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A mathematical model for business sector participation in relief logistics

Ali Ghavamifar[1], S. Ali Torabi [1*]

[1] *School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran*

ali.ghavamifar@ut.ac.ir, satorabi@ut.ac.ir

Abstract

Humanitarian organizations are in the dire need of logistical resources for relief operations. Nevertheless, considering their limited resources, they have to seek to use the logistical capabilities of the business sector in order to improve the humanitarian operations. In this paper, we develop a bi-objective mathematical model for using the logistical capabilities of the business sector in the humanitarian logistics. The first objective function minimizes the logistics costs while the second one minimizes the shortage costs. We consider that suppliers are responsible for procurement of relief items and logistics service providers collaborate with a humanitarian organization by providing storage space for pre-positioning of relief items. The bi-objective model is converted into a single-objective one using the TH method as a well-known interactive fuzzy multi-objective programming approach. Finally, the presented model is validated by conducting several sensitivity analyses. The results emphasis on the effectiveness of collaborating with business sector in relief operations.

Keyword: Humanitarian logistics, resource sharing, collaboration, logistics service providers

1-Introduction and related literature

Effective management of humanitarian supply chains has been always as one of the main challenges for managers in this area. In the relief operations, the decisions made by managers directly affect the lives of many affected people. Annually, millions of lives are affected by natural disasters and their impacts. From 1998 to 2017, over 1.3 death and injury of 4.6 billion people caused by crises have been reported. The humanitarian organizations (HOs) and relief agencies are the main actors in the humanitarian relief operations and they should have a proactive plan for the unexpected events and natural disasters. Due to highly uncertain and unstable environment of disasters, HOs require specific strategies that enable them to respond to risks and uncertainties in the demand and supply sides in an efficient and effective manner. Although HOs try to do their best in the relief operations, inefficiency is still observed in some cases (Ghavamifar and Torabi, 2022). The lack of available logistical resources is mentioned by Maghsoudi and Moshtari (2020) as one of the main reasons for the inefficiency of relief operations while the business sector has several capabilities that can be leveraged by HOs. The main logistical activities for which the business sector can collaborate with HOs in humanitarian logistics are summarized in transportation, warehousing, procurement, packaging, capacity building, etc. (Bealt et al., 2016).

*Corresponding author
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However, there are many barriers which can affect the collaboration of HOs with the business sector such as conflicting goals and mandatories, different culture, lack of information sharing mechanism, and technological barriers. Although the business sector can participate in different phases of disasters namely mitigation, preparedness, response, and recovery, HOs should set some agreements with the business sector actors at pre-disaster (Balcik and Ak, 2014). The logistics service providers, suppliers and retailers are the most common private companies that can participate in different phases of disasters with the main drivers of earning income and paying attention to their social responsibilities.

Humanitarian operations include different stakeholders and actors, each of which has different culture, goals, interests, mission, capacity, and logistics expertise but none of the actors alone has all the required resources and does not have enough expertise to efficiently respond to possible disasters (Bui et al., 2000). For example, in the 2004 Japan's tsunami, more than 40 countries and 700 non-governmental organizations cooperated in humanitarian activities in various fields (Jahre and Jensen, 2010). Therefore, using all the capabilities and expertise of different organizations involved in relief operations (governmental and non-governmental) can have a significant effect in improving disaster response.

