Designing a Humanitarian Supply Chain for Pre and Post Disaster Planning with Transshipment and Considering Perishability of Products

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Abstract. Every year, many human lives are endangered by natural disasters. Preparing to deal appropriately with various crises can prevent potential risks or reduce their effects. In this research, for better preparation, both pre and post-crisis stages have been addressed. A multi-product and multi-period model is presented. And location of warehouses and local distribution centers to send the required items in each crisis scenario must be selected between the candidate choice. The perishability of products in warehouses in this study is also considered. The purpose of the model presented in this research is to reduce operating costs in two stages before the disaster and after it. Finally, the presented model is solved by GAMS software and some sensitivity analysis are provided to validate the model and evaluate the parameters.

Keywords: Disaster management · Perishable products · Transshipment · Location

1 Introduction

In the current century, various disasters have endangered human lives, and these incidents fall into the category of natural or manmade, such as earthquakes, floods, storms or wars and fires, etc. Human and natural crises are inevitable, and as the population grows, more crises occur. According to statistics, 106,654 people were killed by natural disasters between 2003 and 2012, and the financial costs are estimated at $ 157 billion [1]. Therefore, we must have accurate plans to respond to the crisis to save human lives and avoid potential dangers. The emergence of a crisis in an area increases the demand for some specific commodity, and responding to these needs as quickly as possible is a factor that must be planned in advance; Because the delay in meeting these needs causes a secondary crisis and doubles the costs of the crisis.

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In general, crisis management is described in two parts. First, we try to reduce the risk of dealing with the crisis, and then we prepare for the crisis, which preparedness for the crisis dramatically reduces the risk of a secondary crisis. Many activities are recommended to prepare, such as educating people or pre-arranged plans for each crisis. In post-crisis management, in addition to improving the relief chain as much as possible, logistics cost issues are also raised, and we should try to minimize them with proper management [2]. In this regard, places are considered for storing the required items before the crisis and then the distribution plan of these items in the post-crisis phase is considered [3]. In previous research, the existence of warehouses before the crisis was discussed, but during a crisis, the proximity of distribution centers to the affected areas can reduce crisis costs and handling time as much as possible [4].

Lateral transshipment between distribution centers is provided to prevent shortages after the crisis. Due to the disaster conditions and the temporary distribution center allocated, some relief items needed may be in short supply to respond as soon as possible [2]. Relief Items can be considered as perishable items due to their particular characteristics. At this stage, to determine a policy, we must consider the shortcomings and losses resulting from the maintenance and disposal of corrupt inventories [5].

In this study, we examine the maintenance of items required for the crisis that have perishable properties in the pre-crisis periods and replace them according to cost factors, and then in the post-crisis phase by considering shorter periods, we will reduce the cost of providing relief items, and consider lateral transshipment between temporary distribution centers.

In the next section, related works are reviewed and research gap is determined. Problem description and mathematical modeling are presented in Sect. 3. Numerical experiments and sensitivity analysis are conducted in the fourth section and in the final section, conclusion and some suggestions for future research are discussed.

2 Literature Review

In this part of the research, a review of other studies is provided and the research gap is found and the research requirements are clarified.

In a study, a factor such as the volume of the accident occurred and the allocation of a time window for each area was examined [6]. Different methods are used to deal with the shortage of products. In [7] authors have proposed a demand function based on price and inflation. In another study [8], uncertainties in the model are considered and the customer is directly related to the manufacturer. However, in critical situations, it is not possible to produce the required goods at the moment. Rawls & Turnquist [9] considered responding to the shelters in a timely manner and in the shortest possible time, and the aim of the pre-crisis preparations was to reduce the response time. Then, a model was presented with the decision to buy the required items before and after the crisis because the location of items before the crisis and the ability to purchase items after the crisis will reduce the shortage of emergency items. The items required vary depending on the type of incidents and even the earthquake and flood are different. In a study, different types of earthquakes have been studied [3]. There are also studies that are presented in a scenario-based manner. Scenarios were proposed for the probability of each scenario occurring. Another study used the Monte Carlo simulation method for the probability of scenarios occurring [10]. Some research has been conducted on the location of distribution centers after the crisis. Finding optimal locations for distribution centers minimizes logistics costs [11]. In the pre-crisis phase, distribution centers are considered warehouses for items needed for the crisis. When a crisis occurs, the facilities available in the warehouse are used and placed in the chain as distribution centers. Roh et al. [12] used TOPSIS and AHP methods to find the best locations for warehouses.

