IJE TRANSACTIONS C: Aspects Vol. 31, No. 12, (December 2018) 2068-2076

International Journal of Engineering

Journal Homepage: www.ije.ir

A Multi-attribute Reverse Auction Framework Under Uncertainty to the Procurement of Relief Items

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PAPER INFO

Paper history:
Received 30 March 2018
Received in revised form 20 May 2018
Accepted 18 June 2018

Keywords:
Humanitarian Relief Chain
Procurement
multi-attribute Reverse Auction
mathematical Modeling
Augmented ε-Constrained Method

ABSTRACT

One of the main activities of humanitarian logistics is to provide relief items for survivors in case of a disaster. To facilitate the procurement operation, this paper proposes a bidding framework for supplier selection and optimal allocation of relief items. The proposed auction process is divided into the announcement construction, bid construction and bid evaluation phases. In the announcement phase, the bidder (purchaser or relief organization) invites certain suppliers to the auction. Next, the construction phase is formulated as a bi-objective fuzzy model from the perspective of suppliers. This phase provides the bidder with several suggestions, each of which containing the amount, price, and lead time of the delivery of relief items. Then, in the evaluation phase, the bidder determines the winners and optimally assigns orders by a multi-objective fuzzy model. Each of the fuzzy mathematical models in the paper is formulated under the uncertainty of parameters and is then solved by a two-stage fuzzy approach. Finally, to illustrate the validity and applicability of the proposed model, a numerical example is provided and its result is analyzed.

***doi**: 10.5829/ije.2018.31.12c.11*

1. INTRODUCTION

In recent years, many areas around the world have been affected by natural disasters. Disasters can be natural (such as earthquake, famine, tsunami, cyclone, hurricane, flood, etc.), manmade (such as terrorism, war, civil disorder, etc.), disease-related (like HIV/aids or malaria) or extreme poverty situations [1]. After a disaster, demand of the people in the affected areas is satisfied through pre-positioned items, donations, and instance procurement. Post-disaster procurement is one of the main components of humanitarian supply chain which can make relief operations faster and more efficient. The uncertain nature of disaster makes post-disaster procurement a highly challenging process [2]. Location, time, magnitude, and number of affected people are among the factors that make the procurement operations a highly exhaustive task [3]. Estimations show that 65% of the total budget of relief chain is devoted to the procurement of relief items [4]. Therefore, it is of high importance to develop a model for purchasing relief item operations in order to optimize and quicken the relief operations.

The main purpose of this paper is to propose a model to coordinate purchaser and suppliers in the humanitarian supply chain. Accordingly, as a coordination mechanism, we consider multi-attribute reverse auction with bid construction and bid evaluation phases. Construction phase is formulated from the perspective of suppliers as a bi-objective fuzzy mixed integer model (MIP) under the disruption risk of supplier centers. Solving this formulation reveals the best suggested package from the suppliers to the purchaser (i.e. relief organization). Each package contains the details of quantities, price, and delivery time of relief items. In the evaluation phase, we develop a multi-objective mathematical model from the perspective of purchaser, which when solved, chooses the supplier, assigns orders, and determines winner(s) of the bid.

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Please cite this article as: R. Dabbagh, M. Khoshsirat, A. Bozorgi-Amiri, A multi-attribute Reverse Auction Framework under Uncertainty to the Procurement of Relief Items, International Journal of Engineering (IJE), IJE TRANSACTIONS C: Aspects Vol. 31, No. 12, (December 2018) 2068-2076

The remainder of the paper is organized as follows: Section 2 provides a literature review. In section 3, the mathematical model is elaborated. Coping with uncertainty and solution methodology for the multi-objective model is explained in section 4. In section 5, a numerical example is presented and results of the proposed model are discussed. Eventually, we make conclusions and provide some future directions.

2. LITERATURE REVIEW

Although the purchase operation is critical in humanitarian logistics, only few papers have evaluated purchase problem from both purchaser and supplier perspectives.

Trestrail el al. [5] considered purchase operation from the bidder perspective and developed a mathematical model for bidding in agriculture sector of the United States. Bagchi et al. [6] suggested a model to improve bidding mechanism in food procurement and transportation service. In their model, the coordination among suppliers and relief item shippers not only increases supplier participation, but also increases the amount of dispatched items to the affected areas. Ertem et al. [7] proposed a bidding strategy to relief item purchase. The authors suggested two mathematical models; the first one determined optimal suggested quantities from the supplier perspective, while the second model evaluated the suggested package by an MIP model. Results of implementing these models revealed that using this bidding model under different scenarios could streamline the procurement of relief items by relief organizations. In the same research, Ertem and Buyurgan [8] developed the bidding strategy by assuming that demand data were given to suppliers by the relief organization. In 2012 and 2013, Ertem et al. [9, 10] evaluated bid construction phase from the perspective of supplier. Results showed that considering substitution and partial procurement could improve inventory utilization of suppliers. Shokr and Torabi [11] developed reverse auction for post-disaster item procurement. In order to cope with the uncertainty of parameters, they proposed two possibilistic models for the construction and evaluation of the bid. The model for the construction phase had a single objective from the perspective of supplier and showed profit obtained from selling relief items. The model for the evaluation phase, on the other hand, aimed to reduce purchase costs and delivery time of relief items and resulted in supplier selection and order assignment.