In the recent years, several studies have developed mathematical optimization models for optimizing logistical activities in humanitarian supply chains. However, most of these models have devoted on developing prepositioning plans for relief supplies (e.g. Bai et al., 2018; Hu and Dong, 2019; Rawls and Turnquist, 2010; Sabbaghtorkan et al., 2020; Turkeš et al., 2019; Wang et al., 2022; Wang and Nie, 2022), determining the location of relief facilities (Akbarpour et al., 2020; Fahimnia et al., 2015; Ghavamifar et al., 2018; Makui and Ghavamifar, 2016; Parragh et al., 2022; Rodríguez- Pereira et al., 2021; Shehadeh and Tucker, 2022; Taleizadeh et al., 2020; Torabi et al., 2018; Zhu et al., 2022) and the procurement process of relief items (Aghajani and Torabi, 2019; Aghajani et al., 2020; Chen et al., 2022; Kaur and Singh, 2022; Zhang and Kong, 2022). Most of these studies have tried to make decisions about distribution of items, supplier selection, facility location, contract design, vehicle routing, etc. under uncertainty for which some uncertainty programming approaches have been developed for handling the embedded uncertainty. Although several works have been done on humanitarian logistics, there are only a few studies for collaboration of business sector in relief logistics. In this area, most of the papers are presented to indicate the challenges, barriers, and the opportunities of humanitarian-business collaboration in relief logistics (Arcala Hall, 2008; Balcik et al., 2010; Bealt et al., 2016; Chen et al., 2013; Guan et al., 2018; Horwitz, 2009; Kapucu, 2008; Lieb et al., 1993; Maldonado et al., 2010; Maon et al., 2009; Nurmala et al., 2017; Simatupang and Sridharan, 2005; Stewart et al., 2009; Tomasini, 2018; Tomasini and Van Wassenhove, 2009; Wachtendorf and Kendra, 2004).

There are a few studies in which mathematical models are developed for formulating the participation of business sector in relief operations. Li et al. (2018) have presented a maximum coverage model by considering the cooperation between several organizations to determine the location of relief facilities and the amount of prepositioning and distribution of relief items, in which the use of different capacities of relief organizations based on the coverage criterion is possible. Guan et al., (2018) have determined the optimal public-private partnership using a game theory model which takes into account the risks of private and commercial sectors. In this paper, the private sector cooperates with the public sector as a supplier of items, while the humanitarian logistics network design has not been considered. In this research, the best strategy of the commercial sector is obtained by considering the characteristics of risk-neutrality and risk-aversion using the Nash equilibrium. Rodríguez-Espíndola et al. (2018) have developed a mixed integer multi-objective model by considering the role of cooperation of humanitarian aid organizations to deal with the flood crisis. The cooperation of the private sector is modeled through the provision of expert human resources during a crisis. In this paper, the location of relief facilities, storage and allocation of resources are the important decisions that are determined through the mathematical model. It is worth mentioning that in this paper, only the sharing of human resources is considered as a concept for cooperation and participation of the private sector with HOs.

Fikar et al. (2016) have provided a decision support system to facilitate coordination between the private and public sectors. In this work, different plans are developed for distribution of relief items from transfer points to demand points by a simulation model. In this paper, the private sector cooperated with the public sector by providing transport fleets in the distribution of relief items. Also, by using an integer programming model and simulation, the routing and scheduling decisions of transport fleets owned to different partners are determined in relief operations. Coles et al. (2018) used the game theory approach to investigate the selection of the best partner in order to cooperate in relief activities before the crisis. In this article, taking into account different organizations, each of which has its own goals and commitments, it has been examined how participation and cooperation can improve preparedness before a crisis occurs. Using a multi-criteria decision-making approach, Carland et al. (2018) have investigated the preferences of the commercial and government sectors for cooperation in humanitarian activities. Using a multi-criteria model, it has been investigated how considering these preferences can facilitate the cooperation of these two sectors. Dufour et al. (2018) have investigated the role of humanitarian service providers in carrying out humanitarian logistics operations in African countries. In this paper, finding the location of an intermediate warehouse is considered in order to improve the service and transportation operations; so that the suppliers of relief items can also deliver the relief items to this intermediate warehouse in cooperation with humanitarian organizations.

In a recent study, Balcik et al. (2019) designed a collaborative prepositioning network to strengthen the disaster preparedness of the Caribbean countries against hurricane. They used a stochastic programming approach to determine the locations and amounts of relief supplies that should be stored. In the most recent study, Rodríguez- Pereira et al. (2021) studies a multi-country disaster preparedness partnership using a joint prepositioning of emergency items. They used an alternative cost allocation method among the partner countries by considering their risk level and their ability to pay. Hu and Dong (2019) developed a two-stage stochastic model for using supplier-owned inventory by integrating the decisions related to supplier selection and prepositioning of relief items. In a recent study, Ghavamifar et al. (2022) proposed a hybrid contract for supplying a relief item using the supply and storage capabilities of a supplier. Kandler and Siller (2022) examined the collaboration of HOs and business sector in each phase of the disaster management cycle and determined some criteria for selecting LSPs in relief logistics. Kucukaltan et al. (2022) explored the capabilities of LSPs which can be used in humanitarian operations using the canvas business model. They also reviewed those studies in which LSPs are used in humanitarian logistics.

