POMS PRODUCTION AND OPERATIONS MANAGEMENT

PRODUCTION AND OPERATIONS MANAGEMENT POMS

Vol. 23, No. 6, June 2014, pp. 1028–1041
ISSN 1059-1478 | EISSN 1937-5956 | 14 | 2306 | 1028

DOI 10.1111/poms.12098

Supplier Selection for Framework Agreements in Humanitarian Relief

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In this study, we consider the supplier selection problem of a relief organization that wants to establish framework agreements (FAs) with a number of suppliers to ensure quick and cost-effective procurement of relief supplies in responding to sudden-onset disasters. Motivated by the FAs in relief practice, we focus on a quantity flexibility contract in which the relief organization commits to purchase a minimum total quantity from each framework supplier over a fixed agreement horizon, and, in return, the suppliers reserve capacity for the organization and promise to deliver items according to pre-specified agreement terms. Due to the uncertainties in demand locations and amounts, it may be challenging for relief organizations to assess candidate suppliers and the offered agreement terms. We use a scenario-based approach to represent demand uncertainty and develop a stochastic programming model that selects framework suppliers to minimize expected procurement and agreement costs while meeting service requirements. We perform numerical experiments to understand the implications of agreement terms in different settings. The results show that supplier selection decisions and costs are generally more sensitive to the changes in agreement terms in settings with high-impact disasters. Finally, we illustrate the applicability of our model on a case study.

Key words: supplier selection; framework agreements; humanitarian relief; procurement; stochastic programming
History: Received: February 2012; Accepted: March 2013 by Luk Van Wassenhove and Martin Starr, after 2 revisions.

1. Introduction

In the aftermath of natural disasters, large amounts of demand occur for a variety of relief supplies (such as water, food, and tents). Humanitarian relief organizations meet these demands from various sources such as pre-positioned supplies, in-kind donations, and procured supplies. Post-disaster procurement is the most common sourcing method in humanitarian relief; the majority of relief supplies are purchased from global and local suppliers after a disaster occurs. Despite the scale and importance of procurement in humanitarian supply chains, there are few studies that address procurement issues and decisions in the relief literature.

There may be various challenges associated with meeting the demands quickly and efficiently through post-disaster procurement. As the timing, location, and impact of disasters are highly unpredictable and each disaster may create special requirements, procurement is not a routine process for relief organizations. For instance, depending on the location and timing of the disaster, relief supplies may not be available in sufficient amounts at local/global markets for immediate purchase and quick delivery. Moreover, there is usually competition among relief organizations for purchasing certain types of supplies after a disaster, which may create shortages in the market. Furthermore, the sudden increase in demand may significantly inflate prices. Finally, post-disaster procurement can be a very time-consuming process when most organizations use a competitive bidding procedure in which the entire procurement process (i.e., generating and announcing appeals, waiting for supplier bids, evaluating bids; see Ertem et al. 2010) takes place after a disaster occurs. Therefore, to streamline the procurement process and guarantee the availability, quick delivery, and cost-effective procurement of critical relief items after a disaster, relief organizations are increasingly establishing close relationships with suppliers and making contractual agreements in the disaster preparedness stage. This study focuses on such supply contracts, which are generally called *"framework agreements" (FAs)* or *"long-term agreements" (LTAs)* in relief practice.

In FAs, suppliers reserve inventory for the relief organization and promise to deliver supplies according to pre-specified terms (such as prices, packaging, etc.) once an order is made. After a disaster occurs, the relief organization decides whether to use an existing agreement and give an order. Depending on post-disaster conditions and needs, the orders may be delivered directly to the affected area or other logistical points (e.g., depots, transshipment areas). FAs can be considered as a variant of stock pre-positioning; indeed, the stocks secured from suppliers under FAs are called "virtual stocks" (Schulz 2009). In pre-positioning, relief organizations keep physical inventory at strategic locations to deal with demand uncertainty and accelerate disaster response; however, warehousing and inventory costs can be very high (Balcik and Beamon 2008). FAs allow relief organizations to reserve critical supplies and equipment which may not be economically pre-positioned in warehouses in large amounts. The main benefit of FAs to the suppliers is confirmed business over a particular period of time.

The benefits of establishing long-term relationships with suppliers via FAs are increasingly highlighted in research and practice. Many relief organizations use FAs systematically for procurement of relief supplies. For example, the International Federation of Red Cross and Red Crescent Societies (IFRC) introduced the practice of establishing FAs with suppliers of basic relief items in 2001 (International Federation of Red Cross and Red Crescent Societies (IFRC) 2012, A. Petrosyan, International Federation of Red Cross and Red Crescent Societies, pers. comm.). According to these agreements, suppliers agree to supply a certain commodity at a certain price for a particular period of time (usually for two years). Armen Petrosyan, the Procurement Unit Manager of the Global Logistics Service at the IFRC, notes "having pre-established FAs in place enables us to secure the right price, guaranteed quality and quantity and agreed delivery terms for emergency supplies. This is a mutually beneficial arrangement between our organization and suppliers leading to reliable business relationship and drastically facilitating direct purchases. IFRC managed to achieve 28% increase in response capacity, 13% decrease in delivery delays and 7–14% cost reduction on the relief supplies procured from FAs" (A. Petrosyan, International Federation of Red Cross and Red Crescent Societies, pers. comm.).

The procedure followed in establishing FAs may depend on the context (e.g., organization, item, etc.). For instance, World Vision International (WVI) first determines the specifications for the items to be purchased via FAs and forecasts the needs for the agreement period (G. Fenton, World Vision International, pers. comm.). Then the organization announces its interest internationally. Based on the proposals of suppliers, the WVI makes a shortlist and may further negotiate with the suppliers on the agreement terms. Finally, the organization selects suppliers and agreements are signed. In this study, we focus on the supplier selection phase of this process, which is very critical to the success of the FAs. Armen Petrosyan states that "the thorough process prior to any FA establishment allows us (i.e., the IFRC) to make a solid consideration about the supplier selection based on key factors such as knowledge of international trade, previous record of service and performance, production capacity, competitive price and stock availability. This win–win proposition leads to maximum benefits for people we aim to assist" (A. Petrosyan, International Federation of Red Cross and Red Crescent Societies, pers. comm.). Humanitarian organizations use similar criteria in evaluating and selecting suppliers to agreements; particularly, quality, price, and supplier's ability to meet lead time and demand fulfillment requirements are important factors (Logistics Cluster 2011). Our model incorporates these critical factors; specifically, given a set of candidate suppliers which qualify for quality and delivery terms, we minimize procurement costs in selecting suppliers to FAs.

Despite their benefits, establishing FAs and selecting suppliers can be challenging for relief organizations due to the complexities and uncertainties in humanitarian supply chains (Balcik et al. 2010). In particular, relief organizations may be reluctant to make binding pre-purchasing commitments in a highly unpredictable environment. Given the uncertainties in disaster demands (in timing, location, amount, and type), there may be cases in which the agreements are not activated and the costs for not using the products attached to agreements may be high. Therefore, it is critical for relief organizations to carefully assess the implications of the agreement terms offered by candidate suppliers.