As the literature review suggests, most of the bid-based models only focus on cost objectives in the construction phase, which does not suffice to cover all the objectives of the suppliers. Furthermore, in case of disasters, warehouses of suppliers and distribution centers lose a portion of their capacity and, thus, inflict the relief operations with disruption risks. Omitting disruption risk is another gap in the previous papers. Moreover, most researchers have evaluated the bid by only one objective (cost reduction) and overlooked one of the main objectives of the relief operation, which is to reduce time of relief item delivery when evaluating suppliers.

According to the literature review, the main contributions of this paper can be summarized as follows:

1. Improving the construction phase of bid from the perspective of supplier to purchase relief items. This improvement is done through a mathematical non-linear fuzzy formulation with two objectives;
2. Considering disruption risk in supply and distribution centers and considering uncertainty in both construction and evaluation phases of the bid;
3. Formulating evaluation phase of the bid as a three-objective fuzzy mathematical model; and
4. Implementing augmented ε-constrained method to solve multi-objective models.

3. PROBLEM DESCRIPTION

Although relief organizations pre-position relief items in warehouses and distribution centers, it is likely that, after the disaster, the demand surges and they are no longer able to provide vital items. If this is the case, the required items are purchased from available suppliers. In this paper, procurement operation is modeled as a reverse auction.

The bid consists of a purchaser and a number of suppliers. Reverse auction begins with a bid announcement. After the disaster, the relief organization collects data for necessary items estimates demand, and then invites the available suppliers to the bid. In the second step, the suppliers compare demand for items with their inventory level and, then, construct the bid. In this phase, package of suppliers is offered to the relief organization with full details about quantities, price, and optimal delivery time. Eventually, in the third phase, the relief organization evaluates packages and determines winner(s) and assigns orders; then, relief items are transported to the affected areas. The structure of the bid is illustrated in Figure 1.

3. 1. Bid Construction

3. 1. 1. Multi-Objective Formulation for Bid Construction Phase

Sets/indices:

I : Set of suppliers $i \in I$

J : Set of local distribution centers $j \in J$

K : Set of affected areas $k \in K$

C : Set of relief items $c \in C$

M : Set of transportation modes $m \in M$

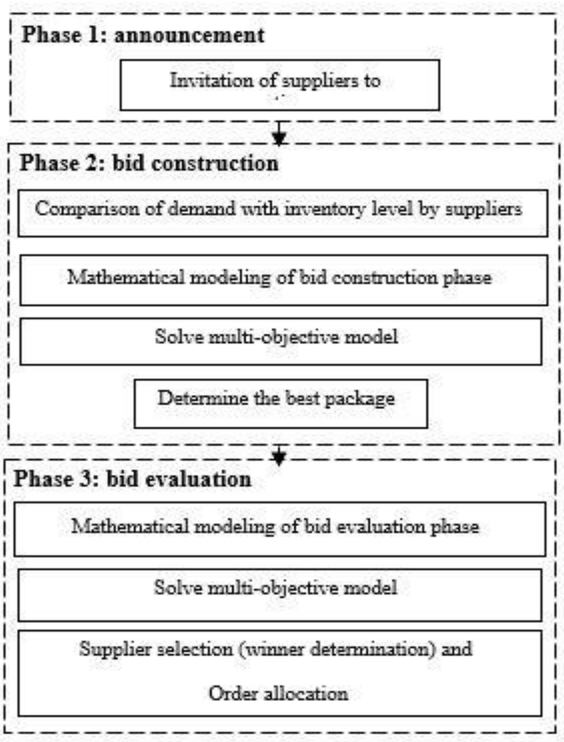

Figure 1. Structure of the proposed bid

Deterministic Parameters:

cap_{jc}: Capacity of local distribution center j for relief item c

π_{ic}: Minimum acceptable price for relief item c for supplier i

I_{ic}: Inventory level of supplier i for relief item c

ρ_i: Probability of disruption in supplier i

α_{ic}: Portion of relief item c for supplier i lost by disruption

ℓ_j: Probability of disruption in local distribution center j

β_{jc}: Portion of supply capacity of local distribution center j for relief item c lost by disruption

ω_{ic}: 0 if supplier has enough inventory to cover i minimum required amount of relief item c ; 1 otherwise

δ_c: 1 if the partial procurement is allowed for relief item c ; 0 otherwise

Fuzzy Parameters:

$\tilde{t}_{imcj}$: Lead time of relief item c by supplier i with transportation mode m to local distribution center j

$\tilde{C}_{imcj}$: Transportation cost of relief item c from supplier i to local distribution center j by transportation mode m

$\tilde{u}_{ic}$: Estimation of other suppliers for the maximum proposed price of supplier i for the relief item c

$\tilde{D}_{ck}$: Demand of relief item c in affected area k

$\tilde{B}$: Available budget to purchase relief items

Decision variables:

p_{ic}: Proposed price of supplier i for relief item c

x_{imcj}: Amount of relief item c proposed by supplier i in order to be transported to local distribution center j with transportation mode m

z_{imcj}: 1 if supplier i uses transportation mode m to carry relief item c to local distribution center j

Mathematical formulation:

$$\min \ Z_i^1 = \sum_m \sum_c \sum_j \tilde{t}_{imcj} z_{imcj} \tag{1}$$

$$\max \ Z_i^2 = \sum_c p_{ic} \sum_m \sum_j x_{imcj} - \sum_m \sum_c \sum_j x_{imcj} \tilde{c}_{imcj} z_{imcj} \tag{2}$$

st :

$$\sum_j \sum_m x_{imcj} \le (1\text{-}\rho_i \alpha_{ic}) I_{ic} \qquad \forall i, c \tag{3}$$

$$\sum_j \sum_m x_{imcj} \ge \tilde{D}_{ck} \qquad \forall i, c, k \tag{4}$$

$$p_{ic} \sum_j \sum_m x_{ijc} \le \tilde{B} \qquad \forall i, c \tag{5}$$

$$\pi_{ic} \le p_{ic} \le \tilde{u}_{ic} \qquad \forall i, c \tag{6}$$

$$\sum_j \sum_m x_{imcj} \ge \delta_c I_{ic} - M\left(1-\omega_{ic}\right) \qquad \forall i, c \tag{7}$$

$$\sum_m x_{imcj} \le (1-\ell_j \beta_{jc}) cap_{jc} \qquad \forall i, j, c \tag{8}$$

$$\sum_m z_{imcj} \ge 1 \qquad \forall i, c, j \tag{9}$$

$$x_{imcj} \le M z_{imcj} \qquad \forall i, m, c, j \tag{10}$$

$$z_{imcj} \in \{0,1\} \qquad \forall i, m, c, j \tag{11}$$

$$p_{ic}, x_{imcj} \ge 0 \qquad \forall i, m, c, j \tag{12}$$

Objective function (1) minimizes lead time while objective function (2) maximizes profit of each supplier from selling relief items. Constraint (3) restricts the proposed amounts of suppliers to less than their inventory levels. Constraint (4) states that the amount proposed by suppliers should be greater than the demand of the organization. The fact that maximum revenue of suppliers is smaller or equal to the budget of the organization is specified in Constraint (5). Price proposed by a supplier should be greater than the minimum acceptable price and less than that of the rivals. This estimation of the rival prices increases the probability of winning for the supplier. This argument is guaranteed by Constraint (6). Constraint (7) allows every supplier to participate in the bid, regardless of their inventory level. Constraint (8) stipulates the capacity of local distribution center for pre-positioning. Constraint (9) states that every supplier should at least select one of aerial or land transportation modes. Constraint (10) asserts that relief items are shipped to distribution centers if one of the transportation modes is selected by the supplier. Constraints (11) and (12) determine types of the variables.

3. 1. 2. Linearization of Multi-Objective Fuzzy Model for Bid Construction Phase The formulation proposed in 3.1.1 is non-linear due to the multiplication of two continuous variables p_{ic} and x_{imcj} as well as binary variable z_{imcj} in continuous variable x_{imcj}. We follow Vidal and Goetschalckx [12] to linearize the multiplication of two continuous variables by defining a new variable r_{ic} as:

$$p_{ic}\sum_m\sum_j x_{imcj} = r_{ic} \qquad \forall i,c \tag{13}$$

Therefore, after multiplying $\sum_m\sum_j x_{imcj}$ by Constraint (6), we have:

$$r_{ic} \geq \pi_{ic}\sum_m\sum_j x_{imcj} \qquad \forall i,c \tag{14}$$

$$r_{ic} \leq \tilde{u}_{ic}\sum_m\sum_j x_{imcj} \qquad \forall i,c \tag{15}$$

Also, to linearize the other non-linear term, we consider Glover's [13] paper and replace $x_{imcj}z_{imcj} = w_{imcj}$, so the following constraints need to be added to the formulation:

$$w_{imcj} \leq Mz_{imcj} \qquad \forall i,m,c,j \tag{16}$$

$$w_{imcj} \leq x_{imcj} \qquad \forall i,m,c,j \tag{17}$$

$$w_{imcj} \geq x_{imcj} + M\left(z_{imcj}-1\right) \qquad \forall i,m,c,j \tag{18}$$