Considering the above-mentioned studies, in this paper, we propose a new mathematical model for using the storage capacities of LSPs as well as the relief supply capacity of suppliers in the relief operations simultaneously. To the best of our knowledge, it is the first study that considers the logistical capacity of LSPs alongside the suppliers' capability in the humanitarian logistics. The above-mentioned challenges in decision making highlight the motivation for the present study whose main research questions (RQs) include:

RQ1: How to use the capabilities of business section in humanitarian logistics?

RQ2: How to formulate the participation of business sector in relief logistics using mathematical modelling?

The main contributions of our study can be summarized as 1) presenting a mixed integer programming model in order to use the logistical capabilities of LSPs and suppliers in relief operations 2) LSPs participation in providing warehouse for storage of relief items, 3) using multiple suppliers in procurement through a framework agreement.

The rest of the paper is organized as follows. In section 2, problem definition is explained. The proposed model is presented in Section 3 and then the model is examined in a numerical study in Section 4. Finally, Section 5 concludes the paper and suggests some directions for future studies.

2-Problem definition

In this section, we present a mathematical model for using the capabilities of LSPs and suppliers in the humanitarian logistics. The main actors include a relief agency, multiple LSPs and multiple suppliers of a relief item. The relief agency decides to collaborate with the business sector to facilitate the procurement of the relief item as well as the storage of procured items. In the business side, there are some suppliers which are inclined to have partnership with relief agency. In addition, regarding the lack of available storage space for relief items, the relief agency seeks to have connection with some LSPs providing storage service. Therefore, in this paper, we assume that a relief agency outsources a part of its need for a relief item to the available suppliers and then the relief items procured from the suppliers are prepositioned in the LSPs' warehouses. The framework agreement approach proposed by Balcik and Ak, (2014), is used for collaboration with suppliers and LSPs. Actually, the proposed model is aimed to strengthen the capabilities of the relief agency in the procurement and prepositioning of procured relief items at pre-disaster via collaboration with these LSPs and suppliers. The main assumptions of our model are as follows:

- The main goal of suppliers and LSPs for participating in the relief logistics is economical.
- Both LSPs and suppliers have capacity limitation for participating in relief logistics.
- The procured items from the suppliers are prepositioned in the LSPs' warehouses.
- At least one supplier and LSP should be selected for supplying and storing relief items.
- both LSPs and suppliers have a minimum expected income for participating in relief logistics which should be satisfied by the relief agency.
- The relief agency has a pre-defined budget for this collaboration.
- Demand for relief items is determined by the relief agency based on the total demand of relief items. In fact, the demand size is the quantity of items that the relief agency wants to outsource to the suppliers. Therefore, we consider it as a deterministic parameter.

According to the above assumptions, the relief agency wants to make the following decisions using the presented decision model:

- Selecting the most suitable suppliers and LSPs for collaboration.
- Determining the quantity of relief items supplied by each supplier.
- Determining the required warehouse capacity for storing procured relief items provided by each supplier.

3-Mathematical model

The following notations are utilized to formulate the problem:

Indices	
i	Index of suppliers, $i \in \{1,2,\dots,I\}$
j	Index of Logistics service providers, $j \in \{1,2,\dots,J\}$
n	Index of capacity levels, $n \in \{1,2,\dots,N\}$
Parameters	
f_i	Fixed cost of making an agreement with supplier *i*
g_j	Fixed cost of making an agreement with LSP *j*
Dem	The outsourced demand for relief items procured by the suppliers
c_i	Supplier i^{th} capacity for supplying relief items
l_j^n	LSP j^{th} warehouse capacity with capacity level *n*
ns_i	Minimum acceptable income for supplier *i*
nl_j	Minimum acceptable income for LSP *j*
CSL	Unit shortage cost of relief items
pc_i	Unit procurement cost of relief item from supplier *i*
cs_j^n	Cost of sharing LSP *j* warehouse with capacity level *n*
Decision variables	
P_i	Equals to 1, if the framework agreement with supplier *i* is executed; 0, otherwise.
Q_j	Equals to 1, if the framework agreement with LSP *j* is executed; 0, otherwise.
Z_j^n	Equals to 1, if LSP j^{th} warehouse at capacity level *n* is selected by the relief agency; 0, otherwise.
SHL	The quantity of unfulfilled demand
QS_i	The quantity of relief item supplied by supplier *i*.

