

Shipment Planning, Capacity Contracting, and Revenue Management in the Air Cargo Industry: A Literature Review

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Abstract

A wide variety of goods nowadays is transported by air, especially those of high value-to-weight ratio such as electronics and luxury goods and those perishable such as cut flowers and fish. The contemporary logistics practices that require shipping more frequently with smaller quantities also favor air transport. However, decision-making in air cargo business is challenging. Air cargo demand is highly unstable and sensitive to global economic conditions. The shipping process typically involves many parties, such as carriers, forwarders, trucking companies, and terminals; poor coordination between them might cause considerable delay. Furthermore, the special characteristics such as demand imbalance and capacity 2-dimensionality also raise issues in both strategic and operational decision-making. Due to such challenges, practitioners and academic researcher have begun to apply operations research/management science (OR/MS) to the air cargo industry in recent years. In this paper, we review academic papers in three categories, namely, shipment planning, capacity contracting/booking, and revenue management. Other related literature and some possible future research directions are also discussed.

Keywords

Air cargo industry, shipment planning, capacity contracting, revenue management, OR/MS literature

1. Introduction

The air cargo industry, representing more than 30% of the value of all goods transported, has been playing a vital role in the global economy. Although air transport costs approximately six times as much as ocean transport, a wide variety of goods nowadays is transported by air, especially those of high value-to-weight such as electronics and luxury goods and those perishable such as cut flowers and fish (Kasarda et al. 2006). The products shipped by air also include those traditionally shipped by other means, due to the contemporary logistics practices requiring shipping frequently with small quantities. For example, Zara's merchandise destined for stores outside Europe is mainly delivered by air within 24-36 hours (Ghemawat and Nueno 2003).

Air cargo traffic is forecasted to be triple over the next 20 years with an annual growth rate of about 5.9% (Boeing 2011). However, air cargo demand seems highly unstable and can be greatly influenced by economic conditions. It is characterized by seasonality reaching the peak at October then falling down sharply. The global economic downturn in 2011 has led to marked decline in world airfreight volumes (IATA 2011).

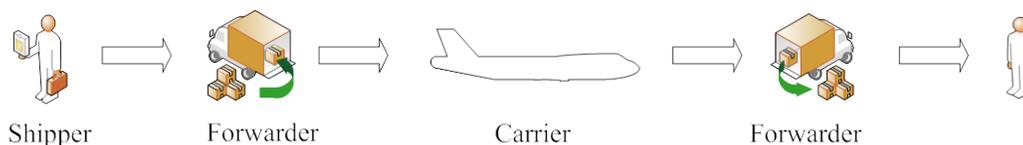


Figure 1: The cargo flow

The air cargo shipping process typically involves carriers, airfreight forwarders, terminals, and other parties (Figure 1). Carriers own planes carrying shipments from the original airport to the destination airport, which can be passenger-cargo combination or all-cargo airlines. Airfreight forwarders, analogous to travel agents, are

intermediates between carriers and shippers (customers), responsible for arranging the whole shipping process. They receive shipments from shippers, consolidate these shipments into pallets or containers, and book capacity from carriers. Forwarders also provide value-added services on behalf of shippers, including door-to-door delivery, warehousing, and paper work of importing and exporting. Shippers may directly let integrators such as DHL and UPS deliver their shipments rather than the airline-forwarder coalition. But airline-forwarder coalitions usually offer lower rates than integrators and more importantly, they might have expertise for certain types of goods or certain routes which integrators do not have.

While the contemporary logistics practices favor it, air cargo business also faces many challenges. One of them is the highly volatile demand mentioned, which makes capacity planning difficult. As air cargo capacity is capital-intensive, both over-capacity and under-capacity might imply revenue losses for carriers and forwarders. Another challenge arises from the fact that the shipping process usually involves many parties which results in difficulty in coordination. Actually, a large portion of air cargo's total travel time is spent on waiting (Christiaanse and Damsgaard 2001). Such delay may be caused by forwarders having the shipment consolidated with other shipments or the lack of communication between parties. Finally, the unique characteristics of air cargo business make decision-making in this area challenging. For example, the cargo demand imbalance, meaning that out-bound flows and in-bound cargo may differ considerably, might necessitate a new approach in network planning. The 2-dimensionality of cargo capacity, measured in weight and volume, is likely to raise pricing issues.

