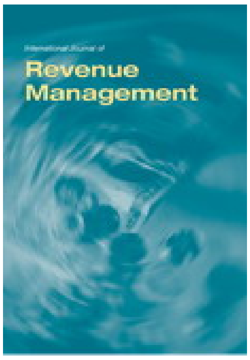

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Air cargo revenue management: a state-of-the-art review

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Air cargo revenue management: a state-of-the-art review

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Abstract: In addition to serving high-value-to-weight goods, the air cargo market is expanding substantially mainly because of globalisation and the need for increased responsiveness in supply chains. At the same time, the theory of air cargo revenue management is far from the contemporary practices because of cargo-specific complexities like uncertain, multidimensional capacities, variable tendering, and forwarder's market power. This paper surveys the scientific contributions relevant to air cargo revenue management. We provide a comprehensive review of the developments in both quantity and pricing revenue management decisions. Additionally, we substantiate each decision with the appropriate dynamic programming formulation, which helps in highlighting the extensions to the current literature. We conclude our discussion by enumerating the potential prospects that are great revenue-yielding opportunities. This review links theoretical contributions and practical problems and serves as the signpost for the 30-year-old air cargo revenue management.

Keywords: air cargo industry; revenue management; quantity and pricing decisions; dynamic programming.

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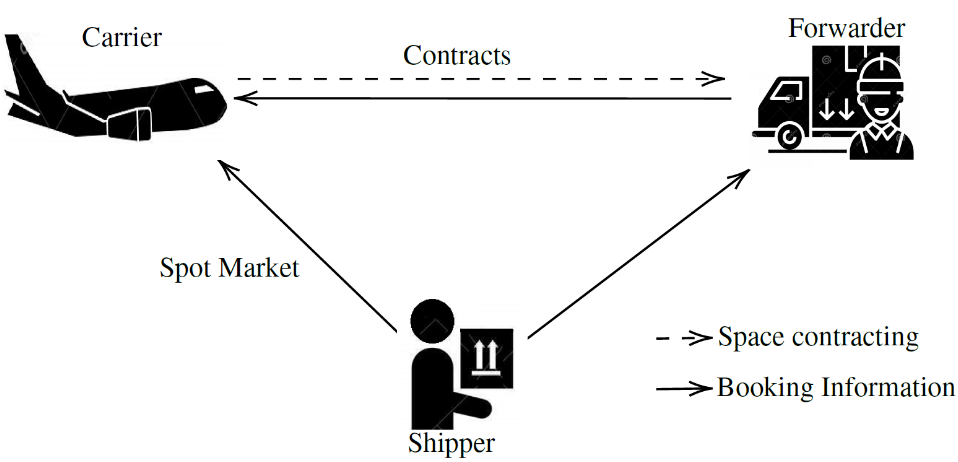
1 Introduction

Air cargo industry transports over US$6 trillion worth of goods that accounts for 35% of world trade by value and is a vital player in driving the global economy (IATA, 2021b). According to a recent survey, the compound annual growth rate of the air cargo market is estimated to be 5.6% during the year 2021–2027, and the market value is expected to be US$376.8 billion by 2027 (Halmare and Mutreja, 2021). Back in the 1980s, freights were carried in the bellies of the aircraft along with passengers, and revenue from cargo was treated as an auxiliary to the airlines. An airline business article in 1998 asserts that "...an incremental revenue gain of 1% could offset $1–3 million cost, which in turn would make the managers move from revenue maximization to profit maximization." The market potential continued to increase, yet the combination carriers dominated the air cargo market compared to dedicated freighters. A further increase in market potential was observed with the rising need for responsiveness in supply chains because of technological advancements and globalisation. The rising potential is evident from the estimates of Boeing and Airbus. Boeing (2022) forecasts that the global dedicated freighter fleet will increase to 3610 in 2041 (by 80% than today), whereas Airbus estimates it to be 3070 (Airbus, 2022). Moreover, the COVID pandemic has catalysed the growth process rather than being the fundamental reason. Given its magnitude, Barz and Gartner (2016) reprove that "...it is quite surprising that research in cargo revenue management is by far not as advanced as in passenger revenue management", which motivates the need for a comprehensive review of the literature. In this paper, we address the hindrances to air cargo revenue management (ACRM), present an overview of its scientific contributions, and offer the potential directions from which the industry can derive benefits.

There are three main players in the air cargo industry: carriers, shippers, and forwarders. Their combined interactions form the basis for characterising the market structure, depicted in Figure 1. Carriers are the asset-providing companies that supply aircraft to the market and are the sole players in providing airport-to-airport service. Supply can be used either by shippers or forwarders. Shippers are the consumers of the industry from whom the cash flow starts as they need to transport a package from one origin to another destination. That being the case, they can either go to spot markets and book directly with the carriers or approach forwarders to transport the package. If they choose spot markets, shippers are responsible for further logistic activities like dropping the shipment at the origin airport. The consignee must get the shipment from the destination airport after independently performing customs clearance and commissioning tasks. On the other hand, if shippers choose forwarders, forwarders do auxiliary logistics activities like commissioning, handling, and door-to-door services, which eases the work of shippers. Therefore, most shippers approach forwarders, which explains the market power of forwarders in the industry. Forwarders are freight-forwarding companies that consolidate shipments from atomic shippers and perform third-party logistics to ensure the consignees get their packages from the corresponding shippers. Due to the consolidation and their market power, forwarders sign long-term, flexible quantity contracts with carriers and can transport the shipment at a lower price than spot market prices.