In this study, we address supplier selection decisions of relief organizations in establishing FAs under demand uncertainty and develop a mathematical model that captures the important aspects of the FAs and supplier selection decisions in the real world. Specifically, we consider a relief organization that is interested in establishing FAs with a number of suppliers for procurement of a single relief item. Accordingly, the relief organization commits to purchase a cumulative amount of supplies from each supplier over a fixed agreement horizon and may place an order when a disaster occurs over this period. In return, each supplier commits to reserve inventory for the relief organization, offers a fixed pricing schedule, and delivers supplies within requested lead times. As each candidate supplier may have different characteristics (i.e., reserve capacities, geographical coverage, commitment requirements, and pricing schedules), supplier selection decisions may significantly affect important performance metrics in disaster response such as the sufficiency and quickness of deliveries and costs.

Although there is a rich literature that addresses supply contracts and supplier selection problems in the commercial context, these topics have not received much attention in humanitarian logistics. In this study, we take a first step in defining and modeling a supplier selection problem for FAs in the relief context. Motivated by the FAs applied in practice, we focus on a type of quantity flexibility contract between a relief organization and suppliers. Considering the supplier selection criteria that are important for relief organizations, we define a supplier selection problem which determines the set of framework suppliers to minimize total expected agreement and procurement costs over an agreement horizon while satisfying quantity- and lead time-based service requirements in meeting demands. We represent demand uncertainty by a set of disaster scenarios and develop a stochastic programming model for the problem. We perform numerical experiments to develop insights about the effects of agreement terms on supplier selection decisions and illustrate our model on a case study.

In section 2, we review the relevant literature. In section 3, we introduce the problem and present the mathematical model. In section 4, we perform numerical experiments. In section 5, we present a case study. Finally, we discuss future research directions in section 6 and conclude in section 7.

2. Literature Review

Despite the importance of procurement in humanitarian logistics, the related literature is scarce. There are several practitioner resources that describe relief procurement practices (e.g., Logistics Cluster 2011, Procurement Practice Group 2010). Also, several studies focus on the competitive bidding process and develop models (e.g., Bagchi et al. 2011, Ertem et al. 2010, Trestail et al. 2009). To the best of our knowledge, there is no study that addresses FAs and presents models for supplier selection decisions in the relief literature.

Unlike in humanitarian relief, there is a rich literature that addresses procurement decisions in business supply chains. Our study is particularly related to the literature that develops *supplier selection* models under demand uncertainty (e.g., Hazra and Mahadevan 2009, Li and Zabinsky 2011, Liao and Rittsche 2011, Zhang and Ma 2009). Various criteria are used for selecting suppliers in commercial supply chains. In particular, price, delivery times, and quality are among the most important factors (Aissaoui et al. 2007). Although there are some studies that investigate supplier selection criteria for humanitarian organizations (e.g., Pazirandeh 2011, Shahadat 2003), there is no study that particularly explores the criteria used in selecting suppliers for FAs. In our supplier selection problem, we consider the main criteria discussed in practitioner resources (e.g., IFRC 2012, Logistics Cluster 2011), which are quantity- and lead time-based service requirements and procurement costs.

Our problem differs from those in the existing supplier selection literature in several aspects. First, the nature of demand uncertainty is different in the relief context. Specifically, the demand pattern is quite irregular and lumpy, and the timing, location, and amount of demands are highly unpredictable; hence, it is difficult to represent demand by using specific closed-form probability distributions. In this study, we characterize demand uncertainty by using scenarios that do not have to be set according to a specific probability distribution and use stochastic programming as the modeling approach. There are only a few studies in the literature that use stochastic programming models for supplier selection problems. Moreover, the existing supplier selection problems either do not consider any contractual setting or they focus on contracts which may not directly apply to relief environment. Finally, only a few studies that address supplier selection decisions under demand uncertainty consider quantity-based price discounts (e.g., Li and Zabinsky 2011, Zhang and Ma 2009). The price discount schedule in this study is additionally affected by the lead time requirements and shipment destinations.

In summary, this study contributes to the literature by addressing FAs and supplier selection decisions for relief procurement. We consider the important criteria for selecting suppliers in relief and define a new problem for supplier selection in FA design. We develop a mathematical model for supporting relief organizations to create an effective portfolio of suppliers and FAs. We perform numerical experiments to develop insights and present a case study.

3. Problem and Model

We describe the problem in section 3.1 and present the mathematical model in section 3.2.

3.1. Problem Description

A relief organization is interested in procuring a relief item which is urgently needed in large amounts when a disaster occurs. As it is not economical to pre-position large amounts of inventory for this item, the demand will be mostly met from post-disaster procurement. On one hand, given the uncertainties in disaster occurrences, the relief organization prefers making procurement decisions after a disaster occurs.

On the other hand, it may be difficult to acquire supplies quickly and efficiently if the entire procurement process is postponed to the post-disaster stage. Hence, the relief organization wants to develop FAs with a number of suppliers before disaster occurrences to meet relief demands over a planning horizon. Our objective is to support the supplier selection decisions of the relief organization for establishing FAs in the pre-disaster stage to guarantee availability, efficient procurement, and quick delivery of supplies in responding to sudden-onset disasters (such as earthquakes).

We consider a type of FA that is practiced by relief organizations in reality to procure supplies in responding to sudden-onset disasters. According to the agreement, the relief organization commits to purchase from each framework supplier a pre-specified minimum total quantity during a fixed agreement horizon (e.g., one or two years), during which multiple disaster events may occur. Each time a disaster event occurs, the relief organization decides whether to execute the existing agreement with a framework supplier and place an order. The amount of each order is limited by the supplier's reserve capacity. According to the agreement, the supplier agrees to provide supplies at a fixed pricing schedule and meet delivery requirements. If the relief organization purchases under the minimum total commitment quantity by the end of the agreement horizon, a penalty cost is incurred for the underage quantity. In addition, a fixed agreement fee is paid to the supplier as a representative of the commitment; the fixed agreement fee may also represent other costs associated with managing an agreement (e.g., overhead and coordination costs).

We consider a set of candidate suppliers, each of which can provide the relief item in the desired quality specifications. Each supplier may have different characteristics and offer different agreement terms. Specifically, suppliers may differ in terms of their

- *commitment requirements*: minimum total purchase quantity over the agreement term;
- *reserve capacities*: maximum quantity to purchase from the supplier in each order;
- *pricing schedules*: unit commodity prices, discount rates, and agreement fees; and
- *geographical coverage*: lead times and prices for delivering supplies to different regions.

We assume that each supplier ships the orders directly to the affected regions, and the unit commodity price offered by each supplier includes unit purchasing and transportation costs. Each supplier applies a pricing schedule based on an all-units discount scheme, thereby encouraging the relief organization to buy more (and place an order close to the supplier reserve capacity). Furthermore, the pricing schedule depends on the shipment destinations and requested lead times. A single order from a supplier can be divided into smaller orders, each with different lead time requirements. For each demand region, a pricing schedule is characterized by assigning a unit price for each quantity and lead time interval. For instance, a pricing schedule with two quantity intervals and two lead time intervals can be defined by specifying three quantity breakpoints (q_0, q_1, and q_2) and three lead time breakpoints (τ_0, τ_1, and τ_2). Consequently, the unit price $u(Q,LT)$ for delivering Q units to a particular region within lead time LT is as follows:

$$u(Q,LT) = \begin{cases} u_0 & \text{if } q_0 \le Q < q_1 \text{ and } \tau_0 \le LT < \tau_1 \\ u_1 & \text{if } q_1 \le Q < q_2 \text{ and } \tau_0 \le LT < \tau_1 \\ u_2 & \text{if } q_0 \le Q < q_1 \text{ and } \tau_1 \le LT < \tau_2 \\ u_3 & \text{if } q_1 \le Q < q_2 \text{ and } \tau_1 \le LT < \tau_2. \end{cases}$$

The unit price decreases with increased order amounts and lead times. Hence, it is expected that $u_0 \ge u_1$, $u_0 \ge u_2$, $u_1 \ge u_3$, and $u_2 \ge u_3$. The relation between u_1 and u_2 depends on the relative magnitudes of discount rates for quantity and lead time intervals.