Few research works have been done in the field of supply chain in the COVID19 situation. A production–distribution–inventory–allocation–location problem in a sustainable medical supply chain was designed, and three new hybrid meta-heuristic algorithms were developed to solve the problem [15].

Doodman et al. [2] considered several local distribution centers (LDC) to enhance communications between affected areas and warehouses. The perishability of products is one of the vital matters that has received less attention. Several other studies exist in this field are as follows: [9, 13, 14]. Using mobile technology in rigs location problem can help in crisis [15]. Momeni et al. [16] designed a humanitarian relief supply chain by considering repair groups and reliability of routs. The related works are summarized in Table 1. We proposed a multi-product, multi-period, MINLP model. In disaster situations, the number of items needed by the victims is more than one item. Here, it is necessary to examine the model in the case of multiple products. The main contributions of our paper are handling both pre and post-disaster phase in planning and also considering a different scenario in preparing phase. Transshipment between LDCs and the perishability of products are two cases that were used less in other studies.

Table 1. The summary of literature review

Name	Objective function			Scenario	Pre-disaster	Post-disaster	Transshipment	Perishable	Solution
	Cost	Time	Covering demand						
Alem et al.	*				*	*			Heuristic & CPLEX
Najafi et al.		*				*			(DDRA)
Rath & Gutjahr	*		*			*			NSGA-II
Sebatli et al.		*			*	*			
Tavana et al.	*	*			*	*		*	NSGA-II, RPBNSGA -II
Shahparvari et al.	*				*	*			
Yeon Roh et al.	*	*				*			fuzzy AHP, fuzzy TOPSIS

(*continued*)

Table 1. (*continued*)

Name	Objective function			Scenario	Pre-disaster	Post-disaster	Transshipment	Perishable	Solution
	Cost	Time	Covering demand						
Baskaya et al.		*				*	*		
Dehghani et al.	*					*	*	*	
Pradhananga	*				*	*			
Bozorgi-Amiri et al.	*				*	*			
Noham, et al..		*	*		*	*			
Loree et al	*					*			
Doodman et al.	*				*	*	*		
This study	*		*	*	*	*	*	*	GAMs solver

3 Problem Description

Response to demand happens in two stages before and after the disaster. There are many suppliers and warehouses before the disaster. Periodically warehouses are filled by suppliers and issues of supplier selection are raised before the disaster. When a disaster occurs, a series of local distribution centers (LDCs) are specified. One of their essential features is its proximity to the disaster site and warehouses feed them. Warehouses and DLCs can be used depending on the circumstances. Allocation of each facility is based on the time between locations (points). In the event of a disaster, a number of goods are essential for the disaster area. So we should prepare for this kind of situation. In this study, we consider perishable goods, with the possibility of a breakdown of goods purchased from suppliers with α percent degradation. Sometimes an LDC does not meet the needs of the allocated points. Therefore, it is possible to transfer commodities between LDCs to respond to demand in the best possible way. Hence the humanitarian constraints have been implemented to investigate this in the model. This model aims to minimize the costs of preparing for crisis situations while considering humanitarian relief supply and shortage and perishability of products. The main assumptions of the model are as follows:

- Communication between suppliers and warehouses even remains after the disaster.
- After the disaster, the goods can be transferred between supplier and warehouses.
- The first period after the catastrophe, the transfer of goods from suppliers to warehouses is prohibited.

