Alliance Revenue Management in Practice: Techniques and Simulation Analysis

by

Himanshu Jain

Bachelor of Technology in Civil Engineering

Indian Institute of Technology, Bombay (2009)

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Signature of Author . . . .

Department of Civil and Environmental Engineering

May 6, 2011

Certified by . . . .

Peter Paul Belobaba

Principal Research Scientist of Aeronautics and Astronautics

Thesis Supervisor

Accepted by . . . .

Heidi Nepf

Professor of Civil and Environmental Engineering

Chair, Departmental Committee for Graduate Students

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Abstract

The primary motivations for the formation of airline alliances have been to increase revenues and decrease costs for alliance partners. A major advantage comes through increase in the number of destinations served by an airline at little costs, by using codesharing. Airlines share seat inventory on each other's codeshare flights which complicates their revenue management practice and leads to sub optimal revenue gains. This thesis analyzes the challenges related to alliance revenue management in practice and proposes innovative and feasible solutions to increase revenues for the combined alliance.

The four key dimensions of the alliance revenue management problem are analyzed: recording & forecasting, seat allocation method or optimizer, codeshare valuation in the optimizer and availability control of codeshare bookings. The performance of different techniques is quantified using the Passenger Origin-Destination Simulator (PODS). It is found that sharing of information between partners to different degrees can be used to improve revenues. A new valuation scheme called dynamic valuation is developed in an effort to increase the combined alliance revenues by using bid price sharing, a method of sharing information related to codeshare legs.

Dynamic valuation leads to additional revenue gains in the range of 0.30% to 0.50% over other techniques. This can translate into an incremental revenue gain, up to $ 100 M per year, for larger airlines in alliance partnerships. Dynamic valuation also provides a basis for further development of models related to revenue sharing proportions of alliance partners. The challenges and risks involved in implementing dynamic valuation are discussed.

Thesis Supervisor: Peter Paul Belobaba
Title: Principal Research Scientist of Aeronautics and Astronautics

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Dedicated to:

Jain Saint Pujya Basant Muniji Maharaj

My spiritual mentor and source of inspiration, energy and strength

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1. Chapter 1

Introduction

1.1 Airline Alliances

An airline alliance is defined as "any kind of agreement between independent carriers to mutually benefit from the coordination of certain activities in the provision of air transportation services" (De la Torre, 1999).

These activities may include the following, in the order of increasing commitment:

- ∞ Codesharing (this activity is described in detail in section 1.3)
- ∞ Scheduling of flight arrival and departure gates
- ∞ Location of arrival and departure gates
- ∞ Joint frequent flyer programs
- ∞ Share of airport lounges and other ground facilities
- ∞ Share of passenger services like baggage handling and check-in
- ∞ Share of support services like maintenance and catering
- ∞ Share of distribution and retailing functions
- ∞ Joint purchasing of such items as fuel, passenger service goods and aircrafts
- ∞ Joint advertising campaigns and creation of a common brand
- ∞ Joint allocation of resources (fleet and crew planning)
- ∞ Equity investment in partner's stock

Airline alliances are different than mergers because the carriers still remain independent and operate individually in alliances. The degree of commitment in an alliance can be customized depending on mutual agreement between the partners. Joint venture is another vehicle of partnership which involves a higher degree of commitment from partners and a legal arrangement to create a new business entity, whose ownership is shared by the partners.

The motivations behind the formation of airline alliances and their advantages and disadvantages are discussed in Chapter 2 in the literature review.

Both passenger and cargo alliances exist between carriers to coordinate activities in respective areas. This thesis deals with passenger alliances only. The current three major passenger alliances are: Star Alliance, Sky Team and One World. Some key facts and figures about these alliances, for the year 2010, are provided in Table 1.1.

	STAR ALLIANCE	SKYTEAM	oneworld
Year of Formation	1997	2000	1999
Member Airlines	27	13	14
Available Seat Kilometers	1569.1 B	963.9 B	944.6 B
Revenue Passenger Kilometers	1205.1 B	755.1 B	725.1 B
Annual Passengers	604 M	385 M	336 M
Daily Departures	21000	12597	9381
Countries Served	181	169	145

Table 1.1: Facts and Figures for Three Major Passenger Alliances, 2010

1.2 Traffic Components in Airline Alliances

In the context of airline alliances, the total traffic carried by an alliance partner can be categorized into three components which will be explained here with the help of the example shown in Figure 1.1.

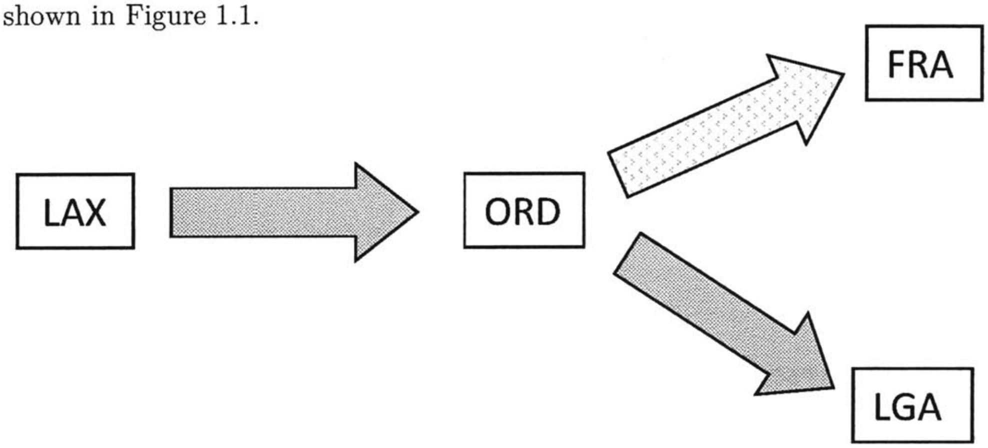

Figure 1.1: Traffic Components Example

1. Local Traffic: It consists of passengers who travel on a single flight leg to complete their itinerary i.e. whose origin-destination pair is the same as the city pair of the flight leg. For example: passengers traveling between LAX-ORD, ORD-LGA and ORD-FRA in Figure 1.1. Local passengers can be booked only by the airline operating the given flight leg.
2. Connecting Traffic: Passengers traveling on multiple flight legs operated by the same airline in order to complete their itinerary constitute the connecting traffic. For example: LAX-LGA passengers in Figure 1.1 who connect in ORD. Both LAX-ORD and ORD-LGA are operated by the same airline. Similar to the local passengers, connecting passengers can be booked only by the airline operating the connecting flight legs.
3. Codeshare Traffic: Passengers traveling on multiple flight legs all of which are not operated by a single airline, form the codeshare traffic (except in virtual

codesharing, refer section 1.3). For example: LAX-FRA passengers in Figure 1.1 where LAX-ORD flight leg is operated by partner 1 in the alliance while ORD-FRA leg is operated by partner 2 in the alliance. Unlike local and connecting itineraries, codeshare itineraries can be booked by any partner operating at least one of the flight legs in the itinerary.

Similar to the traffic components, all the itineraries offered by an airline can be divided into three types: local paths, connecting paths and codeshare paths. Paths are flights and combinations of flights that will take a traveler from origin to destination.

1.3 Concept of Codesharing

The U.S. Department of Transportation defines codesharing arrangement as "an arrangement in which a carrier's designator code is used to identify a fight operated by another carrier" (Lehman Jr., 2010). It reflects a marketing arrangement allowing an airline to sell seats –in its own name- on a flight operated by another airline. For example: a flight from Boston to Frankfurt operated by Lufthansa Airlines under the flight number LH 342 can be marketed by United Airlines under the flight number UA* 7683, with the asterisk indicating that this flight is a codeshare flight operated by a different airline. For such a codeshare flight Lufthansa Airlines is called as the *operating carrier* while United Airlines is called as the *marketing carrier*.

Codesharing is one of the most common activities coordinated between alliance partners. Codesharing began in 1967 (Lehman Jr., 2010) when the first codesharing agreement was signed between Henson Aviation, a regional carrier, and Allegheny Airlines to serve Hagerstown, MD and Washington National Airport (DCA). Codesharing expanded greatly after deregulation when larger carriers expanded hub and spoke operations. Larger carriers started forming relationships with smaller carriers, usually commuter carriers through codeshare agreements to feed their hubs. Codesharing also quickly expanded to international markets. The first international codesharing agreement was signed between in 1985 American Airlines and Qantas (Darot, 2001), which gave the American carrier access to the Australian market.

Codesharing agreements can be customized based on the objectives of the airlines involved. A variety of codesharing agreements can be found in the industry and the key types are explained here.

1. Parallel codesharing: Codesharing between two partners on a route which is operated by both of them is called as parallel codesharing. This is the case with the codeshare flights operated between hubs of two airlines. Parallel codesharing may prove to be disadvantageous to customers because of the possible reduction in combined frequency and rise in fares on that route.
2. Complementary Codesharing: When partners use each other's flights to provide connecting service to markets which are out of their own network, it is known as complementary codesharing. Complementary codesharing is instrumental in increasing the number of destinations served by an airline. It helps in extending the service to many international destinations without incurring huge incremental costs.
3. Virtual Codesharing: Unlike other codesharing agreements, virtual codesharing consists of flight leg(s) which is/are operated by a single carrier (Ito and Lee, 2007). The itinerary can still be marketed by a partner of the operating carrier in the alliance. Virtual codesharing is common in domestic alliances only. This thesis excludes virtual codesharing from simulation experiments.
4. Point-specific Codesharing: These agreements require little commitment from alliance partners and can be customized to fit the specific needs of partners on several markets. They often involve one airline's purchasing blocks of seats on

another airline's flights and then reselling them, referred to as a block space arrangement.

5. Strategic Codesharing: These agreements involve codesharing between airlines on a vast number of routes so as to strategically link both airlines' networks. Here the seats are accessed between the partners using free sale agreement (De la Torre, 1999) which is aimed to provide a seamless availability.

1.4 Motivation and Goal of the Thesis

The motivation for undertaking this research originates from the increasing importance of alliances to the airlines around the world and the consequent challenges they face on the revenue management front. Airline alliances have grown rapidly in the last decade and have become central to the business strategy at many of the larger carriers in the world. The three major passenger alliances: Star Alliance, Sky Team and One World constituted more than half of the capacity and traffic in the year 2010. Figure 1.1 shows the global market shares of airline alliances in terms of Revenue Passenger Kilometers (RPK).

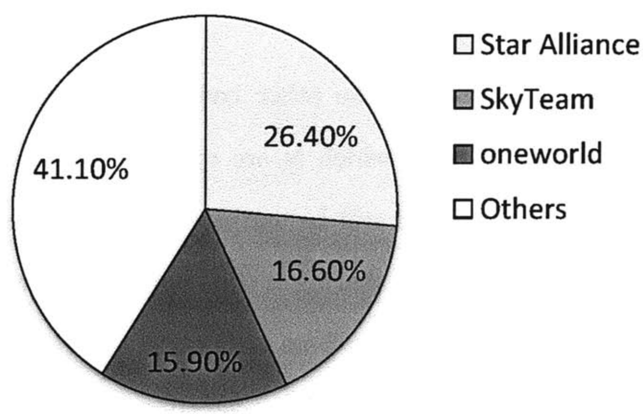

Figure 1.2: Distribution of Revenue Passenger Kilometers (RPK), 2010

The revenue gains from alliances can become sub-optimal and potentially negative network effects can be produced due to improper revenue management. Partner airlines in an alliance carry an additional type of traffic, besides local and connecting passengers, called codeshare passengers as explained in section 1.2. The codeshare traffic creates new challenges for airline revenue management systems (De la Torre, 1999), which now have the added complexity of dealing with itineraries which partially lie outside an airline's network. It creates sub-optimality in the system and affects the local and connecting passengers as well because of network effects.

Researchers from the field of Operations Research (OR) have tried to solve the problem of revenue management for airline alliances in past and have proposed advanced models to find optimal solutions to the problem. However, they make unrealistic assumptions in the areas of demand forecasting, network effects, competition effects, and availability of partner's information. It should be recognized that the alliance partners and their revenue management systems remain independent in an alliance and have to deal with network and competition. This creates many complexities for the airline revenue management systems in the real world which are usually ignored by the OR models.

The goal of this thesis is to first identify the challenges and critical issues involved in revenue management for airline alliances and then propose innovative and feasible solutions to increase revenue gains for the combined alliance. The performance of current techniques used by airlines, those proposed in the literature, and newly developed techniques is quantified using a software simulator tool called Passenger Origin-Destination Simulator (PODS).

1.5 Thesis Overview

This first chapter provides a brief overview of the thesis topic, motivation of the thesis and its goal. The second chapter presents a review of the existing literature on airline alliances. It covers literature related to motivation for formation of alliances, their economic impacts, revenue sharing and revenue management for airlines alliances. It emphasizes the importance of optimizing the combined alliance revenues and underscores the need for a comprehensive study of the practical steps involved in alliance revenue management.

The third chapter describes the implementation details of revenue management system components in the context of alliances. It presents the challenges faced by airline alliances in the real world through four key dimensions of recording & forecasting, seat allocation method, codeshare valuation and availability control. Each dimension is explained in detail providing relevant examples. Various techniques, which are currently being practiced in the industry or are proposed in the literature, are also discussed under each of the four dimensions.

The fourth chapter presents simulation results which are obtained using PODS. The first section of this chapter provides a brief overview of PODS and its different components. The next section provides details of the simulation environment. It lays out the network structure which is used for simulations and presents a baseline case for the purpose of comparisons. The remaining sections present findings from numerous experiments related to the different dimensions of alliance revenue management.

The fifth chapter introduces a new valuation scheme for codeshare paths called dynamic valuation. The first section describes its formulation while the successive sections discuss the PODS simulation results of its implementation. A detailed and comparative analysis is made with the static valuation schemes as well as with the techniques of bid price sharing control, which are discussed in Chapters 3 and 4.

Finally, the sixth chapter summarizes the findings of this thesis, draws conclusions from them and proposes future research directions.

2. Chapter 2

Literature Review

Revenue management is the practice of maximizing revenues obtained through the sale of given products having an uncertain demand. In the case of airlines, the products are seats on flights which are fixed in number and perishable. Literature on airline revenue management dates back to 1970s and the field has seen tremendous progress since late 1980s. The first section of this chapter provides a brief overview of the existing literature on airline revenue management. An extensive overview is covered in several papers, for example, McGill and van Ryzin (1999) and Barnhart, Belobaba and Odoni (2003). The remaining sections focus on the existing literature on airline alliances. Two comprehensive resources in this area are De la Torre's thesis (De la Torre, 1999) and Darot's thesis (Darot, 2001), from which some of the material in this chapter is drawn.

2.1 Airline Revenue Management: Key Components

The two key components of airline revenue management systems are overbooking and seat inventory control. The latter can be further divided into controlling the mix of passengers by fare class and by origin-destination (O-D). Let us understand these components briefly by taking an example. A flight from Boston to Frankfurt with 200 physical seats on the plane is overbooked if the operating carrier accepts more than 200 bookings. Thus overbooking is the practice of selling more seats than available capacity. It allows airlines to prevent any revenue loss due to passengers who do not show up on the day of departure paying little or no penalty and resulting in empty seats. On the other hand, if more people show up than the total number of available seats, then airlines have to deal with costs of denied boardings. There is a rich amount of literature on the overbooking problem and models to estimate the level of overbooking. Some models are based on statistical formulations as developed by Thompson (1961), Taylor (1962), Rothstein and Stone (1967), Martinez and Sanchez (1970) and Littlewood (1972). Alstrup et al. (1986) describes dynamic programming framework where cancellations and reservations in subsequent time periods are taken into account.

The second key component of airline revenue management- seat inventory control consists of fare class control and O-D control. Let us first broadly understand their meanings with the help of our example from the above paragraph. The Boston - Frankfurt flight would carry passengers who booked at many different fares, from low to high depending on the time of booking and associated restrictions like cancellation fees or lack of them. Fare class control essentially refers to limiting the number of seats sold at discount (low) fares and protecting the seats for higher fare classes. Now this flight can carry passengers traveling between many different origin-destination (O-D) markets. Not only BOS-FRA, but also passengers connecting in Frankfurt to further destinations, like BOS-BOM, BOS-HKG, etc. may also travel on this flight. O-D control refers to the ability of distinguishing between the bookings requests pertaining to different O-D markets and estimating a measure called network value to compare all itineraries under same criteria.

The seat inventory control is handled using various detruncation, forecasting and seat allocation tools. The first step in the process is to collect the historical observations.

These observations are stored either by leg/class or path/class depending on the type of seat allocation method which eventually uses the demand forecast estimated from these observations. Detruncation is then applied to unconstrain those historical observations where true demand is not observed due to booking or capacity limits. The next step is forecasting of future demand. Two principal approaches used for forecasting are time series and regression. Skwarek (1996) and Zickus (1998) provide a detailed analysis of various detruncation and forecasting methods. The demand forecast is fed as an input to the seat allocation method along with the specified fare levels. Leg based control and O-D control are two most common approaches used in the industry for seat allocation. Belobaba (1989), McGill (1989), Curry (1990), Wollmer (1992), Brumelle and McGill (1993), and van Ryzin and McGill (1998) discuss the methods for leg based control. O-D control methods are explained by Smith and Penn (1988), Vinod (1989), Curry (1990), Williamson (1992), and Bratu (1998). Seat allocation methods have a large influence on alliance revenue management and Chapter 3 provides a detailed description of the leg based control and O-D control methods.

The topic of alliances is one of the most closely watched topics in the airline industry since 1990s. Several theoretical and analytical studies have been completed focusing on their motivation, evolution, economics, revenue management and sharing, and impacts on fares and customer welfare. However, research in the analytical space has remained sparse. The following sections discuss the existing literature which covers one or more of these aspects of airline alliances.

2.2 Motivation for Airline Alliances

After the expansion of hub and spoke networks post deregulation, the airlines soon realized the advantages of expanding those globally to form intercontinental networks. However, due to regulatory and other constraints the global expansions and mergers were infeasible and airlines thus started forming strategic alliances with foreign carriers. Strategic alliances' partners participate extensively in coordinated activities and show greater degree of commitment in order to achieve common goals. The coordinated activities included codesharing, coordinated flight scheduling, and joint marketing campaigns to create common brand recognition.

Agusdinata and de Klein (2002) provide a thorough explanation of driving forces behind the formation of airline alliances using a system dynamics approach. De la Torre (1999) quotes alliances as "strategic weapons" because of their competitive advantages (Figure 2.1). He provides empirical evidences of the various economic benefits yielded to participating airlines.

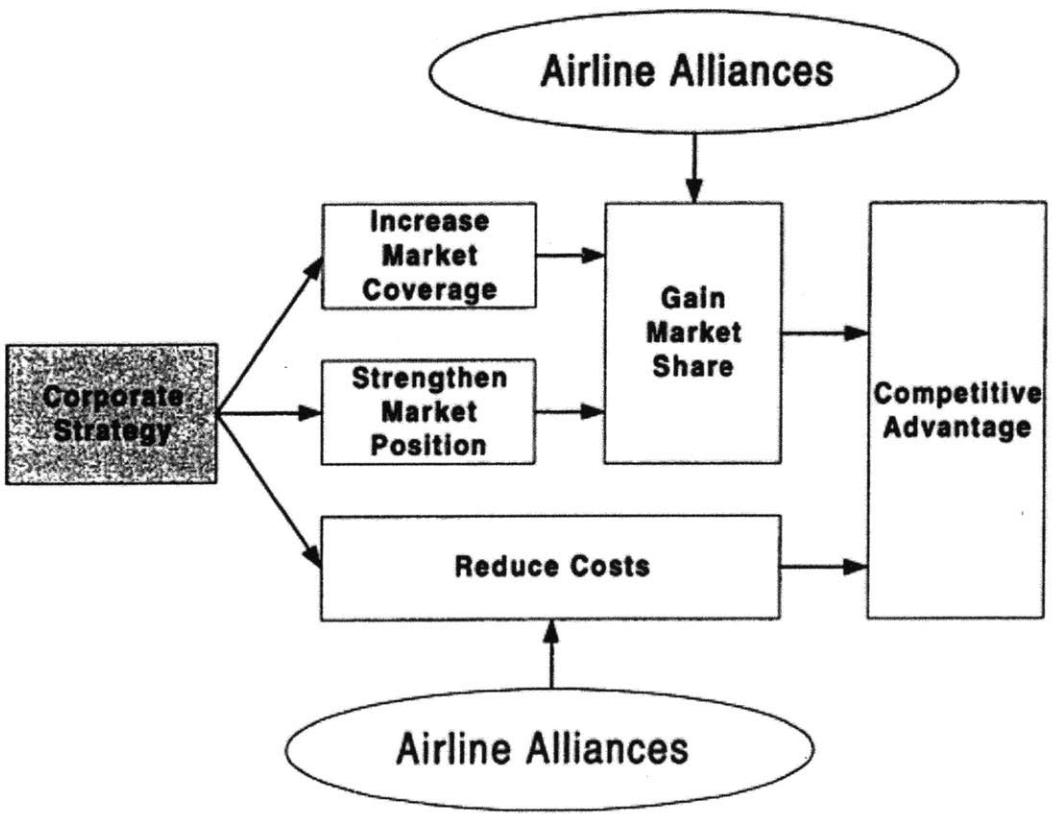

Figure 2.1: Airline Alliances as Strategic Weapons (De la Torre, 1999)

De la Torre (1999) mentions the following major sources of motivation for formation of alliances:

Increased market coverage and traffic volume

Airlines look for wider market coverage and seek to partner with other carriers operating complementary networks that will act as "feeders" for their own networks. Through the use of codesharing, the participating airlines are able to expand the destinations they offer to customers at little or no additional operating costs. In addition, with an extended coverage of their frequent flyer programs, their networks can become much more attractive for their customers. Alliances can also help in gaining access to attractive airports and provide services to relatively thin markets where it would be unprofitable to operate services independently (Oum and Park, 1997). Due to increased market coverage and a competitive market position, airlines gain additional traffic by capturing passengers that would have flown with competing carriers offering direct or connecting services. By linking the partners' networks through hub-to-hub links, alliances use each partner's network to feed traffic to other partner's network.

Reduction in costs

Alliances allow airlines to achieve cost advantages that derive from economies of density, economies of scope and sharing of common activities. Economies of scope occur when an existing airline, by expanding its network, can serve new markets at a lower cost than a new airline can serve them (De la Torre, 1999). Economies of scope are particularly important under the hub-and-spoke network structure. Under such system, the introduction of one new spoke to the system increases the number of total O-D markets served by the airline significantly. Economies of density occur when it is less expensive for an existing carrier to increase service than it would be for some other carrier to provide additional service on the same routes. In the case of alliances, there is an increase in volume of traffic in specific segments of the network. Higher volumes of traffic allow the use of larger aircrafts which result in lower unit cots.