Such challenges suggest that operations research/management science (OR/MS) might assist decision-making in the air cargo industry. Indeed, some practitioners have successfully applied concepts and methods from OR/MS. For example, Slager and Kapteijns (2004) discuss the implementation of cargo revenue management at KLM. Academic research of OR/MS on air cargo has become active in recent years. In this paper, we review papers in three categories, namely, shipment planning, capacity contracting/booking, and revenue management. Shipment planning refers to optimizing the shipping process to minimize cost. Cargo capacity contracting literature studies how carriers design long-term/medium-term contracts to sell their capacity and how forwarders react to the contracts, where the objective can be maximizing carriers' profit or achieving the whole system's efficiency. Air cargo revenue management literature attempts to apply sophisticated techniques to make best of the limited capacity, including overbooking and accept/reject control. We also review several other related literature. Finally, the possible future research directions are discussed.

2. Shipment Planning

Shipment planning, as one of the operational decisions faced by forwarders and carriers, refers to optimizing the shipping process to minimize cost while ensuring shipments are delivered correctly, safely and timely. Airfreight forwarders handle more than 80% of international airfreight volume; it is mainly their responsibility to design the shipment plan and manage the shipping process. Thus, it is not surprising to find that most literature on shipment planning concentrates on the forwarders rather than carriers. Forwarders consolidate shipments from different shippers into a container or pallet, which is then loaded into certain position of aircraft to be transported to the destination airport. Actually, the consolidation capability largely defines a forwarder's profitability. For example, consolidating density complementary shipments may generate considerable profit since a shipment is charged based on its gross weight and volume weight with a ratio of 1 m³ to 166.7kg, whichever is larger. Besides forwarders, carriers also confront various shipment planning decisions. For example, they may need to decide the assignment of shipments to planes, which shipments to offload when under-capacity occurs, and how to arrange the transshipment when the direct flight is not available.

The literature on shipment planning is summarized in table 1. Huang and Chi (2007) consider an airfreight forwarder's problem of assigning collected goods to flights to minimize the expense charged by airlines. The volume and weight rate structure as well as the quantity discount offered by airlines, reflecting the common practice in this industry, are incorporated into the mixed integer programming (MIP) model. A recursive heuristic algorithm is developed to solve this model.

Li et al. (2009) also consider how an airfreight consolidates shipments to minimize the total cost. Specifically, they study how to load cargo into various types of containers (Unit load devices), which differ in fixed reservation fees, pivot weights, and unit costs, among others. This problem is formulated as an integer programming model and solved by large-scale neighborhood search, which is embedded in simulated annealing.

Leung et al. (2009) introduce the problem of integration and consolidation of air cargo shipments. They provide an overall picture of the problem environment such as jobs and resources availability, costs estimation, feasible integrations and consolidations, and job activity assignments. A linear 0-1 program is formulated to optimize the shipping process. Both a branch and bound (B&B) and a heuristic algorithm are developed to solve it.

Table 1: Summary of literature on shipment planning

Paper	Major decision	Special feature	Method
Huang and Chi (2007)	Assign shipments to flights	Quantity discounts	MIP, heuristics
Li et al. (2009)	Plan cargo loading	Various types of containers	IP, heuristics
Leung et al. (2009)	Assign job activities to agents	Integration	IP, B&B and heuristics
Wong et al. (2009)	Assign job activities to agents	Integration, time	MIP, heuristics
Wu (2010)	Book containers and plan cargo loading	Uncertain demand	SP
Li et al. (2012)	Assign shipments to flights	Network	MIP, heuristics

Wong et al. (2009) extend the model of Leung et al. (2009), and explicitly address integration and consolidation's impact on the timely delivery, which has become an important dimension of service quality. They formulate the problem as a mixed 0-1 linear program and design a customized Tabu-search algorithm to solve it.

Unlike the above works, Li et al. (2012) study the forwarder's shipment planning problem in a network setting, where there are multiple origins and multiple destinations. The time aspect is also incorporated.

Wu (2010) integrates container renting decisions with cargo loading decisions. Containers are booked in advance when demand information is inaccurate. A stochastic programming (SP) model is formulated to the demand uncertainty. This paper considers decision-making in both tactical (container renting) and operational (cargo loading) levels. Actually, some papers reviewed at next sections also simultaneously consider issues of different levels and of different time horizons.

