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The application of inventory transshipment modeling to air cargo revenue management

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ABSTRACT

This paper applies an inventory transshipment modeling approach to investigate the air cargo revenue management problem for an airline operating in a two-segment network. Building upon an extension of the classic two-location inventory transshipment model, we develop a framework to optimize an airline's cargo overbooking decisions in a two-segment network setting. We find consistent evidence indicating that network-based global optimization always leads to greater expected profits than does local (i.e., market by market) optimization. Further, the magnitude of profit improvement is found to be most significant when local shipments have a relatively higher freight yield compared to flow-through shipments. Finally, our results indicate that global optimization contributes to greater profit improvement as offloading penalty costs become higher.

1. Introduction

The world air cargo traffic rose by 6.4% annually between 1985 and 2005, compared to an average growth rate of 5.1% per year for air passenger transport during the same period. Despite the unprecedented decline in 2008–2009, air cargo traffic rebounded in 2010 and is expected to triple over the next 20 years, increasing from 166.6 billion revenue tonne-kilometers (RTKs) in 2009 to more than 526 billion RTKs in 2029 (Boeing World Air Cargo Forecast 2008–2009).

With the continued growth of air cargo, it is important for air cargo airlines to establish revenue management systems to maximize their profitability. Revenue management has been widely used in airline passenger operations for more than 20 years. Although revenue management has been applied to air cargo operations, cargo revenue management still mainly relies on the basic framework of passenger revenue management systems. As discussed in Kasilingam (1996), air cargo operations differ from air passenger operations in many aspects, such as shippers' booking patterns, multi-dimensional capacity, and capacity uncertainty, and thus passenger revenue management systems should not be blindly applied to the air cargo sector.

There has been limited research addressing air cargo revenue management issues. Kasilingam (1996) identified the major differences between passenger revenue management and cargo revenue management. As a significant portion of air cargo is carried in the belly space of passenger aircraft, cargo capacity depends on the number of passengers on board and the amount of their baggage. Therefore, air cargo capacity is stochastic in nature, and the uncertainty makes capacity allocation decisions more complex Becker and Nadja (2007). Other special characteristics of air cargo include the multi-dimensional nature of cargo capacity (weight, volume, and position in the aircraft cargo hold), flexibility in routing and itinerary selection, and the cargo allotment arrangement prior to general sales.

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The overbooking decision is one of the most important elements of air cargo revenue management. Overbooking rates are based on estimated show-up rates, forecasted payload capacity, and allotment determination. Existing cargo overbooking methods have been primarily derived from passenger overbooking models, and the overbooking decisions are modeled at a single flight event level, despite the fact that air cargo movements often involve multiple segments. Consequently, there is a lack of coordination in the overbooking rates in related, networked markets. There have been some attempts to improve air cargo overbooking models. For example, Popescu et al. (2006) showed that the use of discrete show-up rate estimators can help an airline improve its overbooking decision. They estimated that the use of a discrete estimator would lead to annual savings of $16.4 million for a combination airline with 300 flights per day and 13 tons of cargo payload capacity per departure.

This paper contributes to the air cargo revenue management literature by developing a two-location newsvendor model to investigate optimal overbooking decision-making for an airline operating multi-segment flights and serving shippers in both flow-through and local origin and destination (O&D) markets. Moreover, the model enables us to compare the profit outcomes between local (market by market) optimization and global optimization under various conditions. The rest of the paper is organized as follows. Section 2 reviews the previous literature on the classic inventory transshipment model and traditional cargo overbooking model. In Section 3, we develop a modeling framework to analyze a simplified overbooking decision problem at the single flight level. Based on inventory transshipment modeling, Section 4 extends the overbooking optimization to a global, network-based setting. Section 5 presents a series of numerical examples to illustrate the potential profit improvements from global optimization. Finally, the conclusion, implications and possible future research are discussed in Section 6.

2. Background and literature review

Similar to passenger bookings, shippers make reservations for their cargo shipments. When a shipment shows up at the time of aircraft departure, it is called a "show-up booking" for that particular departure. If a shipment does not arrive, it is called a "no-show". When the show-up bookings cannot be accommodated by the carrying capacity of the scheduled aircraft, some of the shipments will be "offloaded". An offloaded shipment will be transferred onto another flight, possibly following a different routing or operated by another airline. Transferring an offloaded shipment incurs "offloading" costs, including administrative costs, extra handling and storage costs, additional distance traveled, a delayed shipment penalty, and/or payments for using another airline's capacity. On the other hand, if a large number of no-shows occur, the scheduled aircraft may be underutilized, which is termed "spoilage" capacity. Airlines incur spoilage costs in terms of lost revenue from this unoccupied capacity. The main problem in an *ex ante* overbooking decision is to find the optimal trade-off between the expected offloading costs and spoilage costs.

The classic newsvendor modeling approach has been widely used to analyze the overbooking problem. Kasilingam (1996) attempted to optimize the overbooking level to minimize the sum of the expected offloading and spoilage costs, assuming a payload capacity and a show-up rate follow certain distributions. Lou et al. (2005) and Moussawi and Cakanyildirim (2005) also employed the newsvendor modeling approach to analyze two-dimensional (weight and volume) overbooking decisions. Wong et al. (2009) investigated the baggage-limit policies for passenger-cargo combination airlines based on a variant of the multi-item newsvendor model with weight-volume capacity consideration. However, these studies modeled the overbooking decisions at a single flight-event level. In the current paper, we expand on the previous studies to consider flights with multiple segments by adopting the two-location newsvendor modeling approach that has been primarily used in inventory transshipment research (Krishnan and Rao, 1965; Tagaras, 1989; Robinson, 1990; Rudi et al., 2001).

Transshipments refer to the practice of transferring stock from one location with excess inventory to another location with insufficient supply. As a risk-pooling and resource-reallocation strategy, the implementation of transshipments enables firms to reduce inventory costs without sacrificing customer service. There have been extensive studies investigating transshipments in the inventory management literature. Krishnan and Rao (1965) was the first to model transshipments in a multi-location distribution network consisting of a number of warehouses. Under the assumptions that all the warehouses are centrally controlled, have independent demand, and incur the same inventory holding and stockout costs, they concluded that the practice of transshipments would equalize optimal inventory and service levels across all the stocking locations. Building on Krishnan and Rao (1965), Tagaras (1989) investigated the effect of transshipments on customer service as measured by non-stockout probability and order fill rate. His main finding is that the service levels at both locations will be equalized through transshipments under the condition that the stocking locations have symmetric market demands and inventory cost structures. Robinson (1990) extended the classic two-location newsvendor model into a multi-period, multi-location setting in which a heuristic was developed to solve the optimal order-up-to point, and a model validated using Monte Carlo techniques.

The aforementioned studies have assumed that the inventory decisions at different stocking locations are centralized by an umbrella headquarters, and therefore, transshipments are considered as intra-organizational transferred inventory. Rudi et al. (2001) considered a decentralized environment where each stocking location makes inventory decisions to maximize its own expected profit and found that through transshipments the inventory replenishment decisions of independent firms are interrelated. Moreover, they found that transshipment price could be used to help firms coordinate their inventory decisions to lead to a global profit optimization.

As suggested by Becker and Wald (2008), one major limitation of the current cargo overbooking models is that the overbooking decisions are considered at a single flight level. Therefore, the overbooking rates on various flights are considered to be