Sharing of common activities and facilities with alliance partners bring significant reductions in costs and improve productivity of airlines. The major activity which is also most frequently coordinated in alliances is the joint operation of flights which has been called as codesharing. Coordination of ground operations for handling aircraft, or common check-in and baggage handling facilities at airports can also yield significant cost reductions. Other coordinated activities with a target of reducing costs include joint maintenance, joint marketing and joint purchasing.

2.3 Impacts on Customers and Industry

Alliances can benefit customers through increased accessibility, improved service, and reduced fare levels. Customers have a greater number of paths[1] to choose from in all affected O-D markets. Wider network coverage can also produce a stimulation of demand that will result in additional traffic for the airline. The passengers also have a greater choice in terms of fare levels. They enjoy a better service from more convenient flight schedules, increased proportion of online connections, shared lounges on airports and compatible frequent flyer programs. Some codesharing agreements are implemented in order to reduce the number of aircrafts operated on routes not likely to be profitable otherwise. In these situations, there is a consequent decrease of air traffic congestion that can be beneficial for the industry.

In spite of the above benefits of alliances, certain costs and concerns are also involved. There are concerns of excess market domination and reduced competition attached to

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[1] Paths are flights and combinations of flights that will take a traveler from origin to destination.

alliances resulting in increased scrutiny from regulatory authorities. Oum, Yu and Zhang (2001) examine the regulatory issues related to international airline alliances primarily in the United States and European Union community. The impact of alliances on fare levels is not clear. Brueckner (2001) provides a conceptual framework and simulation analysis to explain the effects of international alliances on fares, traffic levels and welfare. The simulation analysis shows that formation of an alliance leads to lower fares and increased traffic levels in the interline[1] markets while the effects in interhub[2] markets can be opposite. Despite the potential harm to interhub passengers due to increased fare levels, it is found that the overall consumer surplus and total welfare increases with alliances. Alliances can also add to congestion at airline hubs because of concentration of traffic traveling through the hub-to-hub links.

2.4 Revenue Sharing between Partners

It is important to understand that the problem posed by alliances to airline management lies at two distinct but interrelated levels: contractual and operational (De la Torre, 1999). At the contractual level, the partners have to reach an agreement on seat allocation and revenue sharing on codeshare flights. At the operational level, the partners have to separately manage the seat inventory on own flights using their separate revenue management systems, in order to maximize their own revenues and combined alliance revenues.

Is the solution to revenue management problem (operational) identical to that of revenue sharing problem (contractual) for alliances? The answer is both Yes and No. The correct approach would be to first optimize the combined alliance revenues and then share the common revenues in a manner which satisfies all the partners involved. The revenue

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[1] Itinerary completed through booking two or more separate tickets with different airlines.

[2] Origin and destination are the hubs of alliance partners.

management analysis would guide the partners on the kind of sharing schemes which could be beneficial to everyone while simultaneously maximizing the total revenues available on the table. The goal of revenue sharing scheme shall be that it should allow each partner to pursue the combined optimal rather than the individual optimal. If it is decided in the contract that the transfer price (revenue share of operating carrier) would be same as the codeshare valuation used in the revenue management system then the solutions to the two problems at hand become identical. However, any feasible combination of the two is possible; for example, the codeshare valuation could be dynamic while the transfer price could still be static in which case the two solutions would be different.

Some studies in the existing literature, for example work by Wright, Groenevelt and Shumsky (2010), discuss the revenue sharing problem and relate its impacts on the individual airline behavior and combined revenues. However, the author of this thesis believes that the revenue management problem needs to be addressed regardless of the revenue sharing schemes in order to maximize the combined alliance revenues. It will be explained in Chapter 4 that both partners can gain higher revenues even if the codeshare valuation is different from the transfer price, though such a transfer price could be viewed as an unfair distribution of revenues. Moreover, in some cases the codeshare valuation used in revenue management systems itself could provide a natural link to a fair revenue sharing scheme, as explained in Chapter 5.

Vinod (2005) suggests an approach to dynamic revenue sharing which makes use of the passenger name record (PNR) and can result in optimal alliance traffic flow. PNR is a unique number associated with every airline booking which is either created by an airline's own computerized reservation system (RES), if the booking is made directly with an airline or by one of the large global distribution systems (GDS) such as Amadeus, Sabre, Worldspan, Galileo and Abacus. Detailed information about the airline distribution channels can be found in the book by Belobaba, Barnhart and Odoni (2009, p 444). Vinod (2005) suggests that, while accepting a codeshare booking, the dynamic revenue share can be noted with the PNR for the purpose of revenue resolution. He does not provide any framework for the implementation of this scheme in airline revenue management systems.

Wright, Groenevelt and Shumsky (2010) formulate a Markovian game model to discuss the impacts of transfer prices or revenue sharing agreements. They develop an alliance game of two airlines and analyze the effects of static and dynamic transfer price schemes on individual airline behavior. Their findings include following:

1. Static schemes are easy to manage but they can lead to suboptimal decision making by partners and lost revenues for the alliance as a whole. They can perform as well as dynamic schemes for certain networks while degrade quickly as the network parameters change.

2. Performance of dynamic schemes can be significantly reduced if each operating airline chooses a transfer price to maximize its own revenue.

The above findings are based on equilibrium acceptance policies under each scheme and their application to numerical analyses of networks of very small size. The model does not consider any competition and assumes that each partner has perfect information about its partner's inventory level, and both have identical forecasts over the entire alliance network. These assumptions are unrealistic in the current state of the industry and it will be explained in Chapter 3 that airlines are far away from such advancements and are limited in basic capabilities like getting complete information of a codeshare itinerary booked by the partner.

2.5 Revenue Management in Alliances

Revenue management lies at the core of airlines' strategies to improve the revenues and bottom-line. The full potential of alliances cannot be realized without using revenue management to optimize the combined alliance revenues. In addition, it is even more important for alliances in order to avoid any potential losses due to sub-optimality which is caused by the presence of codeshare paths (as demonstrated in Chapter 4). Due to technical incompatibilities and limitations on the degree of coordination between partners (as discussed in Chapter 3), alliance revenue management problem presents many challenges. The ideal solution to the problem would be to combine the networks of the alliance partners and achieve a centralized solution. This is certainly not possible due to numerous operational, organizational and regulatory constraints.

Ferea (1996) performed an analysis on the effects of asymmetric revenue management systems of the alliance partners. He found that specific characteristics of the partners' networks and their revenue management systems can have a significant impact on the revenue performance of the alliance as a whole. Boyd (1998) discusses centralized and decentralized revenue management systems for alliances. A centralized system would require extreme coordination and information exchange between the partners and is difficult to implement due to the constraints mentioned above. A decentralized system is less restrictive and allows the revenue management systems of alliance partners to operate separately.

Network equilibrium conditions which are proposed by Boyd (1998) and Vinod (2005) for decentralized revenue management systems can lead to optimal revenues for the combined alliance. The conditions are based on seat reallocation between partners on a shared leg. Boyd prescribes the conditions in terms of marginal seat revenue while Vinod formulates them in terms of bid prices. The idea is that at the equilibrium point, marginal revenue of an additional seat on a shared leg is identical for each partner and seats are exchanged between the partners until the marginal seat revenues are balanced. This approach can lead to joint optimal revenues but it has several limitations for practical implementation. Airlines in practice estimate the bid prices for their own operated legs and not the legs operated by partners even if they are codeshared. Thus, additional capabilities would be needed to implement the above rules besides real time coordination between partners to update the bid prices and reallocate seats.

De la Torre (1999) discusses various mechanisms of seat allocations for codesharing. Block space codesharing which is now less prevalent in the industry specifies a fixed or flexible number of seats which are solely controlled by the marketing carrier. Another mechanism, automated codesharing or free sale agreement is more dynamic and provides seamless availability for alliance traffic. Both partners have the power to accept or reject a sale. This thesis uses free sale agreement for the purpose of simulation experiments.

De la Torre also explains the potential losses to individual airlines due to overvaluation of the codeshare paths. If the prorates (transfer prices) to be paid to the partner are not accounted for in the valuation, then it could potentially displace higher revenue yielding own locals or connecting passengers. He has suggested using a proration scheme to prevent the individual losses. However, the proration scheme may not be optimal for the combined alliance revenues as shown in the results in Chapter 4. The author of this thesis argues that the focus should be rather to maximize the total alliance revenues and then it can be distributed in a fair manner which satisfies the partners and prevents losses to any individual carrier.

Darot (2001) provides a simulation analysis of an alliance with two airlines which compete with another carrier on all the O-D markets. Half of the connecting markets in the alliance network are own connections while the other half are codeshares leading to an unrealistically high proportion of codeshare traffic per normal standards. The alliance partners also share a common hub.

Darot primarily focuses on the issues of customer perception of codeshare flights and interactions of asymmetric revenue management systems in an alliance. He concludes that the customer perception can significantly impact the alliance revenues in case of leg control revenue management methods and low demand markets. He also introduces the useful concepts of bid price sharing, explained in section 3.5, and bid price inference, which are found to increase the alliance revenues depending on the codeshare valuation used in the system. These are discussed in greater detail in Chapter 3.

The alliance revenue management is not limited to handling the codeshare traffic. It is important to realize that not only codeshare but own local and own connecting traffic is also affected on a network level. Every seat on a codeshare flight can be potentially occupied by either a codeshare passenger or an own local or own connecting passenger. Very few studies, like Darot (2001) and De la Torre (1999), have explicitly considered and analyzed the network effects of alliance revenue management.

Vinod (2005) suggests using leg bid prices as a common currency for inventory control among the alliance partners. Lowest available fares in the market can be used as pseudo bid prices. This would lead to a synchronized availability among the partners on the codeshare paths but could still be non-optimal in terms of revenue maximization for the alliance. For the purpose of achieving optimal alliance network traffic flow, he indicates a dynamic approach as discussed in the previous section.

To the author's knowledge, there is no existing literature which deals with the implementation details of the alliance revenue management. This thesis is an attempt to address the practical and relevant questions like how is the codeshare traffic recorded and forecasted in the revenue management system, how is it valued in the optimizer, what are the implications for the other traffic components and how can the availability control be handled in the system so that the alliance revenues are maximized. In addition, it also fulfills the need of analysis on an alliance network which is realistic in terms of size, competition and proportion of codeshare traffic.

2.6 Chapter Summary

This chapter provides a review of the existing literature on airline alliances. It also provides a brief overview of airline revenue management, its key components of overbooking and seat inventory control and useful sources related to them in the beginning of the chapter. The discussion on airline alliances is structured under various aspects, covering literature related to motivation for their formation, their impacts on customers and rest of the industry, revenue sharing and revenue management.

The relation between alliance revenue sharing and alliance revenue management is explained and the importance of optimizing the combined alliance revenues is emphasized. It is shown that there is a need for a comprehensive study of the steps involved in alliance revenue management. Chapter 3 will discuss the challenges involved in alliance revenue management in practice using illustrations and describes related techniques, which are either used by airlines or are proposed in the literature.

3. Chapter 3

Alliance Revenue Management in Practice

The revenue management (RM) systems of airlines aim to maximize the revenues over their own networks. The major difference and source of complication between individual airline revenue management and alliance revenue management is the existence of alliance traffic or codeshare traffic. All codeshare itineraries (except in virtual codesharing, refer section 1.3) are unique in that they are connecting in nature and only a part of the itinerary is carried on a flight operated by each alliance partner. As discussed in Chapter 2, there are existing models in the field of operations research which attempt to solve the alliance revenue management problem. However, they make unrealistic assumptions and ignore the limitations and complexities which airlines face in the real world. In the current state of the industry, even airlines with the most advanced RM systems have found it difficult to make a significant progress towards optimizing the alliance revenues. This chapter describes the current industry practices and explains the implementation details of RM system components in the context of codeshare traffic. Some of the information in this chapter is based on the discussion and feedback obtained from professionals in the industry.

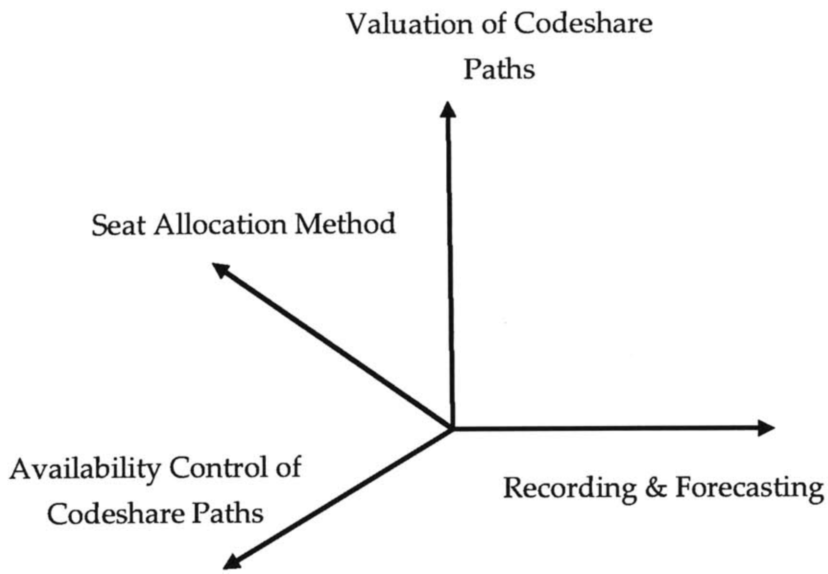

Figure 3.1: Key Dimensions of Alliance Revenue Management

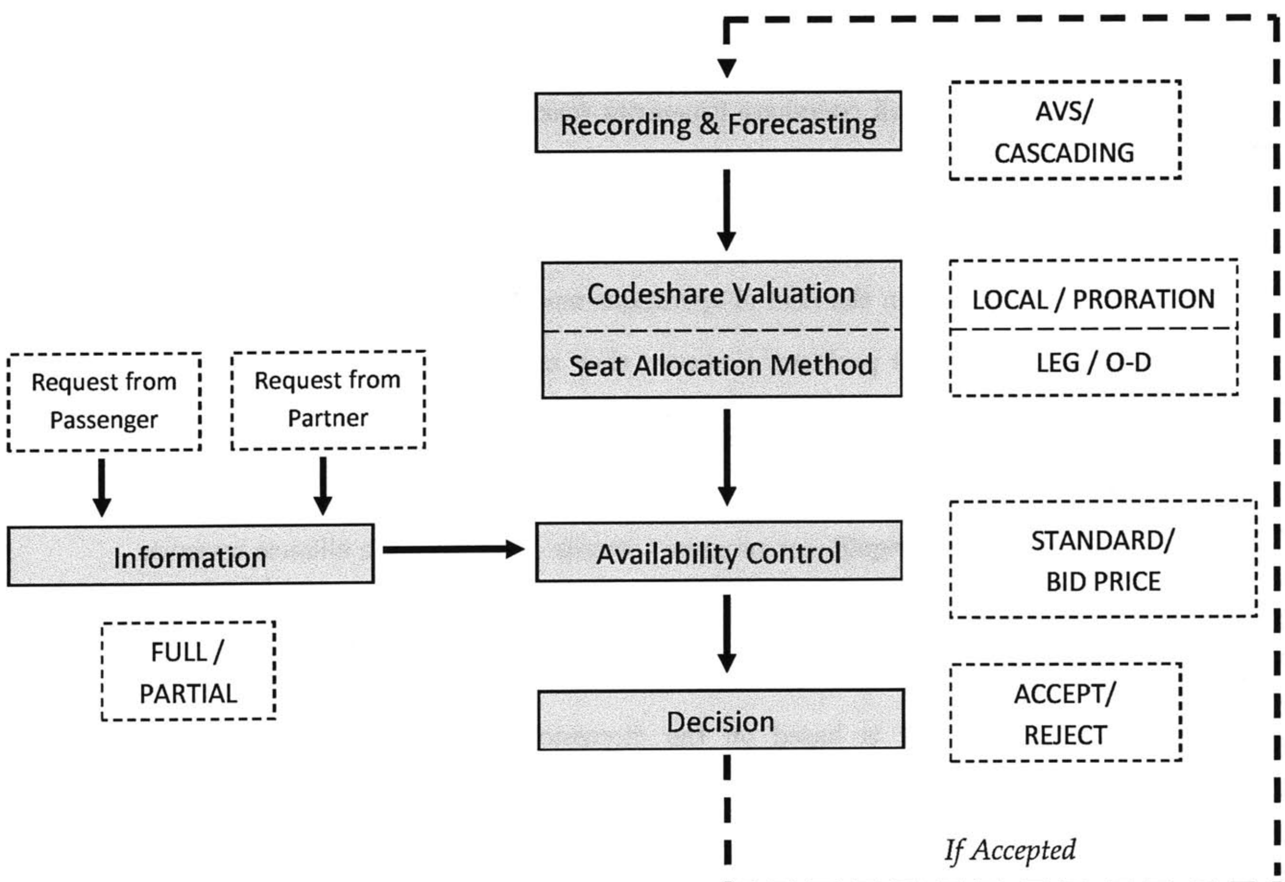

Figure 3.2: Flow of Control between Dimensions of Alliance Revenue Management

Revenue management for alliances, particularly the component of seat inventory control, can be structured under four key dimensions as shown in Figure 3.1. The flow of control between these dimensions is explained in Figure 3.2 where the colored boxes show the different steps involved in alliance revenue management while the boxes adjacent to them show the different techniques related to each step. In the recording & forecasting step, the past bookings are recorded in the airline's historical database and used for forecasting the future demand. The forecast is fed to the optimizer which uses a codeshare valuation scheme to value the codeshare itineraries. The optimizer consists of seat allocation method whose output can be used in the availability control step. The availability control method observes the booking request from a passenger or an alliance partner and accepts or rejects the request by applying relevant criteria. If the booking is accepted, it is recorded in the database.

Now we shall study each of these dimensions in detail and discuss the common techniques and practices in each of them.

3.1 Recording & Forecasting: AVS versus Cascading

The process of recording the accepted bookings by an airline and subsequently using that data for forecasting the future demand is termed as *recording & forecasting*. This forms one of the initial steps in a typical computerized RM system and is highly dependent on the *airline bookings distribution systems* and the form of bookings information available from them. In the context of alliances, the importance of recording & forecasting can be understood from the fact that it can affect all other dimensions of alliance revenue management and can pose serious limitations in terms of which techniques can be used in the further steps.

The biggest challenge here is to get the complete itinerary information of a codeshare passenger. Unlike local bookings where passengers travel on a single flight leg, all codeshare itineraries are unique in that they are connecting and only a part of the itinerary is carried on a flight operated by each alliance partner. This gives rise to two possibilities: either an airline has full itinerary information of a codeshare booking accepted by its partner or it knows only about its own part, a common reason for which is the limited information provided by airline bookings distribution systems. If an airline receives the complete itinerary information of a codeshare booking accepted by its partner, it can perform separate recording & forecasting of the codeshare bookings from local bookings. Not only complete information from the partner is needed, but also capabilities of separate recording of codeshares in one's own RM system are required. Let us have a detailed look into the two common industry practices: AVS and Cascading in the following subsections.

3.1.1 AVS (Availability Status)

AVS stands for Availability Status and the name comes from the practice of exchanging availability status messages between airlines in certain instances to communicate the availability on each other's flights. The messages are purely based on the flight leg and fare class availability and do not depend on some specific itinerary request. AVS was practiced in the industry even before the codeshare traffic came into existence, and has been used by airlines in the absence of seamless availability.

Let us understand AVS in the context of codeshare traffic by taking an example. Figure 3.3 illustrates three codeshare flight legs which are part of an alliance network built of two carriers: partner 1 and partner 2. Partner 1 operates LAX-ORD leg while partner 2 operates both ORD-LHR and ORD-FRA legs. If partner 1 is using AVS, it would convey the seat availability by fare class on the LAX-ORD leg to partner 2 for the purpose of codeshare bookings. As per this fare class availability, partner 2 is allowed to book a codeshare passenger for any O-D market which uses the LAX-ORD leg. Partner 1 gets no information of the final destination of such a codeshare passenger booked by partner 2 and would remain indifferent whether it is FRA, LHR or anything else for that matter. The problem here is quite similar in nature to that of leg based seat allocation control which cannot distinguish between different connecting itineraries in one's own network. Even in a case where the combined alliance revenues or partner 1's revenue share for a LAX-LHR booking would be higher than that for a LAX-FRA booking, it is unable to respond differently to them and provide a preferred availability for one over the other. This implies that AVS does not have the capabilities of treating codeshare traffic separately from local traffic and optimizing the combined alliance revenues.

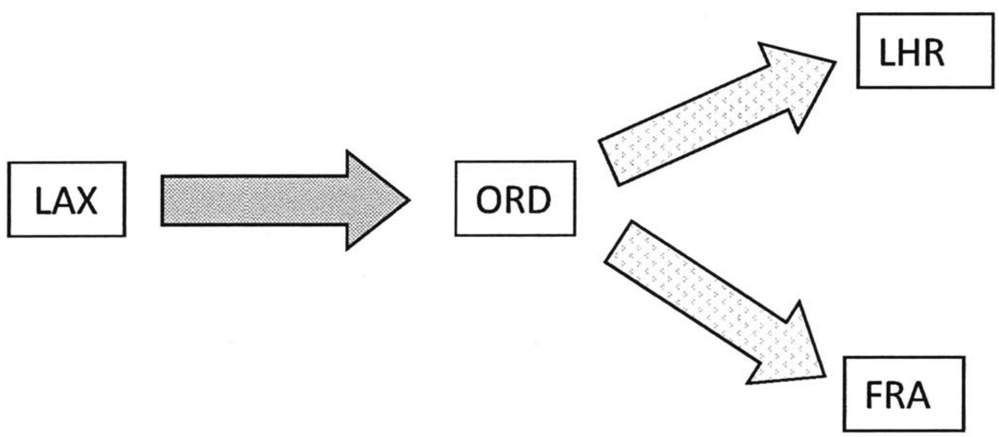

Figure 3.3: AVS/Local Mapping Example

AVS thus requires that the airlines use a *local mapping* of codeshare paths, meaning the codeshare paths are both recorded & forecasted as part of own local paths either due to incomplete information from partner/distribution systems or due to limited capabilities of the airline's own RM system. In the above example, Partner 1 records the LAX-FRA/Q class booking as LAX-ORD/Q while Partner 2 would record it as ORD-FRA/Q. This becomes a serious limitation in the pursuit of optimizing the alliance revenues, combined or individually.

