A novel procurement model for humanitarian relief supply chains

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Abstract
Procurement is one of the most important elements of relief logistics affecting relief operations drastically. In this study, we propose a new multi-attribute reverse auction for relief procurement at post-disaster. This paper focuses on the bid evaluation phase for which a mixed integer nonlinear program (MINLP) model is developed. This paper proposes a novel multi-attribute combinatorial auction model for bid evaluation phase of relief items' procurement under the group-buying strategy. To illustrate the validity and applicability of the proposed model, a numerical example is provided. Also, useful managerial insights are obtained via conducting a number of sensitivity analyses.

Keywords: Procurement, Relief logistics, Multi-attribute reverse auction, Mixed integer nonlinear programming.

INTRODUCTION

The recent worldwide devastations have reemphasized the importance of relief supplies that must arrive on time and in adequate quantities for saving lives. Hence, the success of a relief operation depends on effective logistical planning. Humanitarian logistics is defined as the process of planning, implementing, and controlling the efficient, cost-effective flow and storage of goods and material, as well as related information from the point of origin to the point of consumption for the purpose of improving social welfare and alleviating the situation of vulnerable people. It includes a wide range of activities, which include disaster preparedness, planning, procurement, transportation, warehousing, tracking, tracing, and customs clearance.

The purpose of procurement process in the humanitarian supply chains is to ensure that each humanitarian organization (HO) has the essential material resources to meet disastrous situations. Various procurement decisions made by relief organizations can result in considerably different implications in regards to transport, storage and distribution of relief items. These factors ultimately can influence the performance of the humanitarian supply chain and the delivery of the relief items. Blecken and Hellingrath(2008), estimate that procurement activities account for 65 percent of the total expenditures in disaster relief logistics. Despite that significance, the

existing humanitarian relief logistics literature has focused primarily on problems of facility location (Ukkusuri and Yushimito, 2008; Balcik and Beamon, 2008), inventory management (Beamon and Kotleba, 2006a; Beamon and Kotleba, 2006b) and transportation (Haghani and Oh, 1996; Barbarosoglu et al.2002; Nolz et al.2010),but procurement area has received little attention. For these reasons, there is a strong need for designing appropriate procurement models to improve the performance of humanitarian relief operations.

One of the mostly applied methods to procure the required relief items by several humanitarian organizations is using reverse auctions. A procurement auction is a mechanism by which the buyer (i.e. the auctioneer) announces a bid for the supply of specific goods or services. The main idea for using auctions in the setting of disaster relief procurement is to utilize the inventory of available suppliers more efficiently for humanitarian aids. Because of this benefit and real-life applications of procurement auctions in disaster relief operations, a reverse auction-based model is developed in this study.

LITERATURE REVIEW

In this section, we review the literature in two separate but relevant research streams.

Procurement Auctions in Humanitarian Setting

As mentioned earlier, despite the importance of procurement in disaster relief, surprisingly it has a very limited literature in this field. Procurement auction-based models include bid construction and bid evaluation phases that are managed by the suppliers (bidders) and buyer (auctioneer) respectively. To date there is a limited amount of research in the literature that concentrates on the buyer's perspective and focuses on the bid evaluation phase. Hence, this study specifically focuses on the bid evaluation phase for procurement auctions within the context of disaster relief operations.

Trestrail et al. (2009) analyzed the procurement process from the bidder's perspective and developed a two stage mixed-integer programming model that approximates US Department of Agriculture (USDA) bidding approaches. They reported that this model can improve bid pricing strategies, carrier selection, and optimize total cost. Bagchi et al. (2011) proposed an auction mechanism to improve bid process of USDA for procuring food supplies and transportation services in humanitarian food aid. Ertem et al. (2012) considered an auction-based framework which includes the announcement construction, bid construction and bid evaluation phases. Two mathematical models are applied to determine suppliers in a framework where multiple auctioneers and multiple bidders exist. In similar work, Ertem and Buyurgan (2011) developed an auction-based procurement framework with considering multiple bidders and one auctioneer as a coordinating platform that accumulates demands from humanitarian organizations. Ertem et al. (2012) presented an analysis of the bid construction phase of procurement auctions in disaster relief and humanitarian logistics with considering substitution and partial fulfillment options. They used a genetic algorithm, simulated annealing algorithm and an integer program for the analysis of the bid construction phase with different announcement options.

Procurement Auctions in Commercial Setting

Despite the limited literature about the design of procurement contracts and auctions in the field of humanitarian logistics, there is a rich literature that addresses procurement auctions in

commercial logistics (Iftekhar et al. 2013; Buer and Kopfer, 2014; Hsieh2010; Hsieh and Lin, 2012).Different procurement auction-based models have been used successfully in commercial logistics that could be helpful for the humanitarian supply chains as well. In this regard, multi-attribute reverse auctions, which are frequently used in commercial logistics, have rarely been used in the relief setting.

