Empty Container Allocation in B2C E-commerce

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B2C e-commerce has been increasingly embraced worldwide in recent years. Its global sales has reached 1.82 trillion dollars in 2017, with a yearly growth rate of 17.2% (Ecommerce Foundation 2018). In B2C e-commerce companies, paper boxes are frequently used in the last-mile delivery and the goods transfer among distribution centers (DCs) or fulfillment centers (FCs). During 2016, 35.4 million tonnes of paper and cardboard packaging waste were generated in the EU (Eurostat 2019). The overuse of paper boxes has become a giant burden both economically and environmentally. Therefore efforts should be devoted to reduce the use of paper boxes in logistics.

In a B2C e-commerce company, a DC is normally replenished based on its regional demand forecast. However, due to demand variation, it is possible to encounter surplus or shortage of goods, in which case goods transfer to or from another DC is needed. In its recent practice the transferred goods are normally packed in reusable and foldable containers. When there is a container deficiency, paper boxes serve as a replacement.

In reality, there exists a structural imbalance in container movements among the DCs. For example, the Pearl River Delta area is known as one of the manufacturing centers for electronic products in China. DC Shenzhen is located in the Pearl River Delta area and close to the main suppliers. DC Beijing and DC Shanghai are both far away from the suppliers, and face highly uncertain demands for electronic goods. The transportation from suppliers to DC Beijing and DC Shanghai and the possible goods transfer between them due to demand uncertainty can be costly. Instead, it can be economically beneficial if the company applies a "wait and see" strategy. That is, it holds the products in DC Shenzhen first, and directly ships from DC Shenzhen to DC Beijing and DC Shanghai when the company has a better knowledge of the demand. This imbalanced goods flow gives rise to the buildup of empty containers in Beijing and Shanghai, and the scarcity of them in Shenzhen. Similarly, when a DC is located near a port, the company tends to store more imported goods, rather than sending these goods directly to other DCs.

In order to reduce the use of paper boxes caused by the shortage of empty containers, it is important to allocate the appropriate amount of containers at each DC and to timely reposition the empty containers among the DCs.

In this study, we consider a cyclic operational pattern, where the system repeats in each time horizon (e.g., a week). We focus on the tactical decision on the targeted allocation of empty containers at the beginning of each time horizon, considering demand uncertainty during the horizon. We formulate the problem as a two-stage stochastic program, where we apply a single-level threshold inventory policy at each DC in the first stage and model the repositioning of empty containers under realized demand in the second stage as a multi-commodity network flow model.

There are two kinds of container movements, loaded and empty. The movements of loaded containers are dictated by the transfer of goods, which is stochastic and exogenous to our study. Each demand of goods transfer is associated with an origin (O), a destination (D), a time window, and a required amount of goods. The movements of empty containers are the decisions of our model. Empty containers can only be moved using the remaining capacity of vehicles, and can be unloaded from a vehicle and loaded to another vehicle at a DC during its repositioning. In order to decide the movement (a path comprising of multiple arcs) of an empty container within the network, we need to know the movements of loaded containers on each arc (leg), denoted as leg demand, which is inherently uncertain. Intuitively, demands on legs along the path of the same O-D pair are also correlated.

In order to generate a sample of leg demands that matches the given O-D demand distribution, we first generate a large sample of O-D demands, and transform them into leg demands by solving a multi-commodity network flow model. We then employ a scenario generation method from Kaut (2014), and test the in-sample and out-of-sample stability (Kaut and Wallace 2007). An overview of scenario generation methods can be found in chapter 4 of King and Wallace (2012).

According to Song and Dong (2015), studies on empty container repositioning can be classified into two streams: network flow models and inventory control models. Stochastic network flow models have been well investigated since the 1990s (Crainic, Gendreau, and Dejax 1993, Cheung and Chen 1998), including stochastic programming (Long, Chew, and Lee 2015), robust optimization (Lee and Moon 2020), fuzzy optimization (von Westarp and Schinas 2016), etc. Inventory control models are relatively more easy-to-understand and easy-to-operate, and have been applied by some shipping companies (Lee and Song 2017). The studied inventory policies include the (s, S) policy (Dang, Yun, and Kopfer 2012), single-level threshold inventory policy (Lee, Chew, and Luo 2012), two-level threshold inventory policy (Song and Dong 2008), etc. Some efforts have been put into the integration of the inventory model and network flow model (Chou et al. 2010, Epstein et al. 2012), but there have been very few explicitly considering both loaded and empty containers (Lee

and Song 2017). To the best knowledge of the authors, there have been no studies addressing the stochastic correlated movements of loaded containers on legs. A comprehensive review of empty container repositioning can be found in Lee and Song (2017) and Kuzmicz and Pesch (2019).

In the numerical study, we construct test instances based on the real network of a Chinese B2C e-commerce company. The stability test suggests that a scenario tree with 60 scenarios can achieve the required in-sample and out-of-sample stability level (1%). The preliminary numerical study shows that, compared with the benchmarking non-repositioning policy, the proposed approach reduces the total cost by 7% and the use of paper boxes by 14%. We also examine other heuristic policies in practice, the threshold inventory levels at DCs resulting from the proposed approach, as well as the container and paper box movements on legs.

The contributions of our study are three-fold. First, based on the practice of a B2C e-commerce company, we study an empty container allocation and repositioning problem that combines an inventory control model and a network flow model, jointly considering both the exogenous movements of loaded containers and the repositioning movements of empty containers. Second, we formulate the problem as a two-stage stochastic program, generate the correlated leg demand scenarios from given O-D demand distributions, and test the in-sample and out-of-sample stability. Third, we perform numerical experiments based on the real network of a Chinese B2C e-commerce company and gain useful managerial insights.

Acknowledgments

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