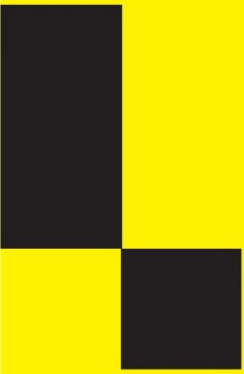
575 LECTURE NOTES IN ECONOMICS AND MATHEMATICAL SYSTEMS



Rolf Hellermann

Capacity Options for Revenue Management

Theory and Applications in the Air Cargo Industry

Lecture Notes in Economics and Mathematical Systems 575

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Theory and Applications in the Air Cargo Industry

With 65 Figures
and 17 Tables

Springer

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Foreword

Arguably the central problem in Operations Research and Management Science (OR/MS) addressed by e-business is better coordination of supply and demand, including price discovery and reduction of transaction costs of buyer-seller interactions. In capital-intensive industries like air cargo, the out-of-pocket costs of excess capacity and the opportunity costs of underutilized capacity have been important factors driving the growth of exchanges for improving demand and supply coordination through e-business platforms.

Hellermann addresses in his dissertation one of the most interesting aspects of this evolution for OR/MS, the parallel development of long-term and short-term markets for capacity and output, accompanied by a range of option and fixed-commitment (i.e., forward) contracts as the basic mechanisms supporting transactions. This has been a fascinating topic for OR/MS research because it builds on the powerful framework of real options, while connecting directly to key operations decisions (capacity planning, network design, staffing, routing, maintenance, and so forth) of the equipment and technologies whose output is the focus of contracts. From the perspective of practice, the integrated use of these Internet-based contracting mechanisms, as facilitated by new B2B exchanges, represents an opportunity for further improving supply chain performance and capital asset productivity.

As Hellermann notes, a central feature of B2B for capital-intensive industries is that contracting needs to take place well in advance of actual delivery. Failure to do so for a non-scalable technology is a recipe for last-minute confusion and huge excess costs, e.g., offloading in the case of air cargo. This has given rise to a general recognition that most of the firm's output in such services industries should be contracted for well in advance. However, there is still a very important role for short-term fine-tuning of capacity and output to contract for, say, the last 10% of a firm's output or a customer's requirements. Doing so requires a conceptual framework, congenial

to e-business, that allows contracting to take place at various points of time, constrained by various commitment and delivery options and flexibilities, and mediated by electronic markets where these are feasible. What Hellermann does here is to characterize the form of options-based instruments required to support this evolution. His results characterize the optimal form of options on capacity and related forward contracts.

In particular, in Chap. 2, Hellermann describes the practice of capacity reservation and dynamic pricing at Lufthansa Cargo AG. In this thesis, the interaction between freight forwarders and carriers is the main focus of the analysis. Shortcomings of existing contracts for the advance sale of capacity in this special services industry are being discussed. In the literature review, see Chap. 3, an extensive overview of flexible contracts for capacity contracting is presented. In Chap. 4, an innovative option pricing model for capacity reservation is proposed. The model accounts for risk in both demand and market price. Chapter 5 contains a comparative statics analysis of the model where fixed-commitment and option-type contracts are being benchmarked. In addition, the Pareto- or win-win efficiency of such option contracts is illustrated (for a wide range of parameter settings). Chapter 6 captures the case of overbooking which is prevalent in the industry. Chapter 7 utilizes sample data obtained from Lufthansa Cargo AG to test the applicability and impact of option-type contracts. The thesis closes with managerial implications, see Chap. 8.

This dissertation represents a solid piece of mature scholarship. The analysis is concise and splendidly readable. The insights for both theory and practice are trenchant. The findings are well connected to the literature of operations and finance, as well as to the broader arena of economics and market efficiency. This research provides a solid platform for further developments and for launching a research career in business studies. In short, this dissertation achieves outstanding marks on everything we consider important for a doctoral dissertation.

We acknowledge financial support through the ADVENTURES (Analysis of Dynamic Ventures Using Real-options in Services) grant under the project number 01HG9992/5, provided by the German Ministry of Education and Research in Bonn, Germany.