With regards to the number of considered attributes, a reverse auction is often classified as single attribute and multi attribute. In single attribute reverse auctions bidding competition is restricted to price dimension alone. While, multi-attribute reverse auctions enable negotiation on price and non-price attributes such as quality, reliability, existing supplier relationships and delivery lead time that reduce the risk of getting low quality products at lower prices. Although this type of reverse auctions is more complicated than traditional reverse auctions, but many studies (Cheng 2008; David et al. 2006; Bichler 2000; Chen-Ritzo et al. 2005) show that the multi-attribute auctions generate more utility for the buyer than price-only auctions. In the humanitarian relief environments, multiple attributes such as quality, lead time, contract terms, supplier reputation and price are important factors. Then, multi attribute reverse auction mechanism is proved to be very effective in addressing this challenge efficiently.

To the best of our knowledge, there is no research work in the humanitarian logistics literature proposing a multi-attribute reverse auction for relief procurement purposes. Hence, in this study, inspired by the procurement auctions in the commercial setting, a multi-attribute reverse auction procurement framework based is proposed for humanitarian supply chains.

PROBLEM DESCRIPTION

Procurement in humanitarian logistics can be done in before or after disaster. Procurement at pre-disaster is necessary for prepositioning relief supplies in strategic locations near disaster-prone areas. The beneficiaries are supplied from pre-positioned inventory during the initial days after the disaster. Therefore, having those supplies ready to dispatch is of critical importance. Nevertheless, only a small percentage of the total relief supply is sourced from the pre-positioned inventory (Balcik and Beamon, 2008). When a disaster occurs, a relief organization is interested in procuring a relief item in large amounts and it is not economical to pre-position large amounts of inventory for this item. Thus pre-positioned inventories are usually insufficient in many disaster relief operations. Also, post-disaster procurement is necessary because disasters are unpredictable in nature (Balcik et al. 2010). The location, timing and severity of a disaster are unknown, hence the relief organization prefers making procurement decisions after a disaster occurs. In this study, a multi-attribute reverse auction mechanism is addressed to purchase required relief items at the post-disaster. It is worth noting that in addition to using pre-positioned inventories and post-disaster procurement auctions, part of relief items' demands can be satisfied via special supply contracts set by some suppliers at pre-disaster and in-kind donations. In the supply contracts, large humanitarian organizations establish long-term agreements with suppliers to supply certain amount of relief goods on demand. Also, the amounts of in-kind donations as another supply source are unpredictable and tend to proliferate after the disaster strikes and needs to be sorted, prioritized, and stored. Since, the suppliers might become unavailable after the disaster occurs, the utilization of all available resources is necessary; hence, we consider these different supply sources in our proposed model.

At below, we give more explanation for the main features, assumptions and formulation of our proposed model.

Bid Structure

A procurement auction is a mechanism that outlines procedures to establish procurement of items based on bids submitted by bidders. Two parties are defined for a specific auction: auctioneer and bidder. The procurement auction considered in this study includes a number of bidders (i.e. suppliers of relief goods) and one coordinating center as the auctioneer that consolidates all the buyers' (i.e. humanitarian organizations') requirements and announces one multi-attribute reverse auction for all the buyers. In this regard, five bid attributes are considered in our analysis which includes: price, quality, delivery time, quantity and probability of on time delivery. The importance degrees of attributes with respect to each relief item or service needed is considered in the bid evaluating phase. At the beginning of the auction, the auctioneer announces the basic requirements and the scoring rules for the procurement goods to all suppliers. The bidders receive the announcement and submit a multi-attribute bid consisting of price and non-price attributes according to their on-hand inventory.

The bid vector of the i–th supplier is in the form of $\{(p_{i1}, l_{i1}, q_{i1}),(p_{i2}, l_{i2}, q_{i2}),\ldots,(p_{iJ}, l_{iJ}, q_{iJ}),(x_{i1}),(x_{i2}),\ldots(x_{iZ})\}$, where p_{ij}, l_{ij} and q_{ij} denote the price, delivery time and quantity of relief items in the j-th bid submitted by bidder i. In addition, we note that the lots and bid price are specified in ascending order, i.e. $q_{i1} < q_{i2} < \ldots < q_{iJ}$ and $p_{i1} < p_{i2} < \ldots < p_{iJ}$. The value of z–th attribute $(z=1,\ldots,Z)$ of each bid placed by bidder i such as probability of on time delivery and quality is denoted as x_{iz}.

Scoring Rule

In order to determine the winner in a multi attribute auction, a scoring function is used by the auctioneer as the bid evaluation tool to maximize the expected utility. Scoring functions simply need to use a weight vector to aggregate multiple attributes to a single composite score. Technically, a scoring function is simply an additive linear utility function over the different attributes (Pham et al. 2015).Using the scoring function; the auctioneer declares a scoring rule for the evaluation of the received bids. In this way, the auctioneer computes the scores for all the bidders and selects the one with the highest score during the winner determination process.

