Computers & Industrial Engineering 111 (2017) 39–49

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Stochastic optimization for joint decision making of inventory and procurement in humanitarian relief

Shao-Long Hu [a], Chuan-Feng Han [a], Ling-Peng Meng [b,*]

[a] School of Economics and Management, Tongji University, Shanghai 200092, China
[b] China Institute of FTZ Supply Chain, Shanghai Maritime University, Shanghai 201306, China

ARTICLE INFO

Article history:
Received 9 May 2016
Received in revised form 18 June 2017
Accepted 19 June 2017
Available online 23 June 2017

Keywords:
Emergency logistics
Inventory control
Product returns
Supplier selection
Stochastic programming
Conditional Value-at-Risk

ABSTRACT

This paper presents a two-stage stochastic programming model for integrating decisions on pre-disaster inventory level and post-disaster procurement quantity with supplier selection in humanitarian relief. Three features are considered in the model, including lead time discount, return price, and equity. Given the uncertainty about the disaster type and occurrence location, a scenario-based approach is applied to represent the uncertain demand. Conditional Value-at-Risk is employed to measure risk at different confidence levels. Based on a real-world example where a surge in demand was incurred by a snowstorm, earthquake, flood and typhoon in China in 2008, a case study is presented to investigate the applicability of the proposed model, and its implications are discussed based on numerical studies. The model can assist relief agencies in managing supplies for disaster response.

1. Introduction

A large, varied demand for basic supplies such as water, food, lighting equipment and tents may occur after a natural disaster. Relief supplies are largely collected from government-owned or other rented warehouses, and then transported to disaster-affected locations. Authorities often perform procurement decisions after a disaster if supplies turn out to be insufficient.

Disaster-induced demand is uncertain, as occurrence time, location, and the intensity of disasters are all highly unpredictable. The inventory costs of maintaining a sufficient amount of physical inventory at strategic locations in order to deal with demand uncertainty and to be able to react swiftly can thus be very high (Balcik & Beamon, 2008). When relief supplies are not available in sufficient amounts at local markets, reliance solely on post-disaster procurement cannot satisfy the needs of a rapid response, and may lead to gaps in supply.

Pre-disaster storage can provide a buffer that gives the supplier the time to produce supplies to satisfy a surge in demand. Incorporating post-disaster procurement into pre-disaster inventory decisions is beneficial for reducing the stock of relief supplies. Hence, joint decisions for determining the pre-disaster inventory level (PDIL) and the post-disaster procurement quantity (PDPQ) might be helpful in the pursuit of accelerating disaster response and savings on inventory costs. In this study, decisions regarding PDIL determine how much relief supplies should be stored before a disaster hits. Depending on PDIL and unsatisfied demand, decisions regarding PDPQ determine how much relief supplies should be procured after a disaster hits, which is limited by the production capacity of suppliers.

Commercial suppliers may have lower inventory costs than relief agencies because of their experience in matters of inventory control. Moreover, perishable supplies generally have a fixed lifetime, which may go to waste if the consumption of the supplies ends up being less than the quantity on stock. Their inventory strategy (e.g. first-in-first-out) may be beneficial for increasing the utility of relief supplies. Although relief agencies play a vital role in successful disaster response in highly uncertain disaster situations, allowing commercial suppliers to reserve and produce the most needed types of supplies may be a better choice since it saves inventory costs. In accordance with relief practice, relief agencies and suppliers all focus on long-term agreements. The main benefit to the suppliers is business that can be guaranteed over a given period of time in the future. Based on the above explanation, supplier selection is incorporated into the proposed model.

This study is conducted as follows. First, a two-stage stochastic programming model for determining the number of selected suppliers, PDIL, locations, and PDPQ with given scenarios is presented. Second, PDIL and PDPQ decisions are characterized as uncertain

* Corresponding author.
E-mail address: lmeng@tongji.edu.cn (L.-P. Meng).

http://dx.doi.org/10.1016/j.cie.2017.06.029
0360-8352/

and equitable. The uncertain parameters (disaster types, locations, and demand) are then used to set scenarios. Finally, the value of perfect information and the stochastic solution are identified. The Conditional Value-at-Risk is employed as a risk measurement method for revealing the extreme impact of a disaster with low probability.

The paper is organized as follows. Section 2 reviews the literature. In Section 3, a two-stage stochastic programming model is formulated. Section 4 describes the case study and summarizes the results. The findings of the numerical analysis and managerial implications are outlined in Section 5. Conclusions are given in Section 6.

2. Literature review

The heightened importance of inventory control, procurement management, and supplier selection in humanitarian relief is generating an increasing literature. Döyen, Aras, and Barbarosoğlu (2012) developed a two-stage stochastic programming model to determine the locations of pre- and post-disaster rescue centers, the amount of relief items to be stocked, and the amount of relief item flows at each stage. Glock, Grosse, and Ries (2014) provided a survey of literature reviews to show which streams of research emerged from Harris' seminal lot size model, and which major achievements have been accomplished in the respective areas. Roni, Jin, and Eksioglu (2015) proposed a hybrid policy that identified a standard order point and an emergency order point, a regular order quantity and an emergency order quantity for a stochastic inventory system facing regular demand and surge demand. Pérez-Rodríguez and Holguín-Veras (2015) developed an inventory-allocation-routing model for the optimal assignment of critical supplies that considers the reduction in deprivation costs for the recipients of the aid and the increase in deprivation costs for those individuals who do not receive the aid. Roni, Eksioglu, Jin, and Mamun (2016) considered split delivery in the hybrid inventory policy under regular and surge demand for saving inventory costs. Rezaei-Malek, Tavakkoli-Moghaddam, Zahiri, and Bozorgi-Amiria (2016) developed a new integrated model to determine the optimum location-allocation and distribution plan, along with the best ordering policy for renewing the stocked perishable commodities in the pre-disaster phase.

