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Dynamic pricing & capacity assignment problem with cancellation and mark-up policies in airlines[☆]

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A B S T R A C T

Revenue management has started on the capacity control by booking classes for available seats, and has been recognized as a powerful tool to maximize the total revenue. Among various RM techniques, pricing and seat controls have played key roles in airlines. Since pricing and seat control problems are highly correlated in RM problem. These two decision problems need to be considered jointly. However, due to the complex interaction between them, a few researches focus on the joint pricing and seat control problem. In this paper we consider a comprehensive problem including a cancellation in booking processes and a mark-up policy in pricing strategy under uncertain demands. To manage the demand uncertainty efficiently, we applied a linear approximation technique and proposed a new approximation model, a simple mixed Integer Programming model. From the computational experiments with randomly generated data, we can find our model makes good performance for deciding pricing and seat controls simultaneously.

1. Introduction

Revenue Management (RM) has received considerable attention both from practitioners and academics for many years. Among various RM techniques, pricing and seat controls have played key roles in airlines. Since airlines have offered competitive prices to customers for coping with severe competition, dynamic pricing, which is to adjust the price in a timely fashion for responding uncertain demand, has become a common strategy to maximize the total revenue. Also, they have tried to protect the high yield customers from the low ones to increase their revenue by seat control optimally (Talluri & van Ryzin, 2005).

Since Littlewood (1972) proposed the expected marginal revenue (EMR) rule for a single flight leg, a lot of studies have been carried on the seat allocation problem for a single flight (Belobaba, 1987, 1989; Brumelles & McGill, 1993; Curry, 1990; Glover, Glover, Lorenzo, & McMillan, 1982; McGill & van Ryzin, 1999), and for the entire network (Curry, 1990; Glover et al., 1982; Jiang, 2008; Song, Hong, Hwang, & Yoon, 2010; Talluri & van Ryzin, 1999). For pricing control to respond to a market change, many researches have been carried out to develop comprehensive models and algorithms. Gallego and van Ryzin (1994) dealt with the dynamic pricing problem for pricing decisions. They showed that the optimal price can be increased with decreasing inventory and approaching the departure time. Useful researches in dynamic pricing problem can be found in many literature (Bitran & Caldentey, 2003; Elmaghraby & Keskinocak, 2003; Feng & Gallego, 1995; Feng & Xiao, 2000; Sen, 2013; Zhao & Zheng, 2000).

Since pricing and seat control problems are highly correlated in RM problem. These two decision problems need to be considered jointly. However, due to the complex interaction between them, a few researches focus on the joint pricing and seat control problem (McGill & van Ryzin, 1999). In fact, a recent survey finds that only

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11% of 479 companies practicing revenue management in Europe and North America manage both price and capacity allocation decisions (Kocabiyikoglu, Popescu, & Stefanescu, 2011). In this paper, we focus on the simultaneous decision problem for pricing and capacity control to maximize revenue in airlines.

Cote, Marcotte, and Savard (2003) presented the bi-level programming approach for solving a pricing and capacity control problem. Maglaras and Meissner (2006) considered the dynamic pricing and capacity control problem and showed that these two problems can be formulated as a single model. Feng and Xiao (2006) considered a pricing and capacity allocation problem under time and capacity constraints. Xiao, Chen, and Chen (2007) studied a semi-dynamic pricing and seat allocation problem in which with assumptions of stochastic customer arrival processes, they suggested an approximation method. However, they did not consider cancellation frequently encountered in the booking process, and the individual arrival rate for each price at each time is very difficult to estimate in reality. Mookherjee and Friesz (2008) considered a joint problem of pricing, resource allocation and overbooking over networks under competition. Recently, de Vericourt and Lobo (2009) developed the optimization model to solve prices and allocations in a dynamic setting under a multiplicative demand model.

In this paper we consider a comprehensive problem including a cancellation in booking processes and a mark-up policy in pricing strategy under uncertain demands. The half of the bookings were resulted in cancellations or no-shows, and 15% of the flight seats would be unused, if bookings were only limited to the capacity (Smith, Leimkuhler, & Darrow, 1992). Furthermore, airlines have offered various discount prices with different refund policies for their customers (Vinod, 2008). For example, the full price tickets guarantee a full refund at any time. However, airlines may sell more than 50% discount tickets with no-refund restriction to attract price sensitive customers. Therefore, the booking cancellation has much attention in airline industry and the refund policy for cancellations becomes an important factor for seat control as well as pricing decision in airlines (Iliescu, Garrow, & Parker, 2008). Yoon, Lee, and Song (2012) studied the capacity allocation problem with cancelation and refund policy in airlines. This study is an extension of their work for combining pricing and capacity control decisions in a single framework.

