596 LECTURE NOTES IN ECONOMICS AND MATHEMATICAL SYSTEMS

Michael Müller-Bungart

Revenue Management with Flexible Products

Models and Methods for the Broadcasting Industry

Springer

Lecture Notes in Economics
and Mathematical Systems 596

Michael Müller-Bungart

Revenue Management with Flexible Products

Models and Methods for the Broadcasting Industry

With 15 Figures and 28 Tables

Springer

Michael Müller-Bungart
CTcon GmbH
Burggrafenstraße 5a
40545 Düsseldorf
Germany
m.mueller-bungart@ctcon.de

Zugl.: Duisburg-Essen, Univ., Diss., 2007

Library of Congress Control Number: 2007928494

ISSN 0075-8442

ISBN 978-3-540-72315-8 Springer Berlin Heidelberg New York

Production: LE-TEX Jelonek, Schmidt & Vöckler GbR, Leipzig
Cover-design: WMX Design GmbH, Heidelberg

SPIN 12058488 88/3180YL - 5 4 3 2 1 0 Printed on acid-free paper

Listen to the Water-Mill:
Through the live-long day
How the clicking of its wheel
Wears the hours away!
Languidly the Autumn wind
Stirs the forest leaves,
From the field the reapers sing
Binding up their sheaves:
And a proverb haunts my mind
As a spell is cast,
"The mill cannot grind
With the water that is past."

Sarah Doudney: "Lesson of the Water-Mill"

Preface

Revenue Management (RM) is a success story in many industries. American Airlines, for instance, estimated in 1992 that its RM system contributes additional revenues of US-$ 500 million per year. Lufthansa attributes a revenue gain of DM 950 million in 1996 and DM 1.4 billion in 1997 to RM. Since the vast majority of costs are fixed in those companies, a revenue surplus due to RM almost fully translates to additional profit. Needless to say that RM is now considered to be a key success factor for airlines, hotels and car rental companies. However, RM techniques nowadays prove to be promising in other industries as well. In make-to-order manufacturing, for instance, cost cutting has been the major means to improve profits for a long time. Having implemented tight cost controlling systems, management's focus shifted to the other source of higher profits – higher revenues – as an important, yet underused lever. This book demonstrates how to tap the potential of RM, in particular if flexible products are involved. Since the majority of products in broadcasting companies is flexible, this industry serves as an example.

The contents of the book can be summarized as follows: RM is defined in chapter 1. In this chapter, applications in a broad range of industries are presented. Chapter 2 describes two basic RM techniques: Capacity control and overbooking. Recent advances in the field are highlighted in chapter 3, namely RM in settings where customers make choices and RM with flexible products. Chapter 4 introduces issues related to the evaluation of RM techniques, i. e. the generation of test instances. Chapter 5 deals with the most important aspect of instance generation: simulation of stochastic demand data streams. Chapter 6 is based on a case study in Spanish broadcasting companies. The RM problem in this setting is thoroughly described, the impor-

tance of flexible products is clarified, appropriate models and methods are developed and tested on 18,000 instances. Chapter 7 concludes the book and outlines future research opportunities.

Writing this book would not have been possible without the support of a number of people: Alf Kimms was both sponsor and mentor of my research projects. He served as a sparring partner in many fruitful discussions. The participants of many conferences, in particular the members of the GOR group "Revenue Management and Dynamic Pricing" (chaired by Alf Kimms and Robert Klein), challenged my point of views and contributed their expert opinions. I am also deeply indebted to Yvonne Bußhoff, Julia Drechsel, Hannah Dürr, Michaela Graf and Maria Merker. The support of Kerstin Petzold was invaluable. Finally, I would like to thank my parents who made so many things possible.

Neuss, April 2007 Michael Müller-Bungart

P.S. If you have comments, questions or any kind of feedback on this book or RM in general, you can reach me at `http://www.mueller-bungart.de/revenuemanagement`.