Figure 1 Interactions in air cargo industry



The work of Oakley et al. (1992) marks the starting point of research in ACRM. Yet, in terms of modernisation, ACRM is far from passenger revenue management (PRM), and such a large gap has to be attributed to the inherent complexities associated with cargo management. Works like Kasilingam (1997a) and Becker and Wald (2010) focus on characterising the challenges and complexities specific to ACRM. The complexities are well documented and can be better understood by comparing them with PRM, which is provided in Table 1.

Table 1 Contrasting ACRM with PRM

Description	*PRM*	*ACRM*
Capacity dimension	One: number of seats	Three: weight, volume and containers
Nature of capacity	Discrete and certain	Continuous and uncertain
Variable tendering	Show-up $\leq$ booked	Show-up $\leq$ or $\geq$ booked
Priority	No	Yes. Contracts
Rerouting	Hard	Easy

We briefly discuss the complexities of ACRM for ease of understanding in the order listed in Table 1.

- With the capacity being three-dimensional, there will be instances where one or two dimensions will be satisfied, but not all. For example, a shipment might satisfy weight and volume requirements but cannot be transported because of its shape.
- There are no fixed weight or volume positions available for sale. They will vary due to payload, weather, fuel, and runways. Such variations create problems in capacity forecasting, which is crucial for quantity-related decisions.
- Variable tendering, also known as resource consumption uncertainty, is not new to ACRM but is complicated because of the possibility that the actual shipment that will be shown up for transporting will be greater than the specifications at the time of booking. Accounting for such allowances further complicates the problem.
- Shipments from forwarders need to be prioritised due to the long-term agreements. The dependency of carriers on forwarders should be addressed conscientiously, which otherwise leads to unfavourable consequences for carriers like contract breach penalties or reputation loss.
- The cargo products allow for high flexibility in terms of routing options. An airline can reroute or postpone the shipments while still delivering them within the due date. But such an opportunity makes the computation of the solution complex, which is already a complex problem.

Among the several ACRM techniques, the critical four are overbooking (selling more space than actual available capacity), capacity control (segmenting requests based on value), contracts (estimating the amount of cargo space to contract and right prospects from the pool of forwarders) and pricing (figuring out the optimal prices for shipments and contract prices). May et al. (2014) show that these four techniques are in the top six key performance indicators. Also, the criticality is further substantiated by the research attention, as they form the focal point of analysis in most ACRM literature. In this paper, we focus on the scientific contributions of these four techniques and classify the scientific contributions such that prospective research directions emerge. Although there are other works relative to cargo revenue management (RM) across domains like container, rail, truck, or feeder services, we limit ourselves to the ACRM literature. Prior to our work, four notable reviews are Yeung and He (2012), Feng et al. (2015), Budiarto et al. (2018) and Klein et al. (2020). However, in these papers, ACRM was treated as a subpart of the paper. We dedicate the entire discussion only to ACRM, which results in some overlaps in those works.

The rest of the paper is organised as follows. An abstract model that deals with generic ACRM techniques is presented in Section 2. Literature on each RM technique is discussed in Sections 3, 4, 5 and 6, respectively. Before concluding the paper in Section 8, prospects are provided in Section 7.

2 An abstract model

This section will present an abstract model comprising all the RM techniques using a dynamic programming (DP) formulation. We choose the dynamic program as the modelling tool, as a DP well approximates the real-world booking process compared to a static or single-period model. We discuss all the works on ACRM rather than just DP-related works. Table 2 provides the list of model parameters that we will use throughout the paper. Note that the notations with asterisks represent the optimal values. Although we deal with network and single-leg structures, we present the formulation of the network from where the single-leg case can be derived through appropriate degeneration.

Our DP formulation consists of a five-dimensional state space ($\mathbf{L}$, $\mathbf{X_F}$, $\mathbf{X_S}$, $\mathbf{Y_F}$, $\mathbf{Y_S}$), where each element in each vector carries the corresponding value for the considered flight of the asset provider. For the time being, let us ignore the nature of the horizon, whether finite or infinite. We count the time forwards from $t = 0$, which denotes the start of the booking period. We assume that the horizon is divided into discrete time intervals such that at most one request arrives per period, which is given by $\sum_i \sum_j p_{ijt} + p_{00t} = 1$, where p_{ijt} and p_{00t} represent the probability of type ij's request and no request at time t, respectively. Let V_t($\mathbf{L}$, $\mathbf{X_F}$, $\mathbf{X_S}$, $\mathbf{Y_F}$, $\mathbf{Y_S}$) denote the value of being in state ($\mathbf{L}$, $\mathbf{X_F}$, $\mathbf{X_S}$, $\mathbf{Y_F}$, $\mathbf{Y_S}$) at time t, and it is given by the recursive equation

$$\begin{aligned} V_t(\mathbf{L}, \mathbf{X_F}, \mathbf{X_S}, \mathbf{Y_F}, \mathbf{Y_S}) = {} & p_{00t} V_{t+1}(\mathbf{L}, \mathbf{X_F}, \mathbf{X_S}, \mathbf{Y_F}, \mathbf{Y_S}) \\ & + \sum_j p_{Fjt} \mathbb{E}[R_{Fj} + V_{t+1}(\mathbf{L} + \mathbf{e}_b, \mathbf{X_F} - \hat{x}_{Fj}\mathbf{e}_b, \mathbf{X_S}, \mathbf{Y_F} \\ & - \hat{y}_{Fj}\mathbf{e}_b, \mathbf{Y_S})] + \sum_{i: i \neq F} \sum_j p_{ijt} \mathbb{E}\left[\max \left\{ \sum_{k=1}^{|D|} V_{t+1}(\mathbf{L} \right.\right. \\ & + \mathbf{e}_{D[k]}, \mathbf{X_F}, \mathbf{X_S} + \hat{x}_{ij}\mathbf{e}_{D[k]}, \mathbf{Y_F}, \mathbf{Y_S} + \hat{y}_{ij}\mathbf{e}_{D[k]}) \\ & \left.\left. + R_{ij}, V_{t+1}(\mathbf{L}, \mathbf{X_F}, \mathbf{X_S}, \mathbf{Y_F}, \mathbf{Y_S}) \right\} \right] \end{aligned} \tag{1}$$