There is a caveat to the above in the case of codeshares with multiple connects. The partner operating multiple legs (ORD-FRA and FRA-TXL in Figure 3.4) may record the codeshare booking as a connection (own) booking, provided that it has O-D control capabilities (to distinguish between different itineraries using the same leg, section 3.2.2), or as local bookings on two legs in case of leg based control.

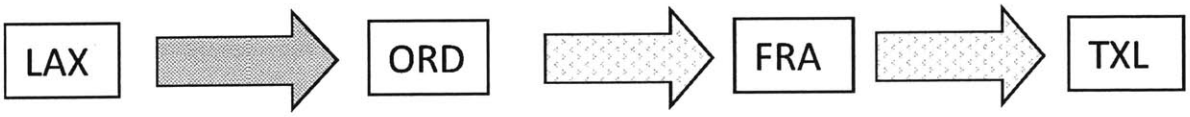

Figure 3.4: AVS/Local Mapping with Multiple Connects

3.1.2 Cascading

In Cascading, the complete codeshare itinerary is known to each partner. It allows the airlines to use *codeshare mapping* where codeshare paths are recorded and forecasted separately from the local paths. This also provides partners with basic capabilities to react differently to different codeshare requests. In the previous example (Figure 3.3) if partner 1 uses cascading then it would record the two codeshare bookings, LAX-FRA/Q and LAX-LHR/Q, separately.

Cascading enables airlines to use the complete itinerary information, to separate codeshares from locals and from each other, and to produce improved forecasts. It yields an increase in revenues over AVS as illustrated in Chapter 4. More importantly, it is the first step in the direction of optimizing the combined alliance revenues. It allows using alternative valuation schemes for codeshares than local valuation, and bid price sharing control in further steps, as explained in the forthcoming sections.

3.2 Seat Allocation Methods: Leg versus O-D Control

The second key dimension of alliance revenue management is the type of seat allocation method used by alliance partners to optimize their own networks. The airlines offer seats to customers under various fare classes differing in fare values and associated restrictions. Seat allocation methods (also known as optimizers) take demand forecasts, by leg/class or path/class, and the fare values for different fare classes as input and produce the availability of seats in forms such as booking limits. Leg based control and O-D control are the two primary types of seat allocation methods which are described in the following subsections.

3.2.1 Leg Based Control Methods

Leg based control is the conventional seat allocation mechanism which focuses on optimizing the revenues on a single flight leg. It uses leg/class demand forecasts and input fare levels of different markets to calculate the seat allocation among fare classes on a leg. Optimizing the revenues on leg basis does not optimize the revenues over the whole network. In the case of alliances, this becomes even a greater disadvantage because the demand forecasts are leg based and the seat availability in a given class would remain same for all the paths (local, connecting or codeshare) using this leg. Thus the codeshares get the same availability as the locals even if they are valued using a different valuation than local valuation scheme (refer section 3.3) if the airline is using leg based RM control.

The standard approach for leg based seat control for multiple fare classes is EMSR-Expected Marginal Seat Revenue developed by Belobaba (1987, 1989). EMSR is a heuristic method which is easier to implement in practice as compared to the optimal solutions which use multidimensional numerical integration or convolution integrals. A later refinement of EMSR, called EMSRb (Belobaba, 1992) produces nested booking limits based on joint protection for upper classes from the next lower class and has been widely implemented in the industry.

For a complete description of EMSRb refer to Belobaba and Weatherford (1996). We shall discuss the implementation details of EMSRb here. EMSRb makes the following modeling assumptions:

a. Demand for each fare class is separate and independent of demand in other classes.
b. Demand for each fare class is stochastic and can be represented by a probability distribution.
c. The lowest fare classes book first, followed by the next lower class, and so on.

The seat inventory on a leg is divided into several classes which are serially nested meaning that the higher fare classes can access the unused lower class seats. Usually the demand for each fare class is described by an independent Gaussian distribution. The mean and standard deviation are determined for each fare class based on detruncated historical data. These are also used to produce mean and standard deviation for joint classes, defined as the combination of each fare class and classes above it.

The problem is to find seat protection levels for higher classes, and booking limits for lower classes. Figure 3.5 shows how nested booking limits work in a fare structure with three fare classes- Y, M and Q, class Y being the highest fare. The capacity (CAP) of flight leg is 100 seats. Protected seats are the seats that are saved particularly for fare classes which are higher than a given fare class (Figure 3.5). The booking limit for all bookings that occur in a fare class and its lower classes is determined by subtracting the number of seats to be saved for higher classes from the capacity.

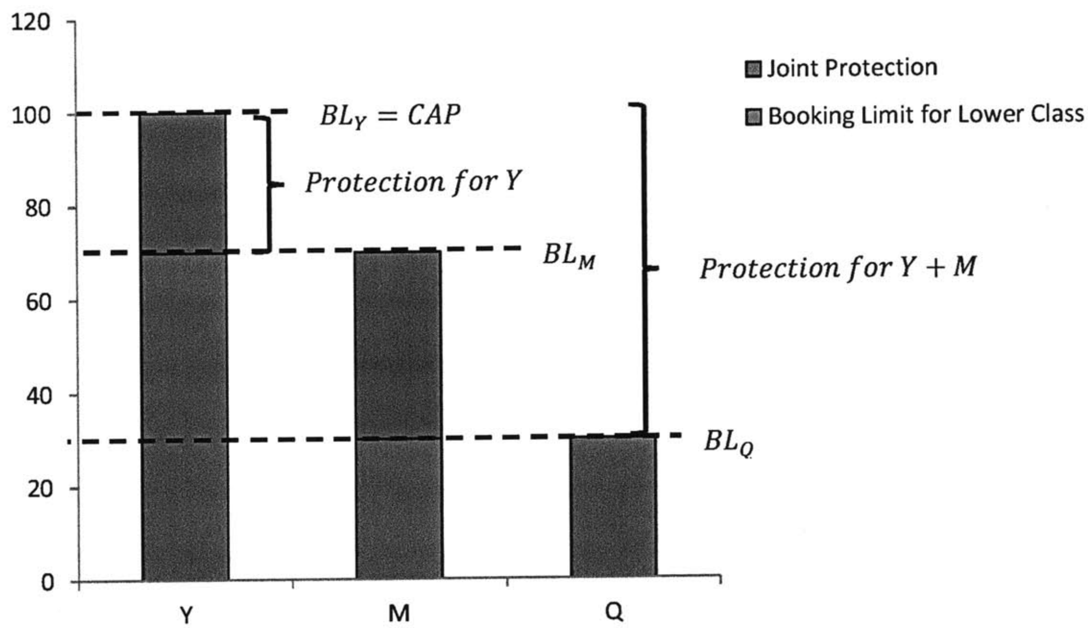

Figure 3.5: Nested Booking Limits in EMSRb

The mathematical framework of EMSRb follows a top down approach meaning that it begins with protecting seats for the top most class, say class 1 from the immediately lower class- class 2. The required protection for class 1- π_{12} and the consequent booking limit for class 2- BL_2 satisfy equations 3.1 and 3.2:

$$EMSR_1(\pi_{12}) = F_1 \times P(x_1 \geq \pi_{12}) = F_2 \tag{3.1}$$

$$BL_2 = CAP - \pi_{12} \tag{3.2}$$

where,

$EMSR_1 = Estimated\ Marginal\ Seat\ Revenue\ of\ class\ 1$

$x_1 = Demand\ for\ class\ 1$

$\pi_{12} = Protection\ level\ for\ class\ 1\ from\ class\ 2$

$F_i = Fare\ value\ for\ the\ class\ i$

$P(x_1 \geq \pi_{12}) = Probability\ that\ class\ 1\ demand\ (x_1)\ is\ greater\ than\ \pi_{12}$

$BL_2 = Booking\ Limit\ for\ class\ 2$

$CAP = Total\ authorized\ capacity\ on\ the\ leg$

Equation 3.2 estimates the probability value $P(x_1 \geq \pi_{12})$ which is then mapped to the corresponding value of the seat protection level using the demand distribution of the class 1. While dealing with a lower class i, a joint protection is calculated for all the above classes and a booking limit is estimated by replacing the appropriate parameters in the above equations by their joint counterparts as shown in equation 3.3:

$$EMSR_{1,2,..i-1}(\pi) = F_{1,2,..i-1} \times P(x_{1,2,..i-1} \geq \pi) = F_i \tag{3.3}$$

$$F_{1,2,..i-1} = \frac{1}{\sum_1^{i-1} \mu_k} \sum_{k=1}^{i-1} \mu_k \times F_k \tag{3.4}$$

$$BL_i = CAP - \pi \tag{3.5}$$

The fare value $(F_{1,2,..i-1})$ used for joint protection in the above equation is a weighted average of the individual fare values, mean forecast being the weights. The estimated probability value is then used to calculate the joint protection using the distribution of a multivariate function $J(\,)$ which is sum of the individual demands as shown in equation 3.6. Since the demand for different fare classes is assumed to be independent, the mean and variance calculations are given by equations 3.7 and 3.8:

$$J(x_1, x_2, \ldots\ldots, x_{i-1}) = \sum_{k=1}^{i-1} x_k \tag{3.6}$$

$$\mu_{1,2,..i-1} = \sum_{k=1}^{i-1} \mu_k \tag{3.7}$$

$$\sigma^2{}_{1,2,..i-1} = \sum_{k=1}^{i-1} \sigma^2 \tag{3.8}$$

3.2.2 O-D Control Methods

Origin-Destination (O-D) control methods enable an airline to distinguish between the booking requests based on O-D market information and act differently to each of them. There are two major limitations of leg based control which can be addressed using O-D control methods as explained in Belobaba (2002):

a. In situations where a short haul flight leg has high demand while some of the legs connecting to it are expected to have many empty seats, the limited fare class availability on that short haul flight leg can block the long haul passengers willing to pay a higher total itinerary fare. This strategy will not maximize the total network revenues.

b. The leg based control is unable to distinguish between O-D itineraries in the same fare class. In a given leg/class, the availability remains same for all O-D markets traversing that leg. However, two local passengers generate substantially more network revenue than a connecting passenger traversing those two legs.

O-D control and cascading together provides the ability to treat codeshare traffic separately than local traffic in the RM system. In the context of alliances, it is important to mention that due to the presence of codeshare paths and their fixed and arbitrary valuation (section 3.3), the O-D control becomes sub optimal and its full benefits are not realized. This issue will be analyzed in detail in Chapter 4. O-D control can be implemented in a variety of ways. The two common approaches which are based on deterministic shadow prices and probabilistic bid prices are discussed in detail here.

3.2.2.1 Displacement Adjusted Virtual Nesting (DAVN)

DAVN is an O-D control method which uses displacement costs (also called as shadow prices) to adjust the total O-D fares of connecting itineraries and estimate their actual network contribution. It uses the framework of serially nested virtual buckets each of which contain several path/classes depending on their actual network contribution. For a leg that is traversed by a connecting itinerary, the passenger's total O-D fare (ODF) will be replaced in the bucketing by a so-called "pseudo-fare" computed as the actual fare minus the sum of the displacement costs associated with all other legs involved in the itinerary. The principle is to apply a penalty to the connecting fares that accounts for the potential displacement of a local passenger. For a complete description of DAVN, refer to Williamson (1992).

The actual contribution of a passenger on a given flight leg to the total airline network revenue must be less than or equal to the total O-D fare (ODF) of the passenger's itinerary. This is because connecting passengers accepted on a given flight leg can displace other passengers and revenue on down-line (or up-line) legs of their itinerary. When the connecting flight legs have high forecasted demand, the corresponding displacement costs will be higher, reducing the *displacement adjusted* network revenue value of the ODF. With a lower network value, this ODF would be mapped to a lower virtual class for seat inventory control purposes, meaning the seat availability for connecting passengers is reduced. At the same time, local passengers (with no down-line displacement costs) would get greater seat availability.

The mathematical problem is therefore how to determine the network revenue contribution of each ODF. The answers come from various mathematical models that have been applied to the airline network RM problem. DAVN applies deterministic linear programming (LP) to calculate the shadow prices (displacement costs) of all the legs in an airline's network and uses them to estimate the network value of all connecting passengers. The deterministic LP formulation is given by equations 3.9, 3.10 and 3.11:

$$\max \sum_{path\, i} \sum_{class\, j} p_i^j \times x_i^j \tag{3.9}$$

subject to

$$x_i^j \le f_i^j \qquad \forall\, path\ i, class\ j \tag{3.10}$$

$$\sum_{path\, i} \sum_{class\, j} x_i^j \times \delta_i^k \le C_k \quad \forall\, leg\ k \tag{3.11}$$

where,

$p_i^j = Fare\ value\ of\ class\ j\ on\ path\ i$

$x_i^j = Number\ of\ passengers\ in\ class\ j\ on\ path\ i$

$f_i^j = Mean\ forecast\ for\ class\ j\ on\ path\ i$

$C_k = Capacity\ on\ leg\ k$

$\delta_i^k = Binary\ variable, set\ to\ 1\ if\ leg\ k\ is\ part\ of\ path\ i, 0\ otherwise$

The above formulation is based on maximizing the total revenues over the network subject to two constraints. The first one is a forecast constraint for each path/class stating that the number of passengers accepted in a path/class cannot be greater than its mean forecast. The second one is a capacity constraint applied to each leg in the network. The solution of this LP provides optimal values for the decision variables x_i^j, but we are interested in the solution to its dual problem. The solution to its dual problem is the displacement cost vector d_k which represents for each leg k, the marginal revenue obtained by adding an extra seat to the capacity on that leg. These values are used in the bucketing process for estimating the network revenue contribution of the connecting passengers. On a leg i that belongs to the connecting itinerary, the connecting fare will be replaced in the bucketing by the total O-D fare minus the sum of the displacement costs associated with all other legs involved in the itinerary as shown in equation 3.12:

$$Bucketed\ Fare_{leg\ i} = ODFare - \sum_{\substack{j \in itinerary \\ j \neq i}} d_j \tag{3.12}$$

where,

$$d_j = displacement\ cost\ associated\ with\ leg\ j$$

The bucketing is managed on the leg level in DAVN. The displacement costs as well as the size of the buckets are regularly re-optimized during the booking process. A connecting booking is accepted only if on every leg of that itinerary, the corresponding fare is in a bucket that is still open. Use of DAVN or any other network optimization method requires path/class forecasting and detruncation. A note about the robustness of DAVN as an O-D control method- it is found that the nested bucketing framework of DAVN makes it more robust to the inaccuracy of input data than other methods (Bratu, 1998). The nested virtual buckets provide a range for decision making and thus building robustness into the system.

3.2.2.2 Probabilistic Bid Price (ProBP)

ProBP lies under a different class of O-D control methods which use bid prices for seat availability control. Unlike DAVN which uses a deterministic LP algorithm, ProBP takes into account the stochastic nature of demand in the algorithm itself. It is one of the most advanced O-D control methods and relies exclusively on the path/class forecasts. Nonetheless, it is found to be more sensitive to the accuracy of demand forecasts required as input. For a detailed description of ProBP, refer to Bratu (1998).

ProBP is based on iteratively prorating fares of the connecting itineraries along the legs they traverse. The network revenue value generated by a connecting itinerary on a leg is the prorated fare of that itinerary on that leg. This proration is different for different itineraries in the network and is also different in different time frames of the booking period for the same itinerary. It is an optimal solution which accounts for the current network conditions and stochastic nature of the demand. ProBP uses critical EMSR values of the traversed legs for the purpose of proration. Critical EMSR value, **EMSRc** is defined as the expected revenue value of the lowest fare seat available on a leg obtained from the EMSRb model (section 3.2.1). Figure 3.6 illustrates the calculations for a typical leg, LAX-ORD in this case. The EMSR values are plotted for all the itineraries (paths/classes) which traverse LAX-ORD leg, using the prorated fare estimated for every itinerary. The value of the EMSR curve which intersects the *capacity left* line is the EMSRc value. At the end of the iterative process of ProBP, these EMSRc values become **bid prices** of the given legs and used for the purpose of seat allocation.

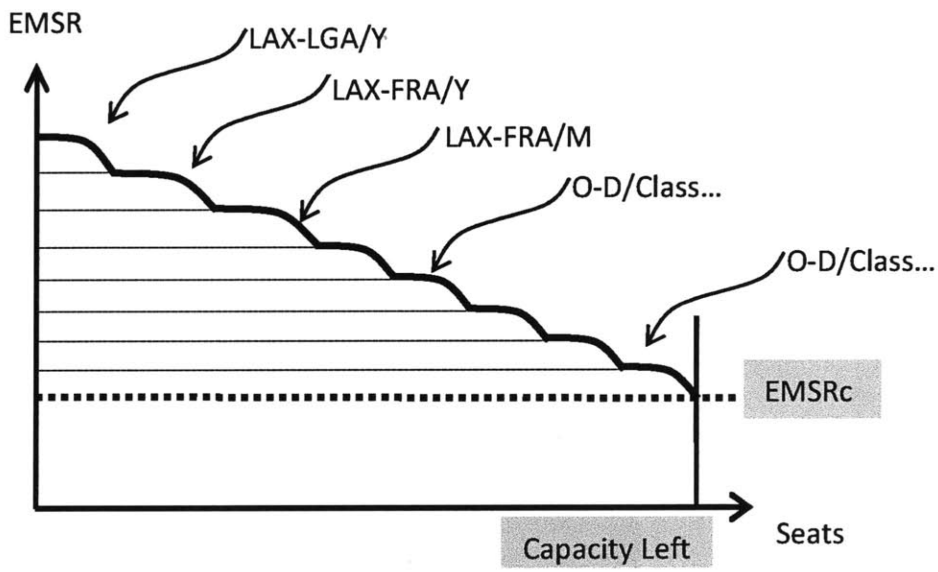

Figure 3.6: Estimation of EMSRc on a Leg (LAX-ORD)

ProBP is an iterative process where the prorated fares are updated at each step using the new set of critical EMSR values estimated in the last step. The prorated fare PRF [j,k] of a connecting ODF j on leg k is defined by equations 3.13 and 3.14:

$$\infty \quad PRF[j,k] = \frac{\mathrm{EMSRc(m)} \times \mathrm{f_j}}{\sum_{\mathrm{m \in L_j}} \mathrm{EMSRc(m)}}, \ if \ \sum_{\mathrm{m \in L_j}} \mathrm{EMSRc(m)} \neq 0 \qquad (3.13)$$

$\infty \quad PRF[j,k] = {}^{f_j}/_{card\,(L_j)}, \; if \; \sum_{m \in L_j} EMSRc(m) = 0 \qquad (3.14)$

where,

$$L_j = \text{ set of legs which form connecting ODF j}$$

$$f_j = \text{Total fare value of the connecting ODF j}$$

$$card(L_j) = \text{cardinality of set } L_j$$

Thus the prorated fare of a connecting ODF on a leg is the ratio of the critical EMSR value on the leg and the sum of the critical EMSR values on all the traversed legs, times the total fare. If the sum of the critical EMSR is null (equation 3.14) then the fare is evenly distributed over all the traversed legs. Since critical EMSR values are by definition positive, this corresponds to the case where all the EMSRc are zeros for all the traversed legs. This happens when the demand forecast is well below the capacity on all the legs belonging to L_j.

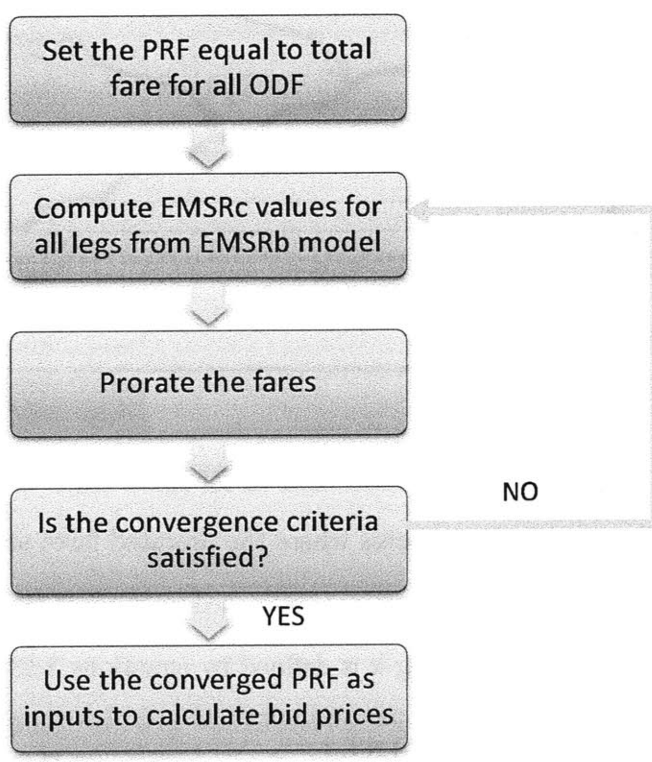

Figure 3.7: ProBP Iteration Steps (adapted from Bratu, 1998)

ProBP iterates the calculations until the convergence criterion on prorated fares is satisfied for all the ODFs over all the legs. Figure 3.7 summarizes the prorated fare convergence method. Finally, ProBP accepts an itinerary request only if the corresponding itinerary fare is greater than the sum of the bid prices (final EMSRc values) of the traversed legs of that itinerary.

3.3 Codeshare Valuation

Codeshare valuation refers to the fare inputs related to the codeshare paths used by an airline in its revenue management system and/or distribution system. These are fed as an input to the seat allocation tool or optimizer. Each airline runs its own optimizer and aims to maximize the individual revenues. The seat availability, as estimated by the optimizer, depends on the valuation. All else being equal, a higher codeshare valuation would lead to a higher availability for codeshare paths and vice versa. In the context of alliances, it is important to recognize that there is a tradeoff between different traffic components and every codeshare booking potentially replaces either a local or a connecting passenger.

Codeshare valuation can be primarily categorized into two types: static and dynamic. The static valuation schemes are explained in detail in this section while Chapter 5 will explain the dynamic valuation scheme. It should be emphasized here that the codeshare valuation which achieves higher combined alliance revenues may not necessarily lead to higher individual revenues for each partner because the individual partners' revenues depend on the revenue sharing contracts.

The two static valuation schemes which are common in the industry are local fares and static proration valuation schemes. Another scheme which is not often used is the total fares valuation scheme. A detailed description of each scheme will be now provided using an example shown in Table 3.1. The codeshare request under consideration is LAX-FRA/Q class, a two leg itinerary, LAX-ORD being operated by partner 1 and ORD-FRA being operated by partner 2 in the alliance. The fare values for the local and codeshare paths are shown.