Arnd Huchzermeier
Vallendar, April 2006

Stefan Spinler
Leipzig, April 2006

Preface

This work was submitted as doctoral thesis at WHU, Otto Beisheim School of Management in October 2004. It summarizes research that I conducted at the Department of Production Management, chaired by Professor Dr. Arnd Huchzermeier, from 2001 to 2004.

I would like to thank Arnd Huchzermeier for the guidance he provided throughout this project and for the inspiring environment with international exposure he creates at his department. Professor Dr. Manfred Krafft, Director of the Institute of Marketing at the University of Münster, kindly agreed to act as co-advisor for my thesis. I am grateful to Dr. Stefan Spinler, Assistant Professor at the Department of Production Management, for always being available for discussions and for being open to my questions with regard to the formulation of the mathematical model.

Furthermore, I am indebted to Felix Keck, at that time Vice President Margin Management at Lufthansa Cargo AG, for providing the professional insights into the air cargo industry that otherwise would have been difficult to obtain. Lufthansa Cargo AG kindly provided the data for the application case study presented in Chap. 7.

The more difficult moments of the dissertation process were eased by my colleagues at the Department of Production Management who made the time spent at WHU in Vallendar a period I will always gladly recall. My "roommate" Rainer Brosch was a great support and sparring partner.

The most thankful I am to my parents, who from the very beginning opened up the way for the education I received over the years and always backed my plans without reservation. To Natalie, my fiancée, I would like to be forever as supportive as she was to me throughout this work.

Detmold, April 2006 *Rolf Hellermann*

Contents

List of Abbreviations, Variables, and Functions

*	(indicates optimality)
~	(indicates uncertainty)
3PL	Third-party logistics
4PL	Fourth-party logistics
A	(subscript:) Asset provider
a	Maximum contract market size (ordinate intercept of contract market demand function)
ACC	Available capacity for contract
B	Booking level
b	Price responsiveness of contract market demand (slope of contract market demand function)
B2B	Business-to-business
C	(subscript:) Contract market
c	Variable reservation cost in contract market
cf.	confer (compare)
c_o	Overage cost
CPA	Capacity Purchasing Agreement
c_u	Underage cost
$\tilde{D}_C$	Contract market demand
$\tilde{D}_S$	Spot market demand
$\tilde{E}$	Number of called on reservations
$\mathcal{E}[\cdot]$	Expectation operator
$\tilde{\epsilon}$	Stochastic error term in contract market demand function
e.g.	exempli gratia (for example)
Eq.	Equation
et al.	et alii (and others)
f	Fixed cost
$F_i(\cdot)$	Cumulative distribution function of demand i
$f_i(\cdot)$	Distribution density function of demand i
f., ff.	following

$\bar{F}_i(\cdot)$	Primitive of the cumulative distribution function of demand i
FS	(superscript:) Scenario with fixed-commitment contract and spot market sales
FTK	Freight-tonne kilometers
G	(subscript:) Integrated firm
Γ	Total expected overbooking cost
g	Offload cost
GCA	Guaranteed Capacity Agreement
$G(\cdot)$	Cumulative distribution function of spot price
$g(\cdot)$	Distribution density function of spot price
GDP	Gross domestic product
GF-X	Global Freight Exchange
η	Price elasticity of demand
I	(subscript:) Intermediary
i.e.	id est (that is to say)
IATA	International Air Transport Association
ibid.	ibidem (the same)
κ	Expected capacity utilization
K	Capacity
ℓ	Lagrange multiplier
λ	Intermediary's markup
$\mathcal{L}$	Lagrangian
$L(\cdot)$	Standard normal loss function
LCAG	Lufthansa Cargo AG
$\tilde{M}$	Spot market sales
μ_i	Mean (expected value) of i
N	Number of reservations
n/a	not applicable
O&D	Origin and Destination
OS	(superscript:) Scenario with capacity-option contract and spot market sales
Π	Expected profit
P	Profit
p	Price paid by shippers to forwarder
p., pp.	page(s)
PARM	Perishable asset revenue management
$\Phi(\cdot)$	Cumulative standard normal distribution function
$\varphi(\cdot)$	Standard normal distribution density function
$\tilde{Q}$	Offload quantity
QF	Quantity flexibility
r	Reservation fee
R&D	Research and development
$\rho_{i,j}$	Coefficient of correlation between i and j
RM	Revenue management
RTK	Revenue-tonne kilometers
S	(subscript:) Spot market
S	(superscript:) Scenario with spot market sales only
$\tilde{s}$	Spot price
SARS	Severe acute respiratory syndrome
SCM	Supply chain management
σ_i	Standard deviation of i
SRS	Standard Rate Sheet
t	Variable cost in spot market