subject to the constraints

$$\sum_m {L_m}^{t+1} - \sum_m {L_m}^{t} \leq 1 \tag{2}$$

$$\sum_m {X_{S_m}}^{t+1} - \sum_m {X_{S_m}}^{t} \leq \hat{x}_{ij} \tag{3}$$

$$\sum_m {Y_{S_m}}^{t+1} - \sum_m {Y_{S_m}}^{t} \leq \hat{y}_{ij} \tag{4}$$

where the superscript term t along the variable in the constraints (2), (3) and (4) indicates the state of that variable at time t. The first term in RHS of equation (1) indicates the updated value function with no arrival, whereas the second term indicates the change in value function given the possibility that the shipment from the forwarder has arrived and is accepted as the shipment for the requested flight b, which leads to a decrease in available space in the next time period. The third term in RHS of equation (1) captures the optimisation part of the whole formulation. It illustrates that whenever a shipment from the shipper arrives, it is accepted if and only if the revenue from serving the request in any available, feasible routes in the set D is greater than not serving it. Constraints (2), (3) and (4) together ensure that the incoming request is accepted in utmost one of the flights, i.e., no double acceptances. For instance, if the shipment is accepted in two of the flights, then equation (2) will be violated as $\sum_m {L_m}^{t+1} - \sum_m {L_m}^{t} = 2$. Similar explanations hold for equations (3) and (4).

Table 2 Model parameters

Notation	*Description*
$\mathbf{C}$	Vector representing the collection of flights considered; $\mathbf{C} = (C_1, C_2, C_3, ..., C_m, ...)$
$\mathbf{X}$	Vector of length $\mathbf{C}$ representing the maximum weight capacity available
$\mathbf{Y}$	Vector of length $\mathbf{C}$ representing the maximum volume capacity available
F	Index to represent the time-sensitivity of forwarder requests
i	Time sensitivity; $i = \{1, 2, 3, ...\} \cup \{F\}$
j	Inherent nature; $j = \{1, 2, 3, ...\}$
$\mathbf{X_F}$	Vector of length $\mathbf{C}$ representing forwarders' available remaining weight
$\mathbf{Y_F}$	Vector of length $\mathbf{C}$ representing forwarders' available remaining volume
$\mathbf{X_S}$	Vector of length $\mathbf{C}$ representing cumulative weight of accepted requests
$\mathbf{Y_S}$	Vector of length $\mathbf{C}$ representing cumulative volume of accepted requests
$\mathbf{L}$	Vector of length $\mathbf{C}$ representing total number of accepted requests
D	Set that consists of admissible, feasible route combination for the given request arranged in the order of increasing importance
$D[k]$	Index to denote the k^{th} element in set D
R_{ij}	Revenue generated by accepting the booking request
$\hat{x}_{ij}$, $\hat{y}_{ij}$	Random variables that represent weight and volume requirements, resp.
b	Actual carrier index that the request prefers
$\mathbf{e}_\kappa$	Vector of length $\mathbf{C}$ whose κ^{th} component is 1, and others are 0
$t(C_m)$	Departure time period of C_m^{th} flight

The above formulation mimics the booking process to an extent, from the commencement of the booking process to time periods into the future. Because of these industries' nature, asset providers must stop the booking process as the corresponding flight has to depart and plan the allocations given the materialised demand. Let $t(C_m)$ be the departure time period of the flight C_m, and we assume that the requests arriving at $t(C_m)$ will arrive after the flight C_m's departure. Also, let $\lambda_L(K)$ denote the penalty cost incurred by the shipment L for K units of delay if the asset provider makes an allocation different from the request specifications. To decide the allocations, we make use of the two-dimensional knapsack formulation that yields the total penalty cost, $\Phi(L'_m, X_m, Y_m, \lambda)$, as follows

$$\Phi(L'_m, X_m, Y_m, \lambda) = \min \sum_{L=1}^{L'_m} \lambda_L(K) \times (1 - \beta_L)$$

$$\text{s.t.} \sum_{L=1}^{L'_m} x_{ij(L)} \beta_L \leq X_m$$

$$\sum_{L=1}^{L'_m} y_{ij(L)} \beta_L \leq Y_m$$

$$\beta_L \in \{0, 1\}$$

with $L'_m = \rho(L_m)$ if $m = 1$, and $L'_m = \hat{\rho}(L_m) + L'_{m-1} - \sum_{L=1}^{L'_{m-1}} \beta_L$, $\forall m \neq 1$, where L_m and L'_m represent the total number of accepted and showed-up shipments in the flight C_m, respectively. In the total penalty cost formulation above, the objective function minimises the penalty cost subject to the flight's space constraints. Given the total cost function, the departure time period, and the assumption at the departure time period, the expected value at the departure is given by

$$V_{t(C_m)}(\mathbf{L}, \mathbf{X_F}, \mathbf{X_S}, \mathbf{Y_F}, \mathbf{Y_S}) = -\mathop{\mathbb{E}}_{\rho}[\Phi(L'_m, X_m, Y_m, \lambda]$$

One drawback with $V_{t(C_m)}$ is that it requires a recalculation for finding the K units of delay and the corresponding λ for each shipment that could be loaded onto the current flight under consideration. In addition to these value functions, we have several boundary conditions, two for each flight, pertaining to forwarder's shipments, i.e., $V_t = 0$, if $X_{F_b} = 0$ or $Y_{F_b} = 0$ provided that the request has come for bth flight and is from forwarder. This boundary condition ensures that the asset provider is unwilling to entertain excess shipments beyond the forwarder's contractual space. Hence, strict adherence to contracts is implicitly assumed.