Booking O-D/Class	Marketing Airline	Fare
LAX-ORD/Q	P1 (Local)	$ 248
ORD-FRA/Q	P2 (Local)	$ 532
LAX-FRA/Q	P1, P2 (Codeshare)	$ 619

Table 3.1: Fares (Q class) for Local and Codeshare Paths

3.3.1 Local Fares Valuation Scheme

A quite simplistic and non-optimal way to handle codeshare bookings is to treat them as local bookings on the traversed flight legs. This minimizes the complexities and does not call for any substantial changes in the RM system (De la Torre, 1999). In this approach, the partners value codeshare bookings at local fares, which are fares on the traversed legs operated by each of them. In the LAX-FRA/Q example (table 3.1) partner 1 would value codeshare bookings at $ 248 (LAX-ORD/Q local) while partner 2 would value them at $ 532 (ORD-FRA/Q local). Thus, the optimizer treats the codeshare demand in the same manner as the local demand on a leg. This is naïve in a manner similar to treating an own connecting passenger equivalent to local passengers on the two traversed legs as is done in leg based control.

Note that the local fares valuation would result in an overvaluation in most of the cases, in the sense that the sum of the valuations used by partners would exceed the total codeshare fare. In the example above, the sum of valuations is $ 780 which exceeds the actual codeshare fare by $161. To state it formally, in the case of an alliance with two partners, both using local fare valuation:

$$L_1 + L_2 \geq T \tag{3.15}$$

where,

$L_1 = Local\ fare\ valuation\ on\ Partner\ 1's\ leg$
$L_2 = Local\ fare\ valuation\ on\ Partner\ 2's\ leg$
$T = Total\ ODF\ for\ the\ codeshare\ path$

This is the only codeshare valuation scheme which can be used with AVS/Local mapping method of recording & forecasting of codeshares as described in section 3.1.1. All other codeshare valuation schemes which treat codeshares different than locals require separate forecasting as discussed in cascading.

3.3.2 Static Prorate Valuation Scheme

A static prorate valuation scheme provides a different treatment to codeshare demand from the local demand and remains unchanged for a given path/class during the booking period. It is based on the logic that local fare valuation scheme overvalues the codeshare paths and that the sum of airlines' codeshare valuations should be exactly equal to the total revenue available from the codeshare booking. Typically, in this scheme the proration for valuation is identical to the revenue share negotiated in the contract. There are several ways to estimate the valuation using this scheme and the most common ones are following:

a. Fixed percentage: Each partner values the codeshare paths at a fixed percentage of the total fare in their optimizer. The individual percentages should sum up to 100%. They can be same for all the codeshare paths or different for different paths like the other two static prorate valuation schemes described here.

b. Y-Prorate: This scheme uses the ratio of full coach (Y) local fares on the traversed legs of the codeshare path in order to calculate the proration for valuation in the optimizer. The ratio is different for each codeshare path.

c. Proration by miles flown: This scheme uses the mileage flown on the traversed legs to calculate the proration used for the purpose of valuation. Again, this is different for each codeshare path.

This thesis uses Y-Prorate scheme for the purpose of static prorate valuation analysis in Chapter 4. It is useful to know that the Y-Prorate scheme values codeshare paths at a lower value than local fare valuation scheme addressing the problem of overvaluation. In the LAX-FRA/Q example (table 3.1), let us assume that the ratio of Y-fares on two legs is 1:2. Partner 1 would value codeshare booking LAX-FRA/Q at $ 206.33 while partner 2 would value it at $ 412.67. Thus in the case of an alliance of two airlines, both using Y-Prorate valuation, the sum of airlines' codeshare valuations satisfies equation 3.16:

$$Y_1 + Y_2 = T \tag{3.16}$$

where,

$Y_1 = Y - Prorated\, fare\ valuation\ on\ Partner\ 1's\ leg$

$Y_2 = Y - Prorated\ \ fare\ valuation\ on\ Partner\ 2's\ leg$

$T = Total\ ODF\ for\ the\ codeshare\ path$

3.3.3 Total Fares Valuation Scheme

In the total fares valuation scheme, an alliance partner values every codeshare path at its total fare value. This scheme also treats codeshares separately from locals like the static prorate valuation schemes but instead of any proration, it uses the complete fare value. This results in double counting by the partners and an overvaluation of the codeshare paths yielding their higher availability. In the LAX-FRA/Q example (Table 3.1), under total valuation scheme both partners would value codeshare bookings at $ 619. Thus in case of an alliance with both partners using total fare valuation, equation 3.17 is satisfied:

$$TF_1 + TF_2 = 2T \tag{3.17}$$

where,

$$TF_1 = Total\ Fare\ valuation\ on\ Partner\ 1's\ leg$$
$$TF_2 = Total\ Fare\ valuation\ on\ Partner\ 2's\ leg$$
$$T = Total\ ODF\ for\ the\ codeshare\ path$$

3.4 Availability Control: Standard versus Bid Price Sharing

Availability control is the last step in alliance revenue management which is executed to take accept/reject decision on a booking request. Usually, the availability control is a part of the seat allocation step in airline revenue management and is not dealt separately. However, in the case of alliances, availability control for codeshare paths can be tweaked to produce different availability from that suggested by the optimizer. For example: the codeshare path LAX-FRA/Q can be manually mapped to a higher class/virtual bucket in order to increase its availability or it can be mapped to a lower class/virtual bucket to decrease its availability.

We shall see in Chapter 4 that this kind of intervention can help in increasing alliance revenues, but only under certain conditions. In the following subsections, we first describe the standard availability control for codeshare paths which does not require any kind of intervention and then the bid price sharing control which overrides the decision of seat allocation optimizer based on partner's bid prices.

3.4.1 Standard Availability Control

In the standard procedure for availability control, accept/reject decision for a booking request is based on a direct comparison of its fare value or its valuation in the system with the current buckets or bid prices. This is similar to the seat allocation controls used for local and connecting paths and is discussed in section 3.2. The only difference here is that in the case of codeshare paths the codeshare valuation (static/dynamic) is used for comparison. To understand this clearly, consider our previous example from section 3.1. The codeshare request under consideration is LAX-FRA/Q class, a two leg itinerary, LAX-ORD being operated by partner 1 and ORD-FRA being operated by partner 2 in the alliance (Figure 3.8). Assume that partner 1 is using DAVN as the seat allocation optimizer and using local valuation for codeshare paths. Now for the purpose of availability control it compares the valuation of the codeshare booking request (local fare valuation: \$ 248) and maps it to the appropriate virtual bucket (Figure 3.9). The booking is accepted or rejected based on the open/close status of that virtual bucket.

This example shows a conceptual implementation of the standard availability control in DAVN. The practice at different airlines could vary in terms of number of buckets and sequence of the steps. On the other hand, in the case of the bid price algorithms like ProBP, the codeshare valuation is compared against the bid price of own leg to accept/reject a codeshare request. Thus, in the above example if the estimated bid price value on LAX-ORD leg is greater than \$ 248, the codeshare request is rejected.

Figure 3.8: Codeshare Itinerary (LAX-FRA/Q)

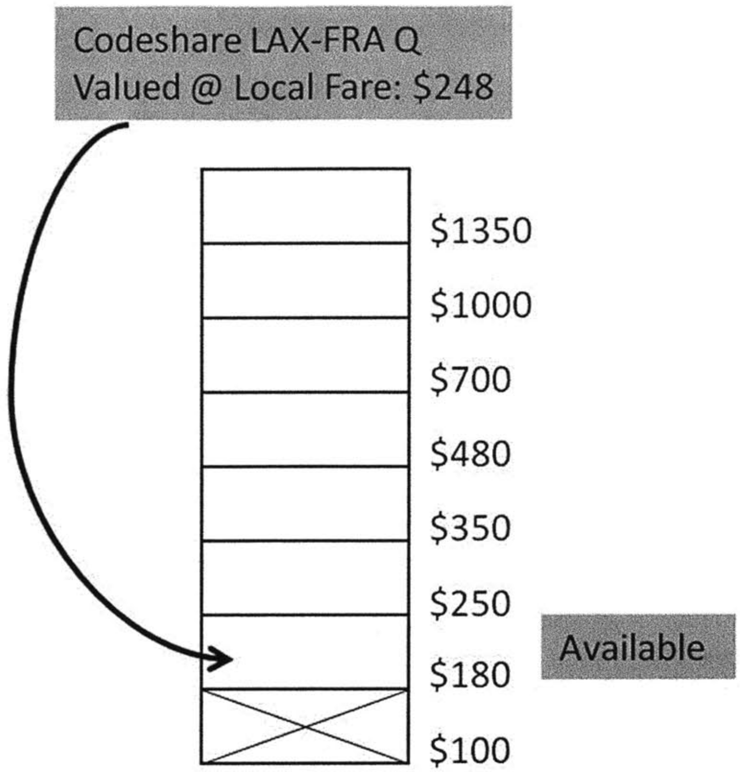

Figure 3.9: Standard Availability Control in DAVN for Alliance Partner 1

3.4.2 Bid Price Sharing Control

Bid price sharing control is a special technique of availability control which attempts to take into account the displacement costs incurred on partner's operated legs and make an intelligent decision for the benefit of the combined alliance. When the partners use O-D seat control methods, they estimate the shadow prices or bid prices for all the legs operated by them. Darot (2001) suggests that the partners can share the displacement costs or bid prices related to the codeshare legs and use this information during the availability control. He terms this mechanism as "bid price sharing" (for sharing shadow prices, bid prices or other forms of displacement cost), which is a prerequisite in order to execute the bid price sharing control. Figure 3.10 is an adaption from Darot (2001) and explains the bid price sharing control mechanism.

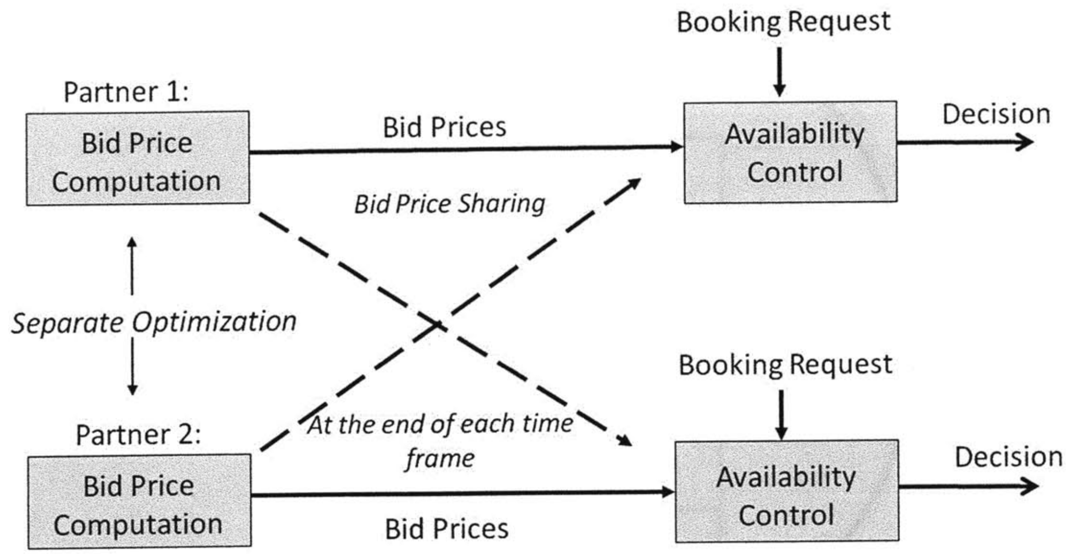

Figure 3.10: Bid Price Sharing Control (adapted from Darot, 2001)

The partners run their optimizers separately and calculate the bid prices over their own networks. They share the bid prices related to codeshare legs at the end of each timeframe (interval between two successive runs of the optimizer). These shared bid prices of the partner are then used in the next timeframe to execute the bid price sharing control.

The implementation details of bid price sharing control are discussed now. In the case of an alliance with two partners both using DAVN as the optimizer, they share the shadow prices and execute the bid price sharing control as per equation 3.18. In case of ProBP or other bid price algorithms, equation 3.19 is used.

$$T - SP_{partner}^{t-1} \geq EMSR_{own}^{t} \tag{3.18}$$

$$T - BP_{partner}^{t-1} \geq BP_{own}^{t} \tag{3.19}$$

where,

$SP_{partner}^{t-1} = Shadow\ Price\ on\ partner's\ codeshare\ leg\ in\ previous\ time\ frame$

$EMSR_{own}^{t} = Lowest\ open\ bucket\ on\ own\ codeshare\ leg\ in\ current\ time\ frame$

$$BP_{partner}^{t-1} = Bid\ price\ on\ partner's\ codeshare\ leg\ in\ previous\ time\ frame$$
$$BP_{own}^{t} = Bid\ price\ on\ own\ codeshare\ leg\ in\ current\ time\ frame$$
$$T = Total\ ODF\ for\ the\ codeshare\ path$$

Let us have a look at the application of bid price sharing control for the same example which we used for the standard availability control. Assuming that both partners are using DAVN, the equation for partner 1 operating LAX-ORD leg becomes:

$$\$\,619 - SP_{partner}^{t-1} \geq \$\,180 \tag{3.20}$$

Thus accept/reject decision now depends on the total fare and partner's shadow price instead of own valuation of the codeshare path. The lowest available bucket in partner 1's system is \$ 180. Thus, if partner 2's shadow price on ORD-FRA leg is greater than \$439 then partner 1 rejects the codeshare booking request.

Bid price sharing can be subjected to legal permissions and antitrust immunity might be required to allow sharing of information between the partners. Darot (2001) also discusses an alternative technique called bid price inference where instead of sharing any real bid prices, partners try to infer them approximately from the publicly available fares on each other's codeshare legs. It should be noted that bid price sharing control does not affect the optimization step and the valuation scheme for codeshare paths also remains same (local/proration). It acts only at the end to override the decision made using standard availability control method. Thus it acts more like a corrective step which attempts to correct the effects of fixed and arbitrary codeshare valuation inputs used in the optimizer. It uses partner's bid prices which are in fact the output from partner's optimizer and in turn dependent on the codeshare valuation inputs used by it. Therefore, the results of bid price sharing control method can be affected by the codeshare valuation inputs used to estimate the bid prices.

3.4.3 Synchronized Availability

The codeshare availability is not synchronized among the alliance partners many times. The partners may show different fares and availability for codeshare paths in the distribution systems. This is due in part to the inconsistent information in airline bookings distribution systems. Apart from availability, there are problems of synchronization when seat assignment or boarding passes issued by one airline are not recognized by partner, or the frequent flyer miles are not honored. In addition, the availability can be different when partners have asymmetric RM systems and lack seamless connectivity as described in the next section.

3.5 Asymmetric Systems and Capabilities

The problem of alliance revenue management becomes more complex and realistic when asymmetric RM systems are considered. In reality, it is uncommon to find two alliance partners with exactly the same RM capabilities. Some partners in the alliance may be using leg based control while others may have advanced O-D control systems. Even under O-D control, there are several methods which may produce different types of information as described under section 3.2. Another source of asymmetry is the codeshare valuation. It is quite possible that the partners do not use same valuation schemes in their individual RM systems. This asymmetry can lead to unsynchronized availability on codeshare paths. In addition, they may face more challenges while using advanced techniques like bid price sharing control or dynamic valuation, as discussed in Chapter 5.

Vinod (2005) suggests using leg bid prices as a common currency for inventory control among the alliance partners. This may lead to a synchronized availability among the partners. The leg bid prices are estimated using bid price algorithms like ProBP as discussed under the section 3.2.2.2. There are also other methods which approximate the bid prices such as bid price inference (Darot, 2001). However, the propriety of bid prices and their standardization among the alliance partners can be another challenge.

3.6 Alliance RM: Summary and Example

Table 3.2 provides a complete summary of the various components of alliance revenue management with the help of the example shown in Figure 3.8. The codeshare request under consideration is LAX-FRA/Q class, a two leg itinerary, LAX-ORD being operated by *partner 1* and ORD-FRA being operated by *partner 2* in the alliance. Table 3.2 illustrates the revenue management components only for *partner 1* and separately for AVS and Cascading. It should be noted that the alternative codeshare valuation schemes and bid price sharing control are possible with cascading only.

RM Component	**AVS Local Mapping**	**Cascading CS Mapping**
Request Information	LAX-ORD/Q	LAX-FRA/Q
Forecast of CS Path Demand	Combined with LAX-ORD/Q Local	Separate LAX-FRA/Q CS Path
Seat Allocation Method	Both Leg and O-D Control possible	Both Leg and O-D Control possible
Valuation of CS Path	LAX-ORD/Q @ Local Fare Valuation only	LAX-FRA/Q @ any CS Valuation Scheme
Standard Availability	Same as LAX-ORD/Q Local Path	LAX-FRA/Q @ CS Valuation Scheme
Bid Price Sharing Control	Not Possible	LAX-FRA/Q @ (Total Fare – BP_2)

CS: Codeshare, BP_2: Bid Price of Partner 2

Table 3.2: Revenue Management and Availability Options for Partner 1

3.7 Chapter Summary

This chapter provides a detailed discussion on the challenges involved in alliance revenue management. The codeshare paths in alliances present complexities on many fronts, from getting itinerary information to making an availability decision on a booking request. The discussion is structured under four key dimensions of alliance revenue management. Each dimension is explained in detail with the help of relevant examples.

The recording & forecasting of codeshare demand depends on the degree of information (full or partial) received from the alliance partner. The codeshares can be recorded & forecasted only as locals if the full information of an itinerary booked by a partner is not available. Cascading, which requires full itinerary information from the partner, is a prerequisite to use alternative valuation schemes other than local valuation. It is also needed for using advanced techniques for handling codeshare paths such as bid price sharing control in availability and dynamic valuation in RM optimizer.

O-D seat allocation control is also necessary to provide a differential treatment to codeshare passengers from local passengers and to distinguish between different codeshare itineraries using the same leg. The two common O-D control methods are Displacement Adjusted Virtual Nesting (DAVN) and Probabilistic Bid Pricing (ProBP). DAVN is based on estimating the network revenue contribution of itineraries using deterministic linear programming. ProBP depends on the optimal proration of fares of all itineraries over the traversed legs and uses an iterative algorithm to calculate leg bid prices.

Codeshare valuation in the optimizer can control the amount of codeshare traffic and hence other traffic components as well due to network effects. The static valuation remains constant throughout the booking period and does not account for the stochastic nature of demand. Among the static valuation schemes, both total valuation and local valuation overvalue the codeshare bookings in that the sum of airlines' codeshare valuations exceed the total codeshare fare while static prorate valuation sums up to the exact amount of codeshare fare.

Bid price sharing is the mechanism of sharing displacement costs (bid prices or shadow prices) between the partners. The partner's bid prices can be used in availability control to override the output from the optimizer and use bid price sharing control to accept/reject a codeshare booking request. Though bid price sharing control accounts for the partner's opportunity cost, it does not use it in the optimizer.

Chapter 4 will present an in depth simulation analysis of all the techniques discussed in this chapter and will explain the advantages and disadvantages of each of them.

4. Chapter 4

PODS Simulations: Experimental Setup and Results

This chapter presents simulation results which are obtained using the Passenger Origin Destination Simulator (PODS). The first section of this chapter provides a brief overview of PODS and its different components. The next section provides details of the simulation environment. It lays out the network structure which is used for simulations and presents a baseline case for the purpose of comparisons. The remaining sections present findings from numerous experiments related to the different dimensions of alliance revenue management. Detailed explanation is provided for the observed results under each section.

4.1 PODS Overview

PODS is a software simulation tool originally developed at Boeing by Hopperstad, Berge, and Filipowski in the mid-1990s. It has been further developed and used by the MIT-PODS Revenue Management Research Consortium which receives participation from nine leading airlines of the world. PODS is used to test the performance of different airline revenue management techniques and strategies in a competitive environment.

With multiple airlines serving numerous markets, PODS is capable of simulating airline competition over a multiple-day booking period. For any given flight departure in PODS, passengers start booking 63 days before departure. This 63 day period is divided into 16 time frames unevenly such that there are more time frames close to the departure.

PODS simulate the airline booking process with two separate but interactive components, namely (i) Passenger Choice Model and (ii) Airline Revenue Management System. Figure 4.1 illustrates the successive steps in each component and interaction between the two components.

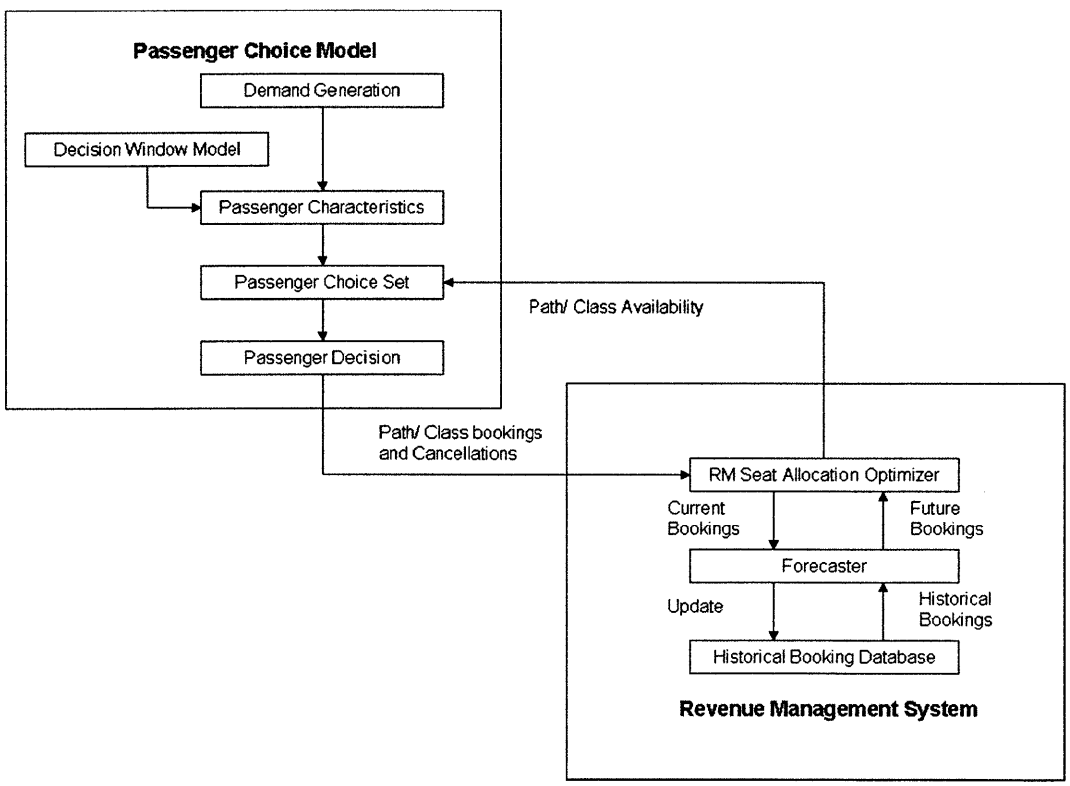

Figure 4.1: PODS Architecture (Belobaba, 2010)

A brief overview of the PODS components is presented in the following subsections. For more information, see Belobaba (2010), Hopperstad (2005), and PODS related theses at MIT like Carrier (2003), Gorin (2000) Lee (2000) and Tam (2008).

