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A linear programming-based method for the network revenue management problem of air cargo

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A R T I C L E I N F O

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A B S T R A C T

One critical operational issue of air cargo operation faced by airlines is the control over the sales of their limited cargo space. Since American Airlines' successful implementation in the post-deregulation era, revenue management (RM) has become a common practice for the airline industry. However, unlike the air passenger operation supported by well-developed RM systems with advanced decision models, the decision process in selling air cargo space to freight forwarders is usually based on experience, without much support from optimization techniques. This study first formulates a multi-dimensional dynamic programming (DP) model to present a network RM problem for air cargo. In order to overcome the computational challenge, this study develops two linear programming (LP) based models to provide the decision support operationally suitable for airlines. In addition, this study further introduces a dynamic adjustment factor to alleviate the inaccuracy problem of the static LP models in estimating resource opportunity cost. Finally, a numerical experiment is performed to validate the applicability of the developed model and solution algorithm to the real-world problems.

1. Introduction

Air cargo plays an important role in global trade. For example, more than 30% of internationally traded merchandise, according to value, is transported by air for the U.S. and Japan (Yamaguchi, 2008). In particular, due to world trade liberalization, the air cargo industry has been booming for the past several decades, and the growth rate of air cargo has surpassed that of air passengers. According to most forecasts, this trend is projected to continue in the future.

Air cargo is an operation-intensive industry and involves complex procedures and many players. As an excellent review of air cargo studies, Feng et al. (2015) summarized the models developed in prior works and highlighted the gaps between research and reality based on industrial interviews. Among the critical operational issues faced by airlines, the control over the sales of their limited cargo space appears to be a very crucial decision. Since American Airlines' successful implementation in the post-deregulation era, revenue management (RM) has become a common practice for the airline industry. Based on certain demand forecasting techniques and optimization models, RM has been found to be very effective in generating extra revenue for diversified and uncertain demand, given a fixed capacity of perishable inventory. According to most estimates, the revenue gain from applying RM is about 4–5%, which is comparable to many airlines' total profitability in a good year (Talluri and van Ryzin, 2004). However, unlike the air passenger operation supported by well-developed RM systems

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with advanced decision models, the process of selling air cargo space to freight forwarders or shippers is usually not highly automated. The decision process is mainly based on experience, without much support from optimization techniques.

The characteristics of air cargo RM differ from air passenger RM in many respects. One fundamental difference is the nature of the product. For air passenger RM, seats are a well-defined product in terms of the demand initiated by the customer and the capacity provided by the supplier. However, air cargo shipments are categorized by both weight and volume, which can be stochastic in practice. In addition, with the current hub-and-spoke operation of most airlines, the focus of RM research has shifted from the traditional single-leg version to the network version. However, no substantial research work is found to ensure the applicability to real-world problems for air cargo RM.

This study formulates a multi-dimensional dynamic programming (DP) model to present a network RM problem for air cargo, in which the weight, volume, and rate of the shipments can be stochastic. The objective of the DP model is to maximize the expected revenue given the fixed capacities (in both weight and volume) of the airline network. The associated computational load makes it impossible to derive the optimal control decision for a problem of practical size, as the curse of dimensionality is an inherited problem for many DP formulations. In order to provide the decision support for air cargo RM, this study develops two linear programming (LP) based models to generate the control decision with respect to shipment booking requests. In particular, given the concern over the static assumptions in LP formulations, this study further introduces a dynamic adjustment factor to alleviate the inaccuracy problem of opportunity cost estimation due to the gap between resource allocation and realized sales.

The remainder of this paper is organized as follows. Section 2 provides the background to the problem and reviews the related literature. The DP model to illustrate the network RM problem of air cargo and the LP-based methods to generate the control decisions are presented in Section 3. The numerical experiment is described in Section 4. Finally, the findings of this study are summarized and conclusions are drawn in Section 5.

2. Problem background and literature review

There are several important RM research areas, such as demand forecasting, pricing and overbooking. The focus of this study is on the control of capacity. For the air passenger side, most early seat-inventory control studies relied on the following six assumptions: (1) sequential booking classes, (2) low-before-high fare booking arrival pattern, (3) statistical independence of demands between booking classes, (4) no cancellation or no-shows, (5) single flight leg, and (6) no batch booking (McGill and Van Ryzin, 1999). For example, Belobaba (1989) developed the Expected Marginal Seat Revenue (EMSR) heuristic for the static problem based on the above assumption. In order to incorporate the time-dependent characteristic of demand, Lee and Hersh (1993) developed a DP model in which the request probability based on the Poisson arrival process is used to represent the demand pattern. In addition, Lee and Hersh (1993) further generalized the single-seat booking assumption to batch booking, and thus the request probability turns out to be dependent upon the booking size as well.

Most airlines nowadays operate a hub-and-spoke type of network so as to serve more origin–destination (OD) pairs with fewer flights. For the simple 4-leg network in Fig. 1, there are 8 OD pairs (one-way). The level of complexity is significantly increased from the single-leg version to the network version problem as multiple resources are now shared by multiple products. The computational load makes it impossible to derive the optimal control for a problem of practical size. One popular approach for the network RM problem is the bid-price control (Williamson, 1992). A bid price is attached to each leg, and a booking request for a product is accepted if its revenue is greater than the sum of the bid prices of the used legs. The key issue for most bid-price based algorithms is finding a suitable set of bid prices, supposedly depending on the available leg seats and the demand before departure. Williamson (1992) set the bid prices as the dual prices of the leg capacity constraints in an LP model, which overlooks the stochastic feature of the demand. Several studies have developed improved approaches to generate better bid prices by addressing the issue of demand uncertainty. For example, Talluri and van Ryzin (1999) proposed the RLP (Randomized Linear Program) method, in which the bid prices are determined by averaging the bid prices from a series of deterministic LP problems with simulated demand. In addition, de Boer et al. (2002) provided the PLP (Probabilistic Linear Programming) method to incorporate the distribution of the demand into an LP model with a

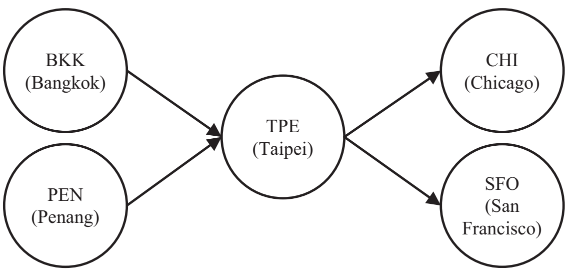

Fig. 1. An illustrative example with a four-leg network.