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Overview Paper

Air cargo operations: Literature review and comparison with practices

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ABSTRACT

This study reviews the literature on air cargo operations and compares theoretical studies with the practical problems of airlines, freight forwarders, and terminal service providers. In particular, we review studies in which mathematical models were used to identify the essential characteristics of air cargo operations, such as the intrinsic differences from passenger operations, and to explore the service processes in air cargo operations. The typical models used in previous studies are summarized. We then highlight the insightful findings from an industrial interview and present the gaps between previous research and practical realities. We finally discuss the new research opportunities of air cargo operations according to the gaps.

1. Introduction

With increasing globalization, the air cargo industry has continued to serve as a key facilitator of world trade and has doubled in volume every 10 years since 1970 (Chang et al., 2007). Goods transported by air account for 36% by value of all goods traded globally (IATA, 2006). Worldwide, air cargo transport has grown about 50% faster than passenger transport during 1995 and 2004 (Wong et al., 2009) and continues to grow in recent years. Air cargo transport is becoming a significant revenue source for airlines (Han et al., 2010; Nobert and Roy, 1998), whose profit has climbed to 40% in average in 2009 from about only 5% in 2000. Boeing (2014) forecasts that the air cargo market will continue to grow by 4.7% per year and will triple in revenue by 2033 from 207.8 billion revenue ton kilometers (RTKs) in 2013 to over 521.8 RTKs in 2033 (see Fig. 1). This growth is largely attributed to the expansion in Asian markets, particularly in China, as shown in Fig. 2 (Petersen, 2007). Several factors drive this dramatic growth, including the rapidly growing global trade, the high demand for fast and timely delivery, and firms' efforts to keep a low inventory through frequent replenishments (Li et al., 2009; Ou et al., 2010).

Airlines are challenged to manage their air cargo operations efficiently by developing strategic operation plans that allow these airlines to promptly adapt and respond to changes in the global competitive environment (Nobert and Roy, 1998; Ferguson et al., 2013). In response to such challenges, an increasing amount of theoretical research has been conducted to address the problems in air cargo operations since the 1990s. However, most problems, real-world problems in particular, remain unsatisfactorily solved, partly because of the complexities of air cargo operations. Therefore, this study aims to present the challenges faced by the air cargo transport industry through a comprehensive review of the literature on all aspects

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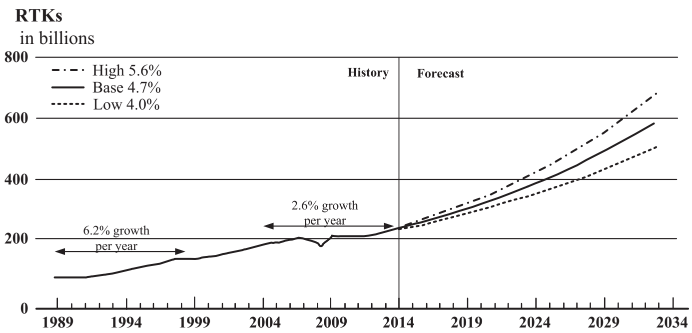

Fig. 1. Growth of world air cargo.

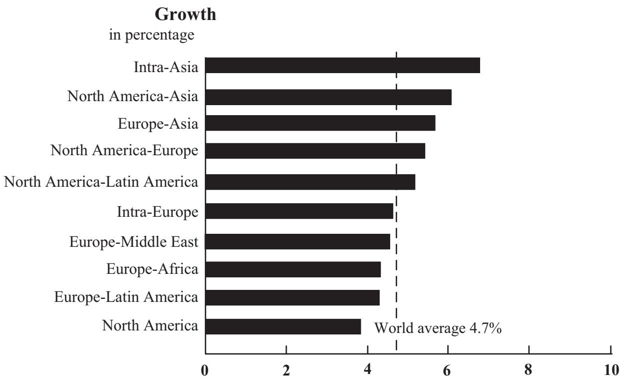

Fig. 2. Asian cargo markets continue to lead industry growth.

of air cargo operations and through a comparison of previous theoretical research with practical realities. In particular, we aim to develop a big picture of air cargo operations to show the highly interdependent decisions among many interfaces and players.

The rest of this paper is organized as follows. Section 2 describes air cargo transport processes and identifies their latent features. Section 3 categorizes and tabulates the air cargo literature. Section 4 presents real-world decision problems in the air cargo industry, highlights the gaps between academic research and realities and then suggests new research opportunities. Section 5 presents the summary.

2. Overview of air cargo operations

Air cargo transport involves a series of services from origins to destinations to move cargo through a *shipper*, a *forwarder*, a *road transporter* (or trucker), an *airline* (or carrier), and a *consignee* (Derigs et al., 2009). The shipper needs the commodity to be sent anywhere in the world at a low cost and at the required service level. The forwarder acts as the "middle man" between the shipper and the airlines. The road transporter provides the ground transportation services before and after air transport. The airline receives, stores, transfers, tracks, loads and unloads cargo, and assigns and manages capacity. The consignee receives the shipment. Fig. 3 depicts the air cargo transport processes (Kasilingam, 2003).

Two types of airlines are involved in this service supply chain: integrated express carriers and passenger and cargo combination airlines. Combination airlines may carry air freight, express packages, and mail in the belly space of passenger aircraft and operate dedicated freight aircraft (Li et al., 2012). Some combination airlines may also run "combi" aircraft whose cargo capacity is adjustable through the removal or addition of passenger seats. All-cargo carriers consist of integrated express carriers (e.g., FedEx, UPS, and DHL) and non-integrated freight carriers.[1] Integrated express carriers mainly sell capacity to shippers directly (direct channel market), but they also sell excess capacity to freight forwarders (indirect channel market). In the indirect channel market, integrated express carriers and non-integrated ones share the same supply chain structure, and they face mostly the same decision problems. In the direct channel market, the decision problems for integrated

[1] All-cargo carrier provides express/small packages services with dedicated freight aircraft in a door-to-door manner using its own air and ground fleet to process the entire shipment. Non-integrated freight carriers provide services for bulk and heavy shipments using dedicated freight aircraft through collaborations with freight forwarders.

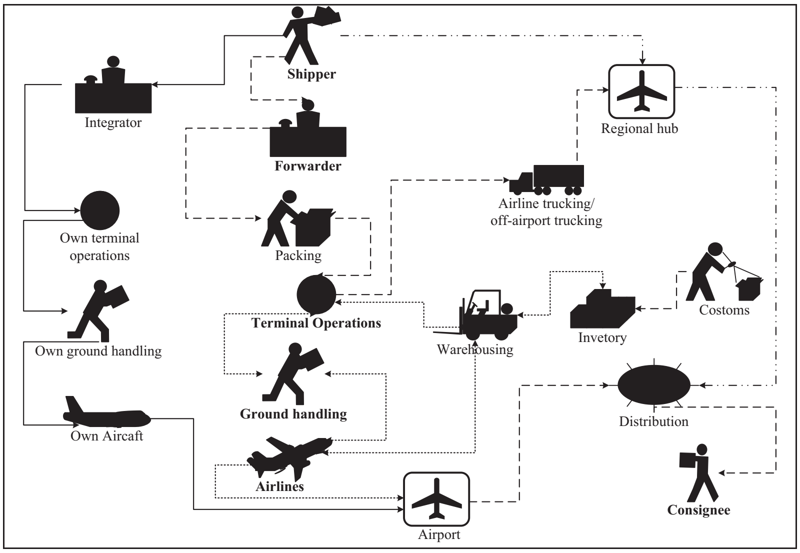

Fig. 3. A landscape of air cargo operations.

express carriers are mostly centralized, and no games on pricing and capacity allocation are played between airlines and forwarders as in the decentralized case. Thus, the decision problems for integrated express carriers are considered relatively simpler than the decentralized decisions for non-integrated carriers. We focus our discussion on the case of combination airlines, which are representative when discussing the air cargo industry.