Therefore, the non-linear model can be reformulated as a linear model:

$$\max\ Z_i^2 = \sum_c p_{ic}\sum_m\sum_j x_{imcj} - \sum_m\sum_c\sum_j \tilde{c}_{imcj}w_{imcj} \tag{19}$$

$$\sum_c r_{ic} \leq \tilde{B} \qquad \forall i \tag{20}$$

After solving a multi-objective linear model for bid construction phase, two parameters w_{ic} and $\tilde{T}_{jc}$ along with the proposed price and quantity are determined.

$$\tilde{T}_{jc} = \sum_i\sum_m \tilde{t}_{imcj}z_{imcj} \qquad \forall j,c \tag{21}$$

$$w_{ic} = \frac{\sum_m\sum_j x_{imcj}}{\sum_i\sum_m\sum_c\sum_j x_{imcj}} - \frac{p_{ic}}{\sum_i\sum_c p_{ic}} \qquad \forall i,c \tag{22}$$

These parameters are used as input parameters of the evaluation phase.

3. 2. Bid Evaluation

3. 2. 1. Multi-objective Formulation for Bid Evaluation Phase

Sets/indices:

I: Set of suppliers $i \in I$

J: Set of local distribution centers $j \in J$

K: Set of affected areas $k \in K$

C: Set of relief items $c \in C$

M: Set of transportation modes $m \in M$

Deterministic Parameters:

p_{ic}: Proposed price of supplier i for relief item c

x_{imcj}: Amount of relief item c proposed by supplier i in order to be transported to local distribution center j with transportation mode m

g_i: Fixed cost of purchasing relief items from supplier i

w_{ic}: Score of supplier i with regard to relief item c

cap_{jc}: Capacity of local distribution center j for relief item c

γ_{ck}: Shortage unit cost for relief item c in affected area k

A_{jc}: Pre-positioned amount of relief item k in local distribution center j

ρ_i: Probability of disruption in supplier i

ℓ_j: Probability of disruption in local distribution center j

Fuzzy Parameters:

$\tilde{T}_{jc}$: Optimal and proposed lead time of relief item c to local distribution center j

$\tilde{c}_{jmck}$: Transportation cost of relief item c from Local distribution center j to affected area k by transportation mode m

$\tilde{t}_{jmck}$: Lead time of relief item c from local distribution center j to affected area k by transportation mode m

$\tilde{D}_{ck}$: Demand of relief item c in affected area k

$\tilde{B}$: Available budget to purchase relief items

Decision variables:

oq_{icj} : Ordered amount of relief item c to supplier i which is stored in local distribution center j

o_{jmck} : Amount of relief item c which is transported from local distribution center j by transportation mode m to affected area k

φ_{ck} : Shortage of relief item c in affected area k

ψ_{ic} : 1 if supplier i is selected to provide relief item c ; 0 otherwise

z_{jmck} : 1 if the relief organization uses transportation mode m to ship relief item c from local distribution center j to affected area k

Mathematical formulation:

$$\max\ Z^3 = \sum_i \sum_c w_{ic}\psi_{ic} \tag{23}$$

$$\min\ Z^4 = \sum_i \sum_j \sum_m \sum_c \sum_k \left(\tilde{t}_{jmck} + \tilde{T}_{jc}\right) z_{jmck} \tag{24}$$

$$\min\ Z^5 = \sum_i g_i \sum_c \psi_{ic} + \sum_i \sum_c p_{ic} \sum_j oq_{icj} + \sum_c \sum_k \gamma_{ck}\varphi_{ck} + \sum_j \sum_m \sum_c \sum_k o_{jmck}\tilde{c}_{jmck} z_{jmck} \tag{25}$$

$$st:\quad oq_{icj} \le \sum_m x_{imcj} \qquad \forall i, c, j \tag{26}$$

$$\sum_i \sum_c oq_{icj} \le \sum_c (1-\ell_j \beta_{jc}) cap_{jc} \qquad \forall j \tag{27}$$

$$\sum_k \sum_m o_{jmck} = \sum_i oq_{icj} \qquad \forall c, j \tag{28}$$

$$\sum_j \sum_m o_{jmck}(1-\ell_j \beta_{jc}) + \varphi_{ck} + \sum_j A_{jc}\left(1-\ell_j\right) = \tilde{D}_{ck} \qquad \forall c, k \tag{29}$$