The notations of model are as follows:

Sets

I set of suppliers
J set of warehouses
L set of candidates LDCs

K set of demand points
S set of scenarios
T set of periods after disaster occurrence
R set of relief goods
T set of periods before disaster occurrence
h set of the remaining life time period of goods type r ($h_r = 1, \ldots, H_r$)

Parameters

C_{Lr} capacity at LDC L for relief goods r
CC_L The cost of stablishing LDC L
RC_r removal cost for commodity type r
P^s probability of the scenario s.
d^s_{rkt} demand of commodity type r at demand point k under scenario s at period t
PS_r Cost of each product's shortage before disaster
Pb Cost of each product's shortage after disaster
pc_{irh_r} The supplying cost of the relief item r from the supplier i in pre-disaster
tc_{ij} The unit transportation cost from the supplier i to the warehouse j
tc^s_{jl} The unit transportation cost from the warehouse j to the LDC L
tc^s_{lk} The unit transportation cost from the LDC L to the demand point k the scenario s
$tc^s_{ll'}$ The unit transportation cost from the LDC L to the LDC L' under the scenario s
β_r allowable remaining lifetime (time period) for commodity type r for removing from warehouses
α_r Current lifetime (time period) for commodity type r for purchasing.
M a large number

Decision variables

Y^s_L Quantity of product j produced in period t
X^s_{rkt} 1 if change-over from product j to j' happens in period t and 0 otherwise
q_{jr} amount of relief item type r held at warehouse j
In^s_{rlt} The backlog of product j at period t
In^s_{rjt} The inventory of product j at the end of period t
$S_{rjt'}$ shortage of relief items type r at warehouse j at time period t'
y^s_{rjlt} 1 if product j is produced in period t and 0 otherwise.
x^s_{rlkt} The quantity of the relief item r sent from the LDC L to the demand point k
$u^s_{rLL't}$ The quantity of the relief item r sent from the LDC L to the LDC L
$b_{rjt'h_r}$ amount of relief item type r that is removed from warehouse j at time period t' with h_r remaining lifetime
B^s_{rkt} Shortage of commodity type r at demand point k under scenario s at period t

The proposed MINLP model is as follows:

Model Formulation

$$\begin{aligned} MinZ = {} & \sum_{t'=2} \sum_{h_r=\alpha_r}^{H_r} \sum_i \sum_r \sum_j qc_{irjt'h_r} \cdot pc_{irh_r} + \sum_{h_r=1}^{\beta_r} \sum_{t'=2} \sum_r \sum_j RC_r \cdot b_{rjt'h_r} \\ & + \sum_i \sum_{h_r=\alpha_r}^{H_r} \sum_{t'=2} \sum_r \sum_j tc_{ij} \cdot qc_{irjt'h_r} + \sum_r \sum_{t'=2} \sum_j S_{rjt'} \cdot sp_r + \sum_s \sum_r \sum_k \sum_t B^s_{rkt} \cdot Pb \\ & + \sum_s P^s \left(\sum_j \sum_L \sum_r \sum_t tc^s_{jl} \cdot y^s_{rjlt} + \sum_L \sum_r \sum_{L'} \sum_t tc^s_{ll'} \cdot u^s_{rLL't} + \sum_L \sum_k \sum_r \sum_t tc^s_{lk} \cdot x^s_{rlkt} \right) \end{aligned} \quad (1)$$

$$s.t.$$

$$\sum_k x^s_{rlkt} \le C_{Lr} \quad \forall s, r, t, L \tag{2}$$

$$X^s_{rkt} = \sum_L x^s_{rlkt} \quad \forall s, k, r, t \tag{3}$$

$$X^s_{rkt} \le d^s_{rkt} \quad \forall s, k, r, t \tag{4}$$

$$B^s_{rkt} = d^s_{rkt} - X^s_{rkt} \quad \forall s, k, r, t \tag{5}$$

$$b_{rjt'h_r} \le In_{rjt'h_r} \quad \forall r, j, t' \in \{2, \ldots, T\}, h_r \in \{1, \ldots, \beta_r\} \tag{6}$$