Airlines (or carriers) provide freight forwarders and shippers with services, including consultation, capacity booking, pickup, receiving, packaging, sorting, loading, transportation, dispatching, and cargo tracking and tracing. Air cargo service is classified into different levels according to the priority level[2] (e.g., speed and reliability) required by the shipper. Rates vary according to service priority and cargo type, such as dangerous goods, live animals, perishable foods, and high-value items (Nobert and Roy, 1998). A typical service flow of air cargo transport consists of several key processes (Nobert and Roy, 1998). It begins when cargo is delivered by forwarders (or the shippers themselves) to the origin airport cargo terminal by trucks in containers or as bulk cargo. The cargo is unloaded and sorted according to its destination and other information on the shipping documentation, such as weight, dimensions, number of pieces, and type of freight. The airline computes tariffs and prepares a waybill that is used to verify the items in subsequent handling. Bulk cargo is consolidated into a container or stacked on a pallet covered with a net and straps. Direct flights are not always available for every destination, so the cargo can be shipped to a hub airport and then unloaded, sorted, and reloaded at the freight terminal before being sent to the destination airport. Once it reaches its destination airport, it is verified and moved to a warehouse for delivery by local freight forwarders or pickup by consignees. Table 1 summarizes the activities or operations of the key players in air cargo service (Kasilingam, 2003).

Air cargo transport is more complex than passenger transport because the former involves more players, more sophisticated processes, a combination of weight and volume, varied priority services, integration and consolidation strategies, and multiple itineraries of a network than the latter. The key differences between cargo and passenger operations have been highlighted in the literature (e.g., Bartodziej et al., 2009; Leung et al., 2009; Li et al., 2009; Wang and Kao, 2008). A summary is presented in the following.

(1) Uncertainty

Air cargo transport has higher uncertainty than passenger transport in terms of capacity availability. In passenger transport, passengers may cancel reservations, and a small number of passengers may not show up. However, in capacity booking for air cargo, freight forwarders have to pledge the use of the cargo capacity on specific flights ahead of twelve (or six) months (Amaruchkul et al., 2011). The quantity of goods to be shipped is actual rather than booked orders, so this creates high fluctuations in capacity management. Usually, freight forwarders do not need to pay for unused capacity. With no penalty charge for unused capacity, the forwarder may book more than the actual need to cut risks or immorally compete with others. Meanwhile, many bookings in air cargo are cancelled, rebooked, and cancelled again because airlines typically do not charge for changing reservations. Therefore, the booking process is subject to considerable volatility (Petersen, 2007).

[2] For instance, priority services ensure "the latest flight", "same day" or "over night" delivery, whereas regular services can take up to a few days depending on the origin and destination of the freight.

Table 1
Activity/operation of key players in air cargo service.

Player	Activity/operation	
Shipper	– Make booking – Negotiate best rates – Select priority – Preparation of documents-customs, insurance	– Track shipments – Accept billings and make payments – Place claims and repair changes
Forwarder	– Make booking – Negotiate best rates – Select priority – Preparation of documents-customs, insurance – Track shipments – Accept billings and make payments – Place claims and repair changes	– Booking acceptance – Bid for space-allotments – Distribution – Warehousing – Invoice shipper – Interact with multi-modal carriers – Massaging and transaction ability – Consolidation of shipments
Airline	– Schedule cargo flight – Plan cargo routs – Initialize and open flights for booking – Negotiate rates – Publish prices/rates – Provide distribution channels – Forecast cargo capacity – Segment and forecast cargo demand – Plan for no-show, cancellations and overbook – Set-up bid prices – Accept/reject shipments orders – Maximize revenue – Improve load factors – Track shipments – Accept bids from customers – Allocate cargo space-allotments – Resource management of terminal staff – Accept shipments tendered – Dangerous goods control – Package validation	– Shipment prioritization – Shipment re-accommodation – Plan loading of cargo-build, containerize, etc. – Unload cargo – Load balancing – Warehousing – Obtain/send flight manifest – ULD management-track, inventory, repairs, etc. – Service reliability – Track and re-route refusals – Offer production services-express, next day – Track shipments, containers – Invoicing/ billing – Prorating – Interline billing – Revenue accounting – Sales accounting – Claims management – Receive/send updates on arrival – Receive/send updates on delivery – Massage interactions
Airports	– Warehousing-storage – Customs – Security clearance – Dangerous goods control	– Package validation – Notify captain – Facilitate smooth cargo operations
Consignee	– Track shipments – Accept billings and make payments	– Place claims and repair charges

(2) Complexity

Cargo capacity forecasting is significantly more complex than passenger aircraft capacity forecasting. While the capacity of a passenger aircraft is fixed by its number of seats, cargo capacity depends on the container types used, called unit load devices (ULDs), which are further specified by multiple dimensions, such as pivot weight, pivot volume, type, and center of gravity (Leung et al., 2009). For instance, the capacity may be enough in terms of volume but not in terms of weight when a heavy cargo arrives. Multiple dimensions are a key feature of freight, which render both complexity and uncertainty to air cargo capacity management.

(3) Flexibility

Transshipment itineraries between an origin and destination (OD) pair for cargo transport benefit the airline more than they benefit passenger transport. In general, all major airlines operate so-called hub-and-spoke networks. Both passengers and cargo are transported from many different origins to a small number of hubs, where passengers and cargo are consolidated and then transported to other hubs with the use of wide-body aircraft. For passenger transport, too many transits are unacceptable, whereas air cargo can be transshipped via several intermediate airports from the origin to the destination to meet the delivery time (Amaruchkul et al., 2011). The airline only needs to declare the origin, stopover (transit) airports, and destination to the forwarders and can make transshipment itinerary plans to optimize the use of network capacity.

3. Research on air cargo operations

Air cargo transport is a widely researched area with methodologies from conceptual to empirical to modeling. Studies on air cargo before the mid-1980s mainly focused on the description of systems, the operational process, and industry development. Since then, an increasing number of studies have examined quantitative decision methods for air cargo operations in response to the dramatic growth of the air cargo market and the emergence of computer-aided decision-making techniques. In particular, the number of studies has sharply increased in the last decade.

This study focuses on research that involved mathematical models and were published during the last two decades. Our search found about 60 closely related articles, which were classified from the perspectives of airlines, freight forwarders, and service supply chains, with clear definitions for each type of decision problem addressed in the literature.

3.1. The airline perspective

The literature indicates that airlines are clearly the dominant players in the air cargo industry. The operational decisions addressed in the literature consist of mainly four types of problems: revenue management, terminal operations, fleet routing and flight scheduling, and aircraft loading.

3.1.1. Revenue management

Air cargo revenue management is the integrated management of the *capacity forecast* of dedicated freighters and passenger aircraft, network *capacity plan and allocation*, *pricing*, *overbooking, reject-or-accept policies*, and *capacity contracting,* with the objective of maximizing overall profitability. Air cargo revenue management differs from passenger yield management in several aspects because of the distinct characteristics of different cargo types in terms of available capacity estimation, network capacity allocation, and capacity booking behavior.

As for existing studies on air cargo revenue management, the majority discussed overbooking and its purpose to compensate for no-shows, cancellations, and variable tenders. Kasilingam (1996) provided a concise review of the literature in the area of yield management and compared passenger yield management with cargo revenue management. Kasilingam (1997) proposed an optimization model for air cargo overbooking by calculating the overbooking levels for discrete and continuous probability distributions of capacity. Popescu et al. (2006) presented an alternative nonparametric distribution estimation method to calculate the show-up rate for cargo booking and compared the proposed discrete distribution with the normal distribution by using real data from airlines. From an information system perspective, Wang and Kao (2008) developed a fuzzy knowledge system to determine the overbooking level based on fuzzy reasoning, in which they expressed fuzzy decision rules in the form of triangular fuzzy numbers. Qin et al. (2012) established a dynamic programming model to achieve dynamic space inventory control for air cargo with consideration of overbooking. Some important structure properties were elicited from their model. Totamane et al. (2014) used the Potluck Problem approach to propose a multi-producer or multi-consumer solution for predicting the cargo demand in a route.