3. Capacity Booking

Most carriers sell a significant portion of cargo capacity via long-term contracts (allotments) (Kasilingam 1996). Carriers typically divide each year into two seasons. Months before a season starts, they would conduct allotment booking processes, inviting their major customers (airfreight forwarders) to bid for the cargo capacity by flight or route of certain days throughout the season. Within one month before the flight departure, forwarders need to make bookings to carriers specifying their shipment information such as weight, dimensions, and type. If the booking is within the allotment weight, it will be automatically confirmed; otherwise, the booking status depends on the space availability on the flight (cargo.koreanair.com/).

The long-term contracts usually do not allow adjustments. The inflexibility makes forwarders reluctant to sign these contracts since the cargo demand is highly unpredictable months in advance. Carriers would offer favorable rates to compensate for the early and fixed commitments. Therefore, questions arise about how to design the contract, for example, how to allow the desirable flexibility, how to price the contract, and how to achieve a win-win situation for both carriers and forwarders. Several papers, summarized in table 2, attempt to answer these questions.

Hellermann et al. (2011) point out that the fixed-commitment contract, as a predominant type of long-term capacity agreement between air cargo carriers and forwarders, have several drawbacks. For example, forwarders with great negotiation power may refuse to pay for the capacity reserved but not used. They thus consider an alternative type, the option contract, with a unit reservation fee payable upon signing the contract and a unit execution fee payable on the used capacity. The option contract also offers flexibility to forwarders. They present an analytical model where

the carrier determines the contract parameters and the forwarder choose the purchase amount. They then incorporate overbooking and analyze its impact. A case study with real data is also provided.

Table 2: Summary of literature on capacity contracting

Paper	Carrier's decision	Forwarder's decision	Contract type	Objective
Hellermann et al. (2011)	Contract parameters	Purchase amount	Option contract	Maximize profit
Gupta (2007)	Contract parameters	Effort level	Flexible contract	Achieve system efficiency
Amaruchkul et al. (2011)	Menu for each type	Purchase amount	Menu contract	Identify information rent

Gupta (2007) also develops an analytical model to study interactions between a carrier and a forwarder. They investigate whether a particular contract type can achieve the whole system's efficiency, that is, the forwarder could use the best effort level on marketing and the carrier could optimally allocate capacity to allotments and ad-hoc request. They propose two flexible contracts allowing carrier to adjust the contract parameters, and characterize the flexibility's benefits.

Amaruchkul et al. (2011) emphasize the asymmetric information between a carrier and a forwarder. The forwarder's type, reflecting its demand, operating cost, margin, reservation profit, is unknown to the carrier. The carrier offers a menu of contracts for the forwarder to choose. They obtain the informational rent and identify conditions under which it can be eliminated.

As opposed to the long-term contracts these works focus on, Chew et al. (2006) propose a short-term capacity planning model for airfreight forwarders. Given the amount of long-term contract air cargo space, they suggest a re-planning of space is needed when the flight departure time is nearer based on the trade-off between the shipment backlog penalty and the cost of acquiring additional space.

4. Revenue Management

Revenue management (RM), coming from the airline industry, mainly concerns firms' selling decisions. In 1970s, to compete with low-cost entrants who target leisure passengers such as college students and holiday travelers, major airlines come up with the idea of selling their excess capacity at even lower prices, with capacity control and advance purchase restriction to ensure that their business customers did not buy these low-price products. Large RM systems were then developed to monitor and forecast passenger demand. So far, many advanced tools have been created by practitioners and researchers, such as network optimization and customer choice models. Beyond the airline industry, RM concepts have also been successfully applied in many other industries (hotels, TV companies, retailers).

It is natural to apply RM to the air cargo business, which is many practitioners and researchers' attempt in recently years. Kasilingam (1996) presents characteristics and complexities of air cargo RM, and compares air cargo RM with passenger RM. Slager and Kapteijns (2004) describe the challenges of implementing RM at KLM cargo, and also how they overcome these challenges. Before reviewing the related literature, we briefly summarize characteristics of the air cargo business, particularly on the demand aspect.

1. *Categories.* Cargo is divided into several categories, such as normal goods, dangerous goods, high-value goods, live animals, and wet goods, with each requiring different facilities and services
2. *Demand variability and uncertainty.* Air cargo demand varies over time, days and seasons. For example, domestic cargos usually prefer morning and afternoon flights to noon flights.
3. *Demand imbalance.* Outbound and the inbound flows may differ considerably. For example, the Shenzhen-Chicago all cargo flight had almost 100% load, but the Chicago-Shenzhen flight was not very successful -- the situation was mitigated when this inbound route was added Shanghai, i.e. Chicago-Shanghai-Shenzhen.

