are activated.

$$\sum_i q_{cimt} + \sum_j y_{cjmt} + it_{cm(t-1)} = \sum_d x_{cmdt} + it_{cmt} + \sum_l u_{cklt} \quad \forall (k,m,c,t), \tag{6}$$

$$\sum_i q_{cimt} + \sum_j y_{cjmt} + \text{it}_{cm(t-1)} + \sum_k u_{cklt} = \sum_d x_{cmdt} + \text{it}_{cmt} \quad \forall (k,m,c,t), \tag{7}$$

$$\sum_m x_{cmdt} + b_{cdt} = d_{cdt} \quad \forall (d,c,t). \tag{8}$$

Constraints (6) and (7) are inventory equilibrium constraints, and constraint (8) states that the amount of goods sent plus the shortage must be equal to the demand of the affected area:

$$\sum_m \sum_t q_{cimt} \le cap_{ci} \quad \forall (i,c), \tag{9}$$

$$\sum_m \sum_t y_{cimt} \le v_{cj}\delta_j \quad \forall (c,j). \tag{10}$$

Constraints (9) and (10) will examine the capacity of the supplier and the central warehouse, which ensures that the maximum number of goods sent is equal to their capacity:

$$\sum_i q_{cimt} \le M\, zu_l \quad \forall (l,c), \tag{11}$$

$$\sum_i q_{cimt} \le M\, zr_k \quad \forall (k,c,t). \tag{12}$$

Constraints (11) and (12) ensure that it is not possible to send to the distribution center unless reliable and unreliable centers are active:

$$\sum_d x_{cmdt} + \sum_l u_{cklt} \le it_{cmt} \quad \forall (k,m,c,t), \tag{13}$$

$$\sum_d x_{cmdt} \le it_{cmt} \quad \forall (m,c,t). \tag{14}$$

Constraints (13) and (14) state that the maximum amount sent to the affected area must be equal to the supply capacity:

$$\sum_j y_{cjmt} + \sum_i ql_{cim} \le w_{cm}\varphi_m \quad \forall (m,c,t), \tag{15}$$

$$\sum_j y_{cjmt} + \sum_i q_{cimt} + it_{cm(t-1)} \le w_{cm} \quad \forall (k,m,c,t), \tag{16}$$

$$\sum_j y_{cjmt} + \sum_i q_{cimt} + \sum_k u_{cklt} + it_{cm(t-1)} \le w_{cm}\varphi_m \quad \forall (l,m,c,t). \tag{17}$$

Constraints (15) to (17) examine the capacity of the distribution center before and after the disaster:

$$\sum_d x_{cmdt} \le M\, zr_k \quad \forall (k,m,c,t,l), \tag{18}$$

$$\sum_d x_{cmdt} \le M\, zu_l \quad \forall (l,m,c,t), \tag{19}$$

$$u_{cklt} \le M\, zr \quad \forall (k,m,c,t,l), \tag{20}$$

$$u_{cklt} \le M\, zu_l \quad \forall (k,m,c,t,l). \tag{21}$$

Constraints (18) to (21) state that no goods must be sent until the distribution center is active.

3.2. Solution Method: Scenario-Based Robust Optimization. Suppose U is a set of all possible scenarios that may occur in the future and S is a specific scenario of this set. These two concepts are in fact the stability of the model and response. In the response stability, the optimal response of the model for each scenario is close to the desired value while the response of the model for each scenario in the stability of the model is nearly practical:

$$Min\, z = \sum_s pr_s(Z) + A \sum_S pr_s \left[Z - \sum_S pr_s \right]^2. \tag{22}$$

The first part is the mean and the second part is the variance of the objective function. A is the weight of variance depending on the decision-maker and is obviously chosen by the degree of risk aversion in the decision-maker. However, since the above function is nonlinear in nature, according to Yu [21], the following function will be used in the problem:

$$Min\, z = \sum_s (Z) + A \sum_S pr_s \left| Z - \sum_S pr_s \right|. \tag{23}$$