4.1.1 PODS Passenger Choice Model

The Passenger Choice Model in PODS generates passengers and their individual preferences. It simulates their decision processes based on these preferences and relative path/class availability of seats on flights. The left component of Figure 4.1 illustrates the four major steps of the Passenger Choice Model. Its first step is demand generation based on the average total daily demand for air travel for each O-D market specified by the user. This total demand is split between leisure and business passengers as per the data from airline industry, for example 40% business and 60% leisure passengers. The arrival of passengers of each type is set according to booking curves which specify the percentage of arrivals of each type in each of the 16 time frames. The business passengers usually arrive later in the booking process than leisure passengers. Note that, as in the real world, the airlines in PODS do not know the underlying market demand and its split. They can only build a history of the accepted bookings and use that to predict the future demand.

PODS is capable of generating random variability in the user inputs of demand using Gaussian distributions. It simulates multiple repetitions of the same departure day and each repetition draws demand inputs randomly from specified distributions. In fact, each PODS simulation performed for this research consists of 2 independent sets of trials, each composed of 600 successive (and thus correlated) simulations of departure days.

The next two steps are generating passenger characteristics (preferences) and consequently their choice sets. Each passenger is assigned a time of travel preference, a maximum willingness-to-pay (WTP)[1] and a set of disutility costs to represent his/her sensitivity to different travel attributes such as schedule time, fare product restrictions, path quality (nonstop vs. connecting) and airline preference. Based on the characteristics

[1] Maximum WTP represents the maximum fare value a passenger is willing to pay.

of each passenger, PODS determines the complete set of available path/class options at any point of time (Figure 4.1). These path/class options are ranked in the order of total cost, which is a sum of an option's fare price and the applicable disutility costs. Lastly, the passenger decides on the lowest total cost feasible option. This simulated purchase then becomes a booking and is stored in the corresponding airline's Historical Bookings Database. If no feasible option exists in the passenger's choice set, it translates into a "no –go" and the passenger chooses not to travel.

4.1.2 Revenue Management System

The Revenue Management (RM) System represents the airline side in PODS and is made up of three components: Historical Bookings Database, Forecaster and Seat Allocation Optimizer. The Historical Bookings Database records every booking for a given airline by leg/class or path/class. The database requires some default bookings at the start of the simulation which are replaced by actual observed bookings as the simulation progresses. The Forecaster utilizes the booking data from the database to provide a forecast of future demand by leg/class or by path/class. This also includes the detruncation of closed observations to account for the actual demand (see section 2.1). The forecast is then fed to the Seat Allocation Optimizer which determines the availability of fare classes on every leg/path. This fare class availability provides a link between the two parent components in PODS. It is the output of the Seat Allocation Optimizer of the RM system fed as an input to the Passenger Choice Set step of the Passenger Choice Model (see Figure 4.1).

All the three components of RM System described above are relevant for this research on airline alliances. Each of them has been discussed in more detail, in the context of alliances, in Chapter 3. This chapter presents an experimental analysis of the different techniques under each of these components, applied to the case of alliances.

4.2 Simulation Environment: Alliance Network- A4 and Baseline Case

Alliance network A4 consists of a simplified international alliance network of two airlines, namely Airline 2 (AL 2) and Airline 4 (AL 4). It includes two other competing carriers, Airline 1 (AL 1) and Airline 3 (AL 3) and all the four airlines have hubs[1] in United States as shown in Figure 4.2. Traffic is assumed to flow in a single direction from cities on the west of a hub to those on its east, with the premise that the other direction would have the same demand behavior. AL 2 with a hub at ORD is the *Partner 1* in the alliance which flies to international destinations on the east. AL 4 with a hub at DFW is the *Partner 2* in the alliance providing service from international destinations on the west. AL 1 with a hub at MSP is a network carrier which competes with alliance carriers on all the routes while AL 3 having a hub at MCI represents a low cost carrier (LCC)[2]. Figures 4.2 displays the network map with airlines' hubs and all the cities served. Figure 4.3 and 4.4 show the codeshare paths via each of the alliance partner's hubs while the double connect[3] codeshare paths are shown in Figure 4.5.

[1] Hubs are airports which facilitate connecting passengers by coordinating timings of inbound and outbound flights.

[2] LCCs usually fly many point to point flights surpassing hubs and have a fare structure with lower fares and fewer restrictions.

[3] Codeshare paths with two connecting stops between origin and destination.

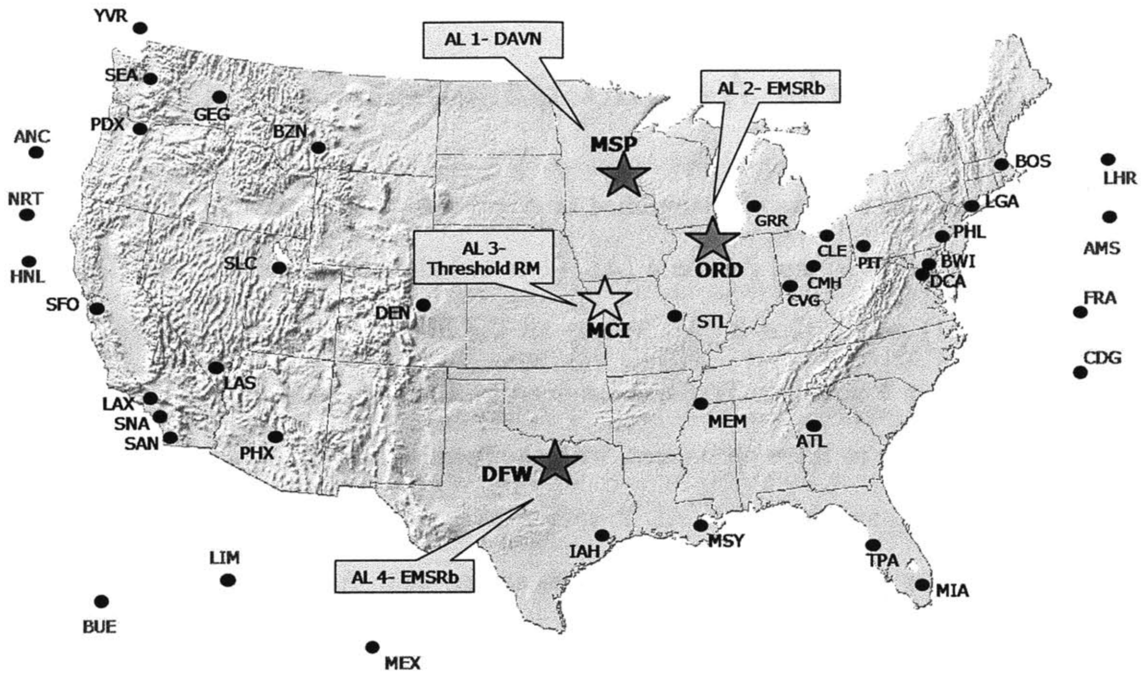

Figure 4.2: Network A4: Hubs and Cities

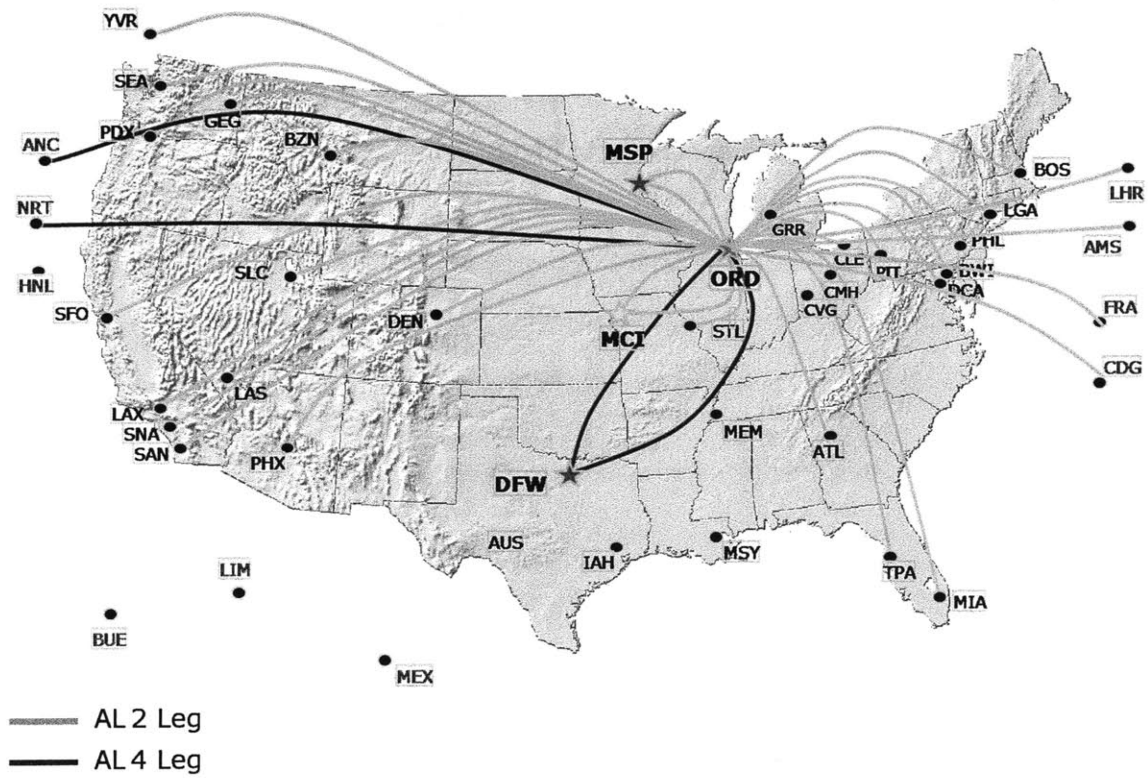

Figure 4.3: Codeshare Paths via AL 2 Hub- ORD

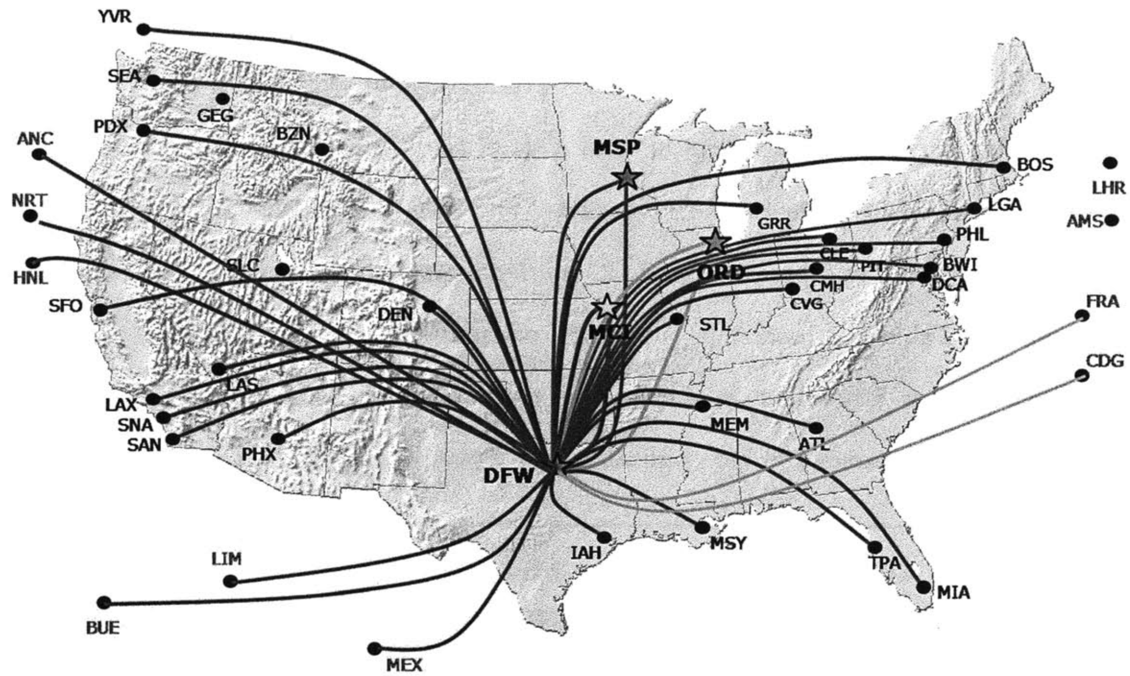

Figure 4.4 Codeshare Paths via AL 4 Hub- DFW

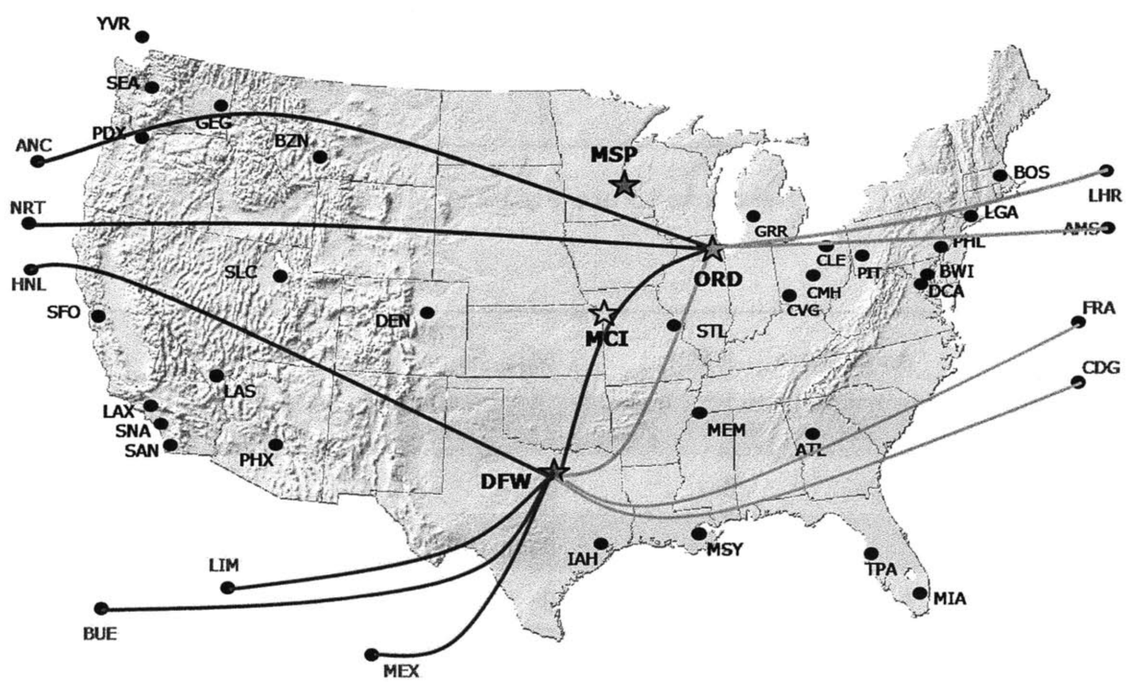

Figure 4.5: Double Connect Codeshare Paths

Network A4 is a modified version of Network T1 in PODS. For a detailed description of Network T1, refer to Boyer (2010). Network A4 consists of 40 spoke cities which result in 444 flight legs and 572 O-D markets in total. Out of the 572 markets, AL 3 is present in 296 markets which are known as LCC markets. The LCC markets have a less restricted fare structure while the other 276 non-LCC markets use a more restricted fare structure as shown in Table 4.1 and 4.2. The AP column specifies the advance purchase requirement for a fare class in days. The next three columns represent a set of restrictions on fare classes and are applicable only if their corresponding entry is 1.

Fare Class	Avg. Fare	AP	Min Stay	Cancel Fee	Non Refund
1	$ 1,919	0	0	0	0
2	$ 1,507	0	0	1	0
3	$ 1,094	10	0	1	1
4	$ 729	10	1	1	0
5	$ 592	14	1	0	1
6	$ 455	21	1	1	1

Table 4.1: More Restricted Fare Structure for non-LCC markets

Fare Class	Avg. Fare	AP	Min Stay	Cancel Fee	Non Refund
1	$ 324	0	0	0	0
2	$ 251	0	0	0	1
3	$ 188	7	0	0	1
4	$ 146	7	0	1	1
5	$ 125	14	0	1	1
6	$ 105	14	0	1	1

Table 4.2: Less Restricted Fare Structure for LCC markets

Now we form a baseline case for network A4 which will be used for all the comparisons in this chapter, unless otherwise stated. In the baseline case, the alliance carriers (AL 2 and AL 4) use a leg based seat allocation method- EMSRb (section 3.2) while AL 1 uses an O-D control method- DAVN and AL 3 uses the adaptive load factor threshold method[1] with a target load factor of 90%. Regarding the four dimensions of alliance revenue management (see Chapter 3), both partners in the alliance use the following in the baseline case:

(i) AVS for the purpose of recording & forecasting

(ii) EMSRb as the seat allocation method

(iii) Local fare valuation scheme to value codeshare demand at local fares in the optimizer

(iv) Standard availability control method to accept/reject a codeshare booking request

Firstly, we present the performance statistics related to the baseline case in Table 4.3:

AIRLINE	ASM	RPM	LF (%)	REVENUE[2]	YIELD ($/ RPM)
1-DAVN	23,817,830	19,983,288	83.90	$ 3,412,699	$ 0.1708
2-EMSRb	16,705,610	13,578,447	81.28	$ 2,117,125	$ 0.1559
3-AT 90	10,218,370	8,002,563	78.32	$ 875,841	$ 0.1094
4-EMSRb	20,455,180	17,152,174	83.85	$ 2,561,975	$ 0.1494

Table 4.3: Baseline Performance Statistics

Throughout our analysis in this chapter, the alliance partners share the codeshare revenues using Y-Proration, i.e. in the ratio of Y class (class 1) fares on the traversed

[1] In this method, a load factor threshold between 0% and 100% is associated with each fare class, and a class is closed down as soon as the booked load reaches the associated threshold level for that class.

[2] Revenues before codeshare resolution in the case of alliance carriers.

codeshare legs. Net revenues are calculated after accounting for the codeshare payments as shown in the Table 4.4. All the revenue comparisons for alliance partners will be made using net revenues, unless otherwise stated.

AIRLINE	REVENUE (PRE-RESOLUTION)	PAYMENT SENT	PAYMENT RECEIVED	NET REVENUE
2-EMSRb	$ 2,117,125	$ 341,227	$ 340,310	$ 2,116,208
4-EMSRb	$ 2,561,975	$ 340,310	$ 341,227	$ 2,562,892

Table 4.4: Baseline Codeshare Revenue Resolution

The passenger mix in the baseline case is shown in Table 4.5. It has been divided into four components, namely:

(i) LOC: Local traffic (refer section 1.2), can be booked only by an airline itself.

(ii) CNX: Connecting traffic, again can be booked only by an airline itself.

(iii) OWN CS: Codeshare traffic booked by an airline itself. Also simply referred to as CS.

(iv) PART CS: Codeshare traffic booked by alliance partner.

AL	LOC	CNX	OWN CS	PART CS
1-DAVN	4019	4638	0	0
2-EMSRb	3426	2484	594	558
3-AT 90	3480	2035	0	0
4-EMSRb	2921	3679	558	594

Table 4.5: Baseline Passenger Mix

It should be noted that the two alliance partners have asymmetric networks and differ in their characteristics and passenger mix. AL 4 is bigger than AL 2 in terms of RPMs by 26%. AL 4 has a higher proportion of connecting traffic while AL 2 has a higher proportion of local traffic. As a proportion of the total traffic, codeshares form 16.3% for AL 2 and 14.9% for AL 4.

The breakup of revenues into local, connection and own codeshare (pre resolution) components is shown in Figure 4.6 for the alliance carriers. For the combined alliance, codeshares account for 25.2% of total revenues while occupying only 8.4% of total traffic by passengers. Most of the codeshare paths have high fares because they involve long distance international flights. Thus, the codeshare traffic is highly valuable in terms of revenue per passenger in this network. However, the biggest revenue component is connection revenue for both the partners, more prominently for AL 4.

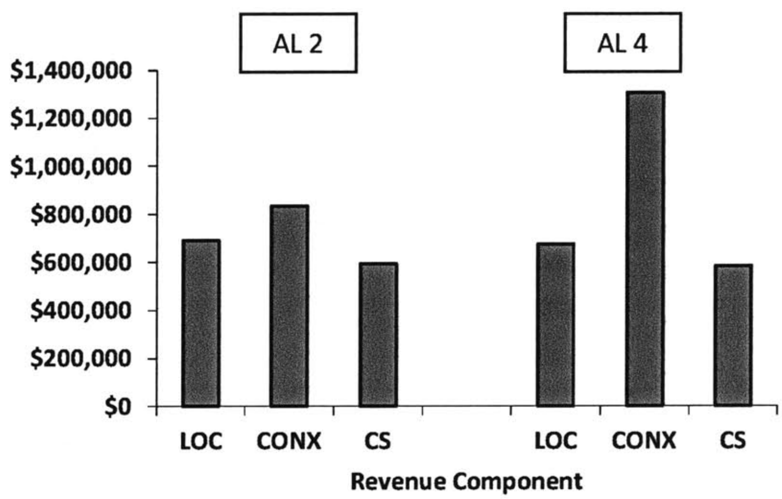

Figure 4.6: Baseline Revenue Components

Let us take a look at the baseline fare class mix of the different traffic components. Figure 4.7 shows the class 1 to class 6 bookings for AL 2 on the aggregate level i.e. summed over its whole network. A higher number of bookings in top classes lead to a higher revenue which is targeted by different revenue management techniques. We will compare this baseline fare class mix with that obtained in our upcoming experiments to gain useful insights.

