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Pre-positioning of relief items in humanitarian logistics considering lateral transhipment opportunities

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ABSTRACT

The main objective of this study is to investigate the inclusion of lateral transhipment opportunities into the humanitarian relief chain and to examine the effect of different parameters on minimizing the average distance travelled per item while serving the beneficiaries. Direct shipment model (DT), lateral transhipment model (LTSP) and maritime lateral transhipment model (MLTSP) are developed and compared between each other by using a real life earthquake scenario prepared for the city of Istanbul by JICA (Japanese International Cooperation Agency). Developed mathematical models decide on the locations and number of disaster relief facilities, quantity of relief items to hold at those facilities, and quantity of lateral transhipment between the facilities. Vulnerability of the roads and heterogeneous capacitated facilities are also considered. It can be concluded that both LTSP and MLTSP models gave better results than DT model and lateral transhipment option helps beneficiaries to obtain relief items faster and with higher service level.

1. Introduction

From 2003 to 2012, annual average of 106,654 people were reported dead, more than 216 million people were reported to be affected by disasters, and close to $157 billion worth of economic damage was reported [12]. These facts reveal the importance of disaster management in mitigating the negative effects of the disaster. Humanitarian logistics, which plays a key role in every stage of disaster relief operations, is defined as "the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from point of origin to point of consumption for the purpose of meeting the end beneficiary's requirements" [28]. When a state of emergency is declared and aid is appealed, resources such as relief personnel, relief goods and equipment are mobilized to the disaster location. By its definition, mobilization of resources as well as its predecessor and successor operations in a relief chain [9] can be categorized as humanitarian logistics, which contribute to more than 80% of the total relief costs [32]. Although local government of the disaster location is mainly responsible to alleviate the suffering of its people [27], non-governmental organizations (NGOs) as well as other relief aid agencies offer their help to transport the right number of relief goods on time to the right place [26].

Supply chains are usually considered to be consisting of vertical transportation through several echelons (i.e. levels) such as manufacturer, warehouse, retailer, customer etc. The practice of allowing horizontal transportation within the same echelon is called lateral transhipment [4] and is mostly used for low demand, high value items where emergency orders are allowed [18,33]. In settings where lateral transhipment is observed, retailers might keep only certain types of items and replenish those items from the warehouses. As a cure to the burden of waiting for next regular warehouse shipment or placing emergency orders with high cost to the warehouse, transhipments from other retailers with adequate inventory is utilized. Thus, retailers face two sources of demand (from customers and other retailers) and two sources of supply (from warehouses and other retailers) [4].

Inspired from the emergency nature of lateral transhipment decisions in commercial logistics, lateral transhipment in humanitarian logistics can also be a viable alternative to alleviate

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the suffering of beneficiaries within the shortest time possible. Lateral transhipment in humanitarian logistics is observed when aid distribution centres transfer relief items among themselves when they cannot satisfy the immediate need of beneficiaries from their own inventory. To the best of our knowledge, lateral transhipment in humanitarian logistics has not been analysed thoroughly in the literature. The objective of this study is addressing this literature gap and proposing an integrated model for facility location and transportation decisions including lateral transhipments.

The rest of the paper is organized as follows. In the second section, we present the related literature. The problem is defined and the related systems are described in the third section. Proposed mathematical formulations are presented in the fourth section. The fifth section provides the results of experimental studies conducted for the city of Istanbul with the real life data. Finally, we conclude with our major findings and possible future research directions.

2. Literature review

Disaster management can be analysed in four phases, namely, mitigation, preparedness, response and recovery [2]. Most of the studies in humanitarian logistics have focused on the preparedness and response phases [2]. In their review study, Caunhye et al. [8] state that inventory pre-positioning, evacuation and relief distribution aims are brought together in location analysis in most of the facility location optimization models in humanitarian logistics. The decisions are varied such as commodity pre-positioning, facility selection among potential local and global distribution centres, and optimizing facility size. In the pre-positioning literature, the most frequent objectives are minimizing costs of setting up relief centres, transportation [11,17,20] and commodity procurement costs, average [10] or maximum response time, unfilled demand [1] and expected number of casualties left behind or maximizing beneficiaries' coverage. Huang et al. [15] describe efficiency, efficacy and equity types of objective functions for relief routing. Facility location problem can also be solved together with the routing of vehicles as in Ukkusuri and Yushimito [30].