As mentioned earlier, the single-leg formulation is straightforward given the network formulation. The following are changes required to arrive at the degenerate single-leg case:

1. Replace all the vectors with scalars. For example, capacity vector **C** should be replaced by a scalar C, which denotes the capacity of the single-leg flight.
2. We used $\mathbf{e_b}$ to navigate the state spaces of multiple flights. Since we have only one flight under consideration, $\mathbf{e_b}$ should be replaced by the numeric 1.
3. Set D will always contain only one element b, which denotes the preferred flight for the request.

3 Overbooking

In conjunction with PRM, the research in ACRM started with the oldest and the most revenue-impacting RM technique, overbooking, which is the process of selling more than the actual capacity available. However, overbooking in ACRM differs from PRM as follows:

1. It is well-known that the primary reason behind PRM overbooking is no-shows. In ACRM, overbooking is practiced because of uncertain capacities, no-shows, and resource consumption uncertainty.
2. While planning for the PRM overbooking, whole space (seats) in the aircraft can be considered, whereas, in ACRM, only the space allotted for the spot market is taken into account because of long-term contracts with forwarders.
3. In the event of excess show-ups, low-revenue-generating passengers are denied boarding in PRM. Conversely, it is not the low-revenue-generating shipments being offloaded, as the low-value shipments are from forwarders with market power.

Since cargo emerged as an auxiliary, it is obvious that initial overbooking models focus on computing optimal levels mainly based on uncertain capacities. As the area evolved, overbooking based on uncertain capacities and resource consumption uncertainty became dovetailed with standard capacity control models. Moreover, those models emphasise more on capacity control rather than overbooking. Hence, the discussion on those models is provided along with capacity control models in Section 4. For a dedicated freighter whose forwarder's share of capacity is known, the boundary conditions in Section 2 capture the essence of overbooking. By the overbooking level of flight C_m, we mean the optimal values of X_m^* and Y_m^*. Table 3 presents the compilation of articles that consider overbooking as a technique to mitigate the loss from no-shows and showcases the complexities addressed by each scientific contribution.

Table 3 Summary: air cargo overbooking

Source	*Setting*	*2D capacity*	*Uncertainty*		
			A	*C*	*R*
Kasilingam (1997b)	Single-leg			✓	
Shenxue (2005)	Single-leg		✓		
Wang and Kao (2008)	Single-leg			✓	
Lei et al. (2009)	Single-leg			✓	
Luo et al. (2009)	Single-leg	✓			
Moussawi-Haidar and Cakanyildirim (2012)	Single-leg	✓			
Wannakrairot and Phumchusri (2016)	Single-leg	✓			
Zou et al. (2013)	Two-leg				

Notes: A – arrival; C – capacity; R – resource consumption.

Apart from these models, researchers emphasise better no-show prediction models to alleviate the losses from unfavourable consequences of overbooking. In this vein, Popescu et al. (2006) propose an alternate show-up estimator for cargo, which is different from the passenger, and stress the need for a discrete estimator pertaining to ACRM. Deriving from passenger name records prevalent in PRM, Becker and Wald (2010) show that shipment information record-based no-show might be a promising area for further research. Risk perspective to overbooking along with capacity options and financial intermediation is discussed in Hertwig and Rau (2010). Additionally, the cryptographic cloud approach and machine learning-based clustering algorithms are discussed in Cimato et al. (2020) and Brieden and Gritzmann (2020), respectively.

From Table 3 and the above-mentioned scientific contributions, four conclusions can be derived that are as follows:

- Much attention is given to single-leg models and the network effects are completely ignored.
- Models focus on only one of the complexities, whereas the holistic incorporation of all cargo-specific complexities is required to address the problem in totality.
- Data-driven techniques for no-show prediction have started marking their presence in ACRM, which is a good indicator of the evolution.
- None of the works on overbooking have considered resource consumption uncertainty as their core research interest.

Additionally, as forwarders can return the unused space closer to the departure, if the carrier is not overbooked, the carrier may not find the customers for the returned space (Hellermann, 2006). To tackle such situations, carriers practice overbooking even to compensate for the forwarder's unused space. Modelling the forwarder shipments to decide the overbooking level is also an interesting avenue, as the amount of work done is minimal and is limited to Wada et al. (2017), Hellermann (2006) and Moussawi-Haidar (2014).

4 Capacity control

The core of RM lies in capacity control, which focuses mainly on segmenting the demand into high and low value, where some low-value demand has to be turned down to accommodate the high-value demand that will arrive closer to the departure. Capacity control as RM is not an overstatement, and most practitioners use both terms interchangeably. To operationalise capacity control, literature seeks to find the answer to the simple question: whenever a request from a customer arrives, given the model parameters and the temperament of the request, should the airline accept the request or not? Since the problem is broken down to a granular level, DP techniques are predominantly used in characterising the capacity control problem (refer to the model in Section 2 while assuming that $\mathbf{X_F}^*$, $\mathbf{Y_F}^*$, $\mathbf{X_S}^*$ and $\mathbf{Y_S}^*$ are given and known). However, because of the inherent complexities of the cargo product, exact solutions become intractable. Some approximation techniques, mainly bid prices-based heuristics, are looked upon to estimate the solution. We refer the interested readers Castelli et al. (2014) and Popescu et al. (2013) for a rigorous discussion on cargo bid prices, and Talluri and Van Ryzin (1998) for generic bid prices. Table 4 summarises the extant works related to capacity control in single-leg ACRM.