3-1-Model formulation

$$Min\, Z_1 = \sum_i f_i P_i + \sum_j g_j Q_j + \sum_i pc_i QS_i + \sum_j \sum_n cs_j^n Z_j^n \tag{1}$$

$$Min\, Z_2 = CSL * SHL \tag{2}$$

The objective function (1) minimizes the total costs of making agreement with suppliers and LSPs, procurement and storage costs of relief items. The objective function (2) minimizes the total shortage cost of the relief item.

$$\sum_i QS_i + SHL = Dem \qquad \forall i \in I \tag{3}$$

According to constraint (3), the outsourced demand of the relief agency equals the amount of relief items delivered from the suppliers and the shortage size.

$$QS_i \le c_i X_i \qquad \forall i \in I \tag{4}$$

The procurement capacity of each supplier is considered in constraint (4).

$$QS_i \le \sum_j \sum_n l_j^n Z_j^n \qquad \forall i \in I \tag{5}$$

The storage capacity of LSPs is considered in constraint (5), where the relief items supplied from the suppliers should be prepositioned.

$$\sum_n Z_j^n \le QS_j \qquad \forall j \in J \tag{6}$$

Constraint (6) expresses that if an agreement has been placed with a LSP, then the warehouses of that LSP can be selected for relief prepositioning. Regarding this constraint, for each warehouse, at most a specific capacity level can be chosen.

$$\sum_i P_i \ge 1 \tag{7}$$

$$\sum_j Q_j \ge 1 \tag{8}$$

Constraint (7) and (8) enforce that at least one supplier and one LSP are selected in order to collaborate with HO.

$$pc_i QS_i \ge ns_i P_i \qquad \forall i \in I \tag{9}$$

$$\sum_n c_j^n Z_j^n \ge nl_j Q_j \qquad \forall j \in J \tag{10}$$

A minimum acceptable level for the expected income of LSPs and suppliers in the partnership is implied in constraint (9) and (10).

$$X_i, Y_j, Z_j^n \in \{0,1\}, Q_i \ge 0 \qquad \forall i \in I, \forall j \in J, \forall n \in N \tag{11}$$

At last, the domain and kind of each variable is determined in constraint (11).

4-Solution approach

In this section, the bi-objective model is converted to a single objective model using the well-known TH method (Torabi and Hassini, 2008). Developing multi-objective models is common in the context of humanitarian logistics to provide a trade-off suite for cost efficiency and responsiveness performance measures (Abolfazli et al., 2022; Desi-Nezhad et al., 2022; Diabat et al., 2019; Eshkiti et al., 2022; Lu et al., 2022; Sabouhi et al., 2020; Sabouhi and Jabalameli, 2019; Vahdani et al., 2018). Most of these quantitative studies have considered some objectives such as the minimization of total costs and unmet demand while making several decisions regarding relief facility location, relief pre-positioning and distribution, and vehicle routing in disastrous situations. The steps of this method are as follows:

Step1: Specify the positive and negative ideal solutions (PIS, NIS) for each objective function. The PISs are obtained by optimizing the model for each objective function separately (Z_1^{PIS}, Z_2^{PIS}), while the NISs are also exactly attainable by solving the two single-objective problems shown by equation (12):

$$\begin{aligned} & Z_1^{NIS} = MinF_1(x) \\ & s.t: \\ & F_2(x) \geq Z_2^{PIS} \end{aligned} \qquad \begin{aligned} & Z_2^{NIS} = MaxF_2(x) \\ & s.t: \\ & F_1(x) \leq Z_1^{PIS} \end{aligned} \tag{12}$$

where $F_1(x)$ and $F_2(x)$ refer to the first and second objective functions of the model, respectively.