Two stage stochastic models are utilized in some pre-positioning studies. Barbarosoglu and Arda [6] propose a two-stage stochastic programming model to plan the transportation of vital first-aid commodities to disaster-affected areas during emergency response where the capacities of the arcs in the road network, the supply amounts and the resource requirements are considered to be random. Mete and Zabinsky [21] develop a stochastic optimization approach selecting the storage locations and amounts of medical supplies to minimize warehouse operation costs, the response time and unfilled demand rate balancing the preparedness and risk despite the uncertainties of disaster events. Bemley et al. [7] develop a two-stage stochastic pre-positioning model to maximize expected amount of repaired ports providing short-term port recovery from weather events such as hurricanes.

Scenario based approaches are also utilized in the pre-positioning literature. Balçık and Beamon [5] propose a scenario-based model for a pre-positioning system balancing the costs against the risks to determine the number and the location of distribution centres in a relief network and the amount of each relief commodity stored at each facility. Duran et al. [10] develop a mathematical model to obtain the configuration of the supply network that minimizes the average response time over all the demand instances and decide which warehouse to open and how to allocate the inventory among them.

Commercial studies on lateral transhipment are not directly related to disaster response, but still have some common characteristics to humanitarian logistics settings. Some of these characteristics are the uncertainty in demand, existence of possible future states, and uncertainty in the number of facilities to be established. These characteristics are related to the uncertainty in the time, place and the effect of a disaster. Most of the commercial lateral transhipment studies are related to repairable spare parts. In one of the earliest studies on lateral transhipment, Lee [19] presents a model of pooling groups with identical retailers. Demand of one retailer is satisfied from another retailer in the same pooling group. Different priority rules between available retailers and optimal stocking levels for various service levels are also analysed. Axsater [3] generalizes the pooling group idea to non-identical retailers. His method shows an improvement on Lee [19]'s work when the proportion of emergency transhipments is large. Commercial studies differ from humanitarian logistics by their demand rate and item value. Commercial lateral transhipment is often used for low demand and high value items. On the other hand, lateral transhipment in humanitarian logistics is used during a demand surge (i.e. high demand) and for low value items (e.g. bottled water and meals-ready-to-eat).

Lateral and emergency shipments occur in response to stock outs. Wong et al. [33] study a multi-item, continuous review model of two-location inventory systems for repairable spare parts. The objective of the study is to minimize the total costs for inventory holding, lateral transhipments and emergency shipments subject to a target level for the average waiting time per demanded part at each of the two locations. Kutonoğlu and Mohajan [18] consider a two-echelon service parts logistics system with one central warehouse and a number of local warehouses that meet all the time-based service level constraints at minimum total cost including inventory holding cost, transportation cost, and penalty cost due to lost demand. Time-based service level constraints are similar to allowable maximum response time or maximum distance constraints in humanitarian logistics.

Ozkapici et al. [23] study the problem of locating disaster relief facilities in the city of Istanbul utilizing the Bosphorus strait. The authors consider maritime transportation for relief item distribution in the city of Istanbul where two main ports and a container ship located on the Marmara Sea are considered as main supply facilities. Ozkapici et al. [23] conclude that including maritime transportation into the relief item distribution system provides a more flexible humanitarian logistics system for Istanbul. Inspired from Ozkapici et al. [23]; one of the mathematical models developed in this study uses maritime transportation with lateral transhipment opportunities.

Three works can be cited as the most related to this study in humanitarian logistics. Reyes et al. [24] show that lateral transhipment in a disaster relief system is more efficient using a simulation model based on system dynamics. Stanger et al. [25] illustrate the use of lateral transhipment in blood transportation for UK hospitals. They demonstrate the real life benefits of lateral transhipment based on comprehensive case studies and surveys. Mulyono and Ishida [22] build a logistics and inventory model using probabilistic cellular automata for the enterprise inventory model and self-repair network model, which is applicable to humanitarian relief situations. Mulyono and Ishida [22] use a real life data set from a volcanic eruption (Sinabung Mountain - September 2013) in Indonesia to validate their model. Although Reyes et al. [24]; Stanger et al. [25]; and Mulyono and Ishida [22] illustrate the use of lateral transhipment in humanitarian relief situations; they do not utilize a mathematical programming model in their studies. In this study, the main objective is to investigate whether lateral transhipment in humanitarian logistics provides flexibility and decreases average travel distance comparing mathematical models with and without lateral transhipment.

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