Table 4 Summary: air cargo single-leg capacity control

Source	*2D capacity*	*Uncertainty*		
		Arrival	*Capacity*	*Consumption*
Karaesmen (2001)				
Amaruchkul et al. (2007)	✓	✓		
Han et al. (2010)	✓	✓		
Huang and Chang (2010)	✓	✓		
Zhuang et al. (2012)	✓	✓		✓
Hoffmann (2013b)	✓	✓		
Rizzo et al. (2020)	✓	✓		✓

One of the main issues with all these mentioned works on single-leg capacity control is that they fail to exploit the inherent opaqueness of the cargo, which can be done either through rerouting or postponing. Luo et al. (2014) try to incorporate such due date restrictions within the model but cannot make the most of it because the setting considered is a single-leg flight. Such flexibility can be exploited only when the setting comprises multiple parallel, sequential, or network of flights. The main idea is that since the airline need not incur any penalty costs if it transports the package within the due date needs, it does not matter how and when the package travels from origin to destination as long as it reaches in time. Unlike overbooking, several works on cargo capacity management consider multiple flights, and Table 5 lists them comprehensively.

Table 5 Summary: cargo capacity control with more than one single-leg flight

Source	*Setting*	*2D capacity*	*Uncertainty*			*Priority*
			A	*C*	*R*	
Pak and Dekker (2004)	Network	✓	✓			
Luo and Shi (2006)	Multi-leg					
Huang and Lu (2015)	Network	✓	✓			
Levina et al. (2011)	Network	✓	✓		✓	
Levin et al. (2012)	Parallel	✓	✓	✓	✓	✓
Barz and Gartner (2016)	Network	✓	✓		✓	
Delgado et al. (2019)	Network	✓	✓		✓	

Notes: A – arrival; C – capacity; R – resource consumption.

Among all the works in Table 5, even though they deal with multiple flights, Levina et al. (2011) is the only paper to consider the allocations based on the due date requirements. However, Levina et al. (2011) suffer from a serious disadvantage because they assume that the delayed shipment is outsourced and will not be a part of the analysis. This assumption is unrealistic because most airlines will try to restrict themselves to their in-house capacity specifications rather than outsourcing.

Taking a deeper look at Tables 4 and 5, the following insights are immediate.

- Invariably, all the listed works in Section 4 require heuristics for computing the solution. However, considering the two-dimensional aspect and arrival uncertainty, Xiao and Yang (2010) efficiently derive the optimal solution analytically under certain conditions and explore the structural properties of the solution.

- It is surprising that overbooking models treated capacity uncertainty as their primary interest, whereas the single-leg capacity control models have not given importance to it. From this, we can deduce that air cargo overbooking is done mainly for capacity uncertainty rather than no-shows, and capacity control is practiced mainly for serving the requests given the fixed capacity, i.e., overbooking decisions are followed by capacity control decisions.
- Barring Levin et al. (2012) in Table 5, forwarder interactions are not captured in the model. As a result, only the part of cargo space allotted for spot markets is optimised.

At a broader level, both the preceding sections approach the cargo RM problem in isolation, i.e., overbooking and capacity control are not dealt with in tandem with each other. These joint optimisation models rely on the combined overbooking and capacity control heuristic proposed by Phillips (2005), where the result of overbooking is fed into the capacity control problem. And such a heuristic is justified because the complexity increases while jointly planning the decisions. For instance, in the formulation presented in Section 2, complexity increases if $\mathbf{X_F}^*$, $\mathbf{Y_F}^*$, $\mathbf{X_S}^*$ and $\mathbf{Y_S}^*$ are endogenous. Yet, with some limitations, Moussawi-Haidar (2014) and Qin et al. (2012) approach the joint capacity management problem and accomplish the objective with implementable solutions. Furthermore, Moussawi-Haidar (2014) is comprehensive as the author even considers the forwarder interactions, thereby optimising for the whole space in the dedicated freighter.

5 Contracts

Hellermann (2006) asserts that the presence of forwarders is a mixed experience, in terms of costs and benefits, for the carriers. Although their presence induces competitiveness in the market, long-term contractual agreements help carriers to mitigate the spoilage risk. In other words, forwarders use the carriers' capacity to compete against the carriers and act as the third-party agent to sell the cargo space that would otherwise go unutilised. Ideally, consensus between forwarders and carriers seems to benefit them equally as they are interdependent. Nevertheless, a larger portion of the space is occupied by forwarders because of the auxiliary activities. Forwarders occupy two-thirds of the space in a typically dedicated freighter (Hellermann, 2006). Moreover, the number of forwarders is not plentiful. As a result of a small number of forwarders occupying a larger space in the carrier, contractual agreements are tilted in favour of forwarders at the cost of carriers.

It is evident that online travel agents in passenger markets are quite different from forwarders in cargo markets. Thence, the area of contract design is specific only to cargo RM. This line of research addresses the primary questions:

1 How much aircraft space should be contracted to the forwarders? ($\mathbf{X_F}^*$ and $\mathbf{Y_F}^*$ values in Section 2 assuming capacity control and overbooking decisions are given and known)

2 Subsequently, among the pool of forwarders, how should the contracting space be split: which forwarder should get? [refer to Subsection 4.1 of Moussawi-Haidar (2014) or Subsection 3.2 of Levin et al. (2012)] and what kind of contracts should

be used? (due to the abundance of types of contracts, we cannot find the unifying model to represent).

Since the agreement period of contracts is longer and contracts are signed long before the departure date, the optimal actions are subject to several uncertainties, from supply to demand. Hence, these decisions are considered strategic rather than operational and airline-specific, which explains why there is comparatively less work in ACRM literature.