The following constraint will be used to linearize the above equation:

$$A \sum_S pr_s (g_s^+ - g_s^+). \tag{24}$$

Therefore, the model under the scenario will be as follows:

$$
\begin{aligned}
&\min z = \sum_s pr_s \left[\begin{array}{c}
\sum_j g_j \delta_j \sum_l fu_l zu_l + \sum_k fr_k zr_k + \sum_i \sum_j \sum_c \sum_s pc_{ic} qc_{cijs} + \sum_i \sum_m \sum_s \sum_c pc_{ict} ql_{cims} \\
+ \sum_i \sum_j \sum_s \sum_c aq_c qc_{cijs} + \sum_i \sum_m \sum_s \sum_c aq_c ql_{cims} + \sum_j \sum_m \sum_c \sum_s \sum_t tc_{jm} y_{cjmts} \\
+ \sum_m \sum_d \sum_c \sum_s \sum_t tc_{md} x_{cmdts} + \sum_i \sum_m \sum_s \sum_t (pc_{ict} + tc_{im}) q_{cimts} + \sum_k \sum_l \sum_c \sum_s \sum_t tc_{kl} u_{cklts} \\
+ \sum_d \sum_c \sum_s \sum_t \pi_{cdt} b_{cdts}
\end{array} \right] + A_1 \sum_S pr_s (g_s^+ - g_s^+) + A_2 \sum_J \sum_s pr_s \Delta_{sj} in\, f\, pen \\
&\sum_i v_c qc_{cijs} = v_{cj} \delta_j \quad \forall (j, c, s), \\
&\sum_i v_c ql_{cims} = w_{cm} zr_k \quad \forall (k, m, c, s), \\
&\sum_i v_c ql_{cims} = w_{cm} zu_l \quad \forall (l, m, c, s), \\
&\sum_i q_{cimts} + \sum_j y_{cjmts} + it_{cms(t-1)} = \sum_d x_{cmdts} + it_{cmts} + \sum_l u_{cklts} \quad \forall (k, m, c, t, s), \\
&\sum_i q_{cimts} + \sum_j y_{cjmts} + it_{cms(t-1)} + \sum_k u_{cklts} = \sum_d x_{cmdts} + it_{cmts} \quad \forall (k, m, c, t, s), \\
&\sum_m x_{cmdts} + b_{cdts} = d_{cdts} \quad \forall (d, c, t, s), \\
&\sum_m \sum_t q_{cimts} \le cap_{ci} \quad \forall (i, c, s), \\
&\sum_m \sum_t y_{cjmts} \le v_{cj} \delta_j \quad \forall (c, j, s), \\
&\sum_i q_{cimts} \le M\, zr_k \quad \forall (k, c, t, s), \\
&\sum_i q_{cimts} \le M\, zu_l \quad \forall (l, c, s), \\
&\sum_d x_{cmdts} + \sum_l u_{cklts} \le it_{cmts} \quad \forall (k, m, c, t, s), \\
&\sum_d x_{cmdts} \le it_{cmts} \quad \forall (m, c, t)/ \\
&\sum_j y_{cjmts} + \sum_i ql_{cims} \le w_{cm} \varphi_{ms} \quad \forall (m, c, t, s), \\
&\sum_j y_{cjmts} + \sum_i ql_{cims} \le w_{cm} \varphi_{ms} \quad \forall (m, c, t, s), \\
&\sum_j y_{cjmts} + \sum_i q_{cimts} + it_{cms(t-1)} \le w_{cm} \quad \forall (k, m, c, t), \\
&\sum_j y_{cjmts} + \sum_i q_{cimts} + \sum_k u_{cklts} + it_{cms(t-1)} \le w_{cm} \varphi_m \quad \forall (l, m, c, t) \\
&\sum_d x_{cmdts} \le M\, zr_k \quad \forall (k, m, c, t, s) \\
&\sum_d x_{cmdts} \le M\, zu_l \quad \forall (l, m, c, t, s) \\
&u_{cklts} \le M\, zr_k \quad \forall (k, m, c, t, l) \\
&u_{cklts} \le M\, zu_l \quad \forall (k, m, c, t, l) \\
&z - \sum_s pr_s = (g_s^+ - g_s^-) \forall (s) \\
&g_s^+ \le tt * m \forall (s) \\
&g_s^- \le (1 - tt) * m.
\end{aligned} \tag{25}
$$

4. Results

In this section, we will first examine the problem in small dimensions in certain conditions and then we will solve the problem in conditions of uncertainty. For this purpose, we should first describe the dimensions of the problem, then initialize the various parameters of the model, and then examine the research variables and how they perform in the model (Table 2).