$$\sum_i \sum_c p_{ic} \sum_j oq_{icj} \le \tilde{B} \tag{30}$$

$$oq_{icj} \le M * \psi_{ic} \qquad \forall i, c, j \tag{31}$$

$$\sum_i \psi_{ic} \ge 1 \qquad \forall c \tag{32}$$

$$\sum_m z_{jmck} \ge 1 \qquad \forall c, j, k \tag{33}$$

$$o_{jmck} \le M z_{jmck} \qquad \forall c, j, k, m \tag{34}$$

$$\psi_{ic} \text{ and } \psi'_{ic} \in \{0,1\} \qquad \forall i, c \tag{35}$$

$$oq_{icj}, o_{jck}, \varphi_{ck} \ge 0 \qquad \forall i, c, j, k \tag{36}$$

Objective function (23) has a selective nature and selects the supplier with the highest score. Objective function (24) minimizes lead time of relief items from supply point to affected areas. The total purchase cost is minimized in objective function (25). Constraint (26) states the amount allocated to each supplier is less than the proposed amount. Constraint (27) deals with the capacity of local warehouses. Constraint (28) is a balance equation of items for distribution centers and ensures that total inflow and outflow of items from a distribution center is equal. Constraint (29) specifies the relation between relief items dispatched to affected areas, demand, pre-positioned level, and shortage in affected areas. Limitation of purchase for the relief organization to its budget is captured by Constraint (30). Constrain (31) ensures that items are provided from a selected supplier. Constraint (32) states that, for every relief item, there should at least be one supplier. Constraint (33) ensures that at least one transportation mode is selected to ship relief items. Constraint (34) ensures the shipment of items to affected areas if the right transportation mode is selected. Finally, types of the variables are stipulated in Constraints (35) and (36).

3. 2. 2. Linearization of Multi-Objective Fuzzy Model for Bid Evaluation Phase The formulation proposed in 3-2-1 is non-linear due to the multiplication of binary variable in the continuous variable. Hence, by adding a new variable $o_{jmck} z_{jmck} = v_{jmck}$, the following linear model is obtained:

$$\min\ Z^5 = \sum_i g_i \sum_c \psi_{ic} + \sum_i \sum_c p_{ic} \sum_j oq_{icj} + \sum_c \sum_k \gamma_{ck}\varphi_{ck} + \sum_j \sum_m \sum_c \sum_k \tilde{c}_{jmck} v_{jmck} \tag{37}$$

$$st:\ v_{jmck} \le M z_{jkmc} \qquad \forall c, j, k, m \tag{38}$$

$$v_{jmck} \le o_{jmck} \qquad \forall c, j, k, m \tag{39}$$

$$v_{jmck} \geq o_{jmck} - M\left(1 - z_{jkmc}\right) \qquad \forall c, j, k, m \tag{40}$$

4. SOLUTION METHODOLOGY

We use a two-step fuzzy approach to solve each of the multi-objective models. In the first step, deterministic equivalent of each model is obtained by Jiménez [14]. Then, augmented ε-constrained method is implemented to solve multi-objective models and obtain Pareto solutions.

4. 1. Step 1: Determinist Equivalent of Fuzzy Models

In this section, we utilize Jiménez et al.'s [14] method to obtain deterministic equivalent of the fuzzy models. This method uses mathematical expectation and expected value of fuzzy numbers to defuzzify a possibilistic model. We defuzzify objective functions and constraints based on Equations (41)-(43).

$$EI(\tilde{c}) = [E_1^c, E_2^c] = [\frac{1}{2}(c^p + c^m), \frac{1}{2}(c^m + c^o)] \tag{41}$$

$$EV(\tilde{c}) = \frac{E_1^C + E_2^C}{2} = \frac{c^p + 2c^m + c^o}{4} \tag{42}$$

$$\left[(1-\alpha)E_2^{a_i} + \alpha E_1^{a_i}\right]x \geq \alpha E_2^{b_i} + (1-\alpha)E_1^{b_i} \tag{43}$$

where $\tilde{c} = (c^p, c^m, c^o)$ is a triangle fuzzy number and p, m, and o are the most pessimistic value, most possible value, and most optimistic value for the imprecise parameter, respectively, and $EI(\tilde{c})$ and $EV(\tilde{c})$ are expectation interval and expected values of fuzzy number $\tilde{c}$, respectively. α is minimum satisfaction level for possibility constraints.

Following the steps of Jiménez et al.'s method, deterministic equivalent of Equations (1), (2), (4), (15), and 20 is reformulated as Equations (44) to (48).

$$\min Z_i^1 = \sum_m \sum_c \sum_j \left(\frac{t_{imcj}^p + 2{*}t_{imcj}^m + t_{imcj}^o}{4} \right) z_{imcj} \tag{44}$$

$$\max\ Z_i^2 = \sum_c p_{ic} \sum_m \sum_j x_{imcj} - \sum_m \sum_c \sum_j x_{imcj} \left(\frac{c_{imcj}^p + 2{*}c_{imcj}^m + c_{imcj}^o}{4} \right) z_{imcj} \tag{45}$$

$$\sum_j \sum_m x_{imcj} \geq (1-\alpha)(\frac{D_{ck}^p + D_{ck}^m}{2}) + \alpha(\frac{D_{ck}^m + D_{ck}^o}{2}) \tag{46}$$

$$r_{ic} \leq (\alpha(\frac{u_{ic}^m + u_{ic}^p}{2}) + (1-\alpha)(\frac{u_{ic}^p + u_{ic}^m}{2})) \sum_m \sum_j x_{imcj} \tag{47}$$

$$\sum_c r_{ic} \leq \alpha(\frac{B^p + B^m}{2}) + (1-\alpha)(\frac{B^m + B^o}{2}) \tag{48}$$

