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Application of an alternative expected marginal seat revenue method (EMSRc) in unrestricted fare environments

Hossein Tavana [a], Larry Weatherford [b, *]

[a] Carnival Cruise Line, Revenue Management Science, 3655 NW 87th Ave, Miami, FL 33178, United States
[b] University of Wyoming, 1000 E. University Ave, Dept. 3275, Laramie, WY 82071, United States

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ABSTRACT

We reintroduce an expected revenue maximization formulation for airline seat allocation. We present a numerical method to find the exact solution to the integer programing problem. We further show that when this method is applied to a nested fare structure, it constitutes a heuristic method which has far better performance in an unrestricted fare environment, where fare buckets are completely undifferentiated, compared to EMSRa, EMSRb and EMSRb-MR. With use of simulation, we show that this method can recapture a significant portion of the potential revenue loss when restrictions are removed, while its performance in a fully differentiated environment is only marginally inferior compared to other methods. This method is also applicable to hotels and cruise lines where not only are there fewer "fences" around different offered rates, but also there is a greater tendency for consumers to buy down since most bookings are fully refundable.

1. Introduction & literature review

Belobaba (1987b), Weatherford (1991), Weatherford and Bodily (1992) and McGill and van Ryzin (1999) have provided valuable overviews of the history and the existing methods of airline revenue management. The first three mostly focus on different seat inventory control methods, while the last presents a more recent review of different aspects of revenue management, including forecasting, overbooking, seat inventory control and pricing.

The earliest reported work of airline seat allocation is attributed to Littlewood (1972), where he proposed that, in a two fare-bucket scenario, a request for the discount-fare booking should be accepted as long as its revenue is greater than the *expected* revenue of future full-fare bookings. This rule, known as Littlewood's rule, has been widely adopted in the airline seat allocation methods and results in an optimal seat allocation when there are only two fare-buckets and demand for the two fare buckets are independent and their arrival is ordered from low to high (Bhatia and Parekh, 1973; Richter, 1982).

More relevant to the development of current revenue management (RM) systems, beginning in the 1980's, is the introduction of more than two different price types, all of which share the entire inventory of the cabin on a single leg, and the concurrent modification of reservations control systems to allow multiple nested booking classes. Belobaba (1989) first developed a heuristic decision rule for finding seat protection levels and booking limits for more than two nested booking classes, a model that has come to be known as the EMSR (expected marginal seat revenue) model. The optimal set of conditions for determining the protection levels and nested booking limits in multiple price class structures were subsequently presented by Curry (1990), in an approach commonly known as OBL (optimal booking limits). Similar and independently derived optimal solutions to the same multiple nested class problem were also published by Brumelle et al. (1990) and Wollmer (1992).

Belobaba (1992) then developed a modified version of his original EMSR seat protection model, more closely approximating the characteristics of the optimal conditions for nested booking classes. This revised model is now known as the EMSRb heuristic model, the details of which were also published by Belobaba and Weatherford (1996). The original version of Belobaba's model is

* Corresponding author.
E-mail addresses: htavana@carnival.com (H. Tavana), Lrw@uwyo.edu (L. Weatherford).

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now referred to as the EMSRa heuristic. In the EMSRb model, joint protection levels are calculated for all higher classes relative to a given lower class, based on a combined demand forecast and a weighted average price level for all classes above the one for which a booking limit is being calculated. The weighting is done based on expected demand to come in that class.

Most airline, hotel, and rental car RM systems currently in use today utilize EMSRa, EMSRb or some variant thereof in determining booking limits for multiple nested booking classes on a single leg. Expected marginal seat revenue has been used for over two decades as the airline industry standard for leg seat inventory control.

However, the mean demand for the lowest fare bucket and its probability distribution are not taken into account with either EMSRa or b. This can cause suboptimal solutions if demand for the fare buckets is not independent (i.e., when the customer can buy down). Belobaba (1989) appropriately discusses that in a two fare-bucket case, the optimal seat allocation is achieved when the expected marginal revenues for the *last* seat allocated to either fare bucket are equal, even though this logic is used in neither EMSRa nor b.

As for research in the area of unrestricted fare environments, where fare buckets are completely undifferentiated and passengers will book in the lowest available fare bucket regardless of their maximum willingness to pay, Kleywegt et al. (2004) have shown that due to modeling errors, the chosen controls would systematically deteriorate, causing the spiral down effect. Furthermore, Belobaba and Hopperstad (2004) assumed all of the demand will spiral down to the bottom fare class (called Q), and thus developed an approach called Q-forecasting. For a mathematical description of spiral down, see Cooper et al. (2006).