After estimating the available capacity in overbooking situations, airlines make the decision to accept or reject a booking request from freight forwarders in order to optimize the expected revenue. With regard to this issue, Amaruchkul et al. (2007) proposed a single flight Markov decision model to help airlines decide if a request from the freight forwarder should be accepted or rejected. Amaruchkul and Lorchirachoonkul (2011) extended this model to multiple flights by using a dynamic programming model and then proposed two heuristics to solve it. As an improvement to Amaruchkul et al.'s model, Han et al. (2010) addressed the capacity allocation problem in single-leg air cargo revenue management with additional consideration of a profit rate for each type of cargo. They assumed that each cargo booking request has a random weight, volume, cargo type, and profit rate, and they proposed a Markovian model to handle booking requests. Meanwhile, Huang and Chang (2010) also modeled the same decision problem by using dynamic programming, and they proposed a joint approximate algorithm to solve the high-dimensional state space problem in order to improve a de-coupling heuristic, which is one of the six algorithms with the best performance, as presented by Amaruchkul et al. (2007). Popescu et al. (2006) addressed the capacity allocation for small and large cargoes by using different polices. In addition to the aforementioned *ad hoc* sales problems, air cargo revenue management includes medium-to long-term contract problems. For instance, Gupta (2008) studied the carrier–forwarder incomplete contract problem, in which the forwarder's effort level determines the magnitude of demands. Amaruchkul et al. (2011) studied the contract with three parameters, namely, an allotment, lump-sum payment, and refund rate, between a carrier and a forwarder within the principal–agent framework. Hellermann et al. (2013) proposed an options contract that considers the overbooking of forwarders. A numerical study further provided analysis about the impact of overbooking on contract parameters and profitability.

In the literature, we find that the air cargo revenue management problem is mostly modeled as a stochastic programming problem. Table 2 summarizes the decision models and their respective attributes.

3.1.2. Terminal operations

Before cargo is moved to the aircraft, it is delivered to the airport terminals by trucks and then unloaded for inspection, information verification, sorting, and packing. This process involves decision problems on manpower planning and scheduling, cargo processing, and truck arrival, as well as on unloading management for air cargo terminal operations, all of which are interdependent. Airlines sometimes need the services of third-party terminal operators, such as the Hong Kong Air Cargo Terminals and the Singapore Airport Terminal Services Limited, especially for international cargo transportation.

Manpower planning and scheduling estimate manpower requirements and determine the work timetable (or shift) for the crew in a fixed or flexible hourly manner, with the objective of minimizing the overall cost. Nobert and Roy (1998) studied the operations of air cargo terminals and addressed the problem of scheduling freight-handling employees at air cargo

Table 2
Air cargo revenue management publications.

Reference	Focus	Environment	Model	Factor
Kasilingam (1996)	Overbooking	Discrete or continuous probability distribution	Stochastic programming	Capacity (show up rate × overbooking rate); spoilage cost; over-sale cost
Kasilingam (1997)	Overbooking	Discrete or continuous probability distribution	Stochastic programming	Capacity (show up rate × overbooking rate); spoilage cost; over-sale cost
Popescu et al. (2006)	Overbooking	Discrete distribution	Nonparametric distribution estimation and forecasting	Show-up rate (weight or volume)
Qin et al. (2012)	Overbooking	Continuous distribution	DP	–
Popescu (2006)	Accept-or-reject policy	Rates as a function of billable weight and cargo class	probabilistic nonlinear programming model; dynamic programming	Capacity (weight and volume); classes
Amaruchkul et al. (2007)	Accept-or-reject policy	Joint distribution of volume and weight	stochastic dynamic programming	Capacity (weight and volume); shipment type; terminal value
Gupta (2008)	Capacity contract	Deterministic demand	Stackelberg game	Forwarder's effort level; freight rate
Wang and Kao (2008)	Overbooking	Fuzziness	Fuzzy reasoning method	Capacity (weight and volume); spoilage cost, over-sale cost, show up rate
Han et al. (2010)	Accept-or-reject policy	Joint distribution of volume and weight	Stochastic dynamic programming	Capacity (weight and volume); profit rate;
Huang and Chang (2010)	Accept-or-reject policy	Discrete distribution	Stochastic dynamic programming	Capacity (weight and volume); profit rate; shipment type; penalty
Amaruchkul and Lorchirachoonkul (2011)	Accept-or-reject policy	Joint distribution of volume and weight	Stochastic dynamic programming	Capacity (space)
Amaruchkul et al. (2011)	Capacity contract	Random demand	Principle-agent game	An allotment, lump-sum payment and refund rate
Hellermann et al. (2013)	Capacity contract	Demand is a function of exogenous parameters and price	Game	Booking level, reservation number
Totamane et al. (2014)	Demand forecasting	Certain demand	Multiagent game	Weight of predictor, number of airlines, number of predictors, cargo capacity.

terminals. They developed an integer linear programming model to determine manpower requirements and a work timetable for a typical day. Yan et al. (2006a, 2008a, 2008b) conducted a series of studies on a manpower supply plan for air cargo terminals and used real operational data from a Taiwan air cargo terminal to verify their models. Yan et al. (2006a) proposed a model to plan long-term stochastic-demand terminal manpower supply, in which the strategies of flexible shifts and flexible working hours were considered. Yan et al. (2008a) further extended their preceding study to stochastic-demand manpower planning models for a weekly time horizon. Yan et al. (2008b) established two long-term stochastic-demand planning models by incorporating stochastic manpower demands. Recently, Rong and Grunow (2009) studied a mixed integer linear programming model to determine manpower requirements and personnel shift associated with the buildup and break-down of ULDs in order to minimize the manpower costs of an air cargo terminal.

The problem of cargo processing encompasses cargo routing among crew and multi-type facilities (e.g., automated guided vehicles, stacker cranes, cargo hoists, and conveyors), as well as cargo scheduling, with the objectives of minimizing the waiting time and maximizing resource utilization. Lee et al. (2006) employed time colored Petri nets to model the air cargo processing of handling equipment in a terminal. Lau and Zhao (2006) developed an approach to solve the problem on the different types of material handling equipment at automated air cargo terminals with consideration of the interactions between equipment. Xu et al. (2014) proposed a flow allocation routing strategy, in which a set of allocation ratios are derived from a multi-commodity network flow model with consideration of congestion.

In the local city transportation of air cargo, air cargo terminal truck arrival and unloading management determine the cargo delivery time intervals, with the objective of minimizing the waiting time, subject to limited service capability. This process affects the decisions on the number of pickups and dispatches and the truck routes for freight forwarders. Hall (2001) addressed the truck scheduling problem at airport terminals and modeled the terminal as a single service queuing system with random bulk arrivals. Ou et al. (2010) developed a model to schedule truck arrivals at air cargo terminals by coordinating the shipments that are directly transferred to the departing flights and other shipments that should be stored at the storage facilities of the terminal.

The literature shows different models to solve the various problems inherent in cargo terminal operations. Table 3 provides a summary of the literature.

3.1.3. Fleet routing and flight scheduling

Air cargo fleet routing and flight scheduling consist of fleet and crew planning, assignments between cargoes and flights, and route selection (i.e., airports linking OD pairs) (Doan and Ukkusuri, 2015). Fleet routing and flight scheduling are central to airline operations, and various decision support systems have been used by different airlines. For example, Lufthansa has

Table 3
Air cargo terminal operations.

Reference	Focus	Model	Objective	Constraint
Nobert and Roy (1998)	Manpower requirements and a work timetable	Integer linear programming model	Minimization of the total cost of the schedule	Number of employees
Hall (2001)	Truck scheduling	Probability model (single server queuing problem)	Maximization of productivity; minimization of the end time	Expected arrival of work
Lee et al. (2006)	Cargo routing and scheduling	Simulation model	Minimization of the cargo processing time	None
Lau and Zhao (2006)	Cargo routing and scheduling	Bi-objective matching model	Minimization of the cargo processing time; minimization of intermission time	Start time; one-to-one matching; actual event time
Yan et al. (2006a)	Manpower requirements and personnel shift	Integer/mixed integer linear programming	Minimization of manpower cost	Manpower demand
Yan et al. (2008a)	Manpower requirements and personal shift	Integer/mixed integer linear programming	Minimization of manpower cost	Manpower demand; amount of available manpower for each time slot
Yan et al. (2008b)	Manpower requirements and a work timetable	Mixed integer linear programming	Minimization of manpower cost	Manpower demand; amount of available manpower for each time slot
Rong and Grunow (2009)	Manpower requirements and personnel shift	Mixed integer linear programming	Minimization of manpower cost	Cargo priority; total build-up quantity; break-down time; break-down quantity; manpower requirements of each period; worker type restriction; different types of break-down and build-up workers; part-time workers share; number of shifts for different types of workers; repeated shift schedule
Ou et al. (2010)	Truck scheduling	Binary integer programming	Minimization of the total handling and storage cost	Each truck at one truck dock; largest number of severed truck during one time period
Xu et al. (2014)	Cargo routing and scheduling	LP model	Minimization of processing and congestion cost	Inflow, outflow, flow class, arc capacity

developed the *Net Line Schedule & Plan*. Much research has been conducted on the fleet routing and flight scheduling of passenger transport, whereas studies on air cargo fleet routing and flight scheduling are scarce.