$$In_{rjt'h_r} = \sum_i qc_{rijt'h_r} + In_{rj(t'-1)(h_r+1)} \quad \forall r, j, t' \in \{2, \ldots, T\}, h_r \in \{\alpha_r, \ldots, H_r\} \tag{7}$$

$$In_{rj(t'+1)(h_r-1)} = In_{rjt'h_r} - b_{rjt'h_r} \quad \forall r, j, t' \in \{2, \ldots, T\}, h_r \in \{1, \ldots, \beta_r\} \tag{8}$$

$$\sum_{h_r=1}^{H_r} In_{rjt'h_r} = q_{jr} \quad t' = 1, \forall r, j \tag{9}$$

$$S_{rjt'} = q_{jr} - \sum_{h_r=1}^{H_r} In_{rjt'h_r} \quad \forall r, j, t' \in \{2, \ldots, T\} \tag{10}$$

$$\sum_{h_r=1}^{H_r} In_{rjt'h_r} \le q_{jr} \quad \forall r, j, t' \tag{11}$$

$$\sum_{h_r=1}^{H_r} In_{rjt'h_r} - \sum_L y^s_{rjlt} = \mathrm{In}^{\mathrm{s}}_{\mathrm{rjt}} \quad \forall r, j, s, t = 1, t' = T \tag{12}$$

$$\mathrm{In}^{\mathrm{s}}_{rjt} = \mathrm{In}^{\mathrm{s}}_{rj(t-1)} - \sum_L y^s_{rjlt} \quad \forall r, j, s \quad \forall t \ge 2 \tag{13}$$

$$\mathrm{In}^{\mathrm{s}}_{rLt} = \sum_j y^s_{rjlt} - \sum_k x^s_{rlkt} \quad \forall r, j, s \quad \forall t = 1 \tag{14}$$

$$\mathrm{In}^{\mathrm{s}}_{rLt} = \mathrm{In}^{\mathrm{s}}_{rL(t-1)} + \sum_j y^s_{rjlt} + \sum_{L'} u^s_{rL'Lt} - \sum_{L'} u^s_{rLL't} - \sum_k x^s_{rlkt} \quad \forall s, r, L, t \ge 2 \tag{15}$$

$$qc_{rijt'h_r} \le M \cdot \mathrm{Uj} \quad \forall i, r, j, t', h_r \tag{16}$$

$$y^s_{rjlt} \le M \cdot Y^s_L \quad \forall s, r, j, t, l \tag{17}$$

$$x^s_{rlkt} \le M . Y^s_L \quad \forall s, r, l, t, k \tag{18}$$

$$u^s_{rL'Lt} \le M \cdot Y^s_L \qquad \forall s, r, L', t, l \tag{19}$$

$$u^s_{rLL't} \le M \cdot Y^s_L \qquad \forall s, r, L', t, l \tag{20}$$

$$X^s_{rkt}, u^s_{rL'Lt}, u^s_{rLL't}, y^s_{rjlt}, qc_{rijt'h_r}, \mathrm{In}^s_{rjt}, q_{jr} \ge 0 \tag{21}$$