Given a set of candidate suppliers, the supplier selection decisions are made at the beginning of the agreement horizon. The agreement terms (i.e., reserve capacities, commitment requirements, and pricing schedules) are associated with supplier selection decisions and hence set once the suppliers are selected. Multiple disaster events may occur at different times over the agreement horizon. The locations of disaster events and the amount of demand that occurs as a result of each disaster event are uncertain. We characterize the uncertainty in disaster demands by defining a set of probabilistic scenarios. A scenario represents the amount of demand at each region due to disaster events occurring during the agreement horizon. In this study, we assume that the decision maker considers the possible disaster events in the agreement horizon in an aggregate way; that is, the sequence of disaster events is ignored. We make this assumption because it is quite challenging (if not impossible) to predict the timing of sudden-onset disasters, let alone their order of occurrence within a particular period.

In selecting suppliers, the relief organization specifies a minimum and maximum number of framework suppliers to work with. On one hand, the relief organization may want to limit the number of suppliers, as it may be difficult to manage agreements with a large supplier base; on the other hand, setting a lower bound on the number of framework suppliers may also be desirable. In supply chain contracts, there is usually no need for setting a lower bound on the number of suppliers; indeed, a company might prefer working with a single cost-optimizing supplier where possible. However, relief organizations may intentionally avoid working with a single supplier for reasons other than cost. For example, providing business opportunities to different suppliers from developing countries may be an important concern. Moreover, due to its non-profit nature, being associated with a single commercial entity might not be desirable for the relief organization. Finally, the relief organization may want to avoid dependency on a single supplier for reducing the risks associated with supplier's failure in meeting the agreement terms. If the relief organization does not have such concerns for bounding the number of suppliers, the associated constraints can be relaxed in the model.

Our supplier selection problem considers the supplier selection criteria that the relief organizations use in establishing FAs in practice. Specifically, procuring supplies in the desired quality and quantity and ensuring low response times and prices are important (IFRC 2012, Logistics Cluster 2011, A. Petrosyan, International Federation of Red Cross and Red Crescent Societies, pers. comm.), and are captured by our formulation. Also, similar to real-world practices, our model selects suppliers to minimize the total procurement costs over the agreement horizon while ensuring the satisfaction of quantity- and lead time-based service requirements for each disaster scenario. We assume that the candidate suppliers already meet quality expectations. Note that it is possible to develop an alternative model with a service-based objective function and budget constraints. However, given that a relief organizations establish FAs for many items, it may be difficult to determine the budget to allocate for the procurement of each relief item for each disaster scenario *a priori*. Therefore, incorporating service requirements through the constraints may be more practical. This would, in addition, allow the relief organization to specify different service targets for different regions easily. For instance, if a region does not have access to other supply sources (such as pre-positioned supplies, local supplies, etc.), the agreements can be established so that a larger fraction of demand is guaranteed from the framework suppliers for that region.

3.2. Mathematical Model

We develop a scenario-based stochastic programming model for the supplier selection problem. Accordingly, the relief organization selects framework suppliers and thereby sets the agreement terms with each supplier at the beginning of the agreement horizon (at the first stage) and orders supplies from the selected suppliers each time a disaster event occurs in the agreement horizon. As multiple disaster events may occur at different times over the agreement horizon, the uncertainty is actually resolved over the course of events. However, as explained before, we consider a simplified setting that ignores the sequence of disaster events and considers all possible events that might occur within the agreement horizon in an aggregate way. Therefore, we ignore the time dimension and assume that all uncertainty is resolved at once. In this way, we represent our problem as a two-stage problem and use a two-stage modeling framework.

We also assume that a particular region may be affected by a disaster event over the agreement term at most once. Although the model can easily accommodate the setting in which multiple disasters may occur in the same region during the agreement term, we make this assumption for simplifying the model representation, more specifically, for avoiding the introduction of an additional index to specify each disaster event.

The following notation is used to model the supplier selection problem for FAs:

Sets

$\mathcal{R}$: set of demand regions; $r \in \mathcal{R}$
$\mathcal{N}$: set of candidate suppliers; $i \in \mathcal{N}$
$\mathcal{L}$: set of delivery lead time intervals; $l \in \mathcal{L}$
$\mathcal{M}_i$: set of quantity intervals offered by supplier $i \in \mathcal{N}$; $m \in \mathcal{M}_i$
$\mathcal{S}$: set of scenarios; $s \in \mathcal{S}$

Parameters

p^s: probability of scenario $s \in \mathcal{S}$
d_r^s: demand for supplies at region $r \in \mathcal{R}$ in scenario $s \in \mathcal{S}$
z_{lr}^s: fraction of total demand to meet from framework suppliers in lead time interval $l \in \mathcal{L}$ for region $r \in \mathcal{R}$ in scenario $s \in \mathcal{S}$
u_{ilmr}^s: unit price offered by supplier $i \in \mathcal{N}$ for delivering the supplies purchased at quantity interval $m \in \mathcal{M}_i$ to region $r \in \mathcal{R}$ within lead time interval $l \in \mathcal{L}$ in scenario $s \in \mathcal{S}$
$[\alpha_{ilmr}^s, \beta_{ilmr}^s]$: lower and upper quantity breakpoints associated with quantity interval $m \in \mathcal{M}_i$ offered by supplier $i \in \mathcal{N}$ for serving region $r \in \mathcal{R}$ within lead time interval $l \in \mathcal{L}$ in scenario $s \in \mathcal{S}$
v_i^{min}: minimum total commitment quantity of supplier $i \in \mathcal{N}$
v_i^{max}: reserve capacity (i.e., maximum order quantity) for supplier $i \in \mathcal{N}$
δ_i: unit penalty cost for underage quantity for supplier $i \in \mathcal{N}$
f_i: fixed agreement fee for supplier $i \in \mathcal{N}$
η_{min}: minimum number of suppliers to select to the FAs
η_{max}: maximum number of suppliers to select to the FAs

First-stage decision variables

$Y_i = 1$, if supplier $i \in \mathcal{N}$ is selected to the agreement; 0, otherwise

Second-stage decision variables

X^s_{ilmr}= 1, if the agreement with supplier $i \in \mathcal{N}$ is executed by purchasing supplies at quantity interval $m \in \mathcal{M}_i$ to serve region $r \in \mathcal{R}$ within lead time interval $l \in \mathcal{L}$ in scenario $s \in \mathcal{S}$; 0, otherwise

Q^s_{ilmr}: amount of supplies purchased from supplier $i \in \mathcal{N}$ at quantity interval $m \in \mathcal{M}_i$ to serve region $r \in \mathcal{R}$ within lead time interval $l \in \mathcal{L}$ in scenario $s \in \mathcal{S}$

W^s_i: auxiliary variable for defining the underage quantity for supplier $i \in \mathcal{N}$ in scenario $s \in \mathcal{S}$