In research on air cargo fleet routing and scheduling, some researchers focused on the airline fleet and scheduling problems for passengers and cargoes separately, and only dedicated freighters were modeled. For example, Yan et al. (2006a) proposed a scheduling model to solve the problems of airport selection, fleet routing, and timetable making for cargo operations. Yan and Chen (2008) further extended the application of this model to an alliance scenario. In early research on fleet routing and flight scheduling for air cargoes, the objective focused on leg-based operation profit or cost (see, for example, Amaruchkul et al., 2007). Derigs et al. (2009) extended the research to network-wide performance and formulated two integrated models to assist in flight selection, aircraft rotation, and cargo routing, with the objective of maximizing network profit. Derigs and Friederichs (2013) further developed an integrated model to modify the existing schedule of air cargo after mandatory and optional flights are identified. Azadian et al. (2012) formulated a novel Markov decision model for the dynamic routing of time-sensitive air cargo by using real-time information and departure delay probability.

Combination flights are extensively used by airlines, but the integrated flight scheduling problem has been seldom discussed in the literature. Li et al. (2006) described an approach for integrated fleet assignment and cargo routing through passenger and freighter networks. Tang et al. (2008) presented an integrated mixed integer programming (MIP) model to determine routes and timetables for passenger, cargo, and combination flights in order to minimize operating cost, subject to demand and operating constraints.

In addition to fleet routing and flight scheduling, network flow techniques were used by Lin and Chen (2003) to construct an MIP model for the selection of transshipment airports to link air cargo networks in Taiwan and mainland China. Derigs et al. (2011) presented two approaches to vehicle routing for air cargo road feeder services with consideration of EU regulations for tractor and trailer drivers. Menou et al. (2010) applied stochastic multi-criteria acceptability analysis (SMAA) to solve the problem of alternative selection for centralizing multi-modal cargo at a Moroccan airport hub. Lin et al. (2012) modeled the capacitated p-hub median problem and applied the proposed model and algorithm to the design of a

Table 4
Air cargo fleet planning and flight scheduling.

Reference	Focus	Flight	Model	Objective	Constraint
Lin and Chen (2003)	Transit airport selection	Cargo flight (belly cargo space)	MIP	Minimization of the cargo transportation cost	Flow conservation; belly cargo space; bundling constrain; number of direct transit airports
Yan et al. (2006a)	Airport selection, fleet routing and timetable making	Cargo flight	MIP	Minimization of system cost	Flow conservation; available airplanes; approved flight quota of airport/ airport pair; aircraft capacity; airport capacity; inbound and outbound node flow
Li et al. (2006)	Cargo routing and fleet assignment	Passenger, cargo and combination flights	MIP	Maximization of the total cargo and passenger profit	Flow conservation; available fleet; fleet type; leg capacity; demand constrain; inbound and outbound node flow
Yan and Chen (2008)	Fleet routing, timetable making and coordinated station selection	Cargo flight	MIP	Minimization of cost	Available airplanes; approved flight quota of coordinated stations; coordinated stations pair; aircraft capacity; station capacity; inbound and outbound node flow
Tang et al. (2008)	Passenger, cargo and combination flight scheduling and routing	Passenger, cargo and combination flights	MIP	Minimization of the system cost	Flow conservation; available airplane; flight leg service; airport pair flight quota; airport flight quota; airplane capacity; arc flow bound constraints and airplane flow integrality
Derigs et al. (2009)	Fleet selection, aircraft rotation planning and cargo routing	Cargo flight	MIP	Maximization of network profit	Leg-based capacity of volume and weight; demand constrain; cargo routing; available aircraft; inbound and outbound node flow; flow conservation; mandatory flight.
Derigs and Friederichs (2013)	Fleet selection ,fleet assignment, rotation planning, and cargo routing	Cargo flight	MIP	Minimization of the total cost	Flight cover, departure and arrival flow, fleet size
Menou et al. (2010)	Hub location	Cargo flight	SMAA	-	-
Derigs and Illing (2013)	Network reconfiguration	Cargo flight		Maximization of network profit	Departure and arrival flow, leg capacity, prohibiting flow, mandatory flights scheduling, additional allowance
Derigs et al. (2011)	Vehicle routing and driver scheduling	Cargo vehicle	MIP	Minimizing the number of trips; minimizing the total cost	Working time limits, net driving time
Azadian et al. (2012)	Dynamic routing	Passenger, cargo and combination flights	DP	Minimization of expected cost	Departure delay probability of a flight; cost of flight; available flight for a route.
Lin et al. (2012)	Hub location	Cargo	P-median	Minimization of total operating cost	Capacity of hub, number of hubs, equality between inbound cargo and outbound cargo

Chinese air cargo network. Derigs and Illing (2013) addressed a very interesting problem, which is air cargo network reconfiguration under the EU emissions trading scheme (ETS). They analyzed the five scenarios of basic EU-ETS, EU-ETS with no free allowances, aggressive EU-ETS, hub relocation, and green fleet, and they found that network reconfiguration by hub relocation might be a proper approach. Table 4 presents a summary of the decision models involved in fleet routing and flight scheduling.

3.1.4. Aircraft loading

Aircraft loading largely takes the form of loading ULDs into the aircraft with multi-dimensional restrictions, such as weight, volume, container position, center of gravity, container types, and random passenger baggage. As a modeling problem, aircraft loading is defined as a 3D bin packing problem (BPP), which is one of the basic problems in combinational optimization and is characterized as an NP-hard problem.

Mongeau and Bès (2003) addressed the problem of how to load the maximum number of containers into an aircraft, with a tradeoff between minimizing fuel consumption and satisfying safety requirements. Yan et al. (2006c) built a cargo container loading plan model and examined this model with the operations of FedEx. Yan et al. (2008c) extended the aircraft loading problem to a stochastic environment and built a mixed integer non-linear model for cargo container loading by considering the stochastic disturbances of daily cargo transportation demands. Wong et al. (2009) identified a new problem, in which the airline sought an optimal baggage limit policy when the cargo was transported in the residual aircraft belly space together with passenger baggage. The authors formulated this problem as a variant of the price-dependent multi-item newsvendor model with weight–volume capacity constraints. Table 5 summarizes these models.

3.2. The freight forwarder's perspective

The majority of extant literature focuses on the air cargo operations of airlines, and only a few discuss those of freight forwarders. The air cargo operations of freight forwarders include specific decision problems, such as *capacity booking*, *supply strategies for airlines*, *container loading*, *integration and consolidation strategies*, and *truck routing and scheduling*.

The freight forwarder executes revenue management through capacity booking and supply strategies for different airlines. Capacity booking determines the capacity allocation between a long-term contract and dynamic capacity booking in view of a random market demand, and it is used to update the weight and cargo type for a scheduled flight for arrived consignments. Chew et al. (2006) proposed a stochastic dynamic programming model for the short-term capacity planning of the freight forwarder; given a long-term contract capacity, the model was used to determine the additional short-term capacity.