$$\mathrm{Uj}, Y^s_L \in \{0, 1\} \tag{22}$$

The objective function (1), we try to reduce logistics and supply chain costs as much as possible which include cost of purchasing from the supplier and the cost of building warehouses before the disaster, cost of transporting relief items from warehouses to (LDCs) and transporting relief items to affected area and also cost of exchanging goods between (LDCs) and cost of removing relief items which have reached the brink of corruption from the decision maker's point of view and finally the costs of shortages. Constraint (2) states that the amount of relief items that are sent to all the affected area should not exceed the capacity of each relief items in each period. Constraint (3) ensure that the total number of relief goods sent to affected area should be equal to the sum of the number of relief goods sent to area from all LDCs in all periods. Constraint (4) state that each damaged point should not receive more than its needs from each relief items in each period. Constraint (5) express the shortage of any kind of relief items at the affected area in each scenario of post-disaster period. Constraint (6) ensures that the number of the removed relief items cannot exceed the inventory level at each warehouse at each time, relief items are removed upon reaching β_r. β_r is determined based on the decision of the decision maker. Constraints (7) and (8) show the inventory balance of warehouses before the disaster. Constraints (9) shows that the quantity of relief items in first period should be equal to the inventory level. Constraints (10) denote the amount of shortage of relief items in warehouses before the disaster. Constraints (11) ensure that inventory level should not exceeds amount of relief items held at warehouse. Constraints (12) to (15) express the inventory balance in warehouses and (LDCs). Constraints (16) to (20) state that the transfer of relief items from warehouse is done if the warehouse is open. Constraints (21) and (22) domain the decision variables.

4 Experimental Analysis

To investigate the proposed model, we use GAMS 25.13 software on a computer of Intel core i7 3.30 GHz and 8.00 GB of RAM to evaluate the proposed model's performance and applicability. We examined the proposed model in two dimensions: small scale problem and medium scale problem. The dimensions and results of each are given in Tables 2, 3 and 4. The following of our study investigate the effects of parameters on decision variables and objective function.

Table 2. Initial information of test problems

Small scale problem		Medium scale problem	
Set of supplier	$I1.I2, I3$	Set of supplier	$I1.I2, \ldots I6$
Set of warehouses	$J1, J2, J3$	Set of warehouses	$J1, J2, \ldots J6$
Set of LDC	$L1, L2, L3, L4$	Set of LDC	$L1, L2, \ldots L6$
Set of demand point	$K1, \ldots K5$	Set of demand point	$K1, \ldots K10$
Set of relief good	$R1, R2$	Set of relief good	$R1, R2 \ldots R4$
Set of period pre disaster	$T', \ldots T'24$	Set of period pre disaster	$T', \ldots T'30$
Set of period post disaster	$T1, \ldots T10$	Set of period post disaster	$T1, \ldots T15$
Set of remaining life time	$h_r1, \ldots h_r5$	Set of remaining life time	$h_r1, \ldots h_r5$
Set of scenario	$S1, S2$	Set of scenario	$S1, S2 \ldots S4$

Table 3. The range of parameters

Input data			
C_{Lr}	Uniform(30,50)	PS_r	Uniform(100,400)
CC_j	Uniform(300,800)	$tc^s_{ll'}$	Uniform(20,50)
CC_L	Uniform(300,800)	pc_{irh_r}	Uniform(20,50)
RC_r	Uniform(20,50)	tc_{ij}	Uniform(20,50)
P^s	Uniform(0.2,08)	tc^s_{jl}	Uniform(20,50)
d^s_{rkt}	Uniform(40,100)	tc^s_{lk}	Uniform(20,50)

All parameters are determined and we solve proposed model. Because of the lack of real data in this field, we produce the values of parameters randomly.

We want to minimize logistics cost. So objective function calculated as below Table 4.

Table 4. The results of solution approach

Objective function	Shortage cost	Removal cost	Post disaster cost
626971.0	219000.0	135000.0	22471.0
61195479.51	109803.262	1466573.764	1902460.507

As we can see in result, large amount of objective function affected by shortage cost. In special situation such as disaster, shortage cost should be more than usual so we investigate effect of cost of each product's shortage in post disaster situation in amount of shortages to evaluate our model in two different test problem, the result in Fig. 1 prove that model condition is right, because by increasing shortage cost, amount of shortage decreasing.

