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Airfreight forwarder's shipment planning under uncertainty: A two-stage stochastic programming approach

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ABSTRACT

This paper addresses the shipment planning problem with random processing times in intermodal logistics via transfer ports. Shipment activities are divided into two groups according to regional settings. Activity processing times in region A are assumed to be random while those in region B are deterministic. At the beginning (stage 1), the forwarder assigns agents to all job activities (planning decision). In case a shipment delay is observed, an in-process adjustment (recourse decision) is implemented (stage 2). A two-stage stochastic programming model is established and an illustrative example is discussed. Managerial insights are presented in a simulation study.

1. Introduction

Consigned by shippers, airfreight forwarders are third-party operators responsible for ensuring that client shipments are delivered on time and at a low cost. They provide transport logistics using in-house resources, partners, and subcontracting agents. Airfreight forwarders account for a majority of international tonnage (Clancy and Hoppin, 2001).

A forwarder shipment plan usually includes several shipments (jobs), and each job requires a number of processing activities such as trucking, warehousing and air transport. If consecutive activities of a job are assigned to the same agent, we call it integration. If several shipments have the same activity, which are processed together by a single agent, it is consolidation. Effective integration and consolidation are crucial to achieving cost- and time-efficiency. Integration achieves cost and processing time reductions by eliminating setups between consecutive activities (Leung et al., 2000). Consolidation can reduce processing costs by achieving better utilization of resources (Bookbinder and Higginson, 2002; Çetinkaya and Lee, 2002). Freight consolidation is also considered to be a major issue in designing network facilities (Popken, 1994; Pirkul and Jayaraman, 1998; Syam, 2002). However, consolidation may lead to increases in inventory costs and delays, and to longer routes (Hall, 1987; Pooley and Stenger, 1992; Higginson, 1995; Bookbinder and Higginson, 2002).

There has been much research works in multimodal networks. Recently, Puettmann and Stadtler (2010) discuss a collaborative approach for intermodal freight transportation. Ayed et al. (2011) propose a transfer graph model for solving the time-dependent multimodal transport problem. Cheng (2012) analyzes the freight multimodal transport costs to select the transport path. Zhang et al. (2013) include the environmental costs in finding the transport policy. Sitek and Wikarek (2012) study the multimodal transportation network based on supply chains.

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International shipments usually are multi-modal in the form of ground–air(sea)–ground transport. As an example, consider a shipment from Guangdong, China to Philadelphia, USA via Hong Kong. The cargo is first picked up by truck from the shipper's factory in Guangdong and moved to Hong Kong, where it is consolidated with other shipments. Then the consolidated cargo is flown to New York. After deconsolidation at the air terminal, it is shipped to Philadelphia by a local freight company booked by the consignee. Throughout the shipping process, there are many uncertain elements. In the Pearl River Delta, bad weather such as rainstorms and typhoons are not uncommon. Other factors such as cross-border customs clearance, carrier overbooking, system malfunctioning, and traffic condition are common causes of shipment delays during ground transport. At the other end, the processing times are relatively stable once the cargo is loaded on the carrier, in particularly in air transport.

A good shipment plan must take uncertainties into consideration. It is well known that the reliability of a shipment – the probability of delivering a shipment on-time – is the most important measure of an airfreight forwarder's performance (Air Cargo World, 2003). Both integration and consolidation affect a shipment's reliability. Integration avoids hand-offs between agents and confines the risks to the same agent. Consolidation, on the other hand, creates interdependency among shipments, thus allowing uncertain elements in one shipment to affect other shipments. For a shipment that does not require consolidations, its reliability can be assessed without the need to consider other shipments. For a shipment that requires consolidations, its reliability depends on the randomness of its own processing, as well as the processing of other shipments prior to the consolidations. Such a situation can be very complicated for a shipment plan that has many shipments with many consolidations. A shipment plan that has shipments with unsatisfactory reliability – even for only a handful of them – should not be considered as satisfactory.

Hong Kong is an international hub in air transport with an extensive network and frequent flight schedule. There were 101 airlines flying to around 160 destinations with 339,000 air traffic movements in 2011/12 (HKIA Annual Report, 2012). When a shipment is experiencing serious delay that threatens missing the target delivery date, a forwarder might make in-process adjustments to the subsequent shipment activities. A major objective of this study is to provide forwarders with a systematic approach to address uncertainty in shipment planning, as well as a rational way to plan for shipping adjustments.

Most of the research related to logistics planning uses deterministic optimization models (Klincewicz and Rosenwein, 1997; Crainic and Laporte, 1997; Leung et al., 2009; Wong et al., 2009). In the supply chain literature, Chang and Makatsoris (2001) show that simulation can be used to study and improve supply chain performance under uncertainty. Manzini et al. (2005) provide a general framework for establishing simulation models to evaluate the operating performance of a supply chain. SteadieSeifi et al. (2013) present a detailed literature review on multimodal freight transportation planning. They point out the importance of reliability in the service network performance. Uncertain factors such as stochastic demands and variability in travel times are discussed in Lium et al. (2009), Andersen and Christiansen (2009), Hoff et al. (2010), Puettmann and Stadtler (2010) and Meng et al. (2012). Farahani et al. (2013) review the recent development in hub location research and Alumur et al. (2012) specifically discuss the uncertainties in hub set-up cost and origin–destination transportation demands.

We address the design of shipment plans under uncertainty using a stochastic programming approach. An overview of stochastic programming can be found in Kall and Wallace (1994). Stochastic programming is closely related to options theory, a connection discussed in Christiansen and Wallace (1998), and later outlined in more details in Wallace (2010). Stochastic programming models are generally very hard to solve, particularly when the deterministic underlying models are NP-hard. However, the alternative chosen by many – that of using sensitivity analysis or what-if analysis, based on the deterministic optimal solution – can be problematic (Wallace, 2000; Higle and Wallace, 2003). So in order to retain the core of the stochastic modeling, a plausible approximation approach is to combine an optimization model with a simulation model (Leung and Cheung, 2000; Manzini et al., 2005).

2. A general deterministic shipment planning model

The first analytical work on designing a forwarder shipment plan appeared in Leung et al. (2009) where a deterministic optimization model (mixed 0–1 LP) to minimize the processing costs with integrations and consolidations is provided. Solution algorithms including LP, heuristics, and branch-and-bound are discussed. Incorporating critical considerations such as on-time delivery, Wong et al. (2009) present a mixed 0–1 LP that enhances the practicality of the work in Leung et al. (2009). The optimization problem is solved using a Tabu search algorithm. The goal of shipment planning is to minimize the total processing cost with a set of operating constraints: target delivery times, target costs, resource capacities, etc. The objective function is:

$$\min_{x_{ijk}} \sum_i \sum_j \sum_k \{s_{ijk} + a_{ijk}\} x_{ijk} - \sum_m w_m y_m - \sum_n r_n z_n \tag{1}$$

where