The formulation for the problem is presented below:

$$\min \sum_{i\in\mathcal{N}} f_i Y_i + \sum_{s\in\mathcal{S}} p_s \left[\sum_{i\in\mathcal{N}} \delta_i W^s_i + \sum_{i\in\mathcal{N}} \sum_{l\in\mathcal{L}} \sum_{m\in\mathcal{M}_i} \sum_{r\in\mathcal{R}} u^s_{ilmr} Q^s_{ilmr} \right], \quad (1a)$$

subject to

$$\sum_{i\in\mathcal{N}} Y_i \geq \eta_{min}, \quad (1b)$$

$$\sum_{i\in\mathcal{N}} Y_i \leq \eta_{max}, \quad (1c)$$

$$\sum_{l\in\mathcal{L}} \sum_{m\in\mathcal{M}_i} Q^s_{ilmr} \leq v^{max}_i Y_i \quad \forall i \in \mathcal{N}, r \in \mathcal{R}, s \in \mathcal{S}, \quad (1d)$$

$$\sum_{i\in\mathcal{N}} \sum_{m\in\mathcal{M}_i} Q^s_{ilmr} \geq z^s_{lr} d^s_r \quad \forall l \in \mathcal{L}, r \in \mathcal{R}, s \in \mathcal{S}, \quad (1e)$$

$$\sum_{m\in\mathcal{M}_i} X^s_{ilmr} \leq Y_i \quad \forall i \in \mathcal{N}, l \in \mathcal{L}, r \in \mathcal{R}, s \in \mathcal{S}, \quad (1f)$$

$$Q^s_{ilmr} \geq X^s_{ilmr} \alpha^s_{ilmr} \quad \forall i \in \mathcal{N}, l \in \mathcal{L}, m \in \mathcal{M}_i, r \in \mathcal{R}, s \in \mathcal{S}, \quad (1g)$$

$$Q^s_{ilmr} \leq X^s_{ilmr} \beta^s_{ilmr} \quad \forall i \in \mathcal{N}, l \in \mathcal{L}, m \in \mathcal{M}_i, r \in \mathcal{R}, s \in \mathcal{S}, \quad (1h)$$

$$W^s_i \geq v^{min}_i Y_i - \sum_{l\in\mathcal{L}} \sum_{m\in\mathcal{M}_i} \sum_{r\in\mathcal{R}} Q^s_{ilmr} \quad \forall i \in \mathcal{N}, s \in \mathcal{S}, \quad (1i)$$

$$W^s_i \geq 0 \quad \forall i \in \mathcal{N}, s \in \mathcal{S}, \quad (1j)$$

$$Q^s_{ilmr} \geq 0 \quad \forall i \in \mathcal{N}, l \in \mathcal{L}, m \in \mathcal{M}_i, r \in \mathcal{R}, s \in \mathcal{S}, \quad (1k)$$

$$X^s_{ilmr} \in \{0,1\} \quad \forall i \in \mathcal{N}, l \in \mathcal{L}, m \in \mathcal{M}_i, r \in \mathcal{R}, s \in \mathcal{S}, \quad (1l)$$

$$Y_i \in \{0,1\} \quad \forall i \in \mathcal{N}. \quad (1m)$$

The objective function (1a) minimizes the sum of fixed agreement fees, expected agreement penalty costs, and expected procurement costs. Constraints (1b) and (1c) ensure that the number of selected suppliers is between the specified minimum and maximum limits. Constraint (1d) limits the amount of supplies that can be ordered from each supplier by its reserve capacity. Constraint (1e) is for meeting quantity- and lead time-based service requirements of each disaster scenario; specifically, they ensure that a fraction of demand in each region is met from the framework suppliers at specified lead time intervals. Constraint (1f) ensures that supplies can be purchased only from the selected suppliers. Constraints (1g) and (1h) are for defining the pricing schedule; they guarantee that each order corresponds to a quantity interval and a lead time interval. Constraints (1i) and (1j) define the amount of underage occurring for each supplier in each scenario. Constraint (1k) is a non-negativity constraint. Constraints (1l) and (1m) define binary variables.

Three types of data are required to feed the model above. First, disaster scenarios must be developed. In humanitarian settings that address sudden-onset disasters, it may be difficult for decision makers to develop demand scenarios and assign each scenario a probability of occurrence. In our model, disaster scenarios and associated probabilities can be determined based on historical data or expert opinion. In our case study (in section 5), we develop earthquake scenarios based on historical real-world data. Second, the data related to agreement conditions that involve quantity commitments, reserve capacities, and pricing schedule elements are needed. These data must be obtained from the candidate suppliers. Finally, the parameters regarding service requirements and the limits on the number of suppliers must be set by the decision makers in the relief organization.

4. Numerical Analysis

In this section, we perform a numerical analysis to investigate the impact of agreement terms on supplier selection decisions. Given the complicating aspects of the supplier selection problem (such as unpredictable demands), it may be difficult for practitioners to evaluate the effects of agreement parameters without performing a systematic analysis. Our objective is to assist practitioners' decisions by providing insights and making recommendations about supplier selection and FAs in different settings.

Although FAs are widely practiced in the relief sector, the detailed data related to the agreement terms and supplier characteristics are not publicly available. Moreover, there is no standard data set that includes data for disaster scenarios and demand forecasts for relief supplies. Therefore, we develop a set of problem instances to perform a numerical analysis. As parameter values are set reasonably without making very restrictive assumptions, the results and insights from these instances can be generalized to similar settings.

We describe the test instances in section 4.1, present base case results in section 4.2, and discuss the results of numerical experiments in section 4.3.

4.1. Test Instances

We consider a relief organization that serves a disaster area with three regions. Four candidate suppliers are considered for agreements. We generate instances with different disaster impact and supplier coverage levels. Accordingly, in some instances, each region is subject to high-impact (low probability) and low-impact (high probability) disaster events, whereas in others, each region is only hit by medium-impact (medium probability) disasters. Furthermore, two types of instances are considered in terms of supplier coverage; specifically, suppliers may cover the disaster area fully or partially in different cases. As a result, we consider the following base case instances.

Case A: High- and low-impact disasters may occur; suppliers provide partial coverage.

Case B: Medium-impact disasters may occur; suppliers provide partial coverage.

Case C: High- and low-impact disasters may occur; suppliers provide full coverage.

Case D: Medium-impact disasters may occur; suppliers provide full coverage.

We assume that at most two events may occur during the agreement term in each region, which leads to 12 disaster scenarios per instance. Disaster demands and occurrence frequencies are generated from the same distribution for the regions affected by similar impact disasters. Specifically, demand is generated from U[100,200], U[200,400], and U[900,1000] for low-, medium-, and high-impact disasters, respectively. To obtain scenario probabilities, an occurrence frequency is assigned to each event that is also generated from uniform distribution, specifically, from U[0,2], U[2,4], and U[8,10] for high-, medium-, and low-impact disasters, respectively.

In each instance, supplier reserve capacities and minimum total commitment quantities are set at 500 and 100 units, respectively. The fixed agreement cost is $100 per supplier. Each supplier charges $10 per unit of item, and the underage penalty cost rate is set at 10% of the unit cost. Moreover, each supplier applies a 10% discount for orders larger than 300 units and an additional 10% for the orders requested from the second lead time interval. The service requirements are set such that 50% of supplies are requested from the first lead time interval in each disaster event. We do not impose constraints on the number of suppliers to isolate the effects of other parameters on supplier selection decisions.