Contents

List of Figures

List of Tables

List of Models

List of Algorithms

List of Acronyms

B&B	Branch and Bound
B&C	Branch and Cut
CRS	Computer Reservation System
DAVN	Displacement Adjusted Virtual Nesting
DB	German Railways (Deutsche Bahn)
DP	Dynamic Programming
EMSR	Expected Marginal Seat Revenue
FCFS	First Come First Serve
FSC	Full Service Carrier
HPP	Homogeneous Poisson Process
ID	Independent Demand
IP	Integer Problem
LCC	Low Cost Carrier
LP	Linear Program
MIP	Mixed Integer Program
MNL	Multinomial Logit
MTO	Make-to-Order
NHPP	Non-Homogeneous Poisson Process
NLF	Nominal Load Factor
RM	Revenue Management
SAS	Scandinavian Airlines (Systems)
SOS	Special Ordered Set

1

Defining Revenue Management

1.1 Introduction

Many readers will have noticed that the same seat on the same aircraft is sold for different prices. These differences can be quite large: Lufthansa German airlines, for instance, sells flights between Dresden and Frankfurt/Main for € 109 (return) – a special discount of very limited availability. There is no such thing like a single "regular" price for that route to compare with, but our impression is that a "usual" fare (i. e. a fare that is not part of a special discount offer) is well above € 200, fares between € 300 and 400 are still not extraordinary, and passengers even have to pay more than € 450 for some travel dates. For this (arbitrarily chosen) example the premium for "regular" tickets compared to the discount is in the order of 100 to 400 %. It is important to stress that we are not talking about different prices for economy, business and first class – all the prices mentioned above are for a single seat in the economy class compartment.

The fact that the same seat on the same aircraft is sold for various prices at the same time implies some challenging decision problems: On the one hand, it is obviously reasonable to sell seats at the highest possible prices. Demand is stochastic, though, and the bulk of passengers with a high willingness to pay (e. g. business travelers) will typically book close to departure, while other consumers who cannot afford the highest prices will submit reservation requests very early. On the other hand, a seat that is empty at the time of departure represents opportunity costs, because it may have been sold to a paying customer; and even if the fare received was low, the contribution margin would have been positive because the marginal costs of carrying an additional passenger are negligible. Given a request of a passenger with a low yield

the airline thus has to decide whether to accept it (running the risk of *displacing* subsequently arriving demand with higher revenue) or to reject it – which is a bad decision if not enough high yield requests arrive in the future. In general, the question arises how the given capacity should be assigned to products (i. e. fares and passengers) such that the total revenue (profit, contribution margin, ...) is maximized. Aspects related to that general question are subsumed under the term *Revenue Management* (RM). We will define that term more precisely in section 1.2 and describe the field of RM research in section 1.4.

Much like a seat on an aircraft after the time of departure a hotel room that has not been sold at the end of the day incurs opportunity costs. A similar reasoning can be applied to rental cars, restaurant tables and capacity in many other passenger or cargo transport businesses as well as a number of non-transport or non-service industries. We will outline areas of RM applications in section 1.3.

RM has been a large success in airlines, hotels and other companies and is nowadays considered to be a key component of capacity management in many industries. Klophaus (1998), for instance, reports that Lufthansa attributes a revenue gain of DM 950 million in 1996 and DM 1.4 billion in 1997 to RM. Smith et al. (1992) of American Airlines estimate that the RM system contributes additional revenues of US-$ 500 million per year. According to Carroll and Grimes (1995), the revenue increase at Hertz (a car rental company) was up to five percent. A new RM system improved revenues by US-$ 56 million in the first year at National Car Rental and was the basis for a successful turnaround saving the company from liquidation (Geraghty and Johnson 1997). Kimes (2004) estimated that RM techniques could improve revenues by more than five percent in a typical restaurant of a US-based chain of Mexican-style restaurants.