Although container loading shares many similarities with aircraft loading, such as the need to consider volume and weight, container loading has some unique characteristics, such as pivot weight and pivot volume, which have drawn much attention from researchers. The problem of container loading is defined as placing cargoes into ULDs, subject to weight, volume, and cargo type, with a time limit for the crew to handle the loading. Xue and Lai (1997) presented an integer programming model for container selection and cargo loading to minimize the total cost. Chan et al. (2006) developed a decision support system to optimize the cost related to air cargo pallet selection and loading. Huang and Chi (2007) studied how a freight forwarder should consolidate its shipments to utilize the quantity discounts offered by airlines. Wu (2008) built an optimization model to help logistics managers make decisions on how to rent containers from airlines with different weight and volume limits. Li et al. (2009) discussed this research issue and developed a large-scale neighborhood search heuristic to determine the container loading plan. Wu (2010) extended his 2008 study to an uncertain environment and formulated a stochastic mixed 0–1 integer model to determine the booking types and quantities of containers, as well as a containerization plan to minimize the total rental cost. Wu (2011) further extended his research to incorporate the decision of renting and returning the number of containers by using a two-stage recourse model with allowance of later transport. Tang (2011) developed a scenario decomposition-genetic algorithm to solve the pure and mixed container loading problem. Chan et al. (2012) developed a multi-agent-based system based on the cargo information obtained by radio-frequency identification (RFID) technology to assist freight forwarders in flight planning.

Table 5
Aircraft loading.

Reference	Focus	Model	Objective	Constraint
Mongeau and Bès (2003)	Aircraft loading	Integer programming	Maximization of mass loading	Stability requirements; aircraft volume capacity; one container for a specific compartment
Yan et al. (2006c)	Aircraft loading	Nonlinear MIP	Minimization of container handling cost	OD demand, container capacity, number of container, container handling capacity for each gateway; air craft capacity
Yan et al. (2008c)	Aircraft loading	Nonlinear MIP	Minimization of the expected value of the total container handing cost	Achievement of original-and- destination transportation demand; container handling capacity for each gateway; air craft capacity
Wong et al. (2009)	Baggage limit policy	Newsvendor model	Maximization of expected profit	–

Table 6 summarizes the literature available on container loading.

Cargo pickup and dispatch are not unique to air cargo operations, and they also occur in general vehicle routing literature. With a slack in time windows, which is often allowed by the terminal, the freight forwarder can optimize its number of daily pickups (from the shipper/airport/terminal) in terms of vehicle routing needs. Patel et al. (2006) provided four models for the pickup times for cargo from the airport to the local distribution center. The first three respectively minimize the number of daily air cargo pickups, average delivery time, and maximum delivery time without weight consideration, whereas the fourth minimizes the total transportation cost with the price discount on cargo weight.

In the process of cargo consolidation, the cargo is packed and loaded into a ULD (e.g., container, pallet) and then into a single transportation vehicle (e.g., truck, aircraft). The purpose of this process is to minimize cost according to the cargo type, OD pairs, density, and other factors. Cargo consolidation services are commonly provided by airlines and freight forwarders to help shippers save costs. The prevalence of these services in practice is unsurprising, especially in third-party logistics. However, theoretical investigation on the consolidation and integration of forwarders and airlines is scarce. One exception is the study of Leung et al. (2009), which discussed a decision problem involving the integration and consolidation of air cargo shipments for freight forwarders from the perspective of outsourcing. They formulated a model to determine the assignment between activities of jobs and processing units, with the objective of minimizing the total cost.

3.3. The service supply chain's perspective

Air cargo service supply chains involve complex decision-making processes, including *outsourcing*, *integratio*n, *coordination*, and *competition*, which have been investigated only sparsely in the literature.

Zhang and Zhang (2002) employed a multi-market oligopoly model to examine the effect of cargo liberalization on the competition between all-cargo carriers and combination carriers. They found that the optimal operation requires dedicated cargo carriers and airlines with committed freighter fleets. However, in real businesses, especially in Asia, most passenger carriers have substantial cargo businesses and operate combination fleets. Zhang et al. (2004) further investigated the effect of alliances, in which partners offer passenger service but jointly provide integrated cargo service by using passenger aircraft and routes. Their findings suggested that such an alliance contributes to joint profit and also benefits passengers. From the perspective of a service supply chain, Zhang et al. (2007) examined the effect of multi-modal integration on the rivalry in a supply chain that consists of integrators, forwarders, and airlines. They found that a forwarder–airline alliance in multi-modal integration will improve the output of the alliance and reduce the output of the integrator. Chang et al. (2007) provided a fuzzy group decision-making method to evaluate the alternative strategies proposed for the development of a national air cargo industry.

In addition, some studies relate to service improvement in air cargo supply chains. Khan (2000) used a case to demonstrate the application of business process reengineering (BPR) techniques to improve an air cargo handing process at airports. Leung et al. (2000) presented a framework for a third-party e-commerce community network to enable the agents of the air cargo industry to develop and engage in online integration of transactions. Li and Shue (2003) proposed a systemic architecture for air cargo information and developed a prototype system to support cargo tracking. Table 7 provides a summary of these studies.

4. The gap between theory and practice: New research opportunities

4.1. Realities of air cargo operations

To investigate the realities of air cargo operations, we conducted a collaborative study with China Southern Airlines Co., Ltd. (CSA) and its 11 freight forwarders, which vary significantly in size. Recording a revenue of CNY 98.1 billion (US$ 15.75 billion) in 2013, CSA is the world's fifth largest airline in terms of passengers carried and is Asia's largest airline in terms of both fleet size and passengers carried. CSA is a member of the Sky Team and code-shares with 14 Sky Team members. CSA is a typical subject to conduct an industrial survey. The Asia air cargo market is a large and emerging market. Intra-Asia and North America–Asia businesses are among the top three markets in the world. The emerging market confronts more uncertain situations and more complex decision problems than the matured market. In addition, the airlines joined in Sky Alliance, Star Alliance, and One World Alliance closely collaborate with one another and share the same policies and similar rules. Allied partners encounter the same situation for a vast majority of decision problems, especially for the international air cargo market.

The 11 freight forwarders are China railway express, Haoyunlai, Nanke, Jinda, Yongxing, Zhengtong, Xinbang, Lianshun, Xuehang, Taishi, and Deppon. Among these, the large freight forwarders pay CSA more than 2 million RMBs of transportation fare per year. The forwarders mainly collaborate with CSA for long distance transportation and use trucking for short distance between neighboring cities. Among the 11 forwarders, Deppon is a leading integrated service-oriented logistics provider, who is dedicated to the domestic road and air freight services. Deppon has more than 5,200 outlets in the 34 provinces, municipalities and autonomous regions (by 2014 October). Deppon boasts its widest customized transport service network coverage in 550-plus cities and regions across China, with more than 8900 freight vehicles and whole warehousing

Table 6
Container loading.

Reference	Focus	Model	Objective	Constraint
Xue and Lai (1997)	Container loading	Integer programming	Minimization of the total cost	Only one cargo load to one container. volume and weight limits of containers
Chan et al. (2006)	Pallet selection and pellet loading	Linear programming	Minimization of the total cost	Weight restriction; volume of selected pallets; weight limit of a pallet; available pallets of each type
Huang and Chi (2007)	Container renting and loading	MIP	Minimization of the total expense	Each item must be assigned into one flight; weight and volume constraints of consolidated shipments; segment weight must be within the segment range
Wu (2008)	Container loading	MIP	Minimization of the total cost	Container volume; container weight; cargo quantity
Li et al. (2009)	Container renting and loading	MIP	Minimization of the total cost	Only one cargo loads into one container, volume and weight limits of containers; maximum capability restriction; extra capability restriction
Wu (2010)	Container renting and loading	Stochastic integer programming	Minimization of the total cost	Container volume; container weight; cargo quantity
Tang (2011)	Container loading	MIP	Minimization of the total cost	Percentage of pure and mixed containers; container volume; aircraft capacity; container handling capacity
Wu (2011)	Container renting and returning	MIP	Minimization of the total cost	Container volume; container weight; cargo quantity
Chan et al. (2012)	Flight planning	System framework	Minimization of the operation cost; minimization of overloading free	–

Table 7
Industrial strategy.

