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Robust optimization for United States Department of Agriculture food aid bid allocations

Jomon Aliyas Paul [a,*], Xinfang (Jocelyn) Wang [b]

[a] Department of Economics, Finance, and Quantitative Analysis, Kennesaw State University, Kennesaw, GA 30144, United States
[b] Department of Management, College of Business Administration, Georgia Southern University, Statesboro, GA 30460, United States

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ABSTRACT

The U.S. Department of Agriculture (USDA) currently uses a bidding system to determine carriers and suppliers that would partner in providing food aid annually in response to global emergencies and famine. We mimic the USDA approach via a robust optimization model featuring box and ellipsoid uncertainty frameworks to account for uncertainties in demand, supplier and carrier bid prices. Through a case study utilizing historical invoice data, we demonstrate our model applicability in improving ocean carrier and food supplier bid pricing strategy and similar supply chain network optimization problems. Through a validation algorithm we demonstrate the value of our robust models.

1. Introduction

Despite innovative humanitarian efforts, such as distributing cash cards and electronic vouchers instead of food to beneficiaries (Starr and Van Wassenhove, 2014), food aid still plays a profound role in combating world hunger, which kills ten million people each year, more than AIDS, tuberculosis, and malaria combined, according to the United Nations World Food Programme (UNWFP, 2008). Food aid accounts for about 2% of the global food trade (Murphy and McAfee, 2005), delivering 8.25 million tons to 93 countries; major recipients in 2005 included Ethiopia, North Korea, Sudan, and Uganda (UNWFP, 2008). Food aid represented 70% and 50% of consumption during civil wars in Somalia and Eritrea, respectively (Shapouri and Rosen, 2004).

At approximately 60% of total food aid (Shapouri and Rosen, 2004), the United States is the world's largest donor followed by the European Union, China, Canada, Japan, and Australia. US foreign food aid can be traced back to 1954 when President Eisenhower signed the Agricultural Trade Development Act, also known as US Public Law (P.L.) 480. A number of foreign food assistance programs were created under this law, with Title II taking on the largest effort. The US Agency for International Development (USAID) manages Title II food aid, procured from US producers with the assistance of the US Department of Agriculture (USDA), and donated to foreign countries in response to emergencies and famines as well as nonemergency development opportunities (United States General Accounting Office [USGAO], 2002). Examples include the ongoing crisis in Syria, the 2004 tsunami disaster in Asia, and civil violence in the Darfur region of Sudan. To date, Title II has provided more than 106 million metric tons of food to 3.4 billion people since its inception in 1954 (USAID, 2007).

* Corresponding author.
E-mail addresses: jpaul17@kennesaw.edu (J.A. Paul), xfwang@georgiasouthern.edu (X. (Jocelyn) Wang).

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The logistics of Title II food aid are mind-boggling, engaging a complex array of suppliers, transportation companies, and intermediaries. Private voluntary organizations (PVOs) must follow USAID guidance about the types and amounts of food aid when submitting requests to implement Title II programs. With assistance from the USDA, USAID procures the food on the open market through a competitive tender process, soliciting bids from both food commodity suppliers and ocean carriers.

While representative of a typical logistic optimization problem, many characteristics of the USDA food-aid problem are further complicated by the association with disaster relief. Unlike commercial supply chains, disaster-based supplier/carrier relationships have not been nurtured over the years but are temporary and short-lived (Oloruntoba and Gray, 2006). Planners have to cater to large demands for relief supplies further complicated by levels of uncertainty (Lin, 2010) associated with, not only the size of the demand, but also changing location and timing patterns (Beamon and Kotleba, 2006). These challenges hold remarkably true for USDA food-aid distribution.