1.2 Characteristics of Revenue Management Problems

An agreed-upon definition that characterizes the concept "Revenue Management" in one or two sentences has not yet appeared in the literature. Kimms and Klein (2005), who review a multitude of definitions in a recent survey, remark that it seems to be rather difficult to pinpoint the field of RM in a short paragraph. Instead, they study a wealth of references and compile four common characteristics of (or prerequisites for) RM problems. Before we discuss these four defining aspects in some detail we note that it is not unusual to describe RM in terms of characteristic conditions which give rise to the spe-

cific problems of the field, see e. g. Bertsch and Wendt (1998), Corsten and Stuhlmann (1998), Kimes (1989a,b), Klein (2001), Netessine and Shumsky (2002), Phillips (2005), Swann (1999), Talluri and van Ryzin (2004b), Weatherford and Bodily (1992) and Wirtz et al. (2003). It is furthermore important to stress that all these references mention characteristics that are quite similar. We therefore forbear from examining various approaches to define the term RM – the reader interested in such a discussion is referred to Kimms and Klein (2005) and Corsten and Stuhlmann (1998) – and draw on the results of the comparative survey by Kimms and Klein (2005). They compile the following four basic characteristics or prerequisites for RM from an extensive study of the literature: It is necessary to integrate external factors, the operational flexibility is limited, customers behave heterogeneously and have different valuations for products (and thus capacities), and a standardized product range is offered over a longer period of time. In the following we will discuss each characteristic aspect in detail.

Necessity to integrate external factors

To begin with the production of a physical good, the provision of a service or a combination of both, one or more *external factors* are necessary. "External" means that these factors have to be supplied by the customer. Such factors can be the customers themselves (this is e. g. the case for passenger transportation or hotels), physical goods owned by the client (e. g. cargo) or intangible items like information (e. g. the exact specification of an order). The last example shows that while the necessity to integrate external factors is considered to be a characteristic element of service industries (see e. g. Fitzsimmons and Fitzsimmons 2001, Maleri 1997, Voss et al. 1985) in make-to-order manufacturing (MTO) crucial external inputs exist as well, namely information. We thus stress here that RM is by no means limited to service companies.

The dependency on external factors implies two important features of the problem at hand: It is impossible to anticipate demand, to build up inventories of finished goods and to satisfy requests from stock; and the goods or services have to be offered before the production has begun – this is necessary to induce the supply of the required external factors by the customers. Frequently, the goods or services are even sold before the beginning of production (airline tickets, for instance, are usually paid at the time of purchase, which can be months before the departure date). This is quite a significant difference compared to, say, retailing or wholesale where it is unreasonable (or even illegal) to

advertise products that are not in stock, and the goods are usually paid after purchase (especially in wholesale).

Limited operational flexibility

A limited amount of resources is given. We know (in a deterministic setting) or expect (under uncertainty) that there is a mismatch between capacity supply and demand. However, our means to increase or decrease supply or demand to overcome this imbalance are limited such that only minor corrections are possible.

Potential causes for that dilemma are that it is simply impossible to alter supply and/or demand for mere technical reasons, or that it is technically possible but economically infeasible to do so. The latter case occurs if the costs of capacity and/or demand adjustments are higher than the opportunity costs of rejecting demand (if demand exceeds supply) or the costs of idle capacity (if supply exceeds demand).

The aforementioned technical difficulties or prohibitive costs of capacity adjustments are frequently caused by the fact that the amount of capacity which can be added (or removed) from the given amount is a large multiple of the average demanded quantity. For instance, a typical request for a flight ticket will be for one or two seats, while a typical aircraft has got a couple of hundred seats. A rental car is usually hired for a few days, but given the enormous loss of value of a new car rental companies will typically keep vehicles in the fleet for some months. Since an adjustment of capacity can thus only be made in relatively high discrete amounts those decisions are rather long-term and associated with excessive costs. Consequently, we suffer from operational inflexibility in the short run.

Heterogeneous valuations and behavior

Thus far we are in a situation where there is a unavoidable mismatch between supply and demand, and external factors have to be integrated such demand cannot be satisfied from stock. If customers are totally homogeneous (i. e. their valuations of the same unit of resource do not differ, everybody demands the same amount of resources etc.) the problem can be solved easily: We just satisfy all requests as they arrive until there is no more demand or no capacity left. This is called a "first come first serve" (FCFS) policy. If the valuations and/or other aspects of customer behavior differ, the problem which requests should be satisfied becomes rather challenging.