Similarly, deterministic equivalent of Equations (24), (29), (30), and (37) for bid evaluation model is:

$$\min\ Z^2 = \sum_i \sum_j \sum_m \sum_c \sum_k \left(\left(\frac{t_{jmck}^p + 2{*}t_{jmck}^m + t_{jmck}^o}{4} \right) + \left(\frac{T_{jc}^p + 2{*}T_{jc}^m + T_{jc}^o}{4} \right) \right) z_{jmck} \tag{49}$$

$$\min\ Z^3 = \sum_i g_i \sum_c \psi_{ic} + \sum_i \sum_c p_{ic} \sum_j oq_{icj} + \sum_c \sum_k \gamma_{ck} \varphi_{ck} + \sum_j \sum_m \sum_c \sum_k o_{jmck} \left(\frac{c_{jmck}^p + 2{*}c_{jmck}^m + c_{jmck}^o}{4} \right) z_{jmck} \tag{50}$$

st :

$$\sum_j \sum_m o_{jmck}\left(1-\ell_j\right) + \varphi_{ck} + \sum_j A_{jc}\left(1-\ell_j\right) \geq \left(\frac{\alpha}{2}\right)\left(\frac{D_{ck}^m + D_{ck}^o}{2}\right) + \left(1-\frac{\alpha}{2}\right)\left(\frac{D_{ck}^m + D_{ck}^p}{2}\right)\tilde{D}_{ck} \tag{51}$$

$$\sum_j \sum_m o_{jmck}\left(1-\ell_j\right) + \varphi_{ck} + \sum_j A_{jc}\left(1-\ell_j\right) \leq \left(1-\frac{\alpha}{2}\right)\left(\frac{D_{ck}^m + D_{ck}^o}{2}\right) + \left(\frac{\alpha}{2}\right)\left(\frac{D_{ck}^m + D_{ck}^p}{2}\right)\tilde{D}_{ck} \tag{52}$$

$$\sum_i \sum_c p_{ic} \sum_j oq_{icj} \leq \alpha(\frac{B^p + B^m}{2}) + (1-\alpha)(\frac{B^m + B^o}{2}) \tag{53}$$

4. 2. Step 2: Solution Approach to Solve Multi-Objective Models

Subsequent to the fuzzy method, we consider augmented ε-constrained method to solve multi-objective models and obtain efficient solutions. This method was first proposed by Mavrotas in 2009 [15] and can be summarized as follows:

Step 1: Create payoff table

Step 2: Calculate lower bound of the objective functions

Step 3: Determine boundaries of the k th objective function (r_k):

$$r_k = f_k^{\max} - f_k^{\min} \qquad k=2,\dots,p \tag{54}$$

Step 4: Divide the boundary of each objective function into g_k equal intervals and determine the value of e_k :

$$e_k = f_k^{\min} + \frac{r_k \times i_k}{g_k} \qquad i_k = 0,1,\ldots,g_k \tag{55}$$

Step 5: Convert multi-objective deterministic model into a single objective one.

Interested readers can refer to Mavrotas [15] for more details.

5. COMPUTATIONAL RESULTS

In this section, we provide a numerical example to validate our model. In this example, there are 4 relief items and 5 potential suppliers. The relief supply chain consists of 5 supply points, 3 distribution centers, and 4 affected areas. Table 1 shows the value of input parameters.

5. 1. Results of Construction Phase As stated, the construction phase is managed by the suppliers. In this phase, each supplier tries to offer the best tender to the purchaser in order to increase their chance. After obtaining the deterministic equivalent of the model, the upper and lower bounds of each objective function Z_1 and Z_2 are calculated by augmented ε-constrained method. Afterwards, objective function Z_1 is selected as the primary objective and Z_2 is added to the model constraints. Quantities, price, and lead time are main variables of the construction phase which are obtained by solving the single objective model with reliability level $\alpha = 0.5$ and are shown in Table 2.

5. 2. Results of Evaluation Phase In this section, the suggestions of suppliers are evaluated by the relief organization. Then, winner suppliers are determined and optimal orders are assigned.

Since disaster causes an emergency situation, the main objective function is to minimize lead time of relief items to affected areas (Z^4). As for the previous phase, first, a payoff table is created by lexicographic method; then, the boundaries of objective functions Z^3 and Z^5 are divided into 5 intervals. Table 3 presents the results of single objective bid evaluation model.