Recently, many low cost airlines have changed their price frequently depending on market demands to attract price sensitive passengers. However, most airlines do not allow the price goes down as the departure approaches. If the price switches to the lower ones, perceived unfairness of advanced purchased customers with higher prices will be increased and hence the airlines' long-term profit will be affected (Kimes & Noon, 2002; Talluri & van Ryzin, 2005). Also, customer demand becomes less price elastic as it gets closer to the departure time. Thus, airlines usually adopt the mark-up policy which is to raise the price continually to the departure time.

The objective of our problem is to find a price and its booking limit at each decision time to maximize the total revenue over the whole planning period. We first develop a stochastic model for dynamic pricing and seat allocation under uncertain demand. To manage the demand uncertainty, we consider an approximation method which is widely adapted to solve the uncertainty with ease (Jiang, 2008; Mookherjee & Friesz, 2008; Szwarc, 1964; Gallego & van Ryzin, 1994). In section 2, we first describe the modeling processes for our stochastic problem. We will show ours can be formulated as a mixed Integer Programming model approximately. In section 3, to evaluate the performance of our model, we will test some computational experiments with randomly generated data. Some discussions and extensions of our research are given in the last section.

2. Dynamic pricing and seat allocation model with cancellation & mark-up policy

In this paper, the whole planning period is divided into T discrete times. At each time, we can select a price from a predetermined price set. In our problem, we assume that the demand for each price is uncertain and independent with others. Let C be the seat capacity and r_j^t be the j-th price among alternative prices at time t. To formulate our problem, we define the following variables and notations.

$\mathbf{R}_t = \{r_1^t, r_2^t, .., r_M^t\}$: a set of predetermined prices at time t,
$\mathbf{D}_t = \{D_1^t, D_2^t, .., D_M^t\}$: a set of demand for price r_j^t at time t,
(D_j^t is a random variable and the maximum demand at time t is $\overline{D}_j^t$.)
θ_j^t, δ_j^t: The cancellation rate and the refund rate for r_j^t at time t respectively
($0 \le \theta_j^t,\ \delta_j^t \le 1$),
x_j^t: the number of seats assigned for the demand for price r_j^t at time t.
z_j^t: 0, 1 integer variable denoting the selection of price r_j^t at time t.

At time t, given a price r_j^t and the number of assigned seats x_j^t, the actual amount of sales is depend on the demand occurred at the time. If the demand D_j^t is greater than x_j^t, the excess demand above the number of assigned seats x_j^t is rejected all. While if the demand is less than x_j^t, all requested demand is accepted. Then airlines can be obtained the actual sales by $\min(D_j^t,\ x_j^t)$. However, among the accepted demand, airlines may have some cancellations by various reasons, thereby they have to refund for the cancellation according to refund policy. Usually, airlines differentiate the refund policy for the different price. Considering the cancellation and refund rates θ_j^t, δ_j^t, the actual revenue can be represented as $r_j^t(1-\delta_j^t\theta_j^t)[\min(D_j^t, x_j^t)]$. Since the demand is a random variable, the expected revenue for price r_j^t at time t can be obtained by $r_j^t(1-\delta_j^t\theta_j^t)E[\min(D_j^t, x_j^t)]$.

Noting the cancellation and the mark-up policy as a pricing strategy, our problem can be formulated as a probabilistic nonlinear programming (PNLP) model to maximize the total revenue.

$$(P_0) Max.\ Z_p = \sum_{t=1}^{T}\sum_{j=1}^{M} r_j^t\left(1-\delta_j^t\theta_j^t\right)E\left[\min\left(D_j^t, x_j^t\right)\right], \tag{1}$$

$$\sum_{t=1}^{T}\sum_{j=1}^{M}\left(1-\theta_j^t\right)x_j^t \le C, \tag{2}$$

$$x_j^t \le \overline{D}_j^t z_j^t, \quad j=1,\dots,M, t=1,\dots,T, \tag{3}$$

$$\sum_{j=1}^{M} z_j^t = 1, \quad t=1,\dots T, \tag{4}$$

$$r_j^t z_j^t \le \sum_{l=1}^{M} r_l^{t+1} z_l^{t+1}, \quad j=1,\dots,M, t=1,\dots,T-1, \tag{5}$$

$$x_j^t \ge 0, z_j^t \in \{0,1\}, \quad j=1,\dots,M, t=1,\dots,T, \tag{6}$$

The objective function (1) describes the total expected revenue which has to be maximized. In general, airlines have made an over-booking to minimize the empty seat resulting from the cancellation, and the over-booking pad depends on the cancellation rate for each