There is an interesting link between heterogeneous valuations and behavior that is very relevant here: We can only profit from heterogeneous valuations if we are able to distinguish different types of customers. This is trivial if e. g. discounts are offered to students or senior citizens – in such cases we only have to check the respective ID cards. Typically, however, customers will not voluntarily reveal their willingness to pay (especially if it is above average), so we have to rely on heterogeneous behavior to separate customer segments. Airlines, for instance, would like to distinguish leisure from business travelers because the latter have a significantly higher willingness to pay. To discriminate those segments airlines impose a lot of conditions on discount tickets, e. g. advance purchase restrictions, cancellation and rebooking fees, Saturday night stay requirements etc. These factors make a discount ticket unattractive for most business travelers. The implementation of such arrangements which should make sure that customers with a high willingness to pay are not able to buy products or services at substantially lower prices is called *fencing*. One might say that companies induce some form of self selection by fencing. The aforementioned airline, for instance, designs its "menu of products" in a way such that business travelers (with a high willingness to pay) will automatically avoid the discount tickets.

Standardized product range

The product range consists of goods or services with given and fixed attributes in the first place, or a product is defined as a bundle of standardized goods and/or services. Furthermore, the standardized product range (or the standardized range of goods and services to create products in the sense of bundles) has to be offered for a longer period of time. Airlines (with the exception of low cost carriers, see page 21) are an example for the former: A product is basically an itinerary between two or more places, associated with departure and arrival times, conditions like cancellation fees etc. and a price. An example for the latter are hotels: The standardized service components are the single night stay in a particular room type, meals, amenities and other features like access to wellness areas. These components can be bundled by guests (according to certain rules), resulting in a price per night (which may also depend on the day). The price for a multiple night stay is then given as the sum of the daily prices. Other examples are rental car or broadcasting companies (see chapter 6 for an extensive treatment of the latter).

Both examples are admittedly somewhat ambiguous. For the airline example one might as well argue that there is a limited number of standardized services (basically non-stop flights) that can be combined to itineraries and various accompanying aspects (e. g. cancellation and refunding conditions). On the other hand, hotels may offer special weekend packages with two overnight stays, special meals etc. This would have the flavor of a product (which can only be bought as a whole or not at all) in contrast to a bundle of standardized goods and services. However, the distinction between both cases is not important in the following, and we will simply use the term "standardized product range" to subsume them.

It is important to stress here that the standardization of the product range does not imply that all features of the products are defined at the time of purchase and there are no degrees of freedom left for both the seller and the customer. At German Railways, for instance, a regular ticket does not fix the exact departure time, i. e. the passenger is free to choose between trains that depart at, say, eight, ten or twelve o'clock. Broadcasting companies, on the other hand, are typically allowed to schedule a particular advertisement freely within a certain time window (whose size is in the order of hours). The latter is an example of so called flexible products. We will introduce these in some detail in section 3.3; and the RM problem at broadcasting companies will be covered extensively in chapter 6.

The four characteristics can be prerequisites for RM problems in two different ways: Firstly, if some aspects are missing problems belonging to other fields arise, and we have lost the distinctive flavor of RM. The first three mentioned characteristics are prerequisites in this sense: If there is no need to integrate external factors we can smooth out the differences between supply and demand by building up inventories of finished goods. If we were flexible enough to adjust supply we would have to decide how much and when to (dis)invest into capacities – the resulting situation would roughly have the flavor of a newsvendor problem. Finally, we have already pointed out that if customers' valuations and behavior are homogeneous a trivial FCFS policy is optimal.

Standardization of the product range is a prerequisite in a pure technical sense – if this prerequisite is not satisfied it is simply impracticable to implement RM methods: If the product range is not standardized and not offered over a longer period of time it is impossible to fore-

cast future demand and to make acceptance/rejection decisions in a reasonable way.