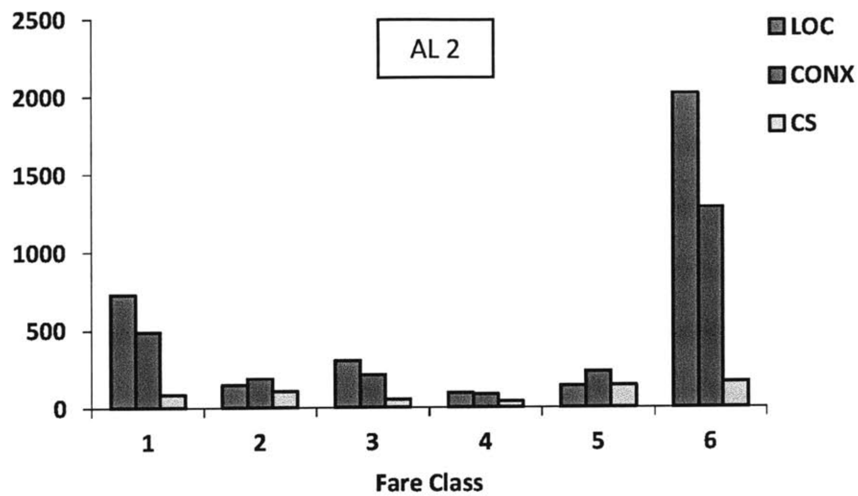

Figure 4.7: Baseline Fare Class Mix of AL 2

Now that we have defined the baseline case, we will proceed to the experimental analysis and results. It should be noticed that throughout this chapter, in all the experiments both alliance carriers use same set of methods for forecasting, seat allocation, codeshare valuation and availability control. The changes are made simultaneously for both the partners and there is no asymmetry with regard to their revenue management systems. All the results are shown on the aggregate level which includes the complete network of each airline.

4.3 Sub-optimality of O-D Control in Alliances

We start our analysis by looking at the impacts of codeshare traffic on the revenue management in alliances. The presence of codeshare traffic becomes a limitation while optimizing the revenues using O-D control methods. O-D control depends on calculating the network contribution of each passenger itinerary in an airline's network and requires fare valuations as inputs for calculations. These inputs are straightforward in the case of local and connecting paths. In the case of a codeshare path part of the itinerary lies outside an airline's network. Thus the valuation input to the airline's O-D optimizer is not simple and can take different values as discussed in the section 3.3. Any fixed and arbitrary valuation of codeshares like local valuation, Y-Prorate valuation and total valuation does not provide optimal revenues for the alliance. This can be verified in the results shown in Figure 4.8. The results come from the comparisons shown in Table 4.6:

Comparison	AL 1	AL 2 (Partner 1)	AL 3	AL 4 (Partner 2)
1	EMSRb	EMSRb/DAVN	AT 90	EMSRb/DAVN
2	EMSRb/DAVN	EMSRb	AT 90	EMSRb

Table 4.6: Experimental Set-up for O-D Control Comparisons

The percentage gains from using O-D control over leg based EMSRb are shown for the alliance carriers and AL 1 which competes with the alliance carriers on all routes. The "ALLIANCE" calculations use a sum of the revenues of the two partners.

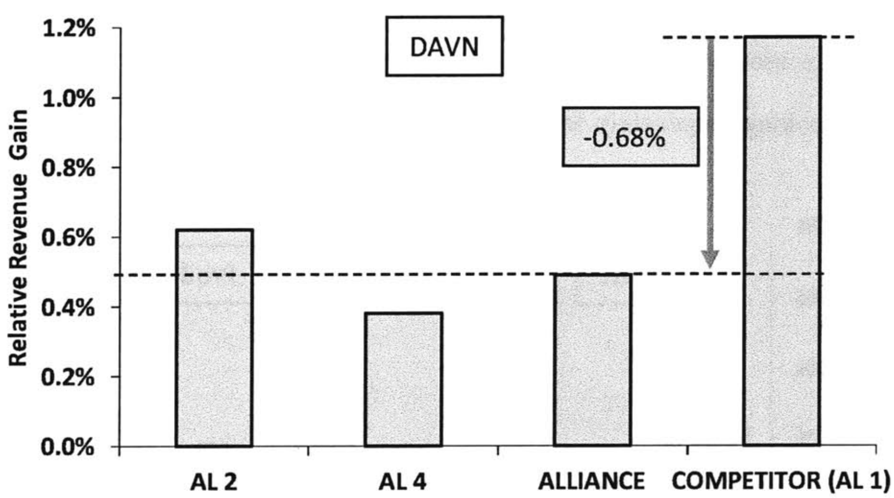

Figure 4.8: Revenue Gains from O-D Control

The typical revenue gains obtained from using O-D control by network carriers lie in the range of 1.0% to 1.8%. AL 1 here gains 1.17% while the combined alliance revenues increase by 0.49% only. It is clear that due to the presence of codeshare traffic and its non-optimal valuation (local fare inputs in this case), the revenue gain for alliance from implementing DAVN on two separate parts of the network is less than half of the gain achieved individually by AL 1. It is not sure that the optimal revenue gains for alliance would be exactly equal to 1.17%, but it would certainly lie in that range. Also there is a difference between the two alliance carriers which is attributed to the network asymmetry and codeshare revenue resolution scheme. As mentioned earlier in the last section, the networks of two airlines are asymmetric. The individual revenue gains can change under different codeshare revenue resolution schemes.

The above result also point out the motivation of this study i.e. to reduce the sub-optimality in revenue gains created by the presence of codeshare traffic.

4.4 Impacts of AVS and Cascading

Cascading is the first step towards reducing the sub-optimality in revenue gains. As we have discussed in section 3.1, cascading allows the alliance carriers to record & forecast the codeshare bookings separately from locals.

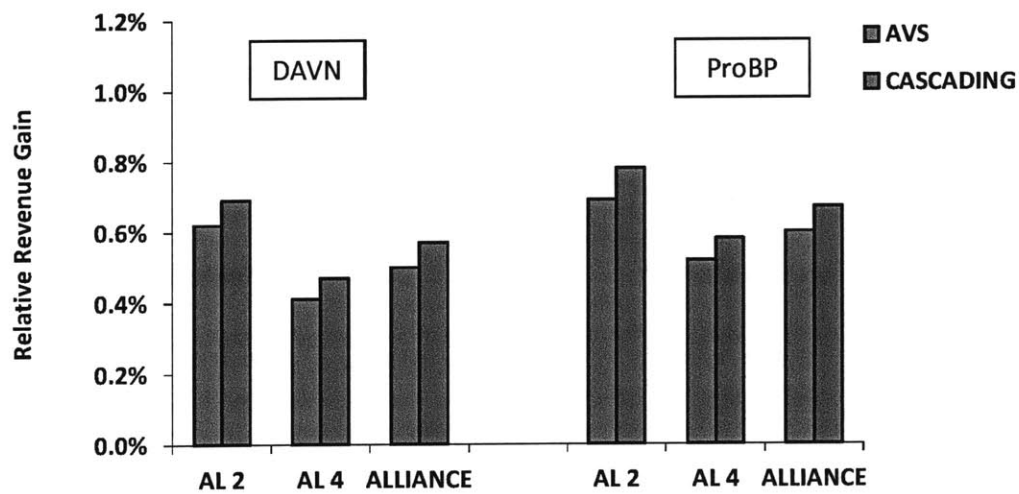

Figure 4.9: AVS vs. Cascading: Comparison of Revenue Gains

Figure 4.9 compares the gains of using O-D control (DAVN and ProBP) with AVS and cascading. In each experiment related to Figure 4.9, both alliance carriers use the same O-D control method and same method for recording & forecasting. The relative gains are shown with respect to the revenues in the baseline case.

There are two key results shown in Figure 4.9: (i) the gains of using DAVN and ProBP over EMSRb for the alliance carriers, (ii) the benefits of using cascading over AVS. The gains of using DAVN over EMSRb are in the range of 0.50% to 0.70%. Gains with ProBP are higher, since ProBP is a probabilistic method based on optimal proration. There are small benefits of using cascading over AVS, close to 0.1% in this network. These are direct gains of cascading over AVS which come from separating the local and codeshare bookings and thus improving the forecast which is used by the optimizer. To take a closer look, we first compare the change in aggregate revenue components of AL 2, relative to the baseline values and pre codeshare revenue resolution, for the two methods.

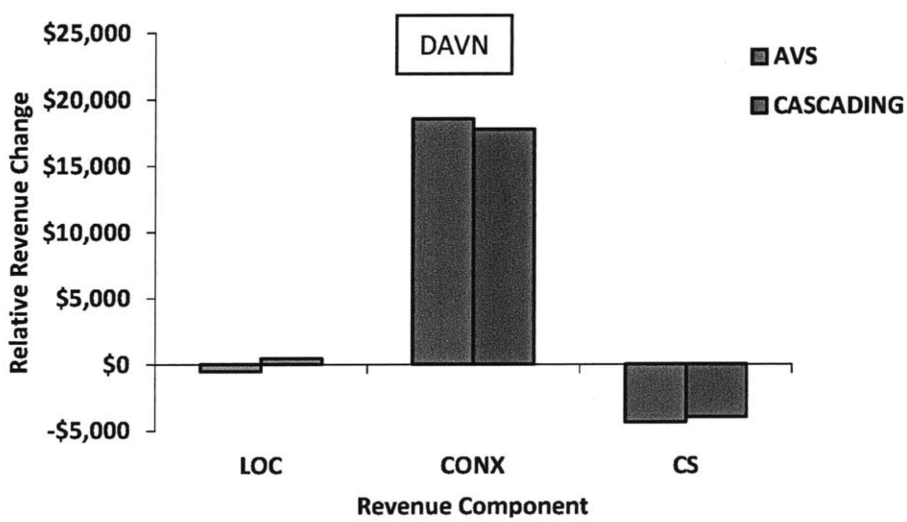

Figure 4.10: Changes in Revenue Components of AL 2

The first observation in Figure 4.10 is that compared to baseline which uses leg based control, the O-D control methods improve revenues (sub-optimally) in alliances through increasing the connecting revenues in large proportions while compromising the codeshare revenues in a lesser amount. The aggregate local revenues are not affected a lot. This is true for both AVS and Cascading. The slightly better performance of cascading comes through a lower reduction in codeshare revenues and a slight increase in local revenues.

Figure 4.11 shows the relative changes in fare class mix of codeshare traffic for AL 2, as compared to the baseline numbers. It considers the aggregate codeshare bookings accepted by AL 2 on all of its legs. On the x axis, fare classes go from 1 to 6 with 1 being the highest fare. With O-D control both AVS and cascading reduce the codeshare traffic in the lower classes and increase it in the higher classes. It should be noted that the changes in the plot which appear small are actually substantial in the case of codeshare traffic which by itself is quite small as shown in table 4.5. These changes go up to 12% when compared to the baseline codeshare traffic.

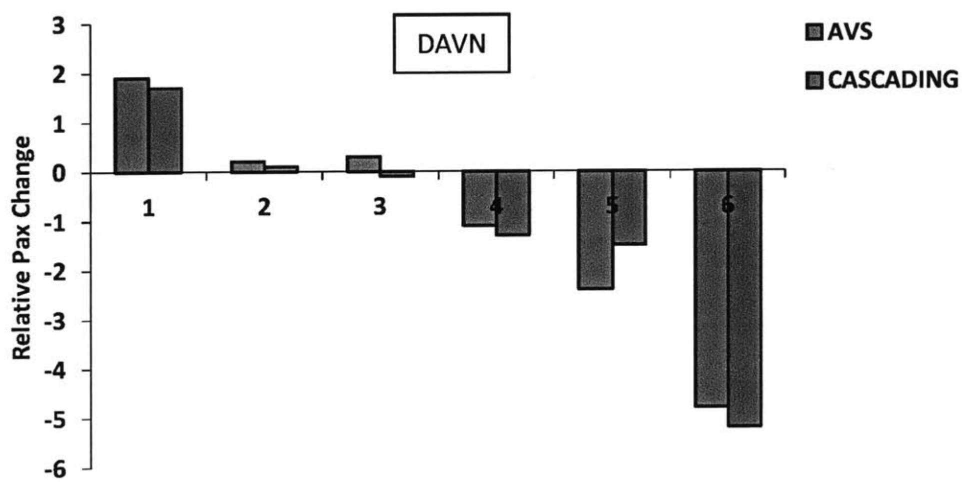

Figure 4.11: Changes in Codeshare Fare Class Mix of AL 2

It should be realized that in a network, the effects of AVS and cascading are not limited to codeshare traffic. The local and connecting traffic components are also affected because each codeshare booking can potentially replace either a local or a connecting passenger on a leg. Figure 4.12 shows the relative changes in fare class mix of local traffic for AL 2. The numbers shown in boxes are the bookings made in cascading relative to those made in AVS. It shows that with an improved forecast cascading leads to an improved fare class mix with more bookings in higher classes and fewer bookings in lower classes and thus higher revenues. Similar is the case of connecting fare class mix as shown in Figure 4.13, except that the reduction is class 6 is very large.

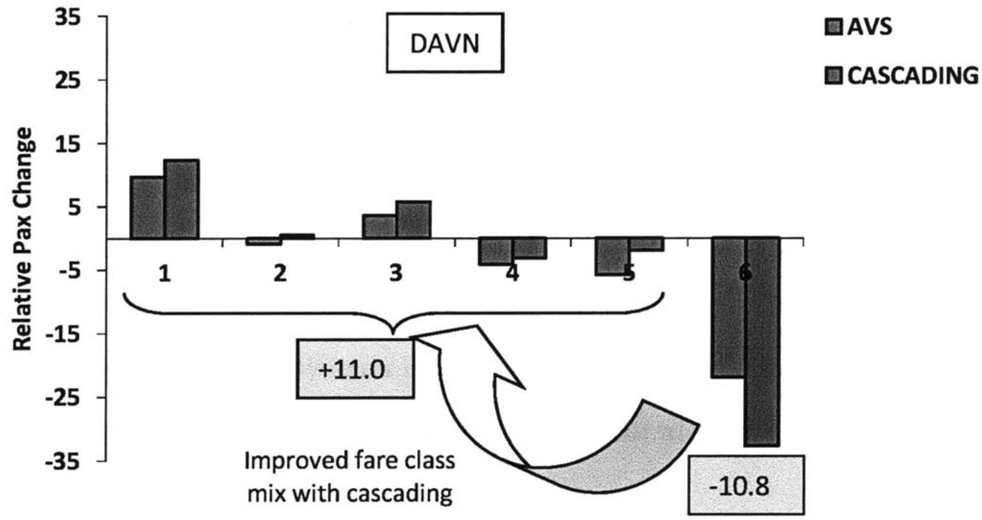

Figure 4.12: Changes in Local Fare Class Mix of AL 2

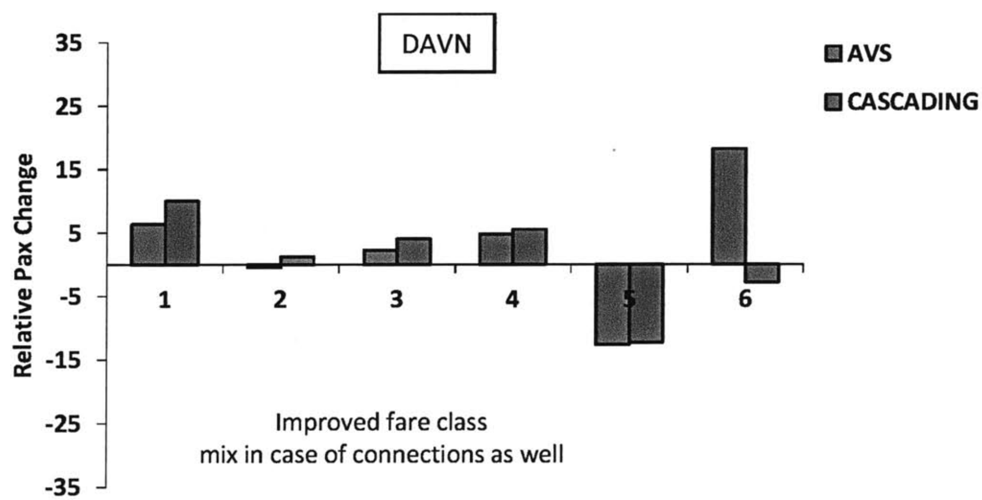

Figure 4.13 Changes in Connecting Fare Class Mix of AL 2

The above discusses the direct gains of using cascading over AVS. The indirect benefits of cascading are much more important because it provides the ability to use different techniques in the later steps of revenue management which includes alternative valuation schemes other than local valuation, bid price sharing control in availability and dynamic valuation in the optimizer.

4.5 Impacts of Codeshare Valuation Schemes

We evaluate three static codeshare valuation schemes: Local, Y-Prorate and Total valuation. These have been described in detail in section 3.3. The baseline case uses local valuation while O-D control and cascading are prerequisites to test alternative codeshare valuation schemes. The alliance partners use the same valuation scheme in each case and the experiments are made in the DAVN and ProBP environments separately.

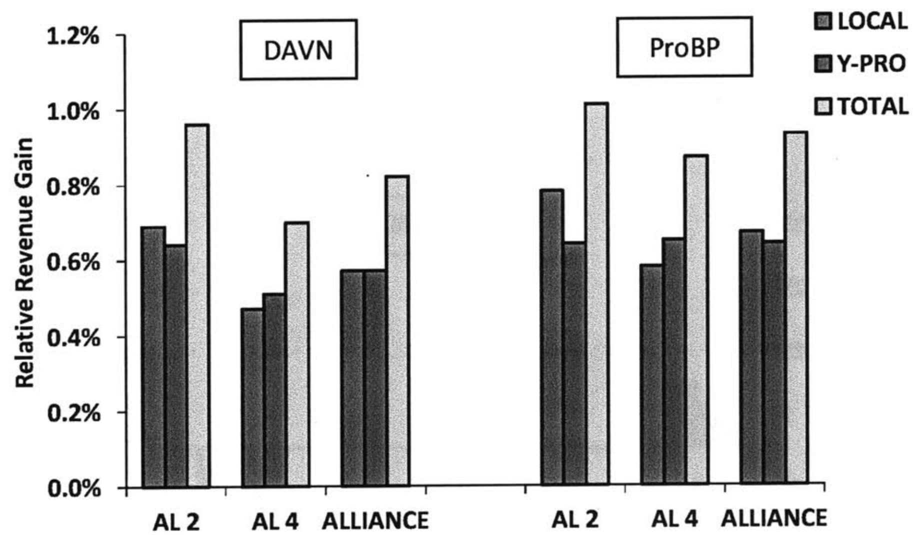

Figure 4.14: Valuation Schemes: Comparison of Revenue Gains

It is found that, of the three schemes, total valuation scheme performs best in this network (see Figure 4.14). The network characteristics of alliance carriers are such that the codeshare bookings are highly valuable. Codeshares represent 25.2% of total alliance revenues with just an 8.4% of total traffic in the baseline case. The total valuation overvalues codeshares and hence takes more codeshare bookings than the other two valuation schemes.

The Y-Prorate valuation scheme values the codeshare bookings at a lower value than both local and total valuation schemes and hence takes fewer codeshare bookings. Figure 4.15 compares the fare class mix of codeshare traffic in these three valuation schemes relative to the baseline codeshare traffic for AL 2. Y-Prorate reduces the number of codeshare bookings across all the fare classes while this number goes up heavily in the case of total valuation.

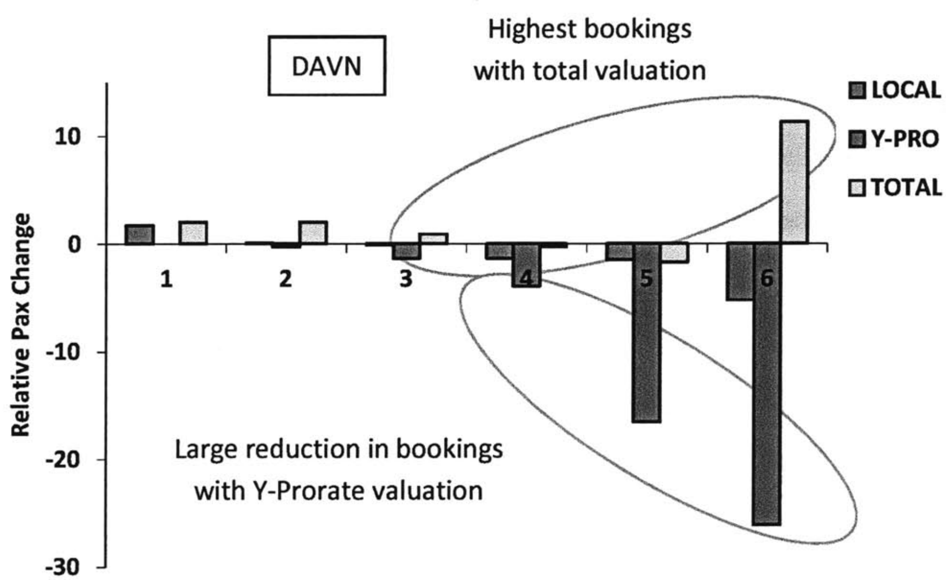

Figure 4.15: Changes in Codeshare Traffic Mix of AL 2

The changes in revenue components, before codeshare revenue resolution, relative to baseline are shown for AL 2 in the Figure 4.16. As expected, the total valuation has the highest codeshare revenues while the Y-Prorate has the lowest. Since there is a tradeoff between different traffic components, therefore increase in connecting revenues is least for total valuation while it is highest for Y-Prorate.

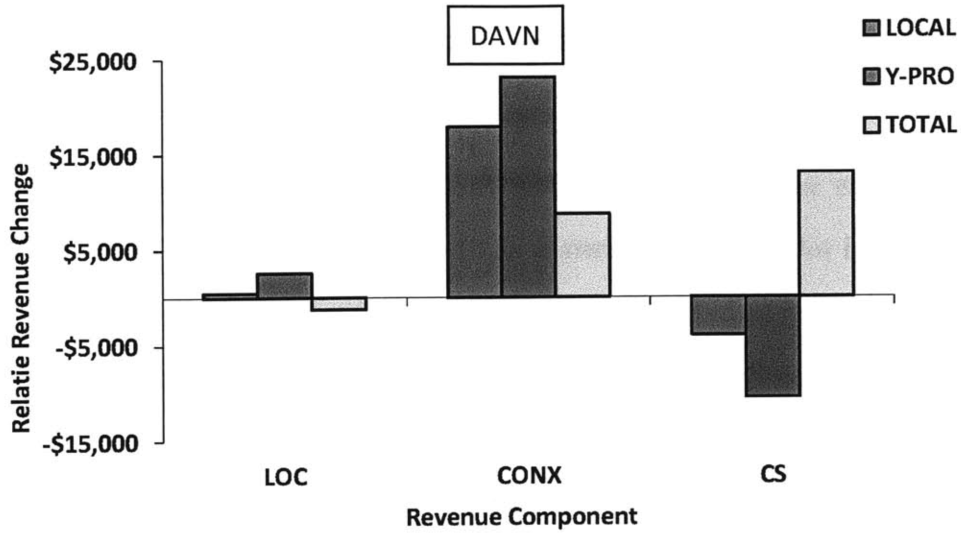

Figure 4.16: Changes in Revenue Components of AL 2

It is interesting to see that the revenue components and traffic mix are very different for the three valuation schemes. Especially in the case of local and Y-Prorate valuation schemes where the overall revenues are not very different because the effects on revenue components offset each other in this particular network (A4). In a different network setting, the revenue difference between the two can easily become large, particularly in networks with a larger amount of codeshare traffic. From the point of view of an airline or alliance, the use of a particular static valuation scheme depends on their network characteristics and system capabilities. A particular scheme can be better in one case while worse in the other.