4.2. Base Case Results

A summary of the results for the base case instances is presented in Table 1. We make the following observations based on the results.

Observation 1. *The number of framework suppliers and total costs are smaller in cases where suppliers provide larger geographical coverage. Furthermore, while expected penalty costs tend to decline with increased coverage, expected procurement costs may stay the same.*

According to the results, a smaller number of suppliers are selected when suppliers provide full coverage. This is intuitive, as in Cases C and D the model may select multiple suppliers only for capacity reasons, whereas in Cases A and B, both capacity and coverage limitations are important. Furthermore, total costs of Cases C and D are 6.3% and 5.0% lower than those of Cases A and B, respectively. When suppliers have greater coverage, the fixed costs and expected penalty costs are lower due to the smaller number of suppliers and larger utilization of supplier reserve capacities, respectively. This implies that having low unit penalty costs in agreements would be especially important in settings that involve suppliers with limited coverage. We also observe that the expected procurement costs are not affected by the differences in supplier coverage levels. This may occur when the same level of quantity discounts applies to the orders in different cases.

Observation 2. *While the number of framework suppliers is larger in cases with high- and low-impact disasters, total costs may be smaller than those of the cases with medium-impact disasters.*

Table 1 Base Case Results

	Case A	Case B	Case C	Case D
Number of selected suppliers	3	2	2	1
Total cost ($)	3214.0	3247.5	3022.1	3093.5
Expected procurement cost ($)	2757.6	2993.5	2757.6	2993.5
Expected penalty cost ($)	156.4	54.0	64.5	0.0
Fixed cost ($)	300.0	200.0	200.0	100.0
Percentage of disaster events responded to by supplier				
1	55.6	66.7	100.0	100.0
2	–	55.6	77.8	
3	55.6	–	–	–
4	55.6	–	–	–
Percentage usage of supplier reserve capacity				
Average	35.5	27.6	53.2	55.1
Maximum	96.9	62.5	97.1	64.8
Percentage of orders made with quantity-based discounts	50.0	0.0	50.0	0.0
Percentage of disaster events responded to by a single supplier	33.3	77.8	22.2	100.0

According to the results, the number of suppliers is larger in cases with high-impact disasters, as additional capacity must be created to meet the demands of extreme events. Note that the percentage of disaster events responded to by multiple suppliers is also larger in cases with high-impact disasters. Surprisingly, the total costs of these cases that involve extreme events are smaller. Whereas fixed costs and expected penalty costs are higher in these cases due to the larger supplier bases, expected procurement costs are smaller due to larger quantity discounts obtained on orders for responding to extreme scenarios. This implies that, depending on the quantity discount schemes offered by suppliers, working in an area prone to high-impact disasters may not necessarily lead to larger costs for a relief organization, although larger supply capacity must be developed.

4.3. Results of Numerical Experiments

In this section, we analyze the impact of agreement terms on supplier selection decisions and costs in different settings. Specifically, we illustrate the sensitivity of our model to changes in (i) supplier reserve capacity, (ii) minimum total quantity commitment, and (iii) pricing schedule.

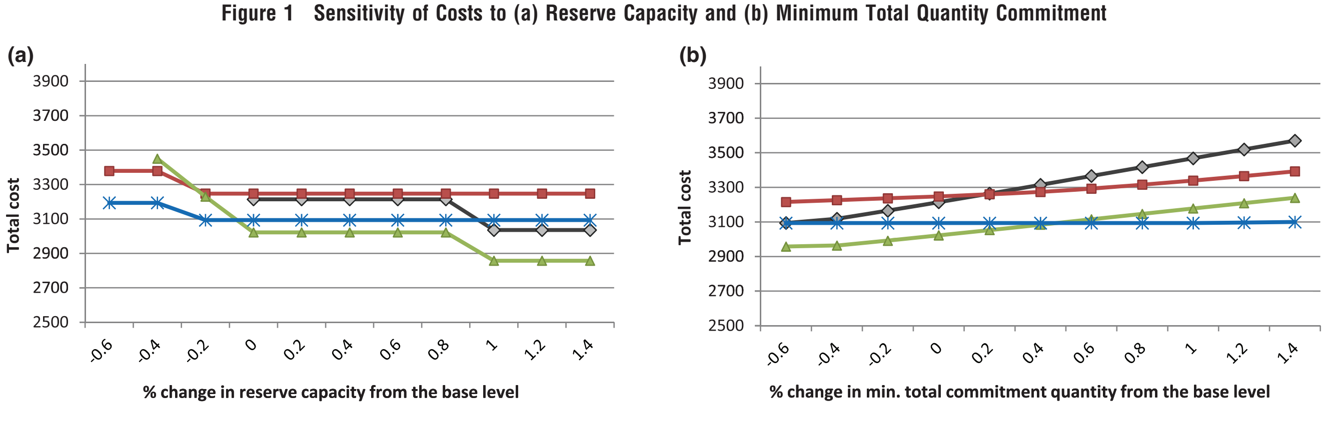
4.3.1. Effects of Reserve Capacity. We modify the supplier reserve capacity from its base level and examine its effects on supplier selection decisions and costs. According to the results, fewer suppliers are selected to agreements as reserve capacity is increased in each case. This is expected, as meeting disaster demands with a lower number of suppliers becomes possible when supplier reserve capacities are increased. The effect of reserve capacity on costs is illustrated in Figure 1a. As shown in the figure, total costs decline with increasing reserve capacities. This occurs because fixed costs decrease due to a smaller number of suppliers, penalty costs decrease due to larger order sizes, and procurement costs may decrease due to a higher percentage of orders benefiting from quantity discounts. We also make the following observation from the results.

Observation 3. *The effect of the changes in reserve capacities on supplier selection decisions and costs is larger in cases that involve high-impact disasters.*

Results show that the number of suppliers is more sensitive to reserve capacities in cases with high-impact disasters. For instance, when reserve capacity is increased from its minimum value to the maximum value, the number of framework suppliers decreases from four to one in Case C and from two to one in Case D. As a large number of suppliers is necessary to create the extra capacity for responding to extreme events, there is a marked decline in the number of suppliers when supplier reserve capacities increase in Cases A and C; however, the number of suppliers is not significantly affected by increasing reserve capacities in Cases B and D, as demands can already be satisfied by fewer suppliers when reserve capacities are small. As a result of the larger decrease in the number of suppliers in Cases A and C, the decrease in fixed costs and penalty costs is also larger. Moreover, larger savings in procurement costs occur in Cases A and C due to higher quantity discounts achieved with increased reserve capacity.

In addition, the results indicate that multiple suppliers would be used only for meeting coverage requirements if reserve capacities are set sufficiently large. Therefore, establishing agreements with suppliers that offer large reserve capacities and geographical coverage would be particularly beneficial for organizations that operate in areas prone to high-impact disasters.

Figure 1 Sensitivity of Costs to (a) Reserve Capacity and (b) Minimum Total Quantity Commitment



4.3.2. Effects of Minimum Total Quantity Commitment. We also illustrate the effects of minimum total quantity commitments on supplier selection decisions and costs. As shown in Figure 1b, total costs increase with minimum total quantity commitments in all cases. While the same number of suppliers is selected to the agreements in our experiments when the minimum total quantity commitments change, as shown in the case study (section 5), the supplier selection decisions may also be affected by the changes in the minimum total quantity commitment. Furthermore, we make the following observation based on Figure 1b.