We will now finally summarize the conditions that constitute a RM problem, or, more broadly speaking, we characterize situations in which RM can gainfully be used: Since it is necessary to integrate external factors supplied by the customer into the production process satisfying demand from stock is impossible. Suffering from a limited operational flexibility we cannot balance capacity supply and demand. Customers behave heterogeneously and have different valuations for the same unit of capacity. Together with the mismatch of available and demanded capacity this implies that there are some non-trivial decisions to make, e. g. which requests to reject if demand exceeds supply. However, since we have been offering a standardized product range for a longer period of time, we are able to forecast future demand and have a basis for our decisions.

The concept of "Revenue Management" stems from the airline industry where those decisions where guided by the objective of revenue maximization – since the majority of costs in that business is fixed (this fact is somewhat related to the operational inflexibility) maximizing revenues is a reasonable approximation of maximizing profits. In MTO environments there may be substantial variable costs, and profit (or contribution) maximization – i. e. maximization of revenue minus variable costs – is certainly more appropriate, but for such problems nevertheless the term "Revenue Management" is used (for historical reasons, one might say). It is interesting to point out in this context that RM was formerly known as *yield management*. In the airline industry, however, the term "yield" signifies the average revenue per passenger. A single full fare passenger on an otherwise empty aircraft would thus represent a solution with maximal yield – this is certainly not useful, and hence the somewhat misleading term yield management was abandoned in favor of "Revenue Management".

In the following sections we will highlight RM applications in various industries (1.3) and describe various problems and methods that are subsumed under the term RM, thereby developing a structure of the field (1.4).

1.3 Revenue Management Problems in Various Industries

The aim in this section is to clarify the general set up of RM problem in various industries using the four characteristics we have just

described. We will furthermore outline major features relevant for RM on a conceptual level, and direct the reader to industry specific references. This complements the expositions in Talluri and van Ryzin (2004b, ch. 11) who focus on current RM implementations in various industries, and Kimms and Klein (2005) who develop models tailored to different businesses.

Airlines

Airlines have probably been the first users of RM on a large scale. Passenger transportation by air is surely the industry that is most often referred to, and many references are explicitly or implicitly focused on an airline's business environment.

For passenger transport the integration of external factors – namely the passengers themselves – is obviously necessary. Distinct customer groups – business and leisure travelers, for instance – certainly have different valuations of the same journey, and they can be differentiated e. g. by the time of booking (leisure travelers tend to book earlier) or by their ability to comply with certain restrictions (Saturday night stay over, for instance). The product range of airlines is fairly stable over time, only prices may be a bit volatile in competitive markets. The flexibility with respect to changes in flight plans or capacities is clearly limited: Published flight plans are usually valid for six months, changes are thus only minor – for instance, it is rare that existing connections are closed or new ones are opened during that time. It is possible to lease aircrafts to increase the available capacity; however, as mentioned before the increase in capacity (a couple of hundred seats for each flight undertaken by an additional airplane) is large compared to the number of seats demanded by an average request. Other limiting factors besides flight plans and airplanes are e. g. landing slots or legal requirements like maintenance rules for aircrafts and working time restrictions for crews.

Given the amount of references that focus on models and methods for passenger airline RM problems it is certainly not useful to mention all of them here. We nevertheless like to point out some contributions by various airline practitioners that give a broader introduction to airline RM: Smith et al. (1992) describe the amazing success of RM at American Airlines. Alstrup et al. (1989) portray the situation at Scandinavian Airlines, focusing on overbooking (see subsection 1.4.1), and Klophaus (1998) refers to Lufthansa German airlines. Fuchs (1987) introduces airline RM from a practical point of view. The popular book by Cross (1998, 2001) contains a case study of People Express, a low

cost carrier (LCC, see page 21) which challenged American Airlines by offering incredibly low fares. The incumbent was only able to introduce competitive fares by a carefully implemented RM system. Calder (2003) and Lawton (2002) cover the history of LCCs in great detail.

Railways and Cargo

It is easy to see that the four defining prerequisites of RM can be found in almost any transport business, let it be passenger or cargo. However, other transport industries feature quite distinctive characteristics.