ϑ_i	Coefficient of variation of i
TKO	Tonne-kilometers offered
TKT	Tonne-kilometers taken
U.S.	United States
v	Variable execution cost in contract market
w	Capacity price in the fixed-commitment contract
x	Execution fee
z	Standardized random variable

1

Introduction

In today's world economy that is marked by increasing trade and volatility, air cargo acts as a facilitator exhibiting steady increases with an annual growth rate of more than 7% since the 1970s (Boeing 2004, p. 11). At the same time, the trend among manufacturing companies to concentrate on core competencies and outsource non-core activities continues unbroken. Especially the responsibility for transportation services is more and more passed on to specialized forwarding and logistics companies, commonly referred to as third-party ("3PL") logistics providers (cf. Murphy and Poist 2000).

On the market for airfreight transportation, there are mainly two types of players facing each other. On the sell side, air cargo carriers offer capital-intensive capacity that must be filled in order to generate their required return on capital. The buy side is dominated by freight forwarding and logistics service companies who try to secure capacity access while pressing for favorable terms.

Sellers strive to assure capacity utilization and mitigate cash flow risk by engaging in advance sale of capacity via long-term contracts. Buyers acting as resellers (intermediaries) are reluctant to commit because they are facing uncertain demand. They expect compensation for the loss of flexibility associated with long-term contracts in form of price breaks. The need for flexibility is even higher since overcapacity in the industry increases the chance that cheap capacity becomes available in the spot market. Air cargo carriers face the problem of designing and especially pricing contracts for advance sale of capacity that incorporate the desired flexibility.

The predominant type of long-term capacity agreement between air cargo carriers and forwarding companies today is a fixed-commitment (forward) contract (Pompeo and Sapountzis 2002), reserving a certain amount of capacity at an agreed-upon rate – payable after capacity usage – on a certain flight for the shipments delivered by the forwarding companies' customers.

Though only some of these contracts actually exhibit a cancellation clause, carriers rarely can enforce the terms of contract vis-à-vis their most important customers, leaving in effect the carrier with the entire utilization risk while giving the forwarder a free call option on capacity.

A contract type currently considered by airline managers is the capacity-option contract, which has, in a different context, been proposed in the recent supply chain management literature (Barnes-Schuster et al. 2002; Spinler 2003, cf.). A forwarding company that signs such an options contract would acquire the right but not the obligation to use the agreed-upon capacity, with a per-unit reservation fee payable ex-ante on signing the contract and a per-unit execution fee payable if capacity is eventually used. By setting reservation and execution fee appropriately, the carrier could adequately price the flexibility offered to the forwarder and potentially ease contract enforcement.

The subject of this thesis is the evaluation of option contracts' suitability to provide for the desired flexibility, the pricing of capacity through option contracts, and the valuation of the financial impact of capacity-option contracts as compared to fixed-commitment contracts. The analysis is conducted by means of an analytical, multi-variate optimization model under price and demand uncertainty. Through an application and feasibility study conducted on the basis of empirical data from a leading air cargo carrier, the applicability and potential impact of capacity-option contracts is demonstrated. Furthermore, it is shown how capacity-option contracts integrate into the context of air cargo revenue management.

The contributions of the thesis to the supply chain management literature are threefold and include

- the development of the capacity-option pricing model,
- the application case study that applies the model to a data set from a leading air cargo carrier, and
- demonstrating under which conditions capacity-option contracts are to be preferred over fixed-commitment contracts.

The key results established in the following chapters include that

- the seller is better off selling capacity options instead of fixed-commitment contracts except for certain market conditions;
- if the seller chooses to sell capacity options, this leads, under most circumstances, to a Pareto improvement, i.e., the buyer benefits, too (or is at least not made worse off);
- however, under rare circumstances, the seller's choice of a capacity-option contract makes the buyer worse off than a fixed-commitment contract, i.e., a Pareto improvement is not achieved;
- the improvement potential suggested by the model is confirmed by encouraging results from the application case study.

