WHITE PAPER

DYNAMIC CAPACITY SHARING MODELS IN AIRLINE REVENUE MANAGEMENT

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Realize Your Potential

EXECUTIVE SUMMARY

Airlines often upgrade passengers from a lower service level compartment to a higher one when the seat capacity at the lower level is depleted and there is still room to book more passengers in higher compartments. Most airlines manage their passenger upgrades in a "static" manner, where a fixed number of higher seat capacities are allocated to the lower compartments at the airline's resource planning and optimization epochs.

This type of allocation is usually based on estimated demands and without sufficient revenue consideration. At PROS, we have conducted research to compare and contrast new dynamic capabilities that help airlines generate more revenue. In this research, we have developed models that simultaneously consider and control capacities of multiple compartments. Our numerical experiments show tangible revenue gains as compared to using the conventional static control methods. In this research, we theoretically prove bid price properties of the models and we use such properties to develop efficient and exact algorithms to solve the problems.

Overview

Airlines traditionally sold tickets for seats on a particular flight in different compartments such as first, business, and economy. In this model, each compartment has a different quality level of seating and service and the number of seats at each level is limited. Segmenting customers by offering tiered products in this way has been a success story in the airline industry. Recently, it started taking a form of so-called "branded fares" or "fare families" where distinct classes of service are offered even within the economy compartment, cf. Carey (2016). To support this initiative and to maintain a level of goodwill, airlines subdivided the compartment into groups of seats with physically different characteristics, such as legroom, seat pitch, or distance from the front of the aircraft. This naturally makes the problem of upgrading the customers from one level of seating and service to another even more relevant.

To illustrate this, let's assume that we have two compartments: business and economy. Revenue managers at airlines have two objectives when considering upgrades. First, they need to decide when it is most profitable to accept additional requests for economy seats and potentially upgrade them into business to reduce potential spoilage in business compartment and make additional revenue. Second, they have to avoid potential displacement of business customers willing to pay the full price for that inventory if enough of them show up and the economy compartment becomes full. Our work solves this problem via upgrade control policies which take into account the dynamic nature of the upgrade problem.

In current practice, the upgrade process is usually based on forecasted expected demand for the seats in the different compartments. Conventionally, this leads to calculation of expected revenues to be generated in the different compartments and a possible (predetermined) relocation of some of the business seats for use by customers requesting economy seats. This situation happens particularly when little demand is expected in the higher compartments and a lot of demand is expected in lower ones.

Currently, this approach to pricing available capacities of multiple resources is conducted in a static manner. After the resource allocation is determined, the virtual capacities are considered fixed until the next re-optimization. It fails to account for the dynamic nature of booking requests, including changes in the available capacity of each resource during the booking period. Consequently, if the predetermined capacity allocation is different from the actual booking requests received (=demand realization) for the various resources, the airline will lose revenue. In particular, the airline will accept too many upgrade requests, which results in more than the optimum number of higher cost seats being allocated to economy and sold at lower prices. Or it will accept too few upgrade requests, which results in an excessive number of business seats and at the same time turn away demand for economy if that compartment runs out of capacity.

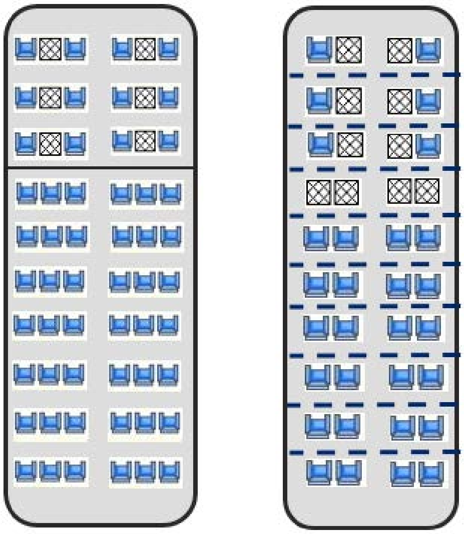
We developed methodologies to dynamically determine prices for capacities in different resources. More specifically, for each combination of remaining time available in the booking horizon and remaining seat inventories in all the compartments, we calculated the opportunity cost (bid price) to accommodate one more booking in each of the compartments, based on information such as expected total demand for each resource, allowable prices, and probabilities of having a customer who purchases at each of the allowable price points for each resource. By jointly considering the remaining capacities in all resources, we reduced revenue loss that results from the conventional approaches when too many economy updates are accepted and also created additional revenue by upgrading some portion of economy passengers into business compartment when the conventional approaches would have rejected them.

We considered two specific cases of capacity sharing. In the first case, the total capacity in each compartment is fixed at the beginning of the booking period, and we allowed for dynamically upgrading passengers who request seats in the lower compartments into higher ones. We named the model the "fixed-compartment" model. Its results are general and are applicable also to the pricing of hotel rooms, car rentals, cabins on cruise ships, etc.

In our second case, the aircraft has one actual cabin and its entire seating capacity can be flexibly divided shortly before departure into business and economy compartments. The respective compartment capacities can be adjusted by means of a curtain depending on demand realization, for instance, on the number of bookings in each level of service. The business level of service is realized because a "business" passenger is guaranteed to have an empty seat next to her and other additional on-board services. We named this model the "moveable-curtain" model.

Figure 1 illustrates our two different settings for capacity sharing. The dotted lines in the RHS aircraft cabin are positions where a curtain may be installed.

Figure 1. Fixed Compartments and Moveable Curtain Aircraft Configurations for Capacity Sharing



Methodology

For ease of explanation, we continue to consider only two compartments, one for economy and the other for business. (Yet, despite this simple assumption, our models are easily extendable to cases with more compartments.) We considered a single-leg flight with no cancellations or over-booking.