Despite being less researched, there are notable contributions in this research arena. Deciding the space to contract is briefly discussed in Levin et al. (2012) and Wada et al. (2017). A great deal of effort is spent answering the subsequent question. Hellermann (2006) pioneers the research in contracts, where he uncovers the details of the status-quo of contract agreements then, and proposes options contracts to balance the unfavourable consequences that the carriers incur. Along the same line, Lin et al. (2017) introduce the concept of a buy-back policy into the Hellermann (2006) model and show that this policy can increase the revenue of both the carrier and forwarders. Considering in tandem the demands from shippers and forwarders, Moussawi-Haidar (2014) deals with choosing the right forwarders given their bids and spot market demand; the author answers both the primary questions. Similar to the supply chain setting, where the forwarders are closer to the market than carriers, Amaruchkul et al. (2011) characterise the contractual agreement through information rent that, in turn, empowers the forwarder to choose optimal allotment capacity. In a very different setting, assuming that the carriers are more powerful than forwarders, Gupta (2008) devises flexible contracts, in which carriers are free to change the fares, such that carriers can extract more revenues, but not in the event of forwarder's loss.

In addition to Moussawi-Haidar (2014), Amaruchkul and Lorchirachoonkul (2011) is the only other paper to address the presence of multiple forwarders, where they implicitly assume that the forwarders are more powerful than carriers. This is one of the primary reasons for the literature's dearth in air cargo contracts. Nevertheless, the situation is changing with several players entering the market because of e-commerce growth (refer Subsection 7.7), leading to a situation where the oligopolistic market moves towards perfectly competitive markets. Forwarders start to lose market power because of competition, and the power imbalance between the carrier and forwarders nullifies. Such a transformation will result in a typical setting that contracting literature focuses on. But cargo-specific complexities hinder us from replicating the well-established contracts for cargo operations. Given the change in the virtue of the setting, we suppose that the notion of contracts will undergo a serious transformation, which calls for novel contracting methods.

6 Pricing

An obvious inference from Section 5 is that the carriers have to do the optimisation for a smaller portion of the aircraft. Given that smaller portion, they exert effort in excelling quantity-related decisions, whereas pricing decisions seem quite naive. Adapting the passenger pricing techniques directly to cargo is difficult because of the multi-dimensional capacities. For instance, p could be the price of an economy seat, while on the contrary, the price p in cargo has to consider both the weight and volume requirements. However, the standard formula to calculate the revenue generated from the request is $r \times \max\{x_{ij}, y_{ij}/\theta\}$, where r, x_{ij} and y_{ij} are the unit contribution margin, weight, volume of the request, respectively, and θ is the International Air Transport Association (IATA) specified inverse cargo density, which is 6 m^3/ton. This formulation allows carriers to charge the low and heavy-weight requests correspondingly. Below is a basic formulation that captures the essence of the pricing mechanism for a single-leg flight. Since we deal with prices, we consider the valuation of shippers and carriers but ignore the valuation of forwarders as we assume that the prices are already finalised through contracts. Let v_{ij}^s and v_{ij}^c denote the valuation distribution of shippers and carrier for the product type ij, respectively. Given the valuations of shippers, the decision problem here is to choose shippers willing to pay more to get the space. Let $U_t(L,\ X_S,\ Y_S)$ denote the value of being in state $(L,\ X_S,\ Y_S)$ at time t. Building on the formulation in Ramkishore and Amit (2019), the DP recursive equation is given by

$$\begin{aligned} U_t(L, X_S, Y_S) &= p_{00t} U_{t+1}(L, X_S, Y_S) \\ &+ \sum_{i:i \neq F} \sum_j p_{ijt} \max_{v_{ij}^s} \mathbb{E}[r(v_{ij}^s, v_{ij}^c) \max\{x_{ij}, y_{ij}/\theta\} \\ &+ U_{t+1}(L+1, X_S + x_{ij}, Y_S + y_{ij}) 1\{s(v_{ij}^s, v_{ij}^c) = 1\} \\ &+ U_{t+1}(L, X_S, Y_S) 1\{s(v_{ij}^s, v_{ij}^c) = 0\}] \end{aligned}$$

with the boundary conditions $U_t(L,\ X_S^*,\ Y_S^*) = 0$, $U_{t(C)}(L,\ X_S,\ Y_S) = 0$. In the optimal pricing formulation presented above, given the request from the shipper has arrived, and whether the trade has happened or not is captured by the indicator functions $1\{s(v_{ij}^s, v_{ij}^c) = 1\}$ and $1\{s(v_{ij}^s, v_{ij}^c) = 0\}$, respectively. If the trade happens, $1\{s(v_{ij}^s, v_{ij}^c) = 1\}$, the shipper makes a payment of $r(v_{ij}^s,\ v_{ij}^c)$max $\{x_{ij},\ y_{ij}/\theta\}$ to the carrier, and the state space is increased by the corresponding shipment requirements. This formulation is novel and encapsulates the underlying theme of the pricing literature. Moreover, v_{ij}^c can also be modified to represent the dependence on the state spaces X_S and Y_S. However, as with all other formulations presented in the paper, tractability becomes a concern, and the complexity increases with the combination of products offered.

The amount of research in cargo pricing is minimal, and there are merely a handful of pricing articles published in the late 2010's. The increased attention to sophisticated pricing techniques is due to globalisation and the increase in online retail, which made the variety of goods transshipped increase manifold. Pertaining to these growing differences in the variety of booking requests in spot markets, Yu et al. (2019) model the interactions between two price-setting carriers and show that the differential pricing strategy performs better in revenue for both the carriers rather than the single pricing approach. Implicitly assuming that there are no prior contract agreements, Amaruchkul (2020) propose a customised pricing approach for B2B clients (forwarders) by formulating the problem as a Markov decision process and validating it with data from a European carrier. Apart from these two works, to the best of our knowledge, there are no other notable contributions to cargo pricing, which stands as a prospect of the future avenue of research.