Balcik and Ak (2014) addressed a supplier selection problem for establishing framework agreements with a quantity flexibility contract in humanitarian relief. Torabi, Baghersad, and Mansouri (2015) proposed a bi-objective mixed possibilistic, two-stage stochastic programming model to address supplier selection and order allocation under operational and disruption risks. Hosseini and Barker (2016) proposed a Bayesian network to quantify the appropriateness of suppliers across primary, green, and resilience criteria. Procurement decisions are specifically related to supplier selection criterion, which are widely studied for selecting suppliers. Such criteria might include quantity discounts, transportation costs, carbon emission tax, currency exchange rates, price discounts, delivery time, service level, supplier capacity, and lead time (Choi, 2013; Hammami, Temponi, & Frein, 2014; Mansini, Savelsbergh, & Tocchella, 2012; Qian, 2014; Ruan, Wang, Chan, et al., 2016; Ware, Singh, & Banwet, 2014). We focus on the joint decision-making for PDIL coupled with the PDPQ. Because of the post-disaster procurement is urgent and massive, we consider that a lead time discount can be obtained if late deliveries are permitted.

To the best of our knowledge, research on return policies in inventory management focus on the field of managing commercial supply chains. There are studies which address optimal decision-making for a production-inventory system when returns are allowed (Flapper, Gayon, & Vercraene, 2012; Vercraene & Gayon, 2013). Mitra (2012) developed deterministic and stochastic models for a two-echelon inventory system with correlated demands and returns in closed-loop supply chains. Another category is the study of the impact of returns on the inventory policy. Chatfield and Pritchard (2013) studied the impact of returns on the extent of the bullwhip effect in a multi-stage supply chain. Tai and Ching (2014) considered an optimal inventory policy for a Markovian two-echelon system with returns and lateral transshipment. Hu, Li, and Govindan (2014) studied the impact of consumer returns policies on consignment contracts with inventory control. Their conclusion is that the vendor's return policy depends crucially on the salvage value of returns. Because of the high uncertainty attached to disasters, a larger surplus of supplies may result. Relief agencies could save inventory costs and obtain the salvage value of relief supplies if returns were allowed. Hence, it is intuitive that an appropriate return policy may promote procurement decisions.

To control the risk of supply disruptions, a large amount of works focuses on risks of supplier failure, and its impacts on operating decisions (Chen & Wu, 2013; Ruiz-Torres, Mahmoodi, & Zeng, 2013). Recently, risk measurement methods, Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR), popular in financial engineering, were introduced to supply chain management (Chahar & Taaffe, 2009; Rockafellar & Uryasev, 2000). Ahmadi-Javid and Seddighi (2013) introduced CVaR to quantify the risk-measurement policies for location-routing problems with disruptions. Sawik (2014) integrated supplier selection and customer order scheduling in the presence of supply chain disruption risks, and CVaR is employed as a risk measurement. Hu, Han, and Meng (2016) presented a coordinated approach to integrate building reinforcement, reinforcement of road networks, and facility location of relief supplies in emergency prevention, in which CVaR is employed as a decision-making tool to evaluate the diverse decisions of prevention based on the degree of risk aversion. Alem, Clark, and Moreno (2016) developed a two-stage stochastic network flow model for rapidly supply humanitarian aid to victims of a disaster. They presented an extension of the model via CVaR to improve demand fulfillment policy.

In sum, our work advances the literature on inventory control and supplier selection in humanitarian relief management in several ways. First, as a holistic consideration, the PDIL and PDPQ with supplier selection decisions are integrated into a two-stage stochastic programming model. Moreover, two features, lead time and supplier type-specific discounts and variation in return price, are used to bring the model closer to reality. Finally, CVaR is employed as a risk measurement method to reveal the extreme impact of disaster with low probability. The impacts of lead time discount, return price, and CVaR on inventory and procurement decisions as well as their implications are then discussed in detail.

3. Modeling

3.1. Two-stage stochastic programming

In this section, a scenario-based two-stage stochastic programming model is proposed for joint decision-making on PDIL and PDPQ with supplier selection. Based on the scenario settings, decisions are made on the locations, number of suppliers, and PDIL in the first stage. Relief agencies have a preference for multiple suppliers in humanitarian relief in the interest of reducing the risks incurred by potential supplier failure. Our work therefore considers multiple suppliers which can be selected in the same location. The PDPQ and transportation decisions are then made in the second stage. Note that PDPQ is restricted by the production capacity of suppliers. Furthermore, the transportation decision is related to the location of suppliers and quantity of supplies (PDIL and PDPQ)