Step2: A linear fuzzy membership function is determined for each objective (Z_1, Z_2) function through equations. (13) and (14), respectively.

$$\mu_1(x) = \begin{cases} 1 & \text{if } Z_1 < Z_1^{PIS} \\ \dfrac{Z_1^{NIS} - Z_1}{Z_1^{NIS} - Z_1^{PIS}} & \text{if } Z_1^{PIS} \leq Z_1 \leq Z_1^{NIS} \\ 0 & \text{if } Z_1 > Z_1^{NIS} \end{cases} \tag{13}$$

$$\mu_2(x) = \begin{cases} 1 & Z_2 > Z_2^{PIS} \\ \dfrac{Z_2 - Z_2^{NIS}}{Z_2^{PIS} - Z_2^{NIS}} & Z_2^{NIS} \leq Z_2 \leq Z_2^{PIS} \\ 0 & Z_2 < Z_2^{NIS} \end{cases} \tag{14}$$

Step 3: The proposed bi-objective model is converted into the single-objective counterpart using the TH aggregation function as equation (15):

$$\begin{aligned} & Max\ \xi(x) = \varphi\theta_0 + (1-\varphi)\sum_i \sigma_i\, \mu_i(x) \\ & s.t. \\ & \theta_0 \leq \mu_i(x), \\ & x \in F(x);\ \ \theta_0, \varphi \in [0,1] \end{aligned} \tag{15}$$

Where θ_0 stands for the minimum satisfaction degree of objective functions. Moreover, φ and σ_i indicate the compensation coefficient and the relative importance weights of objective functions according to the DM preferences ($\sigma_i \geq 0, \sum_i \sigma_i = 1$), respectively. It should be noted that the value of parameter φ balances the importance degrees between the max-min operator (i.e. the first part of TH function) and the weighted sum operator (i.e. the second part of TH function) based on DM preferences (Torabi and Hassini, 2008).

Step 4: Whenever the values of φ and σ_i are set by DM, the resulting single-objective model (S4) is solved to find a Pareto-optimal solution for the original bi-objective model.

5-Numerical study

In this section, we design a variety of experiments and sensitivity analyses to highlight the performance of the model. Several instances are tested whose input parameters are determined using uniform random distributions whose parameters have been estimated based on the field experts' subjective knowledge. Noteworthy, all the numerical experiments are carried out using GAMS software version 24.1 in a laptop with 12GB RAM and Corei7 CPU 2.6GHz.

5-1-Initial observation

The input parameters are generated randomly using the uniform distributions presented in table1:

Table1. The distributions of parameters for instance generation

Parameters	Instance size #		
	$I * J * N$ 10*10*3	$I * J * N$ 15*15*3	$I * J * N$ 20*20*3
f_i	U (10,20)	U (25,50)	U (75,100)
g_j	U (25,50)	U (25,75)	U (25,100)
Dem	U (1000,2000)	U (2000,6000)	U (6000,10000)
c_i	U (200,300)	U (400,500)	U (600,700)
l_j^n	U (200,400)	U (400,800)	U (800,1000)
ns_i	U (1200,1500)	U (1500,1800)	U (1800,2100)
nl_j	U (2000,3000)	U (3000,4000)	U (4000,5000)
pc_i	U (10,20)	U (25,50)	U (75,100)
cs_j^n	U (10,20)	U (25,50)	U (75,100)
CLS	U (100,200)	U (250,500)	U (750,1000)

In table 1, we try to generate random parameters for three different instances. The first instance is considered as the small-scale problem, the second one is a medium-scale problem while the 3rd one is a large-scale test problem. As we expected, the running time of instances are increasing from the small-sized instances to large-sized ones whose results are indicated in table 2.

Table 2. Running time in different test scenarios (in Sec.)

Test Scenario	Instance Size #1	Instance Size #2	Instance Size #3
Test Scenario #1	10	30	46
Test Scenario#2	10	32	40
Test Scenario#3	12	28	40
Test Scenario#4	10	28	47
Test Scenario#5	9	28	40
Test Scenario#6	12	30	40

According to table 2, we can conclude that the model can be solved in a reasonable time and there is no need to develop a specific solution approach for solving the model in different sizes. Therefore, the developed model can be used in the real-life problems directly where the scale of problem can be near to medium or large-scale instances (considered in this study).

We have reported the results of the model in different instances in table 3, where the main decision variables are reported in order to investigate the validity of the model.