As for the seminal research piece on a complete approach to the unrestricted- and partially-restricted fare environment, refer to Fiig et al. (2010), which introduces the concept of fare adjustment using marginal revenue (MR) transformation. Their theory is applied to transform the fares and the demand of a general discrete choice model to an equivalent independent demand model. This powerful transformation allows the continued use of the optimization algorithms and seat inventory control mechanisms of traditional RM systems under the assumption of dependent and independent demands for fare classes. They have applied this marginal revenue transformation to create an alternative EMSR method, namely EMSRb-MR, with specific applications to unrestricted fare structure. We will compare the results of EMSRc with EMSRb-MR in an unrestricted fare environment and will show that the EMSRc method has better performance than leg EMSRb-MR in most scenarios.

Walczak et al. (2010) looked at the analytical relationship between this FA transformation and traditional EMSR and applied it to single-leg RM with price-sensitive customers. Further, Fiig et al. (2012) applied these fare adjustments to “fare families”—an innovative approach to pricing and branded fares that was pioneered by Air New Zealand, Air Canada and Qantas.

The idea for the heuristic discussed in this paper (EMSRc) was first presented by Tavana (2004). He formulated a probabilistic optimization model by which the optimal seat allocation was obtained. This method generates an exact optimal solution when fare-buckets or products are fully differentiated and also partitioned such that no substitution is allowed. A straightforward application of this method can be for the design and configuration of airplanes (front vs. back cabin) or cruise ships (different cabin types) where products are partitioned and the optimal use of space, without free upgrades, is desired.

On the other hand, the EMSRc seat allocation can also be considered a heuristic solution when applied to airline revenue management systems, where fare buckets are nested, products are undifferentiated and substitution from one fare to another is possible. Nevertheless, it will be shown in this paper that the presented method *significantly* outperforms EMSRa, b and EMSRb-MR in an unrestricted fare environment, where passengers will book in the lowest available fare bucket regardless of their maximum willingness to pay. Moreover, its disadvantage compared to these other methods in a fully-restricted fare environment is relatively small.

A similar formulation to the method presented in this paper is introduced in an unpublished work by Wollmer (1985), as also reported by Belobaba (1987a), McGill and van Ryzin (1999), and De Boer et al. (2002). In Wollmer's original work, an integer programming formulation was introduced by incorporating expected seat revenues as a set of monotonically *decreasing* objective function coefficients. The sum of binary decision variables for each fare-bucket resulted in the seat allocation for the corresponding bucket. Wollmer (1992) further suggested an iterative algorithm and an approximation to solve the proposed formulation. De Boer et al. (2002) revisited the mathematical programming for network revenue management and presented a modification to Wollmer's formulation for an OD-network case such that with an approximation, the problem would have fewer decision variables.

The distinction of the new formulation in this paper from Wollmer's is as follows. In the presented formulation, the decision variables directly represent the seat allocation in each fare bucket. Consequently, a set of monotonically *increasing* objective function coefficients are used and a new set of constraints is included. The LP relaxation of the formulation enables us to solve the problem using conventional and efficient linear programming methods. More importantly, by deploying the LP relaxation, the shadow price of the capacity constraint produces the EMSR value, which is widely used in setting bid prices in network revenue management heuristics. Furthermore, we illustrate a numerical method by which the exact solution to the integer program is obtained without the need to solve it mathematically.

The following are the major contributions of this paper. We introduce an alternative linear programming formulation, the shadow price of which is the bid price of each flight leg. This bid price can be used to determine the availability on connecting flights and can be used in heuristic network optimization. We further introduce a numerical method to find the exact solution to the linear program to obtain the optimal seat allocation, without the need to solve the LP program. The solution to the linear program in a nested fare environment can be suboptimal, therefore it constitutes a heuristic. However, with the use of simulation, we show that this method has superior performance over EMSRa, b and b-MR in an unrestricted fare environment, while its performance in a fully differentiated environment is only marginally inferior to the other methods.

The rest of the paper is organized as follows: the new formulation of EMSRc for obtaining seat, cabin or room protection levels is presented in Section 2, then a numerical example (§3) is given. In Section 4, a numerical method to solve the integer-program formulation is explained. In Section 5, simulation results are presented for three different cases with two, six and eight fare buckets, under either a restricted- or an unrestricted-fare environment. In Section 6, the performance of EMSRc is compared to EMSRb-MR, which was presented by Fiig et al. (2010). Finally, conclusions and future work are discussed. It should be noted that even though we refer to airline seats throughout the paper, the same concept is obviously applicable to hotel rooms and cruise ship cabins and their respective inventory control.