Reference	Focus	Model	Implications
Zhang and Zhang (2002)	Air cargo business segmentation	Multi-market oligopoly model	Optimal air traffic needs the dedicated cargo carriers and the airlines with dedicated freighter fleets
Zhang et al. (2004)	Alliance for air cargo market	Oligopoly model	Alliances contribute to partner profit and benefit the passengers.
Zhang et al. (2007)	Alliance in multimodal integration	Strategic alliance model	A forwarder-airline alliance benefits itself
Chang et al. (2007)	Air cargo industry strategy evaluation	Fuzzy group decision making	–
Leung et al. (2000)	E-commerce platform	Framework of logistics community network	–
Khan (2000)	BPR of air cargo handing	Flow diagram of air cargo handing	–
Li and Shue (2003)	System for cargo tracking	System architecture	

area over 1,050,000 m^2. It offers a full range of products and services like precision GPS-enabled road express service, precision intercity freight service, precision road freight service, and precision air freight service, etc.

The research was conducted in three phases: informal interviews, semi-structured interviews, and field observations. The key departments and managers were identified from the informal interviews in the first phase. Semi-structured interviews with the identified managers from the air cargo departments were conducted in the second phase to discuss intra- and inter-department problems. Air cargo transport processes at the warehouses of freight forwarders, cargo terminals, and airports were observed in the last phase in light of feedback from the interviews. Our primary goal is to delineate the real-world operations that are general and universal for most airlines in order to further understand operational decision-making problems and identify the key gaps between theories and practices.

Some of the important findings and managerial insights obtained from the airline interview are detailed below.

(1) Important pre-allocation for air cargo capacity management

Airlines sell the majority of air cargo capacity to forwarders in the long-term, medium-term, and spot markets. In the long-term market, airlines sell cargo capacity to forwarders through pre-allocation, which is done according to the forwarders' performance in the last year. Once the forwarders accept the capacity quota for the coming year, they are expected to commit to the allotments by exerting desirable sales effort. In the medium-term market, forwarders contract with airlines to purchase all-cargo aircraft capacity one season or half a year ahead when they have stable cargo sources. In the spot market, forwarders book cargo capacity from airlines five hours to one week ahead. Note that the pre-allocation or the contracting in the long- and medium-term markets is done through relational contracts; this means that the unused capacity will either be returned with full credits, or simply, no penalty will be imposed on the forwarders.

(2) Dynamic pricing in the spot market

In the spot market of air cargo, airlines use dynamic pricing. Because of the hub-and-spoke structure used by most airlines, a dominant player or leader commonly exists for each regional market. Thus, dynamic pricing is often a leader–follower game. The other airlines just follow the price set by the dominant player in the regional market. The dynamic pricing in the spot market gives difficulty to forwarders, which thus usually allocate their demands among different airlines, especially when the located city is not a hub of a large airline. The rate of air cargo transport is affected by many factors, such as the planned capacity, fuel price, seasonal fluctuation, emergent events, and national policy. However, customers or shippers do not face dynamic prices, and forwarders bear all pricing uncertainties. Therefore, forwarders play a key role in matching the supply and demand and in absorbing the pricing risk. For this purpose, they face a challenging problem on capacity booking, both in the upfront market and the spot market.

(3) Decentralized air cargo capacity management

Airlines manage network capacity through several branches, and each operates its own regional business. In each branch, many representatives allocate and sell the capacity to local forwarders. At the beginning of a planning period, the capacity planning department assigns network capacity to each branch. Then, each branch representative allocates the capacity of the managed routes to forwarders according to their performances in the preceding year. Such a decentralized organization structure is said to be very typical among most, if not all, airlines.

(4) Imbalanced capacity supply for different routes

CSA data indicate that the capacity booking rate for hot-selling routes (accounting for 24.5%) is over 100%, but the utilization rate for underutilized routes (accounting for 33.6%) is less than 50%. For example, the cargo capacity of an early morning passenger flight from Guangzhou to Changsha is very tight, whereas the cargo capacity of all passenger flights from Guangzhou to Sanya is idle. We observed that in reality, forwarders strongly aim for the capacity in hot-selling routes because of their high margin. Multiple reasons contribute to this imbalance. The first is imbalanced interregional and international trade. The second is unidirectional air cargo flows, which are different from passenger flows. The third is the unmatched demands for passengers and cargoes when cargoes are carried in the belly space of passenger flights.

(5) Difficulty of implementing overbooking for air cargo capacity

Air cargo revenue management faces the challenge of uncertain supply and demand because of the unexpected number of passengers and passenger luggage, the fuel level prepared for different weather conditions, aviation control, loading duration, and loading efficiency. With these uncertainties considered, the unaddressed issue of air cargo revenue management has received some attention in the literature (Kasilingam, 1996, 1997; Popescu et al., 2006; Wang and Kao, 2008). However, thus far, airlines have not implemented an overbooking policy in the cargo section. In practice, the arrived cargo demand at the tarmac often exceeds the planned capacity. When this happens, more costs are incurred than in the case of passenger overbooking. A decision on which cargo should be unloaded, postponed, or rerouted in consideration of its value, type, priority, volume, weight, and other factors needs to be made. Despite this reality, examining the feasibility of implementing such a policy in practice remains appealing.

Based on the above findings and on previous literature, we derive the decision problems, mainly those that are directly related to the air cargo industry; those from general freight transportation related to shippers and truckers will not be covered. Fig. 4 shows the decision processes in air cargo operations. Supply chain partners and peripheral players are represented by rounded rectangles and ellipses, respectively. The decision problems are highlighted by rectangles. The dashed rectangles show the decision problems related to the freight forwarder, and the dotted lines show those that are related to airline operations. The shadowed rectangles indicate the degree to which the decision problems have been investigated. The black shadowed rectangles indicate that the problem has been solved in the literature in line with realistic situations. The grey shadowed rectangles indicate that the problem has been examined in the literature, but the gaps remain between theories and realities. The white shadowed rectangles represent the research areas that are currently underdeveloped. Fig. 4 shows that problems 1–6 are related to the freight forwarder, whereas problems 7–23 are related to airline operations. In particular, problems 13–17 are associated with the operations at the air cargo terminal.

As mentioned, some decision problems listed in Fig. 4 have been well studied in the literature, including container loading (Chan et al., 2006; Huang and Chi, 2007; Wu, 2008), truck routing (e.g., Patel et al., 2006), crew supply and scheduling for air cargo terminals (Nobert and Roy, 1998; Rong and Grunow, 2009; Yan et al., 2006a, 2008a, 2008b), passenger baggage limit strategies (Wong et al., 2009), and fleet scheduling and flight routing (e.g., Li et al., 2006; Yan et al., 2006b; Yan and Chen, 2008).

Eight areas, highlighted by shadowed gray rectangles, have been discussed in the existing literature, but we found that the theoretical work in these areas falls short of meeting practical requirements in view of the complexities in the real world. These research problems include demand estimation and dynamic capacity booking of freight forwarders for the short term (Chew et al., 2006), overbooking (Kasilingam, 1996, 1997; Popescu et al., 2006; Wang and Kao, 2008), reject-or-accept policies (Amaruchkul et al., 2007; Han et al., 2010; Huang and Chang, 2010), integration and consolidation of air cargo shipments (Leung et al., 2009), truck scheduling and unloading at the air cargo terminal (see, for example, Hall, 2001; Lau and Zhao,