Table 3. The initial results of the model in different instances

Decision variables	Instance Size #1	Instance Size #2	Instance Size #3
Number of selected suppliers	7	12	14
Number of selected LSPs	5	6	10
Minimum of supplier income (M-Toman)	2563	2632	2952
Maximum of supplier income (M-Toman)	2898	8026	9368
Minimum of LSPs income (M-Toman)	4025	4591	4509
Maximum of LSPs income (M-Toman)	4632	6820	8930
Quantity of unfulfilled demand (*1000)	0	36	56

Obviously, the results in table 3 indicate that the more the demand of the network should meet, the more suppliers and LSPs are selected by the relief agency. In addition, we can see that the minimum income of suppliers and LSPs are nearly same while the maximum income is significantly different in all instances. One general reason could be for the considered limitation in constraints 8 and 9.

5-2-Trade-off between costs and satisfied demand

The well-known ε-constraint method is applied to generate a representative subset of the Pareto optimal solutions for the proposed bi-objective model (Mavrotas and Florios, 2013). At first, we obtain the two extreme efficient points of the Pareto front by determining the PIS, NIS for each objective function. As mentioned before, the PISs are first obtained by optimizing the model for each objective function separately. Next, the NISs are determined by solving two other single-objective problems shown in equation (16). Then, by moving the less important objectives to the constraints (here the second one) and changing the value of (ε) parameter systematically, a new Pareto-optimal solution could be obtained for each ε value by solving the model (16).

$$\begin{aligned} &Min\ f_1(x) \\ &s.t. \quad f_2(x) \geq \varepsilon \\ &\quad x \in f(x) \end{aligned} \tag{16}$$

The obtained results are depicted in figures 1 to 3 for small, medium and large-scale problems, respectively.

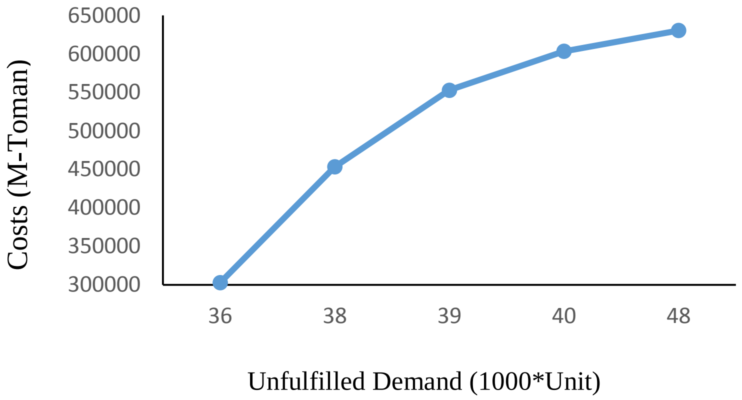

Fig 1. Pareto front surface for the cost and satisfied demand objectives in instance 1

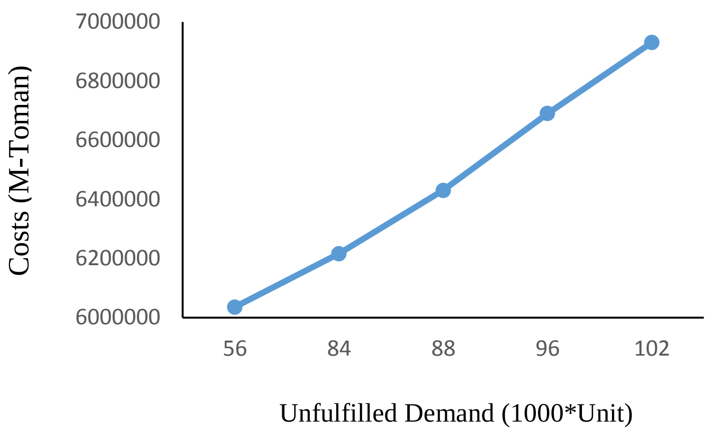

Fig 2. Pareto front surface for the cost and satisfied demand objectives in instance 2