The structure of the subsequent chapters is as follows: Chapter 2 introduces into the research problem by giving an overview of the air cargo industry, its characteristics and current challenges. Through a case study on a world-class air cargo carrier, Lufthansa Cargo AG, the current state of capacity reservation and dynamic pricing in the industry is illustrated. Chapter 3 reviews the relevant literature, including the fields of advance sale of capacity, supply contracts, and revenue management.

Chapter 4 contains the formulation of the analytical model and the derivation of the optimal policies of capacity buyer and seller. The results of the model are presented in Chap. 5, including an illustration of the optimal policies and a comparative static analysis of the exogenous model parameters. Chapter 6 provides extensions and analyses of the model beyond the previously made assumptions, especially including an overbooking model. The insights from the application and feasibility study are presented in Chap. 7. Finally, Chap. 8 proposes managerial implications and concludes the work.

2

Capacity Agreements in the Air Cargo Industry

This chapter introduces the subject of capacity agreements in the air cargo industry. At first, an overview of the air cargo industry with its characteristics and current challenges is given. Then, the current state of capacity reservation and dynamic pricing is illustrated considering as example a major air cargo carrier, namely Lufthansa Cargo AG. The chapter concludes with the formulation of the research questions to be answered in subsequent chapters.

2.1 The Air Cargo Industry

The players in the market for air cargo transportation can be divided into three groups: asset providers, shippers, and intermediaries. In the following, the suppliers that offer airport-to-airport transport and operate physical assets (aircraft) that provide air cargo capacity are subsumed under the term *asset provider*. These are in the first place cargo-only carriers that operate freighter aircraft, passenger airlines that offer lower-deck freight capacity, and carriers offering both. Examples for the latter case include the freight subsidiaries of major airlines, e.g., Lufthansa Cargo AG, Air France Cargo, and Singapore Airlines Cargo.

The term *shippers* designates the airfreight senders. Only for a small part (approx. 5–10%, according to Althen et al. 2001, p. 424) of total airfreight volume, shippers send freight directly with asset providers (see Fig. 2.1). For the major part (approx. 90–95%) of volume, shippers leave it to *intermediaries* to organize and perform transportation (cf. Schneider 1993; Doganis 2002, p. 315). These intermediaries can be freight forwarding companies that operate trucks to cover the door-to-airport and airport-to-door sections of the airfreight transport. Freight forwarding companies that have extended their activities beyond simple (road) transportation to providing integrated

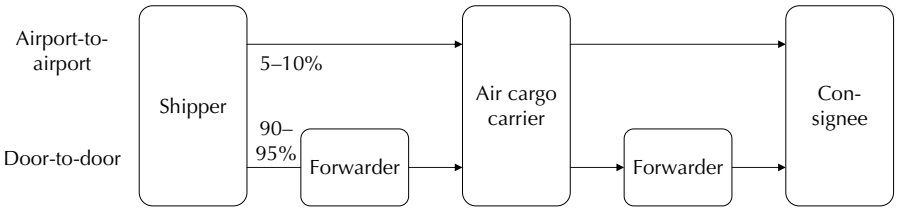


Fig. 2.1. The air cargo supply chain

logistics services that include, e.g., handling, storage, commissioning, and organization of transport chains are often referred to as third-party logistics (3PL) companies (cf. Skjoett-Larsen 2000; Herrmann et al. 1998b, p. 150).[1]

In the course of focusing activities on core competencies, many companies have outsourced their logistics requirements to freight forwarding companies and logistics service providers (cf. Murphy and Poist 2000). Typically, large shippers close agreements with such intermediaries about the terms and rates of service with regard to freight volume, weight, origin, and destination. For those sections of transport chains where the intermediary itself does not operate means of transport, e.g., sea and air, the intermediary purchases capacity from asset providers, e.g., shipping companies and airfreight carriers (cf. Lieb et al. 1993).