4.6 Impacts of Availability Control

The two methods of availability control: standard control and availability control using bid price sharing are analyzed in this section. The latter requires O-D seat allocation control, cascading and bid price sharing between alliance partners as prerequisites. The results here are different with the two seat allocation optimizers, DAVN and ProBP, and are discussed separately under two subsections.

4.6.1 Impacts of Availability Control in DAVN

Bid price sharing control does not change the static codeshare valuation used in the optimizer but acts only in the later step of availability control. To test the impacts of availability control in DAVN, we first test the two methods under local valuation scheme. Figure 4.17 shows the substantial benefit derived from using bid price sharing control over standard method for the alliance.

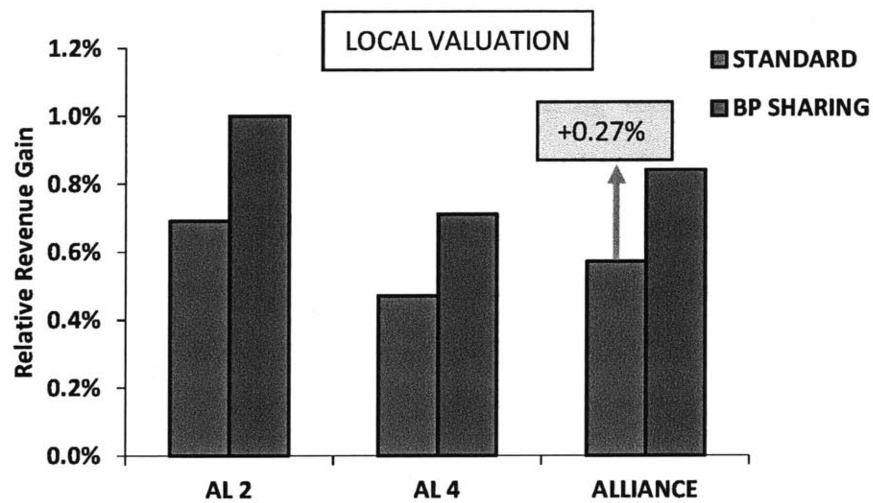

Figure 4.17: Revenue Gains of AL 2 under Local Valuation

The benefits of bid price sharing for DAVN come from better codeshare availability decisions taking into account the status of partner's codeshare legs and achieving a better fare class mix. To take a closer look, we first compare the change in aggregate revenue components of AL 2, relative to the baseline values and pre codeshare revenue resolution, for the two availability control methods.

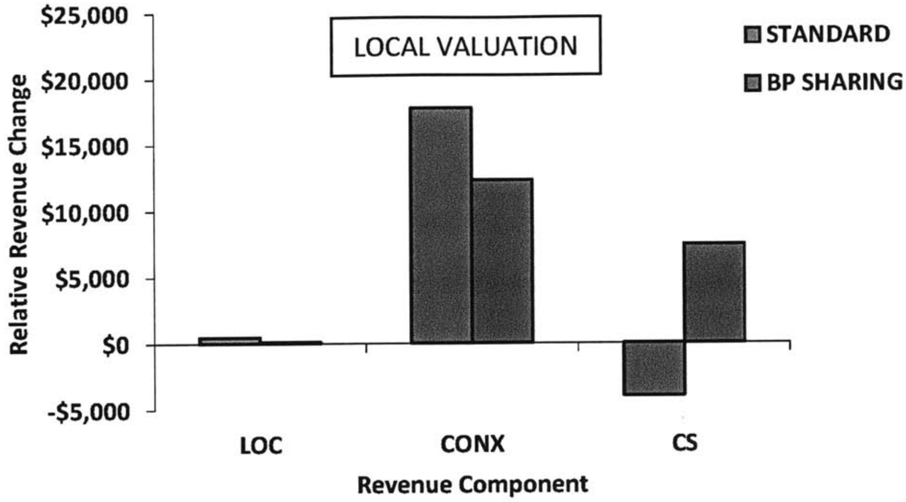

Figure 4.18: Changes in Revenue Components of AL 2

The codeshare revenues increase significantly after using the bid price sharing control. The connecting revenues go down relatively but in a lower amount leading to a substantial increase in overall gains. The bid price sharing control brings a large increase in the codeshare revenues through an improvement in the fare class mix which is achieved through a better seat availability control. Figure 4.19 illustrates this fact comparing the fare class mix of aggregate codeshare traffic (own) for AL 2 under the local valuation scheme. The number of class 5 bookings goes down with bid price sharing control and those seats are used to book passengers in higher classes. The numbers shown in the boxes are bookings for bid price sharing relative to those for the standard control. For example in fare class 5, bid price sharing has 6.8 fewer bookings compared to the standard control. Again, these small changes are substantial in the case of codeshare traffic and the results are shown on the aggregate level.

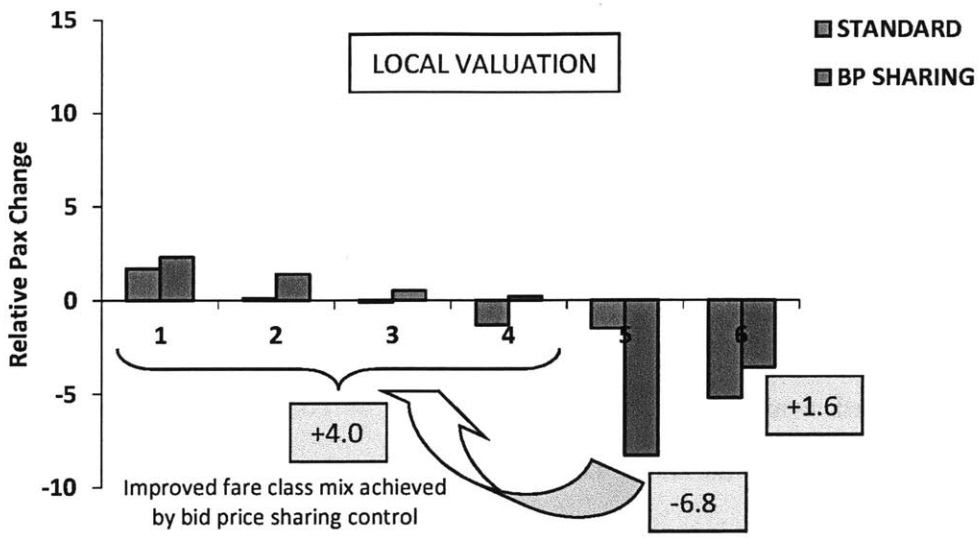

Figure 4.19: Changes in Codeshare Traffic Mix of AL 2

After analyzing the impacts of availability control with local valuation, we will now add the other two valuation schemes to the Figure 4.17 our plot to get a complete picture of the impacts under the three valuation schemes, as shown in Figure 4.20.

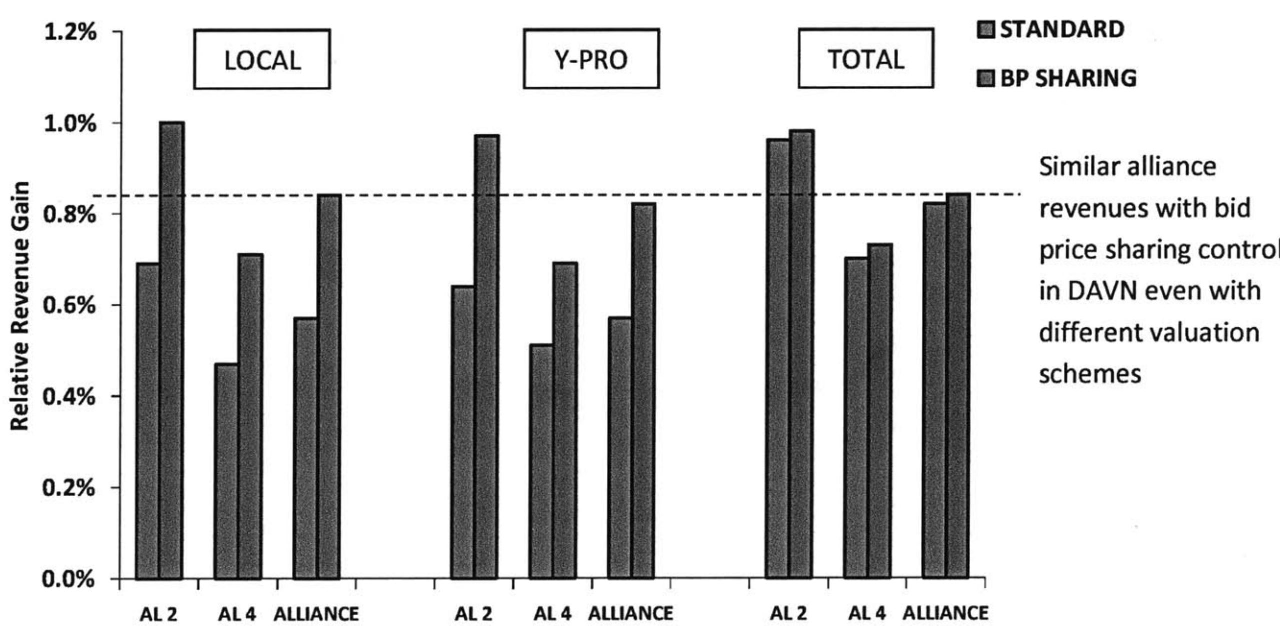

Figure 4.20: Revenue Gains with Bid Price Sharing Control in DAVN

Figure 4.20 shows that the bid price sharing control increases the revenues substantially for the local and Y-Prorate valuation schemes. It is interesting to see that there are no significant revenue improvements by using bid price sharing control under total valuation scheme. In fact, with bid price sharing control all the three valuation schemes perform at par with each other.

Let us analyze the performance of availability control methods under total valuation. With standard availability control, the number of codeshare bookings is very high because of their over valuation. This over valuation also implies that the estimated bid prices on the codeshare legs are also higher. Figure 4.21 shows the average shadow prices, averaged over all the flight legs of AL 2, for the 16 time frames of the booking period. The difference between the values of local valuation and total valuation is smaller in DAVN as compared to that in ProBP which is shown in Figure 4.22. The impact of over valuation of codeshares under total valuation is visible in Figure 4.22 in terms of higher average bid prices. The impact is diluted when averaged over whole network though. It would be prominent for individual flight legs like NRT-ORD, flown by AL 4 into the AL 2 hub (see figure 4.3), which carries high amount of codeshare traffic.

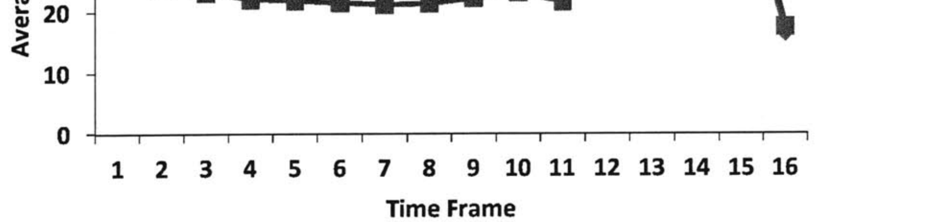

Figure 4.21: Average Shadow Prices of AL 2

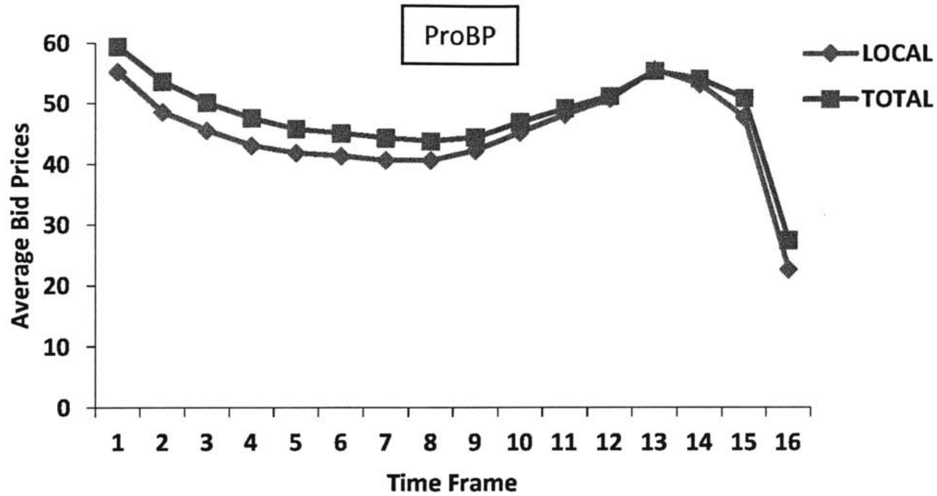

Figure 4.22: Average Bid Prices of AL 2

These bid prices are then shipped to the partner who uses them for the accept/reject decision for a codeshare booking request as explained in the section 3.4. For example consider the acceptance rule for bid price sharing control for DAVN stated in equation 3.20:

$$T - SP_{partner}^{t-1} \geq EMSR_{own}^{t}$$

Thus, higher are the partner's bid prices (or shadow prices in the case of DAVN), lesser is the acceptance rate of codeshare bookings. This is what happens in the bid price sharing control under total valuation. With bid price sharing control under total valuation, codeshare bookings are rather rejected in class 5 and 6 (see Figure 4.23), due to a higher value of bid prices shipped by the partner. They are replaced by the connecting traffic instead leading to a rise in connecting revenues. It is interesting to notice that the revenue components are very different for the local and total valuation schemes under the standard method while they approach each other closely under the bid price sharing control (see the two lines in Figure 4.24).

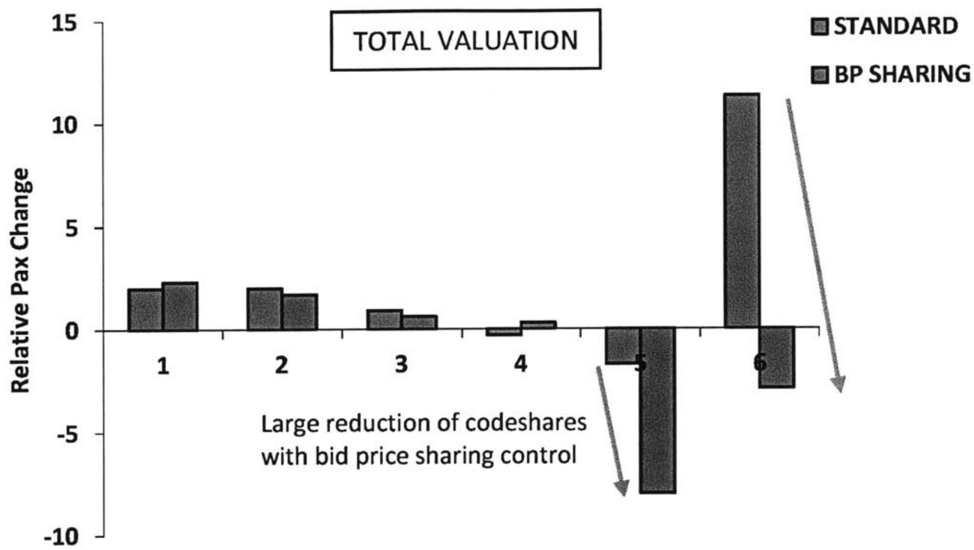

Figure 4.23: Changes in Codeshare Traffic Mix of AL 2

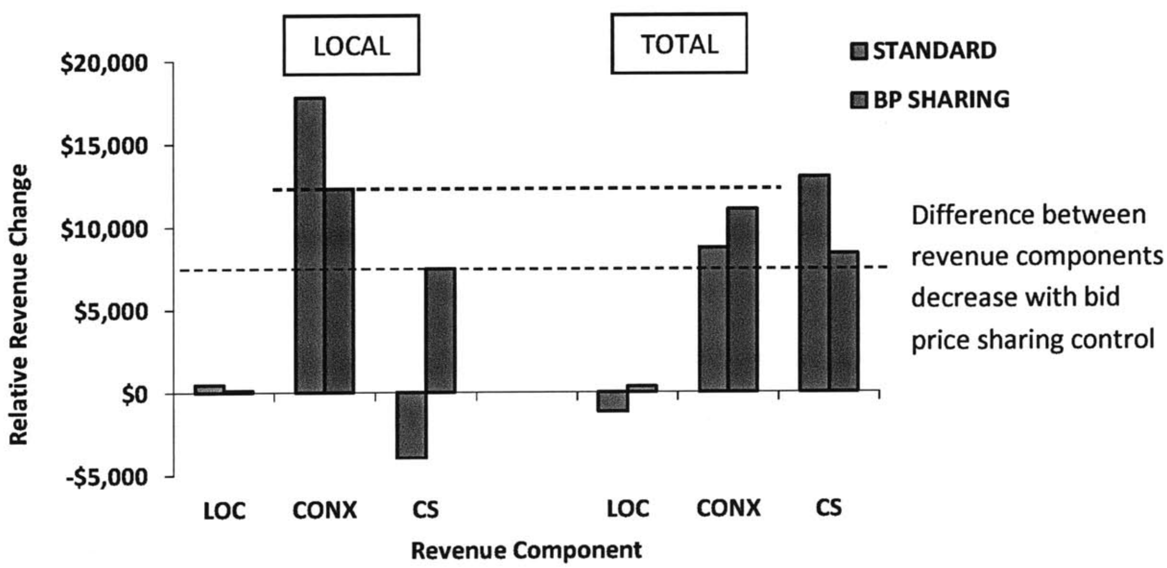

Figure 4.24: Changes in Revenue Components of AL 2

4.6.2 Impacts of Availability Control in ProBP

ProBP is an algorithm based explicitly on iterative proration of fares of the connecting itineraries along the legs they traverse to reflect the network contribution (see section 3.2.2.2). The proration is different for different itineraries in the network and is also different in different time frames of the booking period for the same itinerary. It is an optimal solution which accounts for the current network conditions and stochastic nature of the demand.

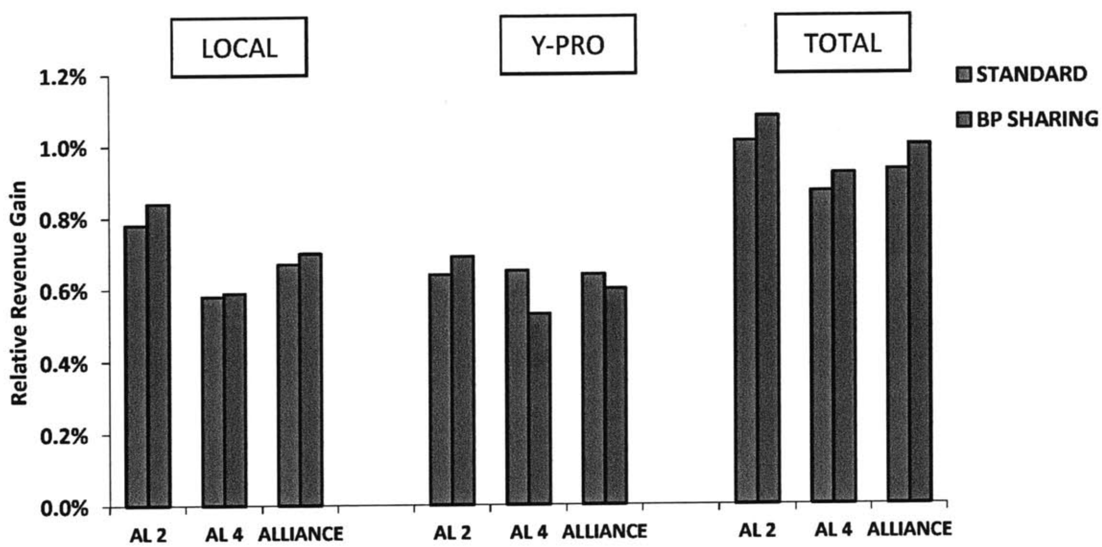

Figure 4.25: Revenue Gains with Bid Price Sharing Control in ProBP

ProBP behaves in a different manner than DAVN with bid price sharing control. Figure 4.25 compares the two availability control methods for ProBP under different valuation schemes. The benefits of bid price sharing control are less here, unlike DAVN which has gained substantially using it with the local and Y-Prorate valuation schemes. The reason for this lies in the underlying differences in the algorithms of these two seat allocation optimizers. In DAVN, the bid price sharing control involves nested booking limits which make it more robust and it becomes more resistant to making any wrong decisions due to some static, non-optimal valuation scheme used during the optimization. On the other hand, ProBP relies on the right proration of fares of the connecting and codeshare itineraries to calculate bid prices. Imperfect inputs (in terms of codeshares valuation) result in a distortion of bid prices as it will be shown in Chapter 5. It is found that the fare inputs have a dominating impact on the final performance of ProBP, irrespective of the method of availability control used. This issue will be further addressed in Chapter 5 under the dynamic valuation scheme.

Let's take a look at the plot of revenue components under ProBP in Figure 4.26. The relative order (like bid price sharing control increases codeshare revenues for local valuation and decreases it for total valuation) remains the same as in DAVN for both local and total valuation schemes.

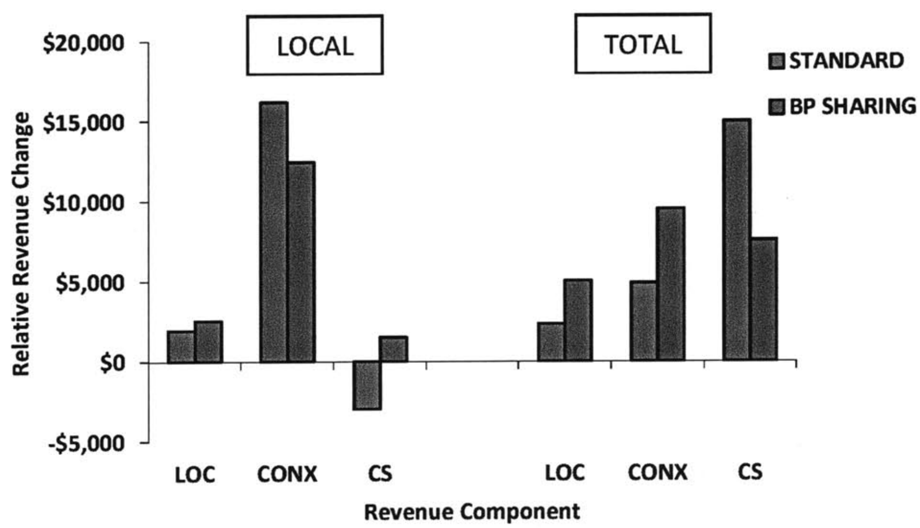

Figure 4.26: Changes in Revenue Components of AL 2

In the case of local valuation the benefits of bid price sharing are not substantial because the increase in codeshare revenues is smaller than what is realized under DAVN. To substantiate this finding, we plot the fare class mix of codeshare traffic under local valuation scheme in Figure 4.27. It is clear that unlike in DAVN, the improvement in fare class is less prominent here. There is a decrease in traffic in both class 5 and 6 while the increase in traffic in higher classes is not comparable. More importantly, the traffic in top fare class- class 1 also goes down with bid price sharing. Thus, the increase in codeshare revenues is restrained to a smaller value in the ProBP environment.