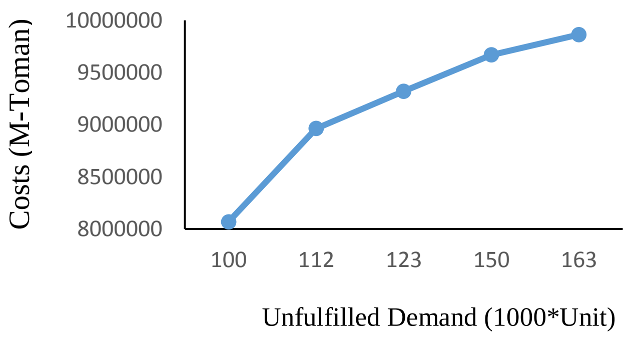

Fig 3. Pareto front surface for the cost and satisfied demand objectives in instance 3

5-3-Collaboration vs. non-collaboration

In this section, we investigate the power of collaboration in the relief procurement. In order to highlight the merits of collaboration, we decrease the weight of the 2nd objective function. In this case, the 1st objective function considers the collaboration when its weight is equal to one. Notably, when the weight of 2nd objective function is equal to one, it mimics the non-collaboration case. Therefore, the value of 2nd objective function is a measure for evaluating the collaboration in this problem. As figure 4 shows, the shortage cost increases significantly when no-collaboration is assumed between the relief agency, suppliers, and LSPs. We assumed the shortage cost as an indicator to measure the efficiency of collaboration in our model. Therefore, the less the shortage costs given in the results, the more the role of collaboration is highlighted through using our model. In addition, figure 4 indicates that although the collaboration is considered in our model, there is a demand shortage, which can be regarded to using the random data.

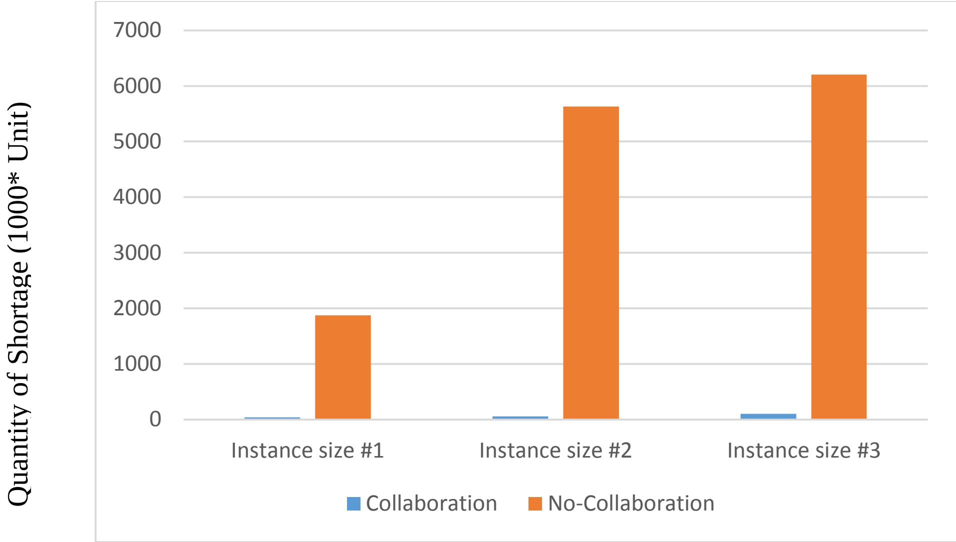

Fig 4. Shortage cost in collaboration and non-collaboration cases

6-Conclusion

Collaboration with the business sector in humanitarian logistics can increase the performance of humanitarian operations. The business sector with its logistical capabilities can participate in the relief logistics using its knowledge, infrastructures, facilities, and supplies. The developed model in this study uses the supply capability of some suppliers as well as the storage capability of some LSPs' in storing the procured relief items. In this model, it is assumed that a relief agency outsources the relief procurement and prepositioning to some suppliers and LSPs to facilitate relief operations. If the relief agency cannot collaborate with the suppliers and LSPs, the demand will be unfulfilled which can make a critical condition for the affected people. Our model is a basic effort to formulate the humanitarian-business collaboration and can be extended in several aspects, for example, including some criteria (such as the quality of items delivered by suppliers, lead times, availability of LSPs) for selecting the candidate suppliers and LSPs. In addition, the possible disruptions in suppliers and LSPs can be considered in designing the collaborative network. Considering multiple HOs and relief items in the developed model can be considered as another avenue for future research as well as developing a supplier relationship management mechanism for using the suppliers' capability in humanitarian operations in the most effective way.

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