Now, the dimensions of the problem have been determined, and we will initialize the parameters for this purpose. The first parameter that will be determined is the amount of product use, which is specified based on Table 3.

As can be seen in the table above, the fixed cost of building a central warehouse is described. After this, we need to describe the fixed cost of building a reliable and unreliable distribution center and the cost of maintaining relief goods, as listed in Table 4.

Table 2: Dimensions of the problem.

I	j	m	k	l	c	d	T
5	4	6	6	6	3	10	3

Table 3: Fixed cost of building central warehouse j.

J1	J2	J3	J4
20857	242163	227519	215057

Table 4: Fixed cost of building a reliable and unreliable distribution center and maintenance cost of relief goods.

K1	**K2**	**K3**
114611	111203	117492
L1	L2	L3
97125	81342	90004
C1	C2	C3
70	62	70

Table 5: Cost of supply of relief goods before the disaster.

	c1	c2	c3
i1	48	41	46
i2	42	43	47
i3	44	44	44
i4	41	42	46
i5	48	42	47

Table 6: Cost of supply of relief goods after the disaster.

		T1	T2	T3
i1	C1	58	53	51
i1	C2	55	52	59
i1	C3	53	53	56
i2	C1	57	56	55
i2	C2	54	51	53
i2	C3	50	53	52
i3	C1	56	56	58
i3	C2	53	57	58
i3	C3	56	53	51
i4	C1	51	56	55
i4	C2	50	58	51
i4	C3	52	55	58
i5	C1	52	50	56
i5	C2	56	54	54
i5	C3	52	52	51

Table 7: Cost of transferring relief goods from supplier to central warehouse.

	j1	j2	j3	j4
i1	29	24	28	23
i2	21	27	21	22
i3	20	23	25	22
i4	22	23	23	23
i5	30	30	24	24

Table 8: Cost of transferring relief goods from supplier to central distributor.

	m1	m2	m3	m4	m5	m6
i1	33	29	34	26	32	26
i2	31	26	25	29	30	31
i3	27	29	28	27	34	29
i4	26	29	29	28	34	27
i5	28	26	29	26	29	28

Table 9: Transfer cost of relief goods from reliable distributor to unreliable distributor.

	L1	L2	L3
K1	18	11	20
K2	16	12	16
K3	13	19	19

Table 10: Transfer cost of relief goods from distributor to the affected area.

	d1	d2	d3	d4	d5	d6	d7	d8	d9	d10
m1	17	17	21	22	16	17	19	17	22	23
m2	17	19	22	23	21	25	15	17	16	20
m3	16	22	16	20	23	20	20	15	20	20
m4	25	17	17	15	17	16	15	23	21	15
m5	17	25	18	21	18	21	17	20	19	23
m6	20	19	21	24	18	15	24	21	18	25

Table 11: Total probabilities of possible scenarios.

Scenario	1	2	3
Probability	0.35	0.40	0.25

Table 12: Different parameters under possible scenarios.

Parameter	Intended value
pc_{citS}	U (200000, 2500000)
π_{cdtS}	U (100, 120)
d_{cdtS}	U (100, 300)
$\varphi_{\mathbf{mS}}$	U (0.2, 0.4)

Table 13: Response of the objective function under different scenarios.

Objective function	s1	s2	0
	5380553	5398653	5377553

Table 14: Robustness analysis of the objective function.