OBSERVATION 4. *The effect of the changes in minimum total quantity commitments on total costs is larger in cases with high- and low-impact disasters.*

As shown in Figure 1b, total costs are more sensitive to minimum total quantity commitments in Cases A and C compared to Cases B and D. We observe that the only cost component affected by the changes in the minimum total quantity commitment is the expected penalty cost. As additional capacity is created for responding to high-impact events in Cases A and C, meeting the minimum total quantity commitments in scenarios that involve low-impact disasters may be difficult, leading to larger underage. Therefore, larger penalty costs occur in cases with large demand fluctuations.

In summary, Observations 3 and 4 imply that negotiating for larger reserve capacities may be more beneficial in settings that involve high-impact disasters and suppliers with large geographical coverage. Furthermore, small minimum total quantity commitments may be more valuable in areas where high- and low-impact disasters may occur and suppliers have limited geographical coverage. Finally, in settings with medium-impact disasters, relief organizations can focus on negotiating for larger reserve capacities with suppliers that offer large coverage and for smaller minimum total quantity commitments with suppliers with limited coverage.

4.3.3. Effects of Pricing Schedule. In this subsection, we examine the effects of quantity and lead time discount rates on total costs. In base cases, equal discount rates (i.e., 10%) apply for purchases made at the second quantity and lead time intervals (i.e., for larger orders and longer response times). Here, we consider alternative instances in which either the quantity or the lead time discount rate is larger than the other while keeping the total discount rate at the same level; specifically, we set 15% for the large discount rate and 5% for the small discount rate. Figure 2a, b, and c show the total cost of the instances with low, medium, and high service requirements, where the percentage of supplies requested from the first lead time interval is 25%, 50%, and 75%, respectively. We make the following observation from the results.

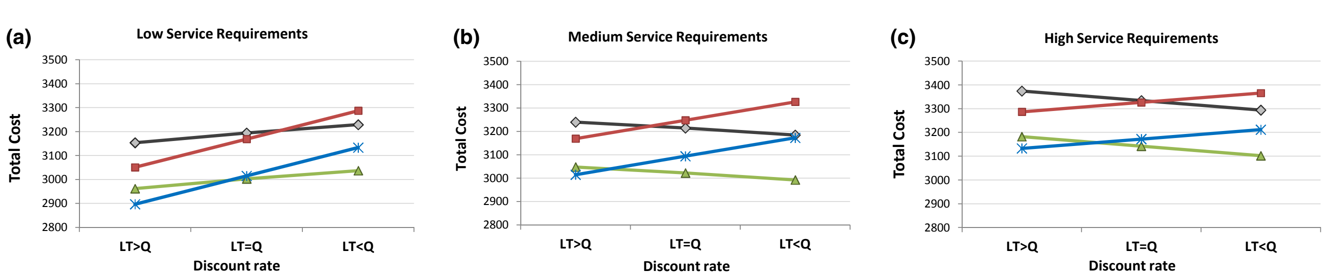
OBSERVATION 5.

(a) *In settings with medium-impact disasters, total costs decrease with increasing lead time discount rates in all instances. However, the effect of larger lead time discount rates becomes smaller as service requirements increase.*
(b) *In settings with high-impact disasters, total costs decrease with increasing lead time discount rates when service requirements are low. However, when service requirements are higher, total costs decrease with increasing quantity discount rates.*

As shown in Figure 2a, b, and c, there is an upward trend in the total cost curves of Cases B and D. As order sizes are small in these cases, increasing quantity discount rates do not lead to cost savings, and hence total costs increase with decreasing lead time discount rates. However, note that the slope of the cost curve decreases with increasing service requirements. This occurs because when a larger portion of supplies are requested quickly, relief organization can benefit from the increased lead time discounts at a lesser degree.

According to Figure 2a, total cost also decreases with increasing lead time discount rates in Cases A

Figure 2 **Total Cost of Cases with Different Quantity (Q) and Lead Time (LT) Discount Rates for (a) Low, (b) Medium, and (c) High Service Requirements**



and C when service requirements are low. However, when service requirements are increased, large lead time discount rates lead to higher costs. As orders are larger in settings with high-impact disasters, quantity-based discounts are used more frequently. Therefore, as service requirements are increased, the cost benefits of higher quantity discount rates dominate the losses due to lower lead time discount rates.

The results imply that relief organizations can focus on negotiating for larger lead time discount rates in settings with small/moderate demands. However, the effect of higher lead time discount rates may be small if quick response is required for a large portion of supplies. In such settings, negotiating on other elements of the pricing schedule (such as unit costs, lead time breakpoints) might be more helpful to decrease costs and improve response. In settings where extreme events occur and quick response is critical, negotiating for higher quantity discount rates may help the relief organization to reduce costs.

5. Case Study

In this section, we present a case study motivated by a real-world network. We describe the case instance in section 5.1 and present results in section 5.2.

5.1. Case Description

This case study focuses on procurement of bottled drinking water through FAs. In particular, we focus on establishing FAs between a relief organization and commercial water suppliers in Turkey. Turkey is located on one of the most active seismic zones in the world, and the country has been hit by several high-impact earthquakes in the past decades. The primary relief organization in the country, Turkish Red Crescent (TRC), manages a domestic relief network with a number of logistic centers that keep inventory for emergency supplies (such as tents and blankets). The TRC currently practices FAs for some emergency items that are not pre-positioned in the logistics centers (such as food).

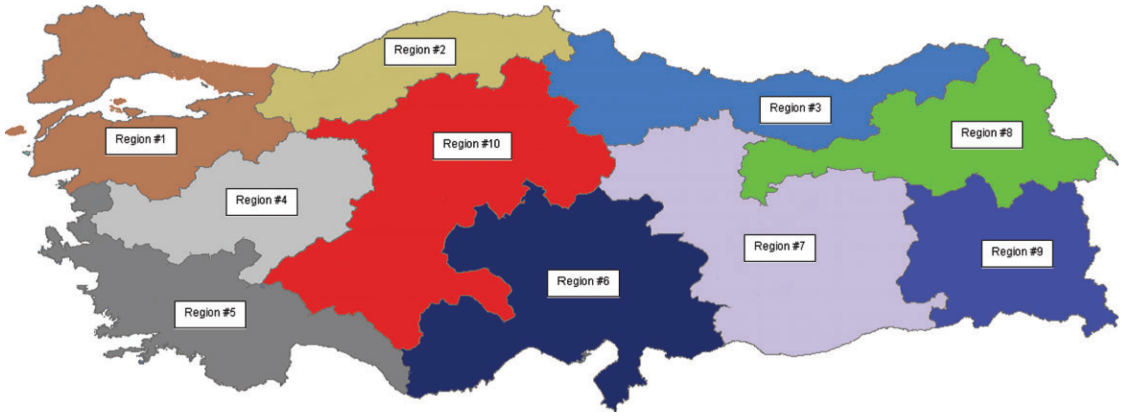
Access to clean drinking water is critical for people's survival and health; a person can survive without water only for a few days. Disasters may destroy the local water distribution infrastructure and contaminate water sources. Therefore, it is important to start providing clean water to survivors immediately after the disaster. Although contaminated water can be purified by various methods (e.g., chlorine tablets, filters, etc.), distributing bottled water to survivors is usually preferred in the initial days of the disaster (Kumar 2011). Therefore, FAs with water suppliers can help the relief organizations to ensure immediate delivery of clean drinking water to disaster areas until a long-term solution for water provision is found.