At German Railways (Deutsche Bahn, DB), for instance, a regular ticket is not bound to a particular time or train. Even the route may not be fixed and can be chosen (within certain limits) by the passenger. In contrast to airlines it is thus uncertain when and on which trains a customer who has bought a ticket will consume capacity. This uncertainty is increased e. g. by special tickets for commuters, where DB does not know how often the customer will travel, and from which origin to which destination. As a consequence, almost two thirds of all passengers belong to the group of what DB calls "uncontrolled traffic" (Köhler 2005).

Other aspects besides revenue increases are relevant for DB as well. In peak demand situations, for instance, there are frequently not enough seats for every passenger, i. e. some customers will have to stand, thus suffering from a very low level of service. An obvious (but costly) solution is to increase the rolling stock when demand is maximum (i. e. adding cars or trains). By driving price sensitive customers who are flexible with respect to travel times to off-peak trains the peak level of service is increased without having to add new capacity, simply by using the existing trains more efficiently.

Treatments of the passenger railway RM problem are very rare, though. Ciancimino et al. (1999) refer to the situation of FS, the Italian public railway company, and present a deterministic and a probabilistic model and solution methods. Whelan and Johnson (2004) consider the situation in the UK and examine how fares and ticket restrictions can be used to shift demand from peak hours to times where capacity utilization is lower anyway in order to avoid overcrowding. Ben-Khedher et al. (1998) describe decision support systems at SNCF (a French railway company) including an RM system. Li et al. (2006) report on a project at Netherlands Railways dealing with pricing issues in the context of automatic fare collection systems based on so called "smart cards".

Cargo industries (regardless of the mode of transport) satisfy in general all four prerequisites as well, the major difference to passenger transportation being that the external factor is not the customer but goods owned by the customer. This difference implies some interesting unique features (see e. g. Kasilingam 1996, Slager and Kapteijns 2004): While each passenger occupies (at most) one seat, the capacity usage of cargo is frequently a multidimensional measure (weight, volume etc.). Passengers will have a preference for a certain itinerary; in particular the route, the connection times and the total travel time will be relevant. For cargo it is often sufficient if the carrier is able to deliver the cargo within a certain time window – waiting and travel times as well as the route taken to the destinations are mostly irrelevant, as long as the final destination is reached on time. Unlike passengers cargo will not travel back from the destination to the origin; in fact cargo traffic is usually asymmetric, i. e. there are many places in the world from which large amounts of cargo are shipped (but only little is received) and vice versa.

In some industries other aspects have to be considered as well: A good deal of air cargo, for instance, is not transported in dedicated cargo aircrafts but together with passengers and their baggage on ordinary scheduled passenger flights. This implies that the amount of belly space remaining free for cargo transportation is uncertain, because it depends on the number of passengers and the amount of baggage they carry with them.

References on the cargo RM problem have been very rare, but it has recently attracted some attention. Kasilingam (1996) outlines a model for air cargo RM. Models and methods for this problem are due to Amaruchkul et al. (2006), Bartodziej and Derigs (2004), Luo et al. (2005), Moussawi and Çakanyıldırım (2005), Pak and Dekker (2004) and Karaesmen (2001, ch. 2). Klophaus (1999) and Slager and Kapteijns (2004) describe the RM system at the cargo division of Lufthansa German airlines and KLM Cargo, respectively. Wendt (1991) deals with pricing of cargo plane capacity. Strasser (1996) describes rail freight RM on a conceptual level, while Campbell and Morlok (1994) indicate methods for that problem. Furthermore, there are some references dealing with so called stochastic knapsack problems. They share common features with some RM problems, in particular with simplified versions of the cargo RM problem, and there are also some loose relationships to the RM problem in broadcasting companies. We give a brief overview on the work on stochastic knapsack problems in section 6.6.

Hotels, Cruise Liners, Casinos, Tour Operators

Much like passenger transport businesses hotels, cruise liners, casinos, tour operators and other companies of the tourism industry require the participation of the customer in person. It is evident that the means to adjust capacities in hotels, cruise liners and casinos is limited: It is certainly possible to add a small bed to a room or cabin, or to accommodate a single person in a double or twin room, but only minor adjustments like these are possible in the short term. Tour operators face RM problems, too, because they rely on the operation of passenger transports, hotels etc. Cruise operators frequently bundle their journeys with trips (mostly flights) to and from the harbor as well.