The urgent need for robust solutions to account for the inherent uncertainty in humanitarian logistics is emphasized in Liberatore et al. (2013) and Starr and Van Wassenhove (2014), among others. The main methodology employed to address uncertainty has been the stochastic programming framework (e.g., Balcik and Ak, 2014; Mete and Zabinsky, 2010; Rawls and Turnsquist, 2010; Rottkemper et al., 2012), which focuses on optimization of the expected value of a given objective function for all possible parameter values governed by probability distributions. This method implies a risk-neutral position that may not be appropriate for risk-averse humanitarian decision makers, who constantly plan for the worst-case scenario because lost sales and backorders in commercial settings now translate into misery and loss of life (Beamon and Kotleba, 2006). In addition, the task of specifying probability distributions for uncertain parameters in a humanitarian logistics setting is extremely challenging due to lack of reliable data; stochastic programming models usually do poorly when the probability distributions are misspecified.

Existing research on humanitarian logistics is mainly devoted to pre-positioning of emergency supplies (e.g., Rawls and Turnsquist, 2010; Balcik and Ak, 2014) or disaster management following events (e.g., Barbarosoglu and Arda, 2004; Sheu, 2007; Najafi et al., 2013) while the complex operations of food aid under uncertainty, albeit important, are seldom studied. The closest work to ours in studying food aid is Trestrail et al. (2009) and Bagchi et al. (2011) but from the perspective of optimal bidding mechanism. Trestrail et al. (2009) successfully modeled the two-stage bidding system used by USDA prior to March 2007 in which suppliers bid first and then carriers bid in a second round; that is, supplier and carrier allocations are determined in two separate stages using optimization models. Bagchi et al. (2011) determined the optimal auction mechanism for food-aid bidding, given concerns about bidder gaming leading to higher prices and deterring competition.

Specifically, our contributions to the field of humanitarian logistics are as follows. First, we model the current one-round bidding system used by USDA; in it, sealed bids are collected from independent suppliers and carriers in a single stage as a mixed integer program. Second, we address the challenges of the USDA's humanitarian logistics problem by developing an extreme-value-driven, robust-optimization counterpart (Ben-Tal et al., 2009) to account for the uncertainties in some of the key parameters. Third, we consider uncertainties that may be introduced by all the main players potentially involved in a food-aid initiative: demand for the USDA and pricing for carriers and suppliers. Fourth, we demonstrate the value of our robust model using real historical data available under the Freedom of Information Act (FOIA) to approximate future bid awards. Last, although inspired by the USDA problem, our deterministic and robust models can be adapted to general humanitarian logistics framework involving multiple levels of players.

2. Literature review

Humanitarian aid is an evolving and expanding field (Kovács and Spens, 2007), unfortunately due to the higher frequency of catastrophes, increased incidence of diseases, and increased incidence and scale of political unrest. The importance of global aid is evident in the estimated $14 billion combined budgets of the top ten aid organizations (Thomas and Kopczak, 2005). Although logistics are the most costly part of any relief effort (Van Wassenhove, 2006), they are not well managed by relief organizations. Some problems can be attributed to poor skills, insufficient use of technology, and inefficient collaboration with other organizations (Thomas and Kopczak, 2005), but humanitarian relief has several unique characteristics that intensify logistical complexity. For example, distribution of food aid, especially seasonal products or demands, is challenging (Boronico and Bland, 1996). In contrast to commercial settings, where demands can be reasonably estimated, food-aid demand is extremely unpredictable, fluctuating with volume, location, and supplies needed (Ratliff, 2007). However, until recently, studies addressing these uncertainties were notably lacking. We next review some of the limited work on modeling uncertainty in humanitarian logistics.

Barbarosoglu and Arda (2004) develop a two-stage stochastic programming model for transporting vital first-aid supplies during emergency response. Chang et al. (2007) apply stochastic programming to the flood emergency logistics problem with the objective of determining a rescue resource distribution system. Mete and Zabinsky (2010) propose a stochastic optimization model for storing and distributing medical supplies for disaster management. Probabilistic scenarios are specified to model the uncertainties and outcomes in disasters of different types and magnitudes. Rawls and Turnsquist (2010) present a two-stage, stochastic, mixed-integer program to preposition the location and quantities of emergency supplies under uncertainties about the occurrence and location of a natural disaster. The model considers uncertainty in demand as well as network availability after an event. Rottkemper et al. (2012) develop a mixed-integer programming model to minimize unmet demand and operational costs of a humanitarian operation. To address uncertainty, demand is split into a