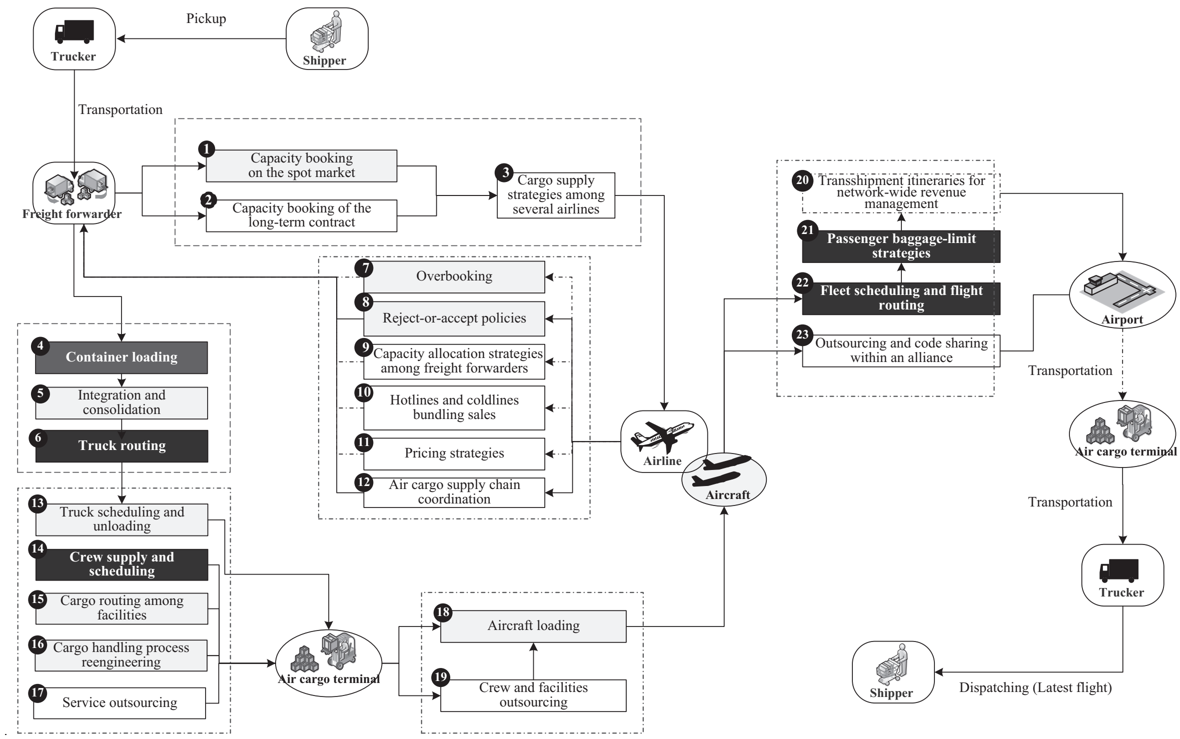

Fig. 4. Air cargo operations: process and the state of research.

2006; Ou et al., 2010), cargo routing among facilities at the air cargo terminal (Lau and Zhao, 2006; Lee et al., 2006), cargo handing process reengineering (Khan, 2000), and aircraft loading at the tarmac (Mongeau and Bès, 2003; Yan et al., 2008c).

Almost half of the decision problems, highlighted by shadowed white rectangles, have not been investigated (see Fig. 4). These problems leave gaps between theories and realities and thus imply new research opportunities. We will highlight some valuable future research directions in Section 4.2. Particularly, the entire problem background is grounded in and is taken from the industry interview.

4.2. New research opportunities

4.2.1. Capacity management of airlines

The capacity management process for a carrier or an airline is mainly composed of four basic steps. First, the operation plan department of an airline forecasts the cargo demands of different routes and develops capacity plans. Second, it allocates the planned capacity to major cargo forwarders according to weight, volume, and service priorities. Third, in line with the reservation behavior of forwarders, the airline dynamically updates the forecasts for demand and plans the sale for the remaining capacity. Fourth, the airline books residual capacity through reject-or-accept policies to maximize network cargo profitability. Next, we discuss some interesting research problems.

(1) Capacity planning

(1) *Network capacity planning.* Network capacity planning for the passenger sector has been well studied in the literature (see, for reference, Talluri and van Ryzin, 2004). However, the capacity planning and allocation problems in the air cargo industry are very different from those in the passenger sector because of the unique characteristics of the former. The findings from CSA show that passengers must fly according to their booked itineraries, and they cannot be transited more than four stops even in an international travel; by contrast, cargoes can use multiple stops under different time priorities. Network-wide (i.e., multiple-leg) capacity planning is desired by airlines, in which not only non-stop flights but also multi-stop flights for OD pairs should be accounted. A hierarchical programming model is suggested, in which capacity planning varies with routing optimization and cargo flow interactions. Furthermore, passengers are identical, but cargoes have different categories, so airlines should consider the linked legs and also the compatibility of cargo categories in the network capacity planning and itinerary design. Multi-category network flow models and online algorithms should be developed to solve this problem.

(2) *Integrated capacity planning*. The majority of airlines utilize the belly space of passenger aircraft to ship cargoes that are regarded as "costless." CSA predicts that this practice will become even more popular as the use of over 60% wide-body aircraft becomes common in the near future. The available cargo capacity is uncertain because of many factors, such as aircraft payload, belly space, weather conditions, fuel weight, number of passengers on board, and passengers' luggage. This issue makes the forecasting of air cargo capacity a very complicated problem. Meanwhile, airlines need to develop integrated capacity planning for passenger flights that carry both passenger and cargo under with class levels/priorities and pricing for passenger and cargo. Furthermore, the optimal baggage limit policy for airlines under the capacity allocation, including prices, weights, and pieces for different classes of passengers, should be investigated.

(2) Capacity allocation strategies

(1) *Tying capacity allocation*. CSA and other airlines commonly suffer the problems that freight forwarders' orders exceed the fixed capacity of the airline for hot-selling routes, whereas the orders for underutilized routes are usually less than 50%. Airlines cannot dynamically change or cancel flights (or capacities) to handle the imbalance because they need to serve passenger traffic when carrying cargo in the belly space of passenger flights. This imbalance problem is likely to be exacerbated when the number of wide-body passenger aircraft increases. Airlines may address the imbalance in cargo demands by tying the capacities of the two types of routes and incentivizing forwarders to act in a desirable way. In such situations, airlines are challenged to design bundling policies (quantity and price) to maximize their profit.

(2) *Strategic forwarder selection*. Capacity allocation in the air cargo industry has some unique features. Trust or relationship plays a key role in dealing with the uncertainty in the industry. Players, airlines, and forwarders value their own "credit," which is their reputation, to fulfill their promise or contract, although they may not be penalized directly if they do not fulfill such a contract. Airlines often work with a number of freight forwarders that vary in size. To mitigate demand risks, airlines tend to allocate capacity among multiple forwarders. Another problem that confronts airlines is the possible simultaneous disruption of supplies from multiple freight forwarders because of, for example, competition from other airlines and forwarders' collusions for more bargaining power. For their long-term benefit, airlines have the incentive to select some strategic freight forwarders by using multiple criteria, such as demand record, cargo demands of returning flights (back-cargo), return of unused capacity, cancellation and no-show records, market potentials, and payment reputation. In this aspect, some kind of relational contracts (Taylor and Plambeck, 2007; Belavina and Girotra, 2012) will be helpful. In addition, data mining in the current big data background is useful to analyze the dependence and relations among criteria and to measure the performance of freight forwarders. Data-driven decision analysis can be conducted to determine the desired levels to be with regard to the criteria, and then to select a portfolio of strategic forwarders.

(3) Pricing and contracting

(1) *Capacity allocation*. Airlines sell capacities to freight forwarders in two ways. One is to sell capacity with dynamic prices that depend on random market demands (a function of price), and the other is to contract with freight forwarders on a long-term basis and with a price discount in advance (e.g., a year or a season). Airlines need to allocate the capacities between long-term contracts and spot markets and then design pricing mechanisms to maximize the overall expected profit.

(2) *Flexible contracts*. For long-term contracts or capacity pre-allocation, the effectiveness of these relational contracts can be questionable because of the absence of a material penalty when one party does not fulfill the contract. An unperformed contract may rise from substantial price changes. From our interview, we have identified three types of flexible contracts that are specific and are assumed to be potentially effective; these are dynamic orders with a high price, fixed orders with punishment, and overall fixed orders. The first type of contract means a forwarder can vary its every order for a specific scheduled flight within a range, but the rate will be high. The second type means that the forwarder can place a fixed order only as stated in the contract and needs to pay for the residual capacity with a punishment cost (lower than the stipulated cost, though) each time. The last type implies that the forwarder can vary its orders daily, but the total size of the orders should be equal to the total amount specified in the contract. Studying and comparing the effectiveness of these contracts under different situations are interesting.

(3) *Multi-leg contracts*. In the literature, single leg-based capacity contracting (see, for example Amaruchkul et al., 2011) has been studied. To extend this to complex and practical scenarios, previous studies should be extended to network-wide scenarios with multiple-leg (or network) contracts, with the utilization of transit shipments and the time priorities of cargoes taken into consideration. While this goal is challenging, such studies will certainly be beneficial.