This table presents bid winners and optimal purchase from each of them. Due to multi-sourcing policy of the purchaser, there are several suppliers selected to provide a single item. For instance, inventory level of suppliers for item 1 is not enough and they are all selected to provide that item.

TABLE 1. The value of the parameters

Parameters	Values	Parameters	Values
I_{ic}	$\sim \text{Uniform}(500,2000)$	$\tilde{D}_{ck}$	$\sim \text{Uniform}(900,1200)$
π_{ic}	$\sim \text{Uniform}(20,30)$	$\tilde{B}$	$\sim \text{Uniform}(2\times10^6, 3\times10^6)$
cap_{jc}	$\sim \text{Uniform}(800,1000)$	$\tilde{c}_{jmck}$	$\sim \text{Uniform}(20,50)$
ρ_i ‘ ℓ_j ‘ α_{ic} ‘ β_{jc}	$\sim \text{Uniform}(0.1,0.3)$	$\tilde{t}_{jmck}$	$\sim \text{Uniform}(0.5,2)$
$\tilde{t}_{imcj}$	$\sim \text{Uniform}(0.5,2)$	g_i	$\sim \text{Uniform}(50,100)$
$\tilde{C}_{imcj}$	$\sim \text{Uniform}(10,40)$	γ_{ck}	$\sim \text{Uniform}(500,1000)$
$\tilde{u}_{ic}$	$\sim \text{Uniform}(25,110)$	A_{jc}	$\sim \text{Uniform}(200,500)$

TABLE 1. Proposed package of suppliers

	(quantity, price)				delivery time
	Item 1	Item 2	Item 3	Item 4	
Supplier 1	(492,42.8)	(1473,53.5)	(1479,64.2)	(442,48,2)	2.14
Supplier 2	(582, 37.5)	(1455,58.9)	(1468,69.6)	(486,53.5)	2.56
Supplier 3	(679,1076)	(1076,56.7)	(1479,71.7)	(587,46.08)	2.16
Supplier 4	(486,39.6)	(1153,61.09)	(1479,58.9)	(676,58.9)	1.7
Supplier 5	(572,53.5)	(1000,64.2)	(1383,72.8)	(779,60)	1.7

TABLE 3. Bid winners and purchase amounts

	Winners of action					Purchase amount		
	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Distribution Center 1	Distribution Center 2	Distribution Center 3
Item 1	✓	✓	✓	✓	✓	1659	572	582
Item 2	✓	✓	✓			508	1488	681
Item 3	✓	✓		✓		-	771	1324

Item 4	✓	✓	✓		✓	1031	368	486

Furthermore, suppliers 1 and 2 are the winners due to their better suggestions for all the items. Table 3, also, presents the amount of relief items purchased from bid winners; these items are pre-positioned to be shipped to affected areas.

Table 4 shows the amount of relief items shipped from every distribution centers to affected areas. For example, 968 means that item 4 is shipped to affected area 1 from distribution center 1. Moreover, due to the importance of time interval between distribution centers and affected areas, items are shipped to the nearest affected areas to accelerate the relief operations. For instance, in Table 4, distribution center 3 serves the nearest affected areas 3 and 4.

5. 3. Sensitivity Analysis This section conducts sensitivity analysis on disruption parameters and budget. In Figure 2, the result of change in disruption percentage on the proposed amount of each supplier is illustrated. As demonstrated, increase in disruption percentage decreases inventory levels at suppliers and, as a result, they propose lesser amounts. Furthermore, supplier 1 has the highest sensitivity to disruption percentage and supplier 4 has the lowest.

Figure 3 shows results of sensitivity of profit of the suppliers and total costs of relief organization with regard to budget. As purchasing power (budget) of the organization increases, each of the suppliers offer higher prices and, as a result, earn more profit. On the other hand, with more budget, the organization purchases more items which itself decreases shortage costs and, eventually, decreases total costs. Profit change for the suppliers and total cost of the organization with respect to budget are illustrated in Figure 3.