In our fixed-compartment model, we defined a dynamic program (DP) with a two-dimensional state space to keep track of the booking levels in economy and business compartments at a given time. We theoretically showed that the bid price for one compartment increased when the inventory in either that compartment or the other compartment decreased. In addition, we showed that the business bid price is never less than the economy bid price and it is optimal to fill the economy compartment before upgrading economy requests to business. We used this structural result to propose an exact algorithm to solve the DP.

In the movable-curtain case, we developed a DP over an even-more-general, three-dimensional state space, which tracked not only the remaining seats available on both sides of the curtain, but also the remaining number of full seat rows. We were able to show that the size of the state space, despite its dimensionality, was actually more manageable than the fixed-compartment model. Meanwhile, the end-user interacted with the model only by providing booking levels in both compartments, and therefore did not need to see its back-end complications. We further extended the model by allowing economy passengers to sit on the business side if that makes revenue sense and by considering a feasible set of curtain positions due to aircraft configuration.

Results

By dynamically sharing capacity between compartments, airlines can generate more revenue compared to using traditional static approaches. Our numerical investigation suggests that in the fixed-compartment case, when the economy compartment is capacity-constrained, there exists a substantial monetary benefit from the optimal dynamic upgrading (revenue gain by 0.5%-1.5%, see table 1).

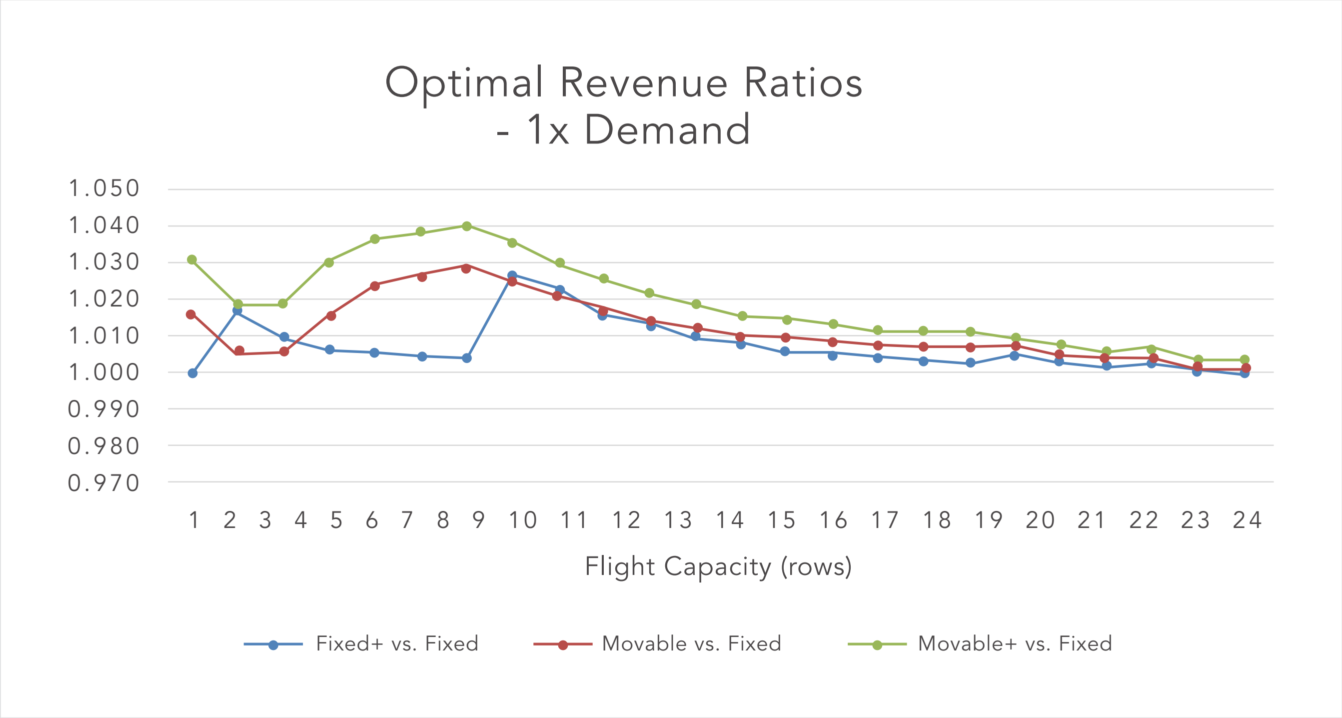
Table 1. Monetary Benefit of Dynamic vs. Static Upgrade – Fixed Compartment Case

	Instance 1	Instance 2
Dynamic Upgrade Value	$20,587.10	$114,213.30
No Upgrade Value	$20,179.72	$113,001.00
Improvement versus No Upgrade	2.02%	1.07%
Static Threshold Upgrade Value	$20,215.94	$113,563.10
Improvement versus Threshold	1.84%	0.57%
Static Revenue Based Upgrade Value	$20,276.48	$113,656.10
Improvement versus Revenue Based	1.53%	0.49%

And in the moveable-curtain case, the revenue performance of several dynamic approaches dominates that of the static approach by as much as 4% depending on capacity and demand level (see Figure 2).

Furthermore, in addition to the standard backward-induction approach to solve DP, our numerical methods utilize theoretically proven bid price properties, and so are efficient enough to make implementation feasible in production revenue management systems.

Figure 2. Revenue Ratio of Dynamic vs. Static Approach – Moveable Curtain Case



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About the Authors

Ang Li joined PROS science team in March 2014. His current work involves researching on new Revenue Management solutions for the airline and passenger railroad industries. In particular, he has developed optimal approaches to controlling airline seat capacity in multiple compartments simultaneously. Ang holds a PhD in Industrial and Systems Engineering from Texas A&M University.

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