An interesting aspect of many tourism businesses is that besides direct revenues associated with staying some nights in a hotel or casino or booking a cruise additional (uncertain) profits are possible. Examples for hotels include restaurants, bars and conference rooms. This extra revenue is especially relevant for casinos and cruise liners. In the former case revenues from gambling, restaurants and entertainment can be quite significant compared to those from room rents. Cruise liners profit from the fact that guests are (in a very real sense) "locked in", only being able to visit restaurants, bars, entertainment facilities, retail outlets etc. on board the ship.

While there is quite a large body of literature on hotels (see e. g. Badinelli 2000, Bitran and Gilbert 1996, Bitran and Mondschein 1995, Chen 1998, Goldman et al. 2002, Jones 1999, Koide and Ishii 2005, Lai and Ng 2005, Liberman and Yechiali 1978, Rothstein 1974) there are only quite a few scientific references on cruise liners, casinos and tour operators. Hoseason (2005) gives an overview on the cruise RM problem. Ladany and Arbel (1991) consider the market segmentation and pricing problem for a cruise liner. Lieberman and Dieck (2002) deal with the cruise operator's problem to purchase flights for guests traveling to and from the harbor by plane. Froeb and Tschantz (2003) examine the effects of the Princess-Carnival cruise line merger on competition. To analyze that antitrust case they consider a pricing problem with two competing firms and study the impact of a merger between both on prices and quantities.

Norman and Mayer (1997) survey the implementation of RM techniques in Las Vegas casino hotels. Hendler and Hendler (2004) give a very readable introduction to the casino RM problem, explaining the different sources of revenues and costs (e. g. discounts and free meals for high-yield gamblers).

Remmers (1994) presents an overview of the RM in the tourism industry in general, highlighting the differences between tour operators which bundle services to a package holiday on the one hand and providers of original services on the other. Hoseason and Johns (1998) summarize the tour operator RM problem as well. In an empirical study, Klein (2000) examines how many tour operators make use of RM and to what extent. Xylander (2003) extensively investigates the potential of RM for tour operators and develops tailored models. Würll (2004) reports on the implementation of an RM system at Thomas Cook UK. He observes that the major challenge of tour operator RM is that there is a large number of heterogeneous resources to be used (planes, hotels etc.) which are frequently purchased from a multitude of companies in long term contracts. Laws (2005) highlights some issues with respect to pricing of inclusive holidays. Oppitz (2004) of Thomas Cook points out that a typical problem of tour operators is that holidays are marked down, i. e. prices decline down to a "last minute" bargain price. He notes that this has lead to strategic behavior: Customers defer purchases to wait for discounts. Such a situation is e. g. considered by Ovchinnikov and Milner (2005) who present models and methods for last minute discounts if strategic customer behavior is to be expected. Su (2005) also deals with strategic customers and derives conditions under which markdown or markup pricing should be used, respectively. Similarly, Anderson and Wilson (2003) consider a situation where customers estimate the probability that a certain fare class which is not available now will be offered again later and defer their purchase if the chance is good enough. Wilson et al. (2006) extend this approach by also considering customers who may purchase products at a higher price (instead of strategically waiting) if their first choice product is not available.

Car Rental

The car rental industry is another area of application that has already received some attention in the RM literature. Evidently, it is necessary to integrate the customer in person for the production of the service. The product range is standardized on the basis of different types of cars, length and date of rent. It is important to distinguish between business and private customers (like holidaymakers) who have different valuations of the service. They also behave differently with respect to the time when they rent (day of week and time of year) and where they rent. We have already mentioned that there are certainly possibilities to increase the fleet by adding cars (even in the short term), but given

the enormous loss of value of a car during the first months this is only profitable if there is a significant, long lasting shift in demand. Analogous arguments hold for decreasing the fleet's size by selling cars earlier than planned.

