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Revenue management under horizontal and vertical competition within airline alliances ☆

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ABSTRACT

We present a model to optimize a competitor's behavior in a network revenue management game within an airline alliance. In particular, we model two forms of competition; horizontal competition with parallel substitutable flights and vertical competition with both competitors operating adjacent connecting flights in a code sharing agreement. We compute pure Nash equilibria with an iterative algorithm presented in an earlier paper. A computational study shows that the algorithm is also suited for computing Nash equilibria taking both types of competition into account and that code sharing increases revenues for both competitors. However, the difference decreases as the network size and mean demand increase.

1. Introduction

The deregulation of the airspace in the US, followed by deregulations in other countries in the past two decades, allowed airlines to enlarge their networks [21]. In order to avoid many of the efforts connected to the entry into new markets, airlines allied in alliances. See e.g. Oum and Park [21] and Park [23] for further reasons for alliance formation as well as its (economic) effects. Chapter 3.2 in Çetiner [3] provides a detailed treatment of this topic as well as a thorough literature overview.

A key characteristic of airline alliances are code sharing agreements that allow the airlines to sell products which involve utilization of partners' capacities as if they were their own [22,p. 57]. Code sharing allows the partners to extend their networks, improve customer service, and raise their efficiency through a higher capacity load factor, among other things. With code sharing agreements in use, the problem is not only to allocate capacity to different products, but also to divide the available capacity among the partners within the alliance.

O'Neal et al. [19] presented a mixed-integer problem to select those flights which should be made available for code sharing. Given these decisions, it must be decided how much of an airline's capacity should be made available to the alliance partners. Graf and Kimms [9,10] have developed procedures based on real options to solve this problem for a two-airline alliance. However, with more than one airline involved in the sale of tickets, the problem of how to divide the profit amongst them arises. Kimms and Çetiner [15] as well as Çetiner and Kimms [4] introduced procedures to allocate the alliance's revenue among the partners in fair ways so that none of them has an incentive to leave the alliance. Their procedures are based on the nucleolus concept from cooperative game theory and turned out to be very effective. Topaloglu [28] proposed a decomposition approach for determining alliance booking limits and transfer prices based on a centralized Deterministic Linear Program (DLP). Belobaba and Jain [1] described the technical difficulties involved in the information sharing process faced by alliance RM and proposed information sharing mechanisms to overcome these.

All these authors assume a cooperative attitude on the side of the partners. However, despite cooperating in certain aspects, the alliance members often remain competitors in other aspects and strive for revenue maximization. In this paper, we investigate the problem of two airlines that on the one hand cooperate within an alliance but on the other hand continue to compete for customers within a revenue management (RM) setting. In this setting, two types of competition arise which are called horizontal and vertical competition in Netessine and Shumsky [18] who first took this circumstance into account. We adopt their terminology in this paper.

In *vertical competition* two airlines have to decide on the number of seats to reserve for connecting (code shared) passengers changing planes at a stopover city. Different legs of a multi-leg itinerary are operated by different airlines. Thus, one airline can sell tickets for products which occupy the partner's aircraft. In this setting the airlines must choose how many seats to protect for local and connecting passengers in the absence of cooperation or coordination. An airline's booking limit for code-shared tickets is thus affected by

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the partner's booking limit for them. In *horizontal competition*, on the other hand, the competitors offer identical substitutable products and customers can request a ticket from the competitor if they are denied by their preferred airline.

Wright et al. [33] also investigated some competitive issues that arise within an alliance, but their approach is different. Namely, they ignored horizontal competition and focused only on the vertical competition the airlines face. Secondly, they did not compute the players' booking limits but rather assumed that the airlines decide for every request whether it should be accepted or not within a Markov game. In this case, the authors provided rules based on bid prices for accepting or denying a request. Altogether, the authors focused on examining which type of revenue sharing agreements, static or dynamic, generated the highest revenues to the alliance and at the same time provided incentives for the airlines to stay in the alliances. Wright [32] implied incomplete information for the case that the alliance partners were unable or unwilling to share certain information concerning code sharing. He introduced a decomposition rule for a central dynamic program to determine approximate bid prices in an airline alliance for the individual partners.

Our approach is more related to that of Netessine and Shumsky [18] who were the first ones to use non-cooperative game theory for determining optimal booking limits for code shared products in an alliance. However, they considered only horizontal or only vertical competition and focused on one-leg and two-leg itineraries only, respectively. Further, the authors considered only two fare classes. Hu et al. [14] used the same setup, yet they described the alliance formation and operation process as a two-stage game. In the first stage, a cooperative game was used to determine optimal revenue sharing rules for code shared products, while the second stage uses a non-cooperative game to determine optimal booking limits for all products using the airlines' legs. The authors focused on revenue sharing mechanisms that lead to maximal revenues for the complete alliance and modeled the individual partners' decisions so that their models incorporated the central solution. We, on the other hand, consider simultaneous horizontal and vertical competition in $\mathcal{F}$ classes. To the best of our knowledge, we are the first to address both of these types of competition simultaneously within airline alliance networks. Decisions about revenue sharing scheme are not treated here.