All the listed works in the preceding sections are carrier-centric and emphasise the improvements from the carrier perspective. Although forwarder interactions are considered, the primary object of interest is the carrier. Nevertheless, works like Zhang et al. (2010), He et al. (2019) and Ha and Nananukul (2017) analyse a similar problem from the forwarder's perspective, considering the interplay between carriers and shippers. It is interesting to point out that even the works from the forwarders' perspective are quantity-related optimisation rather than price-related, which again substantiates the scope for future pricing research.

7 Prospects

There is still a long way to go in researching and developing ACRM techniques. Straightforward extensions are provided after the bibliographic analysis of each technique in the preceding sections. Here, we set forth further research prospects that are mostly new to ACRM. Apart from revenue improvement, we could not find a way to classify the prospects under one unifying theme. However, an increase in complexity while trying to operationalise the prospects is indisputable.

7.1 Cancellations

No-shows pose a significant threat to higher load factors, which can be mitigated through controlled overbooking. The contemporary issue of no-shows is cancellations, which significantly lowers load factors. The only difference between no-shows and cancellations is that the former occurs at the time of departure and the latter occurs well before. Reoptimisation or revising booking limits at subsequent time periods will help mitigate the losses from cancellations. However, it is challenging to incorporate temporal dynamics. With the complexity of the ACRM problems, reoptimisation is time-consuming, and a timely and effective way to deal with cancellations is of great interest. To the best of our knowledge, Vardi and Ghorbanian (2018) is the only work to deal with the possibility of cancellations. Yet their work is a preliminary analysis that deals with single-leg flights. Moreover, due to large memory requirements, the heuristics employed eventually diluted the intensity of the problem. Modelling cancellations will assist the airlines with better managing the unused space returned by forwarders close to departure, which can be seen as a dual benefit. Put together, there lies a captivating avenue of research scope in this direction.

7.2 Alliances

Whenever two or more parties combine to gain mutual benefits, the formed group is called an alliance. Alliances are quite common in maritime or liner shipping industries, which can be regarded as competitors of the air cargo industry. These alliances are huge regarding the volume carried and the parties involved. For instance, more than half of the cargo shipping by sea is carried by two cartels, 2M and Ocean Alliance. These alliances bring a competitive advantage to the parties involved and are useful in penetrating markets where the party does not operate its fleet. Airlines also form alliances through codesharing, and the three major alliances (Star Alliance, Oneworld, and SkyTeam) cover most of the world routes in the passenger segment. It is ambiguous and misleading for the cargo segment to assume that the cargo alliances are similar to the passenger industry. For instance, the largest active alliance in cargo, SkyTeam Cargo comprising of SkyTeam members, was accused of price fixing allegations in 2006

(McKevitt, 2017). As a result, cargo airlines are becoming increasingly reluctant to form an alliance. Van Vliet (2011) delineates the practical reasons and motives for an airline to join or create an alliance.

Once the airlines decide to form an alliance, the questions of primary concern are:

1. Whom should the airline form the alliance with?
2. If an alliance is formed, how much of the capacity should be shared?
3. How should the airlines in the alliance divide the profits accrued?

Although these are strategic decisions, addressing these questions systematically with good background and better knowledge will yield substantial revenue increments. However, these decisions involve multiple stakeholders, so delicate and sophisticated techniques are needed to achieve the intended result. One way could be to use a game-theoretic way of thinking to help formulate the problem efficiently. Moreover, such a modelling technique will implicitly draft the industry's complex interactions and paves the way for a macro-level optimisation approach rather than the airline level. On a lighter note, even if the airlines are unwilling to form alliances, game-theoretic thinking about the competition will be an interesting area. Apart from Cao et al. (2011) and Houghtalen et al. (2011), we could not trace literature examining the competition in the cargo airline industry.

7.3 Making carriers competitive

As mentioned earlier, for carriers to be competitive, they need to consider the other carriers and their forwarders. Forwarders are contemporary to carriers and can also be regarded as coopetitors (a blend of cooperator and competitor as forwarders compete and cooperate with the airline simultaneously). Competing with forwarders will require the carriers to do more activities like last-mile delivery or commissioning than just transporting cargo between airports. Rather than focusing on all auxiliary activities, the asset providers can compete effectively if they can implement the last mile delivery, which is the major differentiating factor between their coopetitors. To implement the last-mile delivery strategy, asset providers must either partner with trucking or feeder companies or own them. Such additional functionalities will lead the airlines to become similar to integrators like FedEx and UPS, who handle all the operations from loading to delivery, eventually making the integrators the direct competitors. Although integrators have well-defined operations and strategies to maximise performance, we focus on the interactions between carriers and forwarders.

Foregoing the competition from integrators, the problem at hand will deal with intermodality, which indicates that the route combines different modes of transportation. With the increased components of the setting, asset providers tend to be cautious as they know that the investment or operational cost has increased. Hence, the requests to accept are not just the function of bid prices of flights but also the availability and coverage possibility of feeder services. Similar to the game-theoretic way of thinking, there are articles like van Riessen et al. (2017), van Riessen et al. (2021) and Li et al. (2015) in container or liner RM, whose main focus is to incorporate the intermodality issues while making RM decisions. Airlines can take a cue from those models and employ last-mile delivery or mimic the integrators' activities, ultimately giving the advantage over forwarders in the long run. To this end, we are unaware of any such model that considers the combined interactions of integrators, carriers with last-mile delivery, and forwarders in the research setting. However, they work together in practice, which could be an interesting research paradigm.