(4) Reject-or-accept policies

The findings from the CSA interview show that in the spot market, airlines reject or accept the orders of freight forwarders on the basis of factors, such as the pivot weight, pivot volume, type, and center of gravity, to maximize the expected profit. One distinct difference of the air cargo industry from the passenger sector is that no fee is charged to make a change in booking request. Therefore, airlines frequently receive several rounds of reservation updating from forwarders for a specific flight. This scenario brings some challenges to the reject-or-accept policy of airlines. In this case, a data-driven decision analysis may be helpful in identifying the booking behavior of freight forwarders. Pragmatic reject-or-accept policies based on the complicated booking behavior of freight forwarders should be developed.

4.2.2. Air cargo terminal operations

(1) *Integrated operations*. CSA practice shows that truck scheduling and unloading, crew supply and scheduling, cargo routing among facilities, cargo handling process reengineering, and service outsourcing are integrated problems that are inherently sub-decisions of the overall operation plan for cargo terminals. However, these problems have been separately investigated in the literature; studies on the overall performance of coordination operations during dependent arrivals are limited. The truck scheduling coordination of cargo terminals and freight forwarders is therefore an interesting research problem. In addition, a cargo terminal can be viewed as a multi-type component manufacture system with multiple workshops. Integrated simulation models are needed to examine various control rules in order to maximize the performance of the service system, including time slot design of truck arrivals, the priority for different cargo types, and the routing of cargoes. The key parameters and cost functions for such a simulation can be derived by data mining. This study will be cross-methodological in nature. From another perspective, integrated operations of the cargo terminal can also be modeled as a stochastic programming problem with consideration of multi-server network queuing with dependent arrivals, uncertain processing time, and fixed paths. The optimal policy of time slot design for truck arrivals should be developed to minimize the waiting time of trucks and maximize the utilization of service facilities and crew under an uncertain cargo process time.

4.2.3. Aircraft loading and cargo consolidation

(1) *Balanced BPP*. The problem of aircraft loading is identified as a BPP problem, as mentioned in Section 3. This problem is complex in real situations. CSA practice shows that the loading level of aircraft depends on the passengers' luggage, weather conditions, loading duration, and even the seat assignments of passengers (e.g., wing first or tail first). In load balancing, for example, ground loading crew members were found to have little time to achieve the optimal loading for a combination or passenger aircraft. A myriad of problems should be addressed. The key decision problems include how to allocate different types of containers, pallets, and non-certified pallets with nets to different aircraft cabins and how to combine heavy and light cargoes in the aircraft to maximize the loading rate and minimize the cost of fuel under different seat assignment policies. The aircraft loading problem needs to extend the traditional BPP model to a balanced BPP model by incorporating mechanical concerns. Realistically implementable policies instead of optimal solutions are desired by airlines.

(2) *Routing BBP*. Unlike passengers, cargo can use several times of transits from its origin to its destination within a fixed arrival time. Designing effective consolidation plans via transit flights is crucial for cost reduction and the efficient utilization of resources for airlines. Only Leung et al.'s (2009) study addressed this issue by considering an OD pair with the same cargo throughout. A dynamic model allows shipments from several origins to be delivered to multiple destinations, where cargoes need to be integrated or distributed at certain transit airports. Such a problem is a routing BBP model with consolidation and disintegration. Effective and efficient heuristic algorithms need to be developed to solve such a model.

4.2.4. Service outsourcing of airlines

(1) *Selection and coordination with partners*. Service outsourcing refers to the selection of a combination of service providers to supply different services and thus minimize the total cost (or maximize the total profit), subject to constraints, such as the crew, network connection, time, and facility capacity. Airlines form alliances to increase the use of resources. For example, the Star Alliance has 27 members, such as Air Canada, Lufthansa, Scandinavian Airlines, Thai Airways, United Airlines, and Air China. The partners share 6570 aircraft and 1829 airport spots. The partners use code sharing and route extension policy to share the capacity of international flights and also link international and domestic itineraries. Partners exchange the same number of positions of containers/pallets for different flights and related services, even if the rates are different. This practice improves network efficiency and lowers the cost of repositioning empty pallets or containers. For code sharing flights, the non-free luggage partner do not charge the passenger and its partners, even if partners may not share the same luggage rules for international and domestic flights; it makes the passenger to have a consistent luggage service during travel. In this aspect, it needs to investigate how airlines can best select and coordinate with partners to minimize total cost in view of a range of factors, which include direct and transshipment demands, back cargo, inbound and outbound load coordination, and scheduling.

(2) *Dynamic outsourcing*. As for the crew and the facilities for aircraft loading, holding a large pool of employees to account for demand variation is uneconomical for airlines. CSA has begun to outsource a part of or all of its crew services with hourly fees and facilities with time-rated fees to airports or third-party cargo terminal operators in order to reduce cost.

4.2.5. Freight forwarders' decisions

The literature has only addressed the problem of spot market demand estimation and capacity booking when a long-term contract has been made. In fact, the freight forwarder must forecast the demands for the shipments of different categories and different legs ahead of time, often a year, and then allocate the demands between a long-term contract with a discounted price and spot market orders with dynamic prices. The freight forwarder forecasts demand by integrating factors, such as trend, seasonality, and *ad hoc* events. Then, the forwarder allots capacity from several airlines and from the long-term contract and the spot market to maximize the expected profit under demand uncertainty and market prices, subject to transport budgets, departure time (e.g., morning or night flight), service priority, and capacity allocation from the airlines. The capacity management problem for the forwarder can be formulated as a robust optimization model because the delivery of the cargo with high priority (with very high probability) should be ensured while the demand of shippers and the capacity allocation from airlines are uncertain.

4.2.6. Air cargo supply chain coordination

The two most important players in an air cargo supply chain are the airlines and the forwarders. A great challenge that airlines face is demand estimation and capacity planning. An effective approach to improve capacity estimation is to make forwarders share their demand information (Hihara, 2014). However, this information sharing, without a proper mechanism to allocate the benefits, is in conflict with forwarders' interest because it might encourage airlines to charge forwarders with high prices. Therefore, the mechanisms of information sharing and coordination between airlines and forwarders are of significant value. What complicates the matter is that in the air cargo industry, an airline usually works with multiple forwarders of a non-negligible size, and conversely, a forwarder collaborates with multiple airlines. This scenario differs from the situation in the goods supply chain literature and makes the mechanism design in the air cargo industry particularly interesting.

5. Summary

In this work, we reviewed the literature on air cargo operations and compared state-of-the-art theories with real-world practices. We first described the air cargo industry and then analyzed the characteristics of air cargo operations compared with air passenger operations. Then, we conducted a bibliographic survey of the literature on air cargo operations, in which we focused on studies that used quantitative models from the perspectives of airlines, freight forwarders, and the air cargo supply chain. Subsequently, we identified the key decision problems in air cargo operations and discussed the gaps between previous research and real-world practices on the basis of our literature review and in-depth interviews with airlines and forwarders.

The literature has already investigated some real-world problems in the air cargo industry. Nevertheless, a number of key issues have not been adequately examined. These issues include network revenue management for airlines, low- and high-demand bundling sales, capacity allocation between long-term contracts and the spot market for forwarders, pricing strategies of airlines, and coordination among players in the supply chain.

This review identified several significant gaps between the theories and practices related to air cargo operations. Operations managers commented that although theoretical models contribute significantly to the literature, some assumptions in the models often deviate from operational realities. In concluding this study, two points are noteworthy. First, numerous real-time operational information systems or decision support systems exist in the air cargo industry, and, thus, a huge amount of data is actually available from airlines and forwarders. Therefore, we expect that data-driven decision making will emerge as a key approach to solving problems arising in air cargo operations, and such applications will in turn benefit the methodological research for big data. Second, the IT infrastructure in the airline industry has long been well developed, and interconnection among different players in the air cargo supply chain is ever-increasing. The use of RFID and a cargo tracking system facilitates the increased visibility of air cargo throughout the supply chain (Gontarz et al., 2015). With such visibility and interconnection, some integrated decision models can be expected because many operational decision problems we have reviewed are closely related to one another.

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