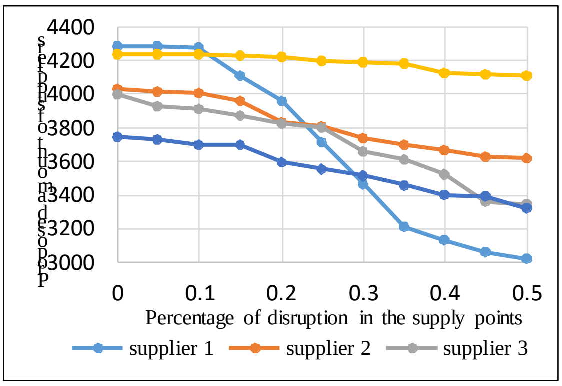

Figure 2. Result of disruption percentage on the proposed amount of suppliers

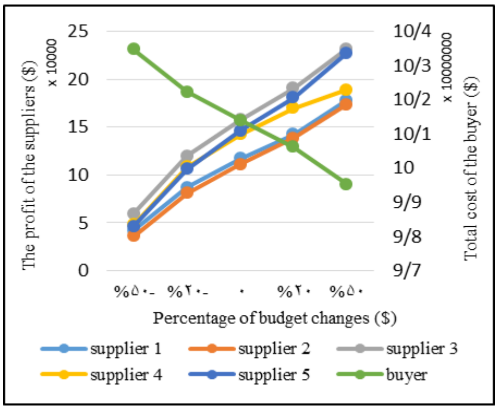

Figure 3. Impact of budget on supplier profit and total cost of the organization

6. CONCLUSION

In this paper, a bidding framework is presented for modeling the purchase of relief items. The main focus of the paper was to construct and evaluate the phases of a bid.

TABLE 2. Amount of items shipped from distribution centers to affected areas

	affected area 1 (item 1, item 2, item 3, item 4)	affected area 2 (item 1, item 2, item 3, item 4)	affected area 3 (item 1, item 2, item 3, item 4)	affected area 4 (item 1, item 2, item 3, item 4)
Distribution Center 1	(872,508, -,968)	-	-	(787,-, -,63)
Distribution Center 2	-	(572,871, 771,368)	(-,616,-,-)	-
Distribution Center 3	-	-	(582,256, 775,486)	(-,425, 550,-)

In particular, this paper dealt with determining bid winners and assigning orders in the process of procurement. In the bid construction phase, a bi-objective fuzzy model was formulated from the perspective of supplier. In this formulation, each supplier solved the model from its own perspective and offered the best suggestions based on its inventory level and required items of relief organization. Each suggestion contained the amount, price, and lead time of relief items to distribution centers. In the bid evaluation phase, bid winners were determined and optimal assignments were made. The objectives of this phase were to select the best suggestions, minimize lead time, and minimize total costs. Due to the uncertain nature of disasters, some parameters such as demand, budget, transportation cost, lead time, and price offered by rival suppliers were considered as non-deterministic. Furthermore, the paper considered disruption risk in distribution centers and suppliers due to the damaged post-disaster environment. Finally, we solved the proposed bidding framework by a numerical example and provided sensitivity analysis.

At the end, there are various recommendations for further research: 1) considering supplier discount in the bid construction phase; 2) implementing the proposed model on a real case study; and 3) adapting metaheuristic algorithms to solve large-scale problems.

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A Multi-attribute Reverse Auction Framework Under Uncertainty to the Procurement of Relief Items

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P A P E R I N F O

Paper history:
Received 30 March 2018
Received in revised form 20 May 2018
Accepted 18 June 2018

Keywords:
Humanitarian Relief Chain
Procurement
multi-attribute Reverse Auction
mathematical Modeling
Augmented ε-Constrained Method

چکیده

تأمین اقلام امدادی موردنیاز برای نجات جان افراد آسیب‌دیده از جمله اقدامات اصلی لجستیک امداد بشردوستانه است. در این مقاله، به منظور تسهیل عملیات خرید، انتخاب تأمین‌کنندگان و تخصیص بهینه اقلام امدادی چارچوبی مبتنی بر مناقصه ارائه شده است. ساختار مناقصه پیشنهادی شامل سه فاز؛ فراخوان، ساخت و ارزیابی مناقصه است. در فاز فراخوان، مناقصه‌گذار (خریدار یا سازمان امدادی) برای تأمین اقلام ضروری تأمین‌کنندگان مشخصی را به مناقصه دعوت می‌کند. در ادامه، فاز ساخت مناقصه از دیدگاه تأمین‌کنندگان (شرکت کنندگان در مناقصه) با استفاده از یک مدل ریاضی دو هدفه فازی فرموله شده است. در انتهای این فاز، حجم، قیمت و زمان تحویل اقلام امدادی به عنوان بسته‌های پیشنهادی در اختیار مناقصه‌گذار قرار داده می‌شود. سپس در فاز ارزیابی مناقصه، مناقصه‌گذار با کمک یک مدل ریاضی سه هدفه فازی، برنده/برندگان مناقصه و همچنین تخصیص بهینه سفارش را انجام می‌دهد. مدل‌های ریاضی فازی چند هدفه در هر یک از فازهای مقاله تحت عدم قطعیت پارامترهای ورودی ارائه شده و برای حل آن از یک رویکرد حل فازی دو مرحله‌ای

عددی ارائه و نتایج آن بررسی شده است.

استفاده شده است. در پایان، به جهت اعتبار سنجی و کاربردپذیری مدل پیشنهادی مثال

***doi**: 10.5829/ije.2018.31.12c.11*