In this case study, we consider a one-year time horizon for the agreements between the relief organization and the water suppliers. We generate demand scenarios and supplier- and agreement-related parameters as explained below.

5.1.1. Demand Scenarios. Each scenario represents the set of regions that might be affected by disaster events over the agreement period and the amount of demand occurring after each event. We generate demand scenarios by applying the following procedure:

- *Historical earthquake events*. We process raw historical earthquake data to obtain the frequency of earthquake occurrences in different regions of Turkey. We extract available raw data from the EM-DAT database and create a list of earthquakes that occurred between 1900 and 2011. We consider earthquakes which are stronger than 5.0, killed at least 10 people, or affected at least 100 people. There are 76 such earthquakes between the years 1900 and 2011. The average time between events is 520 days. There are instances in which multiple earthquakes occur in the same year.
- *Demand regions and amounts*. We categorize earthquakes based on their regions and impacts. We assume 10 demand regions, which is consistent with the 10 operational regions of the relief network managed by the TRC (Figure 3). From the historical data, we calculate the sum of the numbers of people killed and affected, which represents the impact of the earthquake on the population. Given the total increase in the country's population between the years 1900 and 2011, we assume an average 2% annual population growth rate to scale the number of people affected by earthquakes in past years to current time; here, we ignore the possible differences among regions in population growth due to the unavailability of data at the regional level. Then we consider three disaster impact levels: low (less than or equal to 10,000 affected people), medium (between 10,001 and 100,000 affected people), and high (more than 100,000 affected people) and categorize events accordingly. Assuming that each person needs 2 liters of water per day, we estimate the demand for 19-liter demijohn bottles for a two-week period in each disaster region for different impact levels.
- *Scenarios*. We group the disaster events occurring within the same year and obtain 37 demand scenarios. We associate a probability with each scenario based on its occurrence fre-

Figure 3 Disaster Regions



quency over the years. Scenarios used in the case study are available from the authors.

5.1.2. Suppliers. We consider five large reputable commercial water suppliers in Turkey. Each supplier operates a regional distribution network to deliver bottled water across the country. The annual capacity, geographical coverage, and unit price (in Turkish Liras (TLs)) of each supplier is presented in Table 2. We assume that suppliers apply similar discount rates; specifically, each supplier charges the base market price for orders less than 1000 demijohns, applies a 0.50 TL discount for orders between 1000 and 9999 demijohns, and applies a 1.00 TL discount for orders involving at least 10,000 demijohns. In addition, each supplier charges the base unit prices for delivering items within 3 days and applies a 10% and a 20% discount from base prices for delivering items within 4–7 days and 8–15 days, respectively.

5.1.3. Agreement Terms. We assume that the minimum total commitment quantity requested by each supplier is 20% of its daily capacity. Moreover, each supplier promises to reserve 20% of its 15-day capacity. The annual penalty rate for underage is 0.05 (TL/TL/year) and the annual fixed agreement fee is 500 TL for each supplier. Finally, we assume that the relief organization wants to meet 60% of total demand from framework suppliers for each event, and equal proportions of the demand must be satisfied at different lead time intervals (i.e., within 3 days, 4–7 days, and 8–15 days).

5.2. Case Results and Analysis

We solve the case instance by using GAMS/CPLEX 12.1 on a laptop computer with Intel i5-2410M 2.30GHz CPU. All instances in the case study could be solved within a few seconds.

The results are summarized in Table 3. According to the results, suppliers C and D are selected to the agreement. The majority of demand is sourced from supplier C, which has the largest geographical coverage. Supplier D can serve most of the regions and offers the lowest average unit prices for serving regions that are prone to high-impact disasters.

According to the results, the percentage of disaster events responded to by a single supplier is 96.4%. Single sourcing is desirable, as the relief organization can

Table 2 Annual Capacities (in Thousand Liters), Service Regions, and Unit Prices (TL) of Candidate Suppliers

	Supplier				
	A	B	C	D	E
Unit price for region					
1	7.70	6.25	6.50	5.50	6.50
2	–	–	6.00	5.00	6.50
3	–	–	6.00	5.00	6.50
4	7.00	–	–	5.00	5.50
5	7.00	–	–	5.00	5.50
6	7.00	5.50	4.75	6.50	6.50
7	–	–	5.00	–	–
8	–	–	5.00	–	–
9	7.00	–	6.00	–	–
10	7.70	5.50	6.50	6.00	6.50
Annual capacity	4,000,000	1,000,000	1,500,000	1,300,000	1,000,000

Table 3 Summary of the Results for the Case Study Instance

Selected suppliers	C and D
Total cost	580,336
Expected procurement cost	562,936
Expected penalty cost	1640
Fixed cost	1000
Percentage of disaster events responded by supplier	
C	56.4
D	47.3
Average percentage usage of reserve capacity for supplier	
C	9.2
D	8.1
Maximum percentage usage of reserve capacity for supplier	
C	68.3
D	100.0
Percentage of orders made with quantity-based discounts	40.7
Percentage of disaster events responded to by a single supplier	96.4

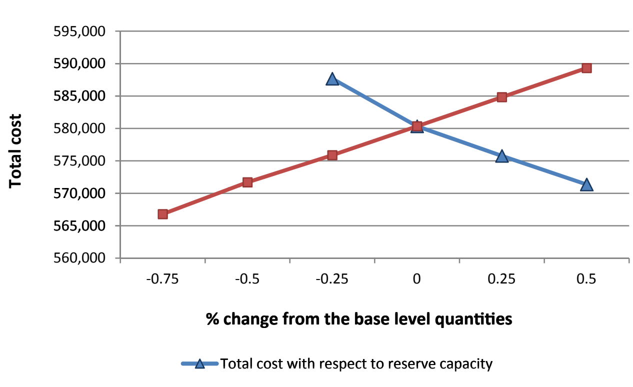
use quantity discounts by ordering more from a single supplier. Indeed, 40.7% of the orders are made from the second or third quantity discount interval. The instances in which multi-sourcing is used correspond to events with the highest demands.

5.2.1. Effects of Agreement Terms. As discussed in section 3 (Observations 3 and 4), supplier reserve capacities and minimum commitment quantities may highly affect the total costs in settings with high- and low-impact disasters. This case study instance involves a mix of scenarios with high-, medium-, and low-impact disasters, and demand fluctuations across scenarios are large. We test the sensitivity of costs and decisions with respect to the changes in reserve capacities and minimum commitment quantities. Specifically, we perform experiments with minimum total commitment quantity and reserve capacity values that range from 25% to 150% of their base levels.

As shown in Figure 4, total costs are sensitive to supplier reserve capacity and minimum total commitment quantity, which is consistent with our previous observations. The instances in which the supplier reserve capacities are reduced to 25% and 50% of their base case levels do not lead to a feasible solution. The same set of suppliers (i.e., suppliers C and D) are selected to the agreement in all experiments except for the case in which minimum total commitment quantity is reduced to 25% of its baseline value. In that case, supplier B is also selected in addition to suppliers C and D, and the total cost is 2.3% lower than that of the base case instance. Note that supplier B can serve some of the regions at lower costs than suppliers C and/or D. Therefore, when the minimum quantity commitments are decreased by 75%, the penalty costs that result from the addition of supplier B can be compensated by the savings from procurement costs.