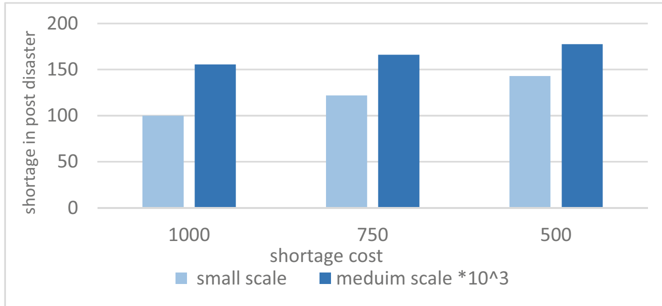

Fig. 1. The amount of shortage cost

4.1 Sensitivity Analysis

In this section, we investigated sensitivity of decision variables and objective function on main parameters. In this study we consider transshipment between LDCs in post disasters scenarios to make network more flexible, we investigate effect of transporting cost between LDCs on the total of transshipped goods.

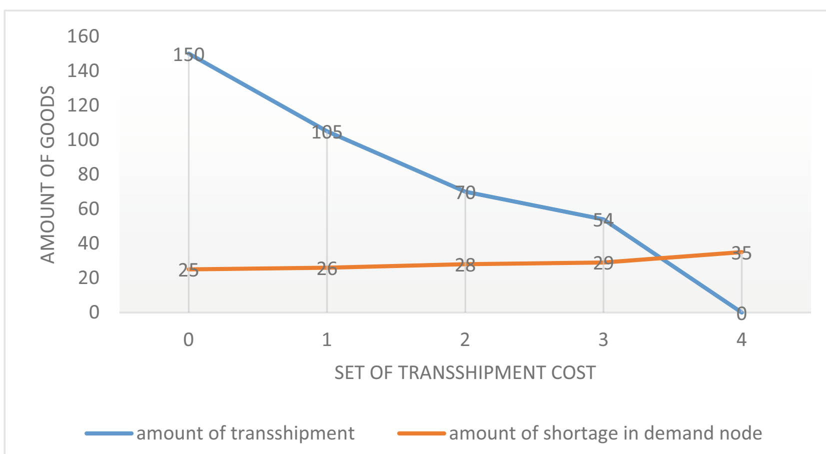

Fig. 2. Transshipment cost effect.

As evident in Fig. 2, increasing transshipment cost, increase amount of transshipped good, Therefore, the cost of transshipment has the reverse effect on the number of goods moved between the LDCs. The reason for using this possibility is to reduce the shortages in disaster situations. The decrease in transshipment goods severely affects the inventory of products in LDCs and it happens shortage in LDCs and this causes a shortage of vital items in affected area as we can see number of shortages become increasing.

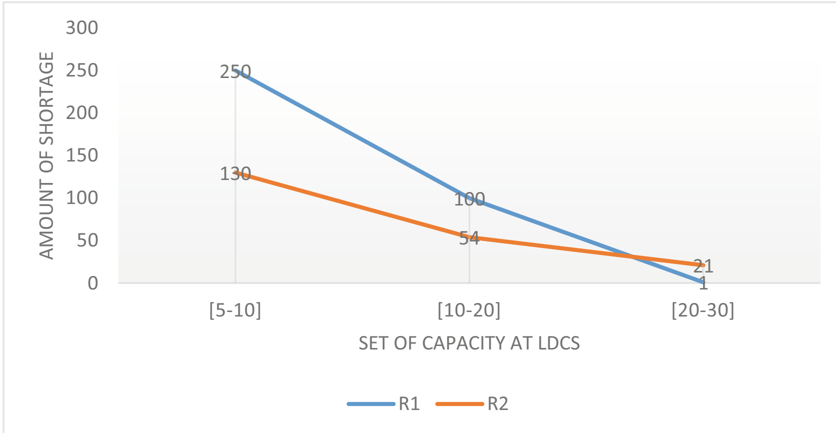

Fig. 3. Capacity of LDC

We investigate effect of LDCs capacity on amount of shortage for each relief in Fig. 3, If the capacity exceeds the demand, it is not logistically difficult to supply, but the reduction of capacities in any LDCs requires the opening of a new one, otherwise we will face a significant shortage. The amount of shortage is inversely related to the capacity of the LDCs (Fig. 4).