We define the scoring function (s_{ij}) as:

$$s_{ij} = p_{ij} + l_{ij} - q_{ij} \sum_{z=1}^{Z} w_z(x_{iz}) \quad (1)$$

Where w_z is the weight associated with z-th attribute. Therefore, minimizing the scoring function is equivalent to minimizing delivery time and price (as negative attributes whose less values are more favorable) and maximizing the values of other attributes (as positive attributes whose more values are more favorable). This selection process is analogous to price-only reverse auction where the buyer selects a supplier with the lowest price. We can interpret this as a process of making a tradeoff between delivery time, price and other attributes.

The following assumptions are made for the problem formulation:

- Humanitarian relief organizations meet demands from various sources such as pre-positioned supplies, in-kind donations and pre-specified agreements with suppliers and procured supplies at post-disaster.

- Humanitarian organizations receive relief supplies donations within one or two days of the onset of the disaster (in the second stage).
- All relief supplies can be pre-positioned in storage facilities.
- Part of prepositioned inventory may be destroyed by the disaster.
- The normal capacity of suppliers may be partially disrupted by the disaster.

Model Formulation

The indices, parameters and variables used to formulate the problem mathematically are described below.

Indices and sets:

i	Set of suppliers (bidders), indexed by $i \in I$
s	Set of suppliers(bidders) with pre-specified agreements, indexed by $s \in S$
j	Set of bids, indexed by $j \in J$

Parameters:

π	Shortage cost (cost of unmet demand)
π'	Delay cost
h	Holding cost
sI	Shortage quantity
I	Prepositioned inventory level
α	Proportion of preposition inventory that is destroyed by the disaster
q_s	Promised quantity by supplier s to be delivered at post-disaster according to pre-specified agreement
p_s	The percentage of stocked material at supplier s that remains usable in disaster
D	Total demand
dd	Due date
bu	Available budget
d	In-kind donation of item k
s_{ij}	Score of the i-th supplier from j-th bid

Decision variables:

y_{ij}	1 if j-th bid of supplier i is selected, 0 otherwise
II	Final inventory

In terms of the above notation, the mixed integer nonlinear programming model can be formulated as follows:

$$\min Z = \sum_{i=1}^{I}\sum_{j=1}^{J}(s_{ij}.y_{ij}) + h.II + s1.\pi + \sum_{i=1}^{I}\sum_{j=1}^{J}\pi'_k.q_{ij}.max(0, y_{ij}.l_{ij} - dd) \quad (2)$$

Based on the aforementioned problem description, the objective is to select bids so that the objective function (2) is minimized. The objective function minimizes the three parts. In the first part, suppliers with the lowest score are selected. Part2consist of holding and shortage cost of relief items. Parts3 include the delay cost of relief items.

$$\sum_{i=1}^{I}\sum_{j=1}^{J} q_{ij}.y_{ij} + (1-\alpha).I + (\sum_{s=1}^{S} p_s.q_s) - II + s1 = D \quad (3)$$

Incoming goods and services into the relief supply chain through different sources, such as pre-specified agreements between suppliers and buyer, in-kind donations, prepositioned inventory and post-disaster procurements, that these different form and sources of relief items is considered in constraint (3).This constraint ensures the total quantity of relief items must be greater than or equal to the desired quantity of the buyer.

$$\sum_{i=1}^{I}\sum_{j=1}^{J} y_{ij}.p_{ij} \leq bu \quad (4)$$

Constraints (4) make certain that total procurement costs do not exceed the level of available budget.

$$\sum_{j=1}^{J} y_{ij} \leq 1 \qquad \forall i \quad (5)$$

The selection of exactly one bid per supplier is specified by the constraint (5).

$$y_{ij} \in \{0,1\} \forall i,j \quad (6)$$

$$s1, II \geq 0 \quad (7)$$

Finally, constraints (6) and (7) enforce the binary and non-negativity restrictions on corresponding decision variables**.**

CONCLUSION

During the last decade, research on humanitarian relief logistics has received an increasing attention but despite the scale and importance of procurement in humanitarian supply chains, there are few studies that address this topic. Bid construction and bid evaluation are the two major phases in a typical procurement auctions. This research proposes a multi-attribute reverse auction mechanism to purchase required relief items after a disaster strikes. Five bid attributes are considered in our analysis: price, quality, delivery time, quantity and probability of on time delivery.

To the best of our knowledge, the literature of procurement auctions in humanitarian supply chain is still in its infancy and this paper is one of the primary works applying a multi-attribute reverse auction model for humanitarian supply chains. There are several research directions for further research in this area. Among them, incorporating data uncertainties (about the level of donations and demand for relief items, etc.) in the model can be considered as a suitable one.

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