4. *Time value.* Air cargo shipments mostly have high time value, and some shipments' time value is even higher. In many airlines, customers can place personalized orders specifying the shipping time limit.

5. *Capacity Multi-dimensionality and uncertainty.* Cargo capacity is constrained by weight and volume. For forwarders, it is often measured in terms of unit load devices, of which the shape depends on its position on the plane. For passenger planes, the capacity for cargo is typically uncertain, depending on passengers' baggage, fuel, weather, and other factors.

Such characteristics make air cargo RM challenging, but also make sophisticated techniques developed by researchers meaningful. Table 3 provides a summary of several academic papers on this topic.

Table 3: Summary of literature on air cargo RM

Paper	Major decision	Uncertainty	Flight	Method
Popescu et al. (2006)	Show-up rate	--	--	Forecasting
Moussawi and Cakanyildirim (2011)	Overbooking	Demand	Single leg	Aggregate
Luo et al. (2009)	Overbooking	Demand	Single leg	Curve and Rectangle
Amaruchkul et al. (2007)	Accept/reject policy	Cargo weight and volume	Single leg	MDP, heuristics
Levina et al. (2011)	Accept/reject policy	Aircraft and Cargo capacity	Network	DP, approximation
Levin et al. (2011)	Allotment, accept/reject	Capacity utilization	One OD pair	DP, approximation

Popescu et al. (2006) report how they estimate the show-up rate of bookings based on real data. The show-up rate is the percentage of the demand booked that actually shows up at flight departure, which is essential for implementing the overbooking policy, i.e. selling more capacity than available.

Luo et al. (2009) consider a two-dimensional overbooking problem on a particular flight to minimize the sum of capacity spoilage and cargo offloading costs and find the optimal overbooking curve. Moussawi-Haidar and Cakanyildirim (2011) study a similar problem and use an aggregate formulation to obtain the optimal overbooking curve.

Amaruchkul et al. (2007) determine whether to accept a booking request or not given that the weight and volume of each request is uncertain until the check-in time. The problem of maximizing the expected profit on a single-leg flight is formulated as a Markov decision process (MDP). They then develop six heuristics to solve it. Han et al. (2010) also study the accept/reject booking control on a single-leg flight and propose a Markovian model where the booking control follows a bid-price policy.

Levina et al. (2011) present a network setting on the booking control problem. The temporal aspect is also incorporated. The exact weight and volume of each shipment are uncertain. They maximize the airline's expected profit while ensuring effective movement of each accepted shipment. The stochastic dynamic control problem is solved by approximation.

Levin et al. (2011) integrate the allotment decisions with the booking control decisions for an airline operating parallel flights between an origin-destination (OD) pair. The airline selects bids submitted by potential customers during the allotment booking process, and decides the accept/reject policy for the ad-hoc demand in the spot market. The problem in the spot market is formulated as a dynamic program with expected profit estimated by approximations.

6. Conclusion

We only review a very small portion of the emerging literature on air cargo in the OR/MS field. Many related papers are not included, such as Wong et al. (2009) studying the optimal baggage-limit policy for a passenger-cargo mixed flight, and Derigs et al. (2009) considering air cargo network planning.

Finally, we conclude this paper by disusing on some topics on which few works have been done.

Competition and cooperation. There are many carriers and many forwarders in the air cargo industry. Forwarders usually form an alliance to expand their network to be able to meet diversified demand in this era of globalization. Many airlines have cooperated with logistics agents such as trucking companies to provide door-to-door services to customers. For airlines and forwarders, the completion from global integrators like DHL and UPS is fierce. However, monopolies are not like to occur since there are so many types of goods. For example, some airlines and forwarders specialize in delivering musical instruments, and some specialize in goldfish.

Cargo network. Traditionally, air cargo shipping just uses passenger flights' network since a significant portion of cargo is carrier in the belly space of passenger aircraft. However, as the air cargo business becomes increasingly important, it might be necessary to develop the cargo's own network. This is a strategic decision involving governments, airports, and airlines. Actually, cargo network is more dynamic than passenger network. It would follow the manufacturing industries. Since the network decision is based on the demand forecast, the forecasting and empirical research is also important.

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