Note that supplier B, which is selected to the agreement when minimum commitment quantities are significantly decreased, has a very limited geographical coverage compared to other candidate suppliers (Table 2). For instance, supplier E offers much greater coverage than supplier B, and, furthermore, the reserve capacities and the minimum commitment quantities of suppliers B and E are the same. Given the potential benefits of working with supplier E, we investigate whether the model would select supplier E rather than supplier B if the agreement terms offered by supplier E could be improved through negotiations. To test this, we consider a new instance in which the minimum commitment quantities of all suppliers remain in their base case values, but the pricing schedule of supplier E is slightly improved. Specifically, we test the case where supplier E reduces its unit price and increases price discounts for serving regions 1, 6, and 10 by 10%. In this case, the model selects suppliers C, D, and E to the agreement; furthermore, the total cost of the solution becomes 3.3% smaller than the base case solution. That is, rather than trying to persuade a set of suppliers to significantly decrease their minimum total commitment quantities, the relief organization can achieve a better solution by just asking for a slightly better pricing schedule from a single supplier. Furthermore, suppose that the relief organization increases its minimum commitment to supplier E by 50% in exchange for the better pricing schedule. In that case, supplier E would still be selected to the agreement, and the total costs would be 2.6% better than the base case. This example demonstrates the importance of investigating the implications of different agreement parameters offered by candidate suppliers. However, these implications may not be obvious to the decision makers without a systematic analysis. Our model would support such an analysis and enable the relief organizations to make effective supplier selection decisions for FAs.

Figure 4 Effects of Reserve Capacity and Minimum Total Commitment Quantity on Total Costs



5.2.2. Effects of Demand Scenarios. In this case study, we generate demand scenarios by processing the available historical earthquake data. There is no general approach for developing scenarios from the historical data; hence, various procedures are used in the literature to process raw data and obtain scenarios. Therefore, different data sets may result from the same raw data depending on the procedure followed. For instance, in our case instance, we categorize historical earthquakes into three impact levels (i.e., low, medium, and high), which leads to 37 scenarios. To test whether a slight change in the data processing approach affects results, we created a new data set by assuming two impact levels and reprocessed the same raw data by categorizing the disasters that affect less than or equal to 10,000 people as low impact and the disasters with more than 10,000 affected people as high impact. We obtain 34 demand scenarios in the modified instance. All other parameters are set at their baseline values.

According to the results, the same set of suppliers are selected to the agreement in the modified case instance. However, the total cost is 24.9% lower than that of the base instance. Penalty costs are higher in the base instance due to additional underage associated with the medium-impact events. In the modified instance, those events are grouped as high-impact disasters; so, penalty costs are incurred in a smaller number of scenarios. Expected procurement costs are also larger in the base instance, as the average demand of the high-impact category in the base data set is much larger than that of the modified data set. In summary, given the same raw data, considering different disaster impact levels in scenario generation may have different cost implications. Therefore, it is important to examine the implications of alternative set of disaster scenarios in making decisions. In particular, the effects of high-impact disasters must be carefully analyzed in establishing FAs.

6. Future Research Directions

This study takes a first step in addressing supplier selection decisions for FAs in humanitarian relief. FA design and supplier selection are important components of the procurement process in humanitarian relief that may highly affect the success and cost of disaster response. Given the lack of studies on these topics, we identify and discuss several avenues for future research.

- *Integrating FAs with other supply sources*. As discussed before, once a disaster occurs, various sources can be used to satisfy demands besides FAs, such as pre-positioned supplies, spot purchases from local/global markets, and in-kind donations. Considering different sourcing options simultaneously could enhance the effectiveness of supplier selection decisions for FAs. For instance, future research can consider the decisions related to the amount of supplies to preposition and reserve from framework suppliers in an integrated way. Furthermore, while making these decisions during the disaster preparedness phase, it would be useful to consider the amount of supplies that will come from in-kind donations and the post-disaster purchases from the spot market. However, there might be challenges to characterizing and modeling the uncertainty related to in-kind donations and spot purchases. The amount and content of in-kind donations are usually highly unpredictable, as they depend on a variety of factors such as the location of the disaster and the public attention received, the donors, the general economic climate, politics, etc. Similarly, it is difficult to reliably estimate the availability and prices of goods in the spot market before a disaster, as they are strongly influenced by the demand surge that the disaster creates. One way to represent the uncertainties related to in-kind donations and spot market conditions would be through the use of probabilistic scenarios, which can be developed based on historical data where available. Future research can extend the stochastic programming model presented in this study or explore alternative approaches to incorporate these additional aspects.
- *Incorporating the uncertainty in post-disaster funding*. Another source of supply uncertainty that might be important in selecting framework suppliers is related to the availability of post-disaster funding. More specifically, the amount of supplies to procure from framework suppliers and/or other sources may depend on the amount of monetary donations collected after disaster occurrences, which are usually very difficult to predict in advance. Again, a scenario-based approach can be used to incorporate the funding uncertainty in models. It would be particularly valuable to demonstrate the implications of reducing funding-related uncertainties on costs and effectiveness of disaster response, which may encourage the relief organizations and the major donors to better communicate on future funding needs and possibilities.
- *Supplier reliability*. The FA in this study assumes that suppliers can send the reserved supplies immediately at all times. However, there might be cases in which the framework suppliers cannot meet the requirements of the

agreement and fail to make deliveries in the requested amounts and times. The stakes associated with a failing supplier may be very high in a humanitarian context. Therefore, future research can focus on developing models which incorporate the risks about the performance of framework suppliers while designing agreements.

- *Investigating alternative types of FAs and supplier selection criteria*. This study focuses on a quantity flexibility contract established with framework suppliers to improve the procurement of supplies in responding to sudden-onset disasters. We identify the important criteria used to select suppliers in this setting. Future research can focus on other types of agreements and criteria that may be suitable for different types of organizations, disasters (e.g., slow onset), and missions (e.g., development).
- *Collaborative FAs*. Reducing the risks and costs associated with FAs may be possible if different relief organizations collaborate in establishing agreements. For instance, small organizations, which may not use quantity discounts due to small order sizes, could especially benefit from collaborative agreements. However, it may be challenging to design effective collaborative agreements for various reasons; for instance, the relief organizations may compete for purchasing from the same framework supplier. Future work can examine the effects of collaborative agreements on procurement costs and response and investigate the conditions under which such agreements are beneficial to all participants.

7. Conclusion

This study addresses a supplier selection problem for establishing FAs in humanitarian relief. A quantity flexibility contract is considered, which requires the relief organization to commit purchasing a minimum total quantity over an agreement horizon, and the suppliers reserve capacity and deliver orders according to terms of the agreement. The relief organization determines framework suppliers and agreement terms at the beginning of a planning horizon under demand uncertainty. We characterize the uncertainty in disaster demands by defining a set of probabilistic scenarios and develop a stochastic programming model for the problem. We perform numerical experiments to understand the effects of agreement terms on supplier selection decisions and illustrate the applicability of the model on a case study. The results provide relief organizations with insights for assessing supplier characteristics and agreement terms in different settings.

Acknowledgments

We would like to thank George Fenton from WVI, Birgitte Olsen and Armen Petrosyan from the IFRC, and Gokhan Dilmac from the TRC for providing us with valuable information about humanitarian relief operations and framework agreements.

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