Similar to cargo transport a significant proportion of traffic may be asymmetric, because customers may rent out cars at one station and return them at another such that some stations will (on average) hire out more cars than are returned to that station and vice versa. In this case cars have to be transferred between stations (at a cost). Much like hotels where we have earlier (or later) departures and arrivals, customers may rent out or bring back cars sooner or later than expected, or cars are even returned to a station other than announced by the customer. Like in the cargo industry capacity is therefore uncertain.

Carroll and Grimes (1995) and Mayr (2005) describe the RM systems at Hertz and Sixt (a large German car rental company), respectively. Geraghty and Johnson (1997) report that the implementation of RM at National Car Rental not only improved revenues by US-$ 56 million in the first year but even saved the company from liquidation. Blair and Anderson (2002) and Anderson and Blair (2004) give an account of a system to measure the performance of RM at Dollar Car Rental.

Recently, RM applications in the rental business in general (i. e. not specific to cars) have received some attention, see e. g. Gans and Savin (2005) and Savin et al. (2005) for models and methods.

Manufacturing

Manufacturing does not seem to be an obvious area for the application of RM techniques because it is possible to stock finished goods and to satisfy incoming requests from stock. This implies that it is not necessary to integrate external factors into the production process, and albeit it is frequently difficult or even impossible to adjust capacity supply to demand, excess capacity can be employed to build up inventories which are subsequently used to satisfy requests in case of a demand surplus. This is not to say that planning aspects related to capacity usage are trivial in this setting; on the contrary this situation actually gives rise to challenging and very relevant problems, e. g. lot sizing and inventory control – but certainly not RM problems. This reasoning is however only applicable to make-to-stock production. If we consider make-to-order (MTO) environments it is certainly necessary to integrate external factors (namely the specification of the order by the customer). Since the variety of possible orders is typically large

and/or the holding costs are extremely high (otherwise a make-to-order production would not make sense in the first place) inventories of finished goods are avoided. Standardization of the product range is possible by focusing on the inputs. For instance, if only a limited number of dimensions is used to specify an order, or production uses only a moderate number of machines these dimensions (or machines) form a suitable basis for forecasting and optimization models. It goes without saying that heterogeneous valuations can easily be exploited with MTO – in the extreme every order has got a uniquely determined price (and consequently, value).

Rehkopf and Spengler (2005a) present an overview on the RM problem in MTO environments and Defregger and Kuhn (2004) outline a model and a heuristic. Spengler et al. (2007, see also Rehkopf 2006, Rehkopf and Spengler 2005b) apply RM techniques to the iron and steel industry. In an empirical study Kuhn and Defregger (2005) find that many paper, steel and aluminum companies satisfy preconditions for a gainful application of RM, but actual implementations are rare. This paper also contains a wealth of references, considering as well related problems if products are made to stock.

Miscellaneous Industries

restaurant RM has recently received some attention, see Kimes (2005) for an overview. Bertsimas and Shioda (2003) address this problem in a "classic" way, focusing on whether to immediately accept demand or not (controlling for waiting times and "fairness"), while other authors consider somewhat more restaurant specific methods like meal duration control (see e. g. Kimes et al. 2002) and demand based pricing (see e. g. Kimes and Wirtz 2002).

Other areas of application include visitor attractions (Hoseason 2006, Leask et al. 2005), computing centers (Dube et al. 2004), telecommunication networks (Humair 2001, Lindemann et al. 2003, 2004), internet service providers (Nair and Bapna 2001), natural gas transport and storage (Dörband 2005, Dörband et al. 2003), golf courses (Kimes and Schruben 2002, Kimes and Wirtz 2003) and tickets for sports, entertainment and other events (Barlow 2005, Cheung 1980, Volpano 2003). In this book we will furthermore indicate applications in the health care industry (see page 82), and broadcasting companies will be extensively covered in chapter 6.

Two papers refer to somewhat special organizations as RM users: Cook (1998) mentions a project conducted with the US Navy where training facilities have to be booked in advance and it is also gainful to