$\mathbf{A}_1$	$\mathbf{A}_2$	Infpen	Objective function
80	40	100	8234814
80	60	100	10675414
80	80	100	13116014
80	120	100	17997214

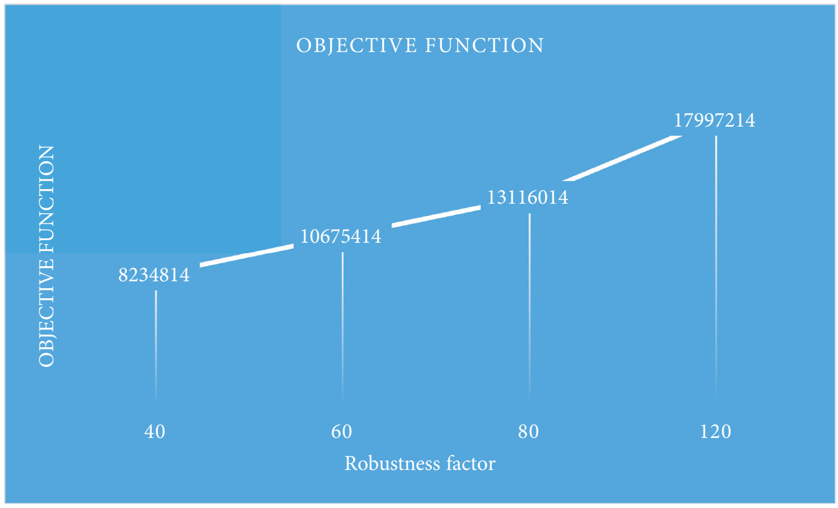

FIGURE 1: Changes in the objective function relative to the robustness factor.

Now, we have to describe the cost of supplying relief goods before the disaster, as listed in Table 5.

Now, the cost of supplying relief goods before the disaster has been determined, and we must now address the cost of supplying relief goods after the disaster, as listed in Table 6.

Now, after the cost of supplying the relief goods has been determined, we have to address the transfer cost of the relief goods, as listed in Table 7.

Table 8 lists the cost of transferring relief goods from supplier to central distributor.

Table 9 lists the transfer cost of relief goods from reliable distributor to unreliable distributor.

Now, we need to determine the cost of transporting relief goods from the distributor to the affected area, as listed in Table 10.

4.1. Examination of the Problem in Conditions of Uncertainty. In order to examine the problem in conditions of uncertainty, it is first necessary to determine values of the parameters in the conditions of uncertainty in the research and then examine the results. For this purpose, it is first necessary to determine scenarios for the occurrence of an accident with certain probabilities, as listed in Table 11.

Now, the different scenarios have been identified, and we need to determine the values of the parameters that have uncertainty in the research, as listed in Table 12.

Now, in order to understand what effect robust optimization has on the objective function of the problem, we will examine different objective functions under different scenarios, and the results are listed in Table 13.

Now, after examining the objective function under different scenarios, the worst value of the objective function must be determined under uncertainty conditions, which is 5398653, that is, the worst answer of the system.

4.2. Analysis of Objective Function Relative to Standard Deviation of Response A_2. In order to investigate how robust optimization works, we intend to perform a sensitivity analysis on the effect of robust optimization on the objective function. For this purpose, we will analyze the objective function based on Table 14, and since the problem is minimization, it has to have an ascending value with an increasing standard deviation of the objective function.

As can be seen from Figure 1, by increasing the robustness coefficient, the response of the objective function increases, which indicates the proper performance of the model.

TABLE 15: Robustness analysis of the objective function relative to the amount of the fine.

A_1	A_2	Infpen	Objective function
80	60	0	0
80	60	10	5895794
80	60	100	10675414
80	60	200	17997214
80	60	300	25319014
80	60	500	39962614
80	60	750	58267114
80	60	1000	76571614

4.3. Changes of the Objective Function Relative to the Amount of the Fine. Now, in order to determine how the objective function changes relative to the amount of the fine, the following experiment has been designed, in which the constant coefficients and the degree of violation of the objective function have increased (Table 15 and Figure 2).