7.4 Joint allocation and pricing

Talluri et al. (2004) classify the area of RM into two strands: pricing and quantity RM. As the name indicates, pricing RM assumes that the quantity decisions are given, whereas quantity RM assumes that the prices are known. Nearly all the works can be classified under either one of these two strands. To reap the utmost benefits available, these two strands should be in tandem with each other, i.e., pricing and quantity decisions should be made jointly. Though we could find works in passenger RM dealing with joint decisions (Cizaire and Belobaba, 2013; Kyparisis and Koulamas, 2018), no work is done to make these decisions jointly in air cargo. Extending passenger works to cargo settings will be misleading, so we must rely on works to capture the computational and implementation parts well. Mechanism design, which focuses on designing optimal or efficient mechanisms, could be a potential direction to deal with joint allocation and pricing. Specifically, Dizdar et al. (2011) is the most relevant paper to cargo setting, where their centre of attention is solving the dynamic knapsack problem when the customer valuations and space requirements are uncertain. In addition to these benefits, the strategic behaviour of the customers is also accounted for when we choose mechanism design as our modelling tool.

7.5 Combination carriers

Throughout Section 7, we implicitly assumed that we were working with dedicated freighters. From the commencement of cargo transportation to date, the amount of cargo carried in the belly space of passenger flights will be in the region of half the total cargo carried across the world. Because of the grounded passenger flights concerning the ongoing pandemic, the ratio of cargo carried is tilted in favour of dedicated freighters. Nevertheless, the prevailing situation is impermanent, and the airlines will shift back to their traditional way of carrying goods, i.e., the belly space of passenger flights. Hence, it calls for novel optimisation techniques for cargo and PRM. Moreover, with the increase in baggage pricing policies, space available in the aircraft has to be split optimally between cargo and passenger baggage. Shaban et al. (2019a, 2019b) and Wong et al. (2009) pursue research along this line; however, their focus is mainly on setting baggage prices given the available cargo space and prices. Rather than dividing the space between cargo and passenger and optimising, we emphasise combined optimisation of the whole aircraft space, which will eventually bring paramount revenue increments to the asset provider as the cargo and baggage spaces can be treated as perfect substitutes based on the nature of demand arrivals. Research by Hoffmann (2013a) serves as evidence of our viewpoint.

7.6 Routing

Basically, the idea of revenue optimisation across the industries except liner shipping (Brouer et al., 2014) is limited to one side of the story, i.e., everything is planned for unidirectional movement from source to destination, implicitly assuming that the return traffic will also be planned similarly. For bi-directional busy routes, the assumption is innocuous. However, there are stark differences between the inbound and outbound transportation of the amount of air cargo goods carried (Morrell, 2011; Doganis, 2009). This imbalance will result in the underutilisation of resources on the return journey of the aircraft if the traffic is less dense. To tackle this underutilisation problem, airlines can implement nonsimple, cyclic routes where the notion of source and destination is blurred. Moreover, the difference in the busy days across routes in a given week urges us to do so. For instance, the busy days in Europe/Asia differ from Asia/North America (Morrell, 2011). One can leverage the existing imbalance of traffic densities to decide the routing. Such a routing will ensure minimal underutilisation but would require system-wide planning, concrete alliances, and knowledge of the international markets, which is a promising research direction.

7.7 E-commerce

IATA (2021a) states that "...e-commerce was key for air cargo; now, air cargo has become critical for e-commerce", illustrating the dependency of e-commerce's success on air cargo. Pieces of evidence to substantiate the importance of air cargo during the pandemic are plenty. One can argue that this phenomenon is mainly due to the pandemic and will fade away. Brendan Sullivan, global head of cargo, IATA, recognises a drastic change in customers' expectations, and air cargo will play a central role in supply chain logistics. To make the most of it, new and radical business models emphasising digitalisation and automation are in demand. Although many models focus on optimising retail operations (Lobel, 2021; Ha et al., 2022a, 2022b), which benefit from air cargo operations, little attention is provided to managing the air cargo's e-commerce logistics. Li (2020) and Rodbundith et al. (2021) list the challenges crucial for the industry's success in logistics. We envision that rigorous mathematical models will follow exploratory studies of such kind, wherein lies the industry's future.

8 Conclusions

In this work, we presented a state-of-the-art review of scientific contributions related to ACRM along with the base models that capture the core of RM techniques. We started with the interactions in the air cargo industry and reasoned out the research lag in terms of sophistication by contrasting it with PRM. Subsequently, we extensively analysed the literature on ACRM techniques, mainly focusing on overbooking, capacity control, forwarder contracts, and pricing. As a result, we identified the extensions and listed them after the bibliographic analysis of each technique. Apart from those extensions, for effective functioning and better yields, we suggested a few prospects deriving from other cargo transportation modes like container, liner, or maritime and trucking services, which are examined meagerly and can help address the larger problem holistically.

This review is not without limitations. We have restricted ourselves only to ACRM techniques, foregoing the other modes of cargo transportation. Secondly, we did not review the literature on other air cargo operations like flight scheduling, terminal operations, and aircraft loading. Finally, we neither discuss nor present prospects for ACRM related to data-driven techniques. With the increasing digitisation, appropriate data-driven techniques substantiated by mathematical models will play a vital role, which the listed prospects will rely on. However, works on data-driven techniques are minimal in ACRM, and we decided to drop them from the analysis as we cannot find the unifying theme. Future reviews can discuss them in detail as the area matures in data-driven techniques.

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