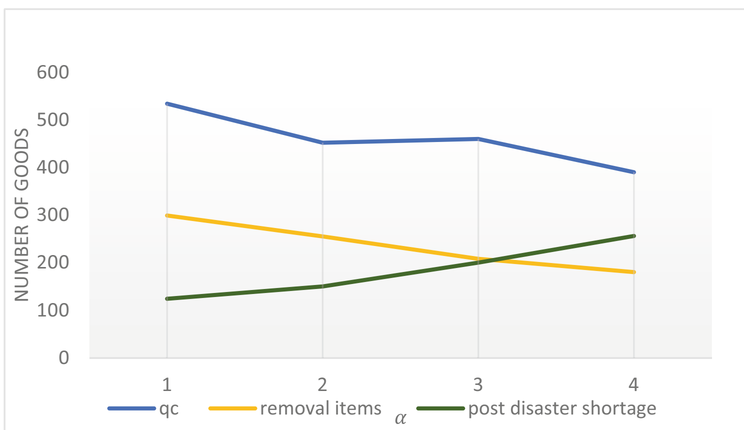

Fig. 4. Comparing between removal items, qc and shortage based α

In this study, we examined the issue of goods corruption. In fact, every product has a certain life. Goods must be purchased (qc) at a certain age and removed from the supply chain at a certain age. The purchasing age and the removing age are determined by the decision maker (DM). DM decisions have a significant impact on supply chain status, such as the amount of deficiency or the amount of corruption that incurs the cost of removal. By keeping the β_r constant in the sixth period, we examine the effect of decision makers on the α_r parameter. With the increase of α_r, the goods with this specific life decrease and as a result, the number of purchases of goods decreases. Decreasing the total purchase also has a significant effect on other decision variables. As inventory of each commodity decreases, commodities that reach the age of six periods decrease relatively and we incur lower removal costs, however, the decline in the initial purchase of products increases the shortage after the crisis and we face the irreparable costs of shortages. So the decision maker has to choose the equilibrium point between the number of deficiencies and the removal number. With analyzing small scale test problem, At the point where the α_r has a value of three, the location of the collision of the two vectors of deficiency and removal item is located, the logistics costs of the system are at a minimum.

4.2 Managerial Insights

Shortages in times of crisis are irreparable and cost more than financial penalties because the lack of facilities endangers many people's lives. Therefore, the sensitivity analysis was performed on the post-disaster shortage. One of the factors influencing the coverage of demand after the crisis is the delivery of important goods to the affected areas promptly, and shortages can be reduced by transshipping goods by LDCs and reducing shipping costs by lower-cost transportation or by establishing closer LDCs and as far as possible measure the capacity of LDCs in each period commensurate with the demand for goods.

5 Conclusions and Future Research

In this paper, a multi-product and multi-period model is presented for pre and post-disaster phase planning. Location of warehouses and local distribution centers to send the required items in each crisis scenario must be selected between the candidate choice. The perishability of the product is also considered, and operation cost is minimized. Finally, the presented model is solved by GAMS software and some sensitivity analysis are provided to validate the model and evaluate the parameters.

For future research, sustainability and resiliency measures can be considered in a mathematical model, and also several parameters can be considered uncertain to increase the reality of conditions. Meta-heuristic approaches such as Non-dominated Sorting Genetic Algorithm, Particle Swarm Optimization, Strength Pareto Evolutionary Algorithm or uncertain solution approaches like possibilistic programming, robust optimization, and stochastic programming should be used to solve the problem and deal with uncertainty.

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