The so called "integrators", e.g., Federal Express and United Parcel Service, represent an exception to this business model. They provide door-to-door transport as an integrated service concept and own and operate all transport assets themselves. So far, these companies have focused on goods and packages up to 50 kilogram. Nevertheless they pose a challenge to non-integrated carriers who also try to attract business in this high-margin segment, but usually lack the selling proposition of a seamless door-to-door transport (cf. Doganis 2002, p. 312 ff.). Because of the absence of the necessity for capacity agreements that structure the relationship between asset provider and intermediary, this market segment is not further considered in the following.

Airfreight carriers have traditionally been anxious to maintain good business relationships to forwarders and logistics-service providers because these represent large aggregated volumes and control the direct contact with end customers for whom they usually decide on the actual carrier (cf. Weiskopf 1984, p. 172 ff.).

[1] A 4PL provider takes this concept one step further by not owning any transport asset or operating any part of the transportation network itself, but focusing on the organization and coordination of an entire supply chain (cf. Barde and Mueller 1999). For the following analysis, this distinction is of no further relevance; 3PLs and 4PLs are collectively referred to as logistics-service providers.

It is standard industry practice that airfreight carriers and intermediaries close capacity agreements by which intermediaries reserve or purchase airfreight capacity upfront and en bloc (cf. Herrmann et al. 1998a; Pompeo and Sapountzis 2002). An intermediary benefits from signing a capacity agreement because it secures capacity access if capacity is scarce and locks in prices. The incentive for the airfreight carrier to write capacity agreements is the reduction of capacity utilization risk since the agreements partially shift this risk to the contractual partner. (The motives for engaging in advance sale of capacity are discussed in greater detail in Sec. 3.1.1.) Capacity agreements, however, cannot be regarded in isolation but have to be seen within the context of an airlines product offering and its revenue management system.

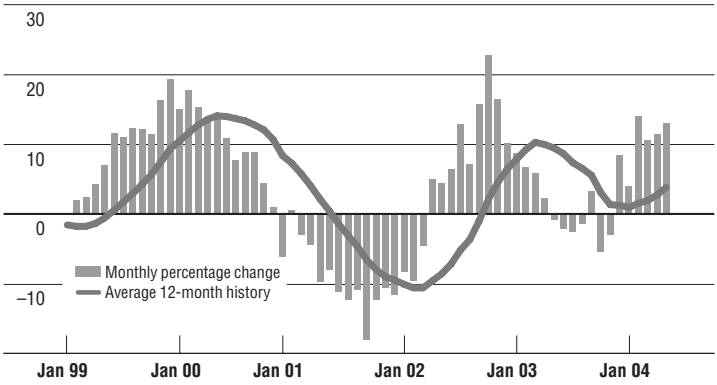
2.1.1 Challenges in Air Cargo Transportation

Though closely related and often even sharing resources and equipment, the air cargo business differs from the passenger business. Especially with regard to network planning and capacity allocation, cargo carriers have more degrees of freedom and hence face additional complexity as compared to passenger airlines (cf. Kasilingam 1996, pp. 37 f.):

- Unlike passengers, cargo shippers do not book round trips. Thus cargo flows are unpaired and, even on a global level, are not necessarily balanced.
- Cargo is characterized by multiple dimensions (volume and weight); while each passenger can be assigned exactly one seat, cargo is characterized by weight, volume, and the number of container positions required aboard the aircraft. The load can be balanced and optimized by mixing shipments with different specific weights, i.e., volume-to-weight relations. Ideally, space can be sold twice, e.g., to one customer with voluminous, light cargo and another with heavy-weight, high-density cargo.
- While passengers purchase tickets for specific flights and routes, cargo airlines can transport goods flexibly with regard to time and route through their network, the only constraint being the promised time of availability at destination.
- On passenger aircraft, the capacity available for cargo is uncertain over the booking horizon; it depends on the number of passengers and the volume and weight of their baggage.