Transchel and Shumsky [29] introduced a closed-loop dynamic pricing game for alliance partners that operate a parallel and substitutable flight. On the one hand the competitors are assumed to compete horizontally on this flight while on the other hand they have to set prices for their local and for their code-shared products. We do not consider the situation in which both partners operate the same route and at the same time share codes on it. Instead, we assume that products subject to horizontal competition are not subject to vertical competition and vice versa.

In the next section our model is formulated. Section 3 provides a computational study followed by a conclusion in Section 4.

2. Model formulation

As the previous sections showed, the amount of research considering competition in airline alliances is close to nothing.

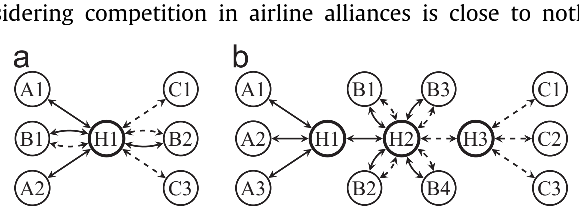

Fig. 1. Simple network structures. (a) Network with one Hub. (b) Network with two Hubs.

The mentioned publications are very restricted in use since the competitors operate different legs. To the best of our knowledge, no paper so far considered simultaneous horizontal and vertical competition within alliances on a network with $\mathcal{F}$ classes. We intend to fill this gap in this paper. The model we present here is an extension of the DLP first described by Williamson [31]. The DLP ignores all stochastic information and is thus very simple. Yet, it allows computing an approximation of the optimal solution of the network capacity allocation problem effectively and fast which cannot be solved optimally except for very small instances because the number of states in a dynamic program used for solving the problem grows exponentially [27, p. 92].

In the remainder of this paper we will call the involved airlines interchangeably *competitors* or, in a game-theoretic sense *players*. Consider two airlines, denoted as $a \in \{1, -1\}$. In this context, index a refers to the considered player, while $-a$ refers to the competitor. The sets of Origin–Destination (O&D) pairs and fares offered by both players together are P and F, respectively. A combination of an O&D pair in a fare class will be called *product*. The set of flight legs served by both airlines together is L. Player a offers a set $P^a \subseteq P$ of O&D pairs (indexed $1, \dots, \mathcal{P}^a$) in a set F of fare classes (indexed $1, \dots, \mathcal{F}$) on a network with a set of $L^a \subseteq L$ legs (indexed $1, \dots, \mathcal{L}^a$).

We will define the further notions with the help of Fig. 1 which shows simplified versions of the networks used in the computational study. The solid and dashed arcs represent the different airlines' networks L^a, respectively. We do not show connecting routes, but these are certainly available in the networks, e.g. a flight from A1 to A2 with a stopover in H1. As the figure shows, in order for code-sharing to be applicable, the networks have to have a common connecting airport at which the code shared customers can switch from one airline's plane to the other's. In our case the connecting hubs are the hubs H1 in Fig. 1a and H2 in Fig. 1b.

The O&D pairs for which the players' demand is affected by horizontal competition are contained in the set $A = \{P^a \cap P^{-a}\}$. These are made up of itineraries offered by both competitors, e.g. itinerary B1–H1 in Fig. 1a. Since we have only two competitors, we need no superscript denoting the player for this set. We assume that both players offer the same fare classes and that competition and code sharing thus affects all classes of an O&D pair.

O&D pairs with demand not affected by horizontal competition make up the set $NA^a = \{P^a \setminus P^{-a}\}$ and are indicated by arcs without overlapping legs by the competitor. These itineraries are available for vertical competition. E.g. O&D pairs A1–H1 in Fig. 1a and A1–H2 in Fig. 1b belong to the set NA^a with the solid arcs belonging to player a's network. This set includes the set $CS^a \subseteq NA^a$ of itineraries available for code-shared products. One part of a code-shared itinerary is carried out by one airline and another part is carried out by the competitor.

To simplify modeling, we further divide the set CS^a into the sets of inbound itineraries $In^a \subseteq CS^a$ originating in the competitor's network and outbound itineraries $Out^a \subseteq CS^a$ originating in player a's own network. E.g. the itineraries from H1 to A1 or to A2 in Fig. 1b belong to the set In^a of player a if the journey originated in the competitor's network, while the itinerary from A1 or from A2 to H1 belongs to this player's set Out^a if the final destination lies in the competitor's network. A code-shared itinerary is a combination of one player's outbound and the other player's inbound itinerary.

We assume the competitors to interact in a game of complete information, i.e. both have complete knowledge about all relevant information concerning the competitor and both know about this fact. Although this is somewhat unrealistic due to technical or legal aspects concerning alliance cooperation (see e.g. [2,24,30]), it simplifies the analysis and allows focusing on the main issues. This assumption was also made in e.g. Netessine and Shumsky [18], Li et al. [17], as well as Grauberger and Kimms [12]. An airline e.g. can conclude from the type of aircraft employed by the competitor the number of seats