5. Managerial Insight and Practical Implication

The benefits of the proposed model in this study can be useful for the Blood Transfusion Organization, the Red Cross, the Crisis Relief Organization, the municipality, and ultimately all people. The main objective of the mathematical model is to minimize supply chain costs while maximizing the level of satisfaction in order to meet the demand of the affected area. Hence, this research seeks to decide whether or

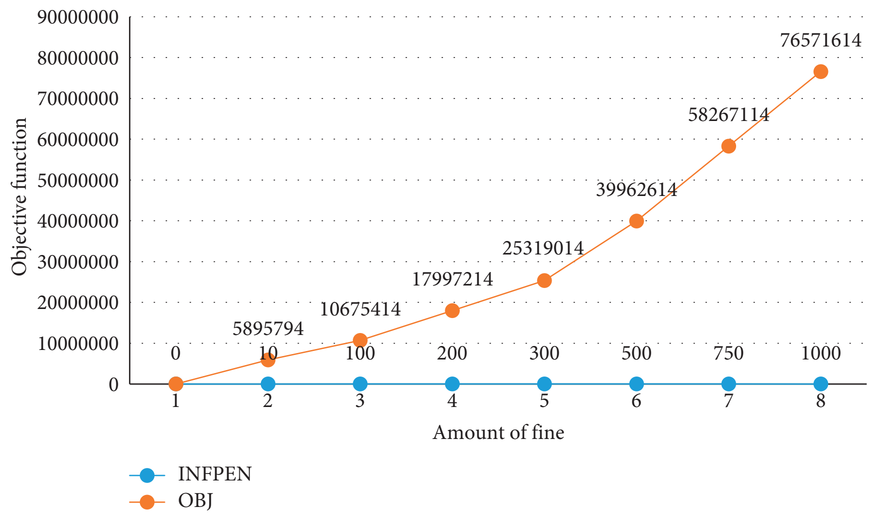

FIGURE 2: Changes in the objective function relative to the robustness factor.

not to establish a reliable distributor, unreliable distributor, and central warehouse. Also, maximizing the satisfaction level during crisis relief can build the trust of the community. Therefore, this study intends to provide a model to meet the needs of managers in these conditions. Also, considering that in response conditions, the main goal is usually a quick response to minimize costs and maximize the satisfaction of the injured; in the presented model, an attempt has been made to provide a plan taking into account the real logistical conditions.

6. Conclusion

In this research, a mathematical model to minimize logistics costs in the blood supply chain in disaster situations is proposed. One of the innovations of the proposed model is to consider the pre- and postdisaster modes simultaneously. Locating and examining the flow between centers are also the other contributions of this study. Solving the proposed model using the robust optimization approach is another innovation considered in this research. The benefits of the proposed model in this study can be useful for the Blood Transfusion Organization, the Red Cross, the Crisis Relief Organization, the municipality, and ultimately all people.

In order to examine the problem in conditions of uncertainty, it is first necessary to determine values of the parameters in the conditions of uncertainty in the research and then to examine the results. For this purpose, it is first necessary to determine scenarios for the occurrence of an accident with certain probabilities. Also, we will analyze the objective function, and since the problem is minimization, it has to have an ascending value with an increasing standard deviation of the objective function. Finally, the robust optimization method was used to solve the problem, which examined the problem in conditions of uncertainty. Future suggestions are as follows: It is interesting to extend the proposed model to perishable relief items. Also, the dangers of disruptions in roads and distribution of the last item and the problem of routing for vehicles can be studied in the future. The resilient supply chain may not be the least expensive supply chain, but the resilient supply chain can overcome uncertainties and disruptions in the business environment. The competitive advantage of the supply chain not only depends on low costs, high quality, reduced latency, and high level of service but also on the ability of the chain to avoid disasters and overcome critical situations, and this is the resilience of the supply chain. Resilience is the ability of the supply chain to overcome unpredictable events. The purpose of creating resilience in the supply chain is to prevent the chain from moving toward adverse conditions. Incidents such as the eruption in Iceland made companies aware of how little control they have over the risks they face, but today, there are companies that are able to return to normal or even get better than before after severe disturbances and fluctuations. Therefore, it is suggested that we try to increase the resilience of the problem by considering redundancy [2, 9].

This research, like other research, is not without limitation and assumptions. Therefore, the limitation of the research is expressed as follows: as there was no official database for some parts of cost elements, the driver's estimations and blood transfusion center officers were asked to help.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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