2.1.2 Market Dynamics

The range of products transported by airfreight has grown beyond documents and traditional air cargo goods (like electronics) to include fash-



Source: Boeing (2004, p. 1)

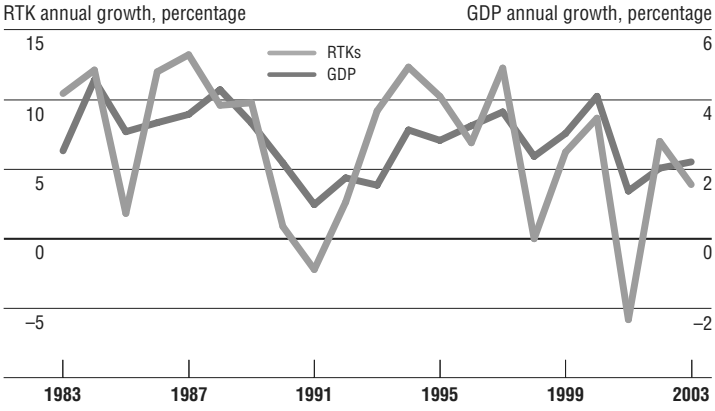
Fig. 2.2. Demand volatility in the world air cargo market: Monthly percentage of change in volume over prior year.

ion goods, perishables, machinery components and spare parts, etc. This growth has been fueled by manufacturers more and more adopting just-in-time strategies and consumers more and more demanding international products (Shields 1998, p. 184). However, these practices have also added to volatility of demand in the world air cargo market. Fluctuations of demand by $\pm$ 15 to 20% within one year are not unusual (see Fig. 2.2).

The major driver behind these fluctuations is the global economy that drives world trade and thus the demand for airfreight transportation services. Fig. 2.3 shows the close link between the development of the growth rate of the world air cargo market and the world gross domestic product (GDP) over the past 20 years. Though the average annual growth rate of the world air cargo market, measured in revenue-tonne kilometers (RTK), amounted to 7.1% since 1970 (Boeing 2004, p. 11), it fluctuates widely and also exhibits phases of market contraction at the beginning of the 1990s and the current decade. Both growth and variability of the air cargo market are typically higher than the world GDP's. Economic cycles thus hit air cargo carriers in an amplified way (cf. Financial Times 2004b).

This poses a challenge for air cargo carriers to plan and adapt capacity accordingly. However, given the lumpy nature and capital intensity of airfreight capacity, capacity cannot easily be changed at short notice. This increases the relevance of risk sharing by advance sale of capacity and the general application of revenue management practices (see Sec. 2.2.3 and 3.3).

During the years of rising demand at the end of the 1990s, carriers have built up freighter capacity which now, after the economy and consequently the demand for air cargo has slowed down (see Fig. 2.2), results in the industry suffering from overcapacity (cf. Kay 2003) because carriers can adjust



Source: Boeing (2004, p. 11)

Fig. 2.3. Historic growth of the global air cargo market: Market growth measured in revenue tonne-kilometers (RTK) is correlated with growth of the world gross domestic product (GDP).

physical capacity only in relatively large increments[2], determined by aircraft size. Pompeo and Sapountzis (2002, p. 92) observe that "[c]ompanies tend to order these [aircraft] simultaneously, when they think the world economy is set to grow. If, as can easily happen, they make a collective mistake about the cycle's timing, they might take delivery of new capacity just as demand drops."

Furthermore, since between 40–50% of global airfreight capacity is made up by belly capacity on passenger aircraft, airfreight capacity supply is partly driven by an unrelated market demand, i.e., demand for air passenger transport (Kadar and Larew 2004, p. 4). This and the above reasons make it generally difficult for airlines to match demand and supply.

Boeing (2004, p. 5) projects the air cargo market growth to continue with more than 6% annually over the years 2004–2023. The aircraft manufacturer also forecasts the world freighter aircraft fleet to grow from 1,766 in 2003 to more than 3,400 in 2023 (ibid., p. 96) and projects a trend to larger aircraft. In 2001, the average load capacity of a freighter amounted to 48 tons, but is projected to grow to up to 60 tons over the subsequent 20 years (Boeing 2002, p. 95), partly as a result of the future availability of larger aircraft like the Airbus A380.

A further component of the dynamics in the air cargo market is the development of yield over time. Yield refers to the average revenue per revenue-tonne kilometer (RTK). In general, yield was declining at –3.4% an-

[2] For example, adding one freighter to Lufthansa Cargo's fleet (see Sec. 2.2 in combination with the information from Table 2.1) increases total capacity by 4–5%.