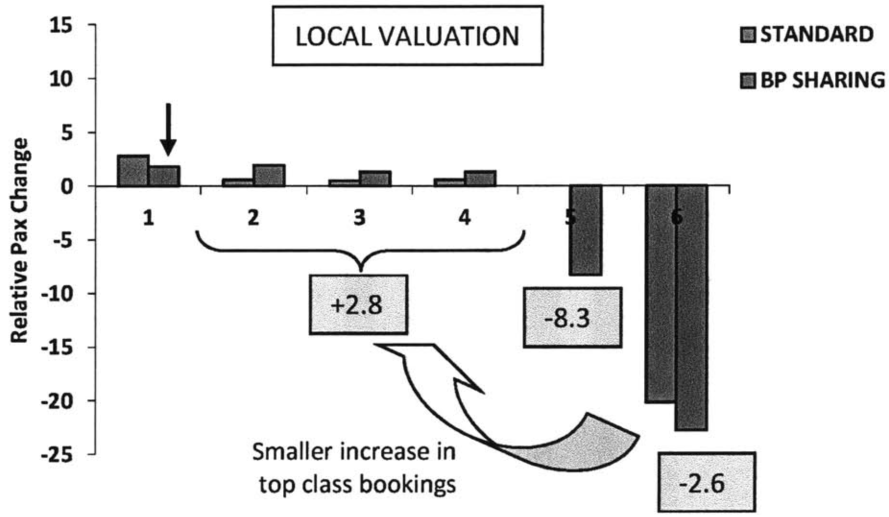

Figure 4.27: Changes in Codeshare Traffic Mix of AL 2

4.7 Evolution of Revenues

As a summary of the results shown in this chapter, plots of the evolution of total revenues and different revenue components are provided. Figures 4.28 to 4.31 are the revenue plots for AL 2 where the horizontal axis shows the different experimental scenarios and the vertical axis shows the change in revenues relative to the baseline values. Note that in all these scenarios AL 2 and AL 4 use O-D control while in the baseline they both use EMSRb. The first scenario uses AVS while all other scenarios use cascading. The middle three scenarios represent the three static valuation schemes. The last three scenarios represent changing the availability control method to bid price sharing control from standard control which is used by the first four scenarios.

It is clear from Figure 4.28 that all the scenarios (using O-D control) perform better than the baseline. Both total valuation scheme and bid price sharing control lead to highest increase in revenues in DAVN. The pattern is same for ProBP except for the scenarios involving bid price sharing control.

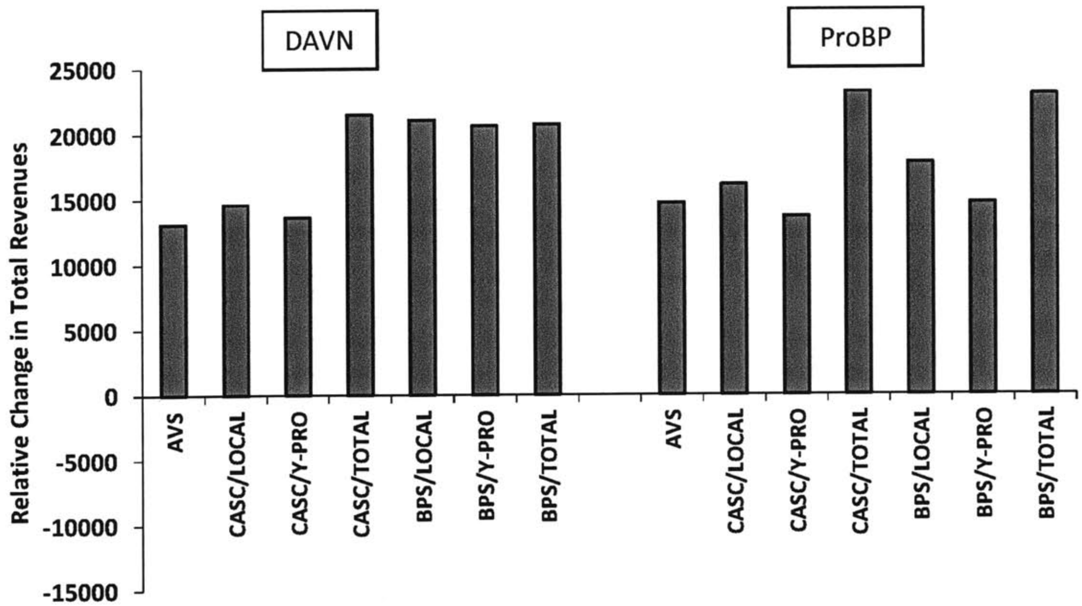

Figure 4.28: Evolution of Changes in Total Revenues of AL 2

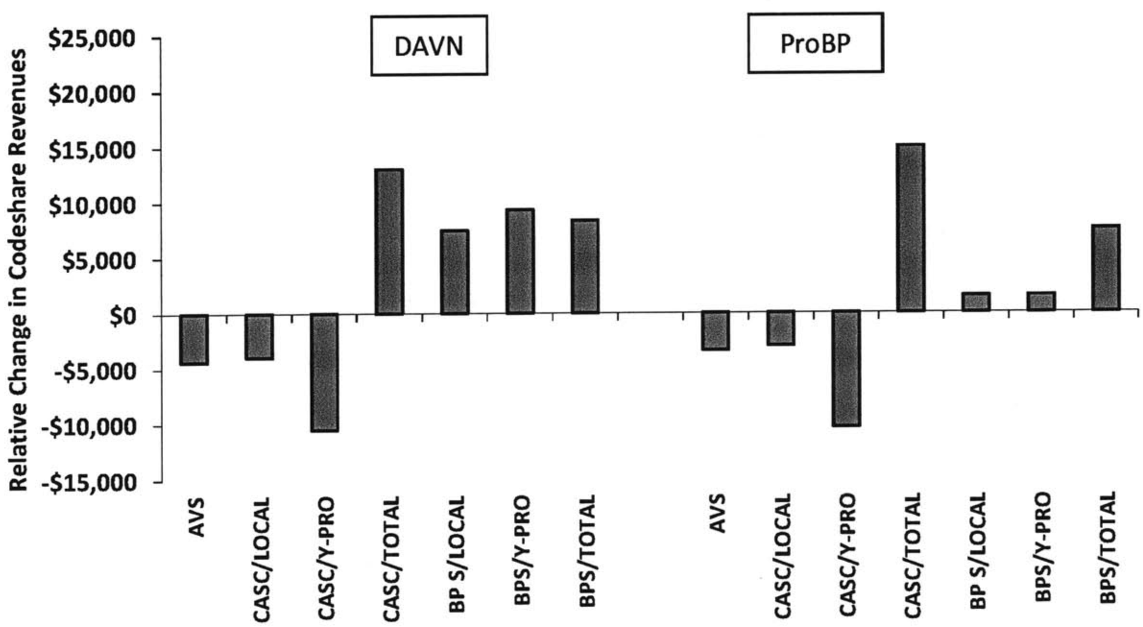

Figure 4.29: Evolution of Changes in Codeshare Revenues of AL 2

The codeshare revenue component decreases with AVS, cascading with local valuation and cascading with Y-Prorate valuation as shown in Figure 4.29. The reduction is highest with Y-Prorate valuation due to its lowest valuation of codeshare bookings. The codeshare revenues rather increase under cascading with total valuation and bid price sharing control. Since the three revenue components are not independent and there is a tradeoff between each of them, it can be seen in Figure 4.30 that the increase in connecting revenues is inversely related to the gains in codeshare revenues of Figure 4.29. Lastly, the local revenues are not affected much overall and its changes are quite small (see Figure 4.31) as compared to the other two revenue components, though the fare class mix is certainly different under different cases.

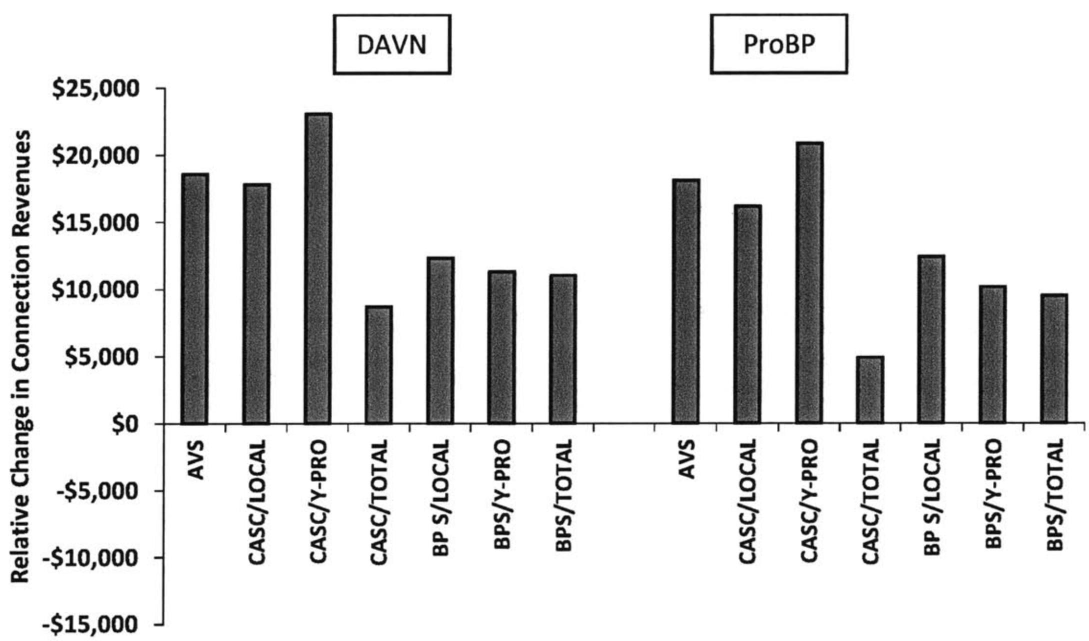

Figure 4.30: Evolution of Changes in Connection Revenues of AL 2

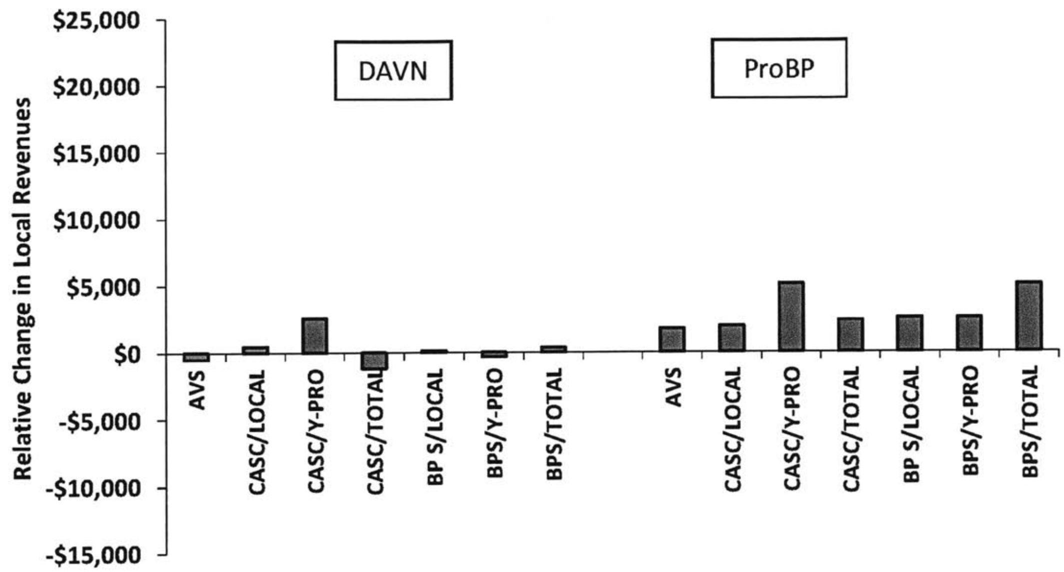

Figure 4.31: Evolution of Changes in Local Revenues of AL 2

4.8 Chapter Summary

The different techniques under each of the four dimensions of airline revenue management are tested in this chapter. The simulation tool- PODS and the simulation environment- alliance network A4 are introduced in the beginning of the chapter. The sub-optimality of revenue management in alliances due to the presence of codeshare traffic is illustrated. In an alliance, compared to the gains for individual airline networks, the gains with O-D RM control are lower by 0.6%-0.8 % due to the arbitrary and fixed valuation of codeshares used in the optimizer.

The direct benefits of cascading over AVS are shown where cascading benefits marginally over AVS in the range of 0.1% by separating the codeshares from locals and improving the forecast. The results for the three static codeshare valuation schemes are compared. It is found that compared to local valuation, the codeshare traffic increases significantly in the case of total valuation while it goes down heavily in Y-Prorate valuation (static proration). Since there is a tradeoff between different traffic components, the local and connecting traffic gets replaced by codeshares in total valuation while they increase in the case of Y-Prorate valuation. None of these static valuation schemes are optimal and one can outperform the other in terms of overall alliance revenues depending on the network structure of the alliance partners. In the current setting of Network A4, the codeshare traffic is highly valuable in terms of revenue per passenger resulting in higher overall revenues with total valuation. Compared to local and Y-Prorate valuation, the revenues are higher for total valuation in the range of +0.2% to +0.4%.

The bid price sharing control for availability affects DAVN and ProBP in a different manner. DAVN benefits substantially from it through improving the codeshare fare class mix and hence the revenues. The incremental revenue gains compared to standard availability control lies in the range of 0.2% to 0.3%. This is true for local and Y-Prorate valuation schemes while total valuation benefits only marginally using the bid price sharing control.

In ProBP environment, the incremental revenue gains from using bid price sharing control are marginal in the range of 0.05%. This is because the rise in codeshare revenue component is much lower in ProBP as compared to that in DAVN. The underlying reason is that bid price sharing control uses the static valuation schemes which feed arbitrary and fixed fare inputs to the optimizer. Performance of ProBP is dominated by fare inputs because it relies on the optimal proration of itinerary fares over the traversed legs.

The next chapter will introduce a new valuation scheme called dynamic valuation scheme which substantially benefits both DAVN and ProBP.

5. Chapter 5

Dynamic Valuation Scheme for Codeshare Paths

This chapter introduces a new valuation scheme for codeshare paths called dynamic valuation. The first section describes its formulation while the successive sections discuss the PODS simulation results of its implementation. A detailed and comparative analysis is made with the static valuation schemes as well as with the techniques of bid price sharing control, which have been discussed previously in Chapter 3. The challenges and risks involved in implementing dynamic valuation are also discussed.

5.1 Introduction

Dynamic valuation is an attempt to develop a valuation scheme for codeshare paths which will allow an airline to account for the information of its partner's legs in its own optimizer. It requires sharing of bid prices between partners in order to calculate the valuation of codeshare paths. The motivation behind dynamic valuation is to use the information available in terms of partner's bid prices to find an optimal valuation of the codeshare paths and use it in one's own optimizer. It recognizes the fact that every codeshare itinerary consists of two or more legs and the "alliance network contribution" of an airline's codeshare leg depends on the opportunity cost of occupying a seat on the partner's codeshare leg. This opportunity cost has no fixed value and depends on the demands of paths which traverse the partner's leg and other network conditions. This dependence cannot be incorporated in the optimizer with any of the static valuation schemes which were considered in Chapter 3. Even the technique of bid price sharing control accounts for the information of partner's legs during the later step of availability control only and does not use it in the optimizer. Figure 5.1, a modification of Figure 3.2, shows this distinction by locating the points of action of dynamic valuation (in the optimizer) and bid price sharing control (in the availability control).

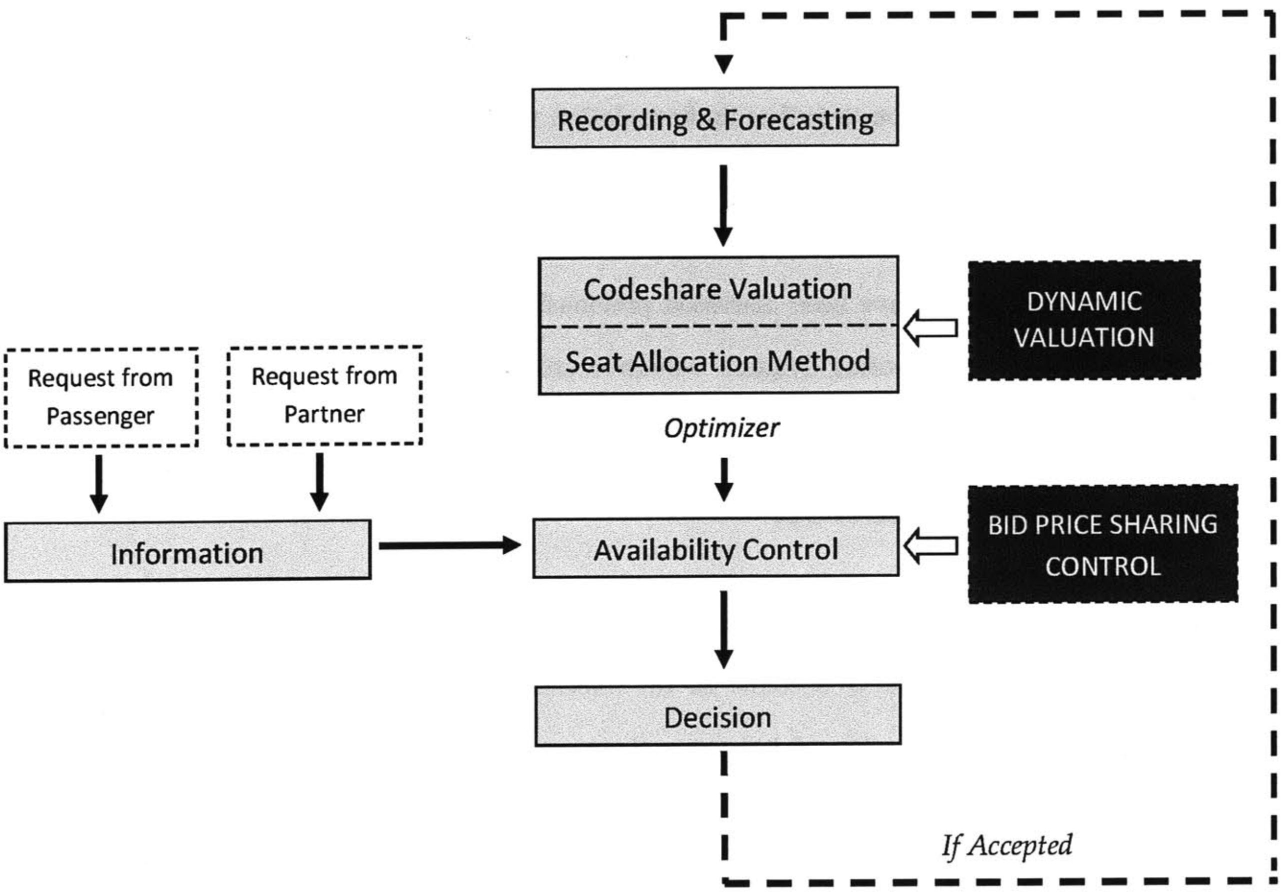

Figure 5.1: Dynamic Valuation vs. Bid Price Sharing Control

Dynamic valuation in the optimizer is an effort to estimate the actual contribution of a codeshare booking for the alliance. There can be several different ways of achieving this. One can use a difference of total O-D fare and partner's bid price or a proration of total O-D fare based on own and partner's bid prices. This thesis uses the difference technique which is formulated in equation 5.1 and 5.2:

If the partner is using DAVN, dynamic valuation of a codeshare path in time frame[1] t is given by:

$$D_{own}^{t} = T - SP_{partner}^{t-1} \tag{5.1}$$

If the partner is using ProBP, dynamic valuation of a codeshare path in time frame t is given by:

$$D_{own}^{t} = T - BP_{partner}^{t-1} \tag{5.2}$$

where,

$$D_{own}^{t} = Dynamic\ valuation\ used\ in\ own\ optimizer\ in\ current\ time\ frame\ t$$
$$SP_{partner}^{t-1} = Shadow\ Price\ on\ partner's\ codeshare\ leg\ in\ previous\ time\ frame\ t-1$$
$$BP_{partner}^{t-1} = Bid\ price\ on\ partner's\ codeshare\ leg\ in\ pervious\ time\ frame\ t-1$$
$$T = Total\ fare\ for\ the\ codeshare\ path$$

To understand this formulation clearly, we will extend the example provided in section 3.4.1. Table 5.1 reiterates the Q class fare structure used in that example and adds the column of shadow prices, from the previous time frame, which are evaluated using dynamic valuation in the optimizer. The codeshare request under consideration is LAX-FRA/Q class, a two leg itinerary, LAX-ORD being operated by partner 1 and ORD-FRA being operated by partner 2 in the alliance as illustrated in Figure 5.2. Here both partners are using DAVN as the seat allocation optimizer. Four different valuation

[1] One time frame is the period between two consecutive runs of the seat allocation optimizer.

estimates, which include the three static valuation schemes (discussed in Chapter 3) and dynamic valuation, are illustrated separately in table 5.2.

Figure 5.2: Illustration: Codeshare Path LAX-FRA

Booking O-D/Class	Marketing Airline	Fare	Leg Shadow Prices
LAX-ORD/Q	P1 (Local)	\$ 248	SP_1
ORD-FRA/Q	P2 (Local)	\$ 532	SP_2
LAX-FRA/Q	P1, P2 (Codeshare)	\$ 619	--

Table 5.1: Fares (Q class) for Local and Codeshare Paths

Airline	Valuation
P1	\$ 248
P2	\$ 532

(a) Local Fare Valuation

Airline	Valuation
P1	\$ 206.33
P2	\$ 412.67

(b) Y-Prorate Valuation (1:2)

Airline	Valuation
P1	\$ 619
P2	\$ 619

(c) Total Fare Valuation

Airline	Valuation
P1	\$ 619 - SP_2
P2	\$ 619 - SP_1

(d) Dynamic Valuation

Table 5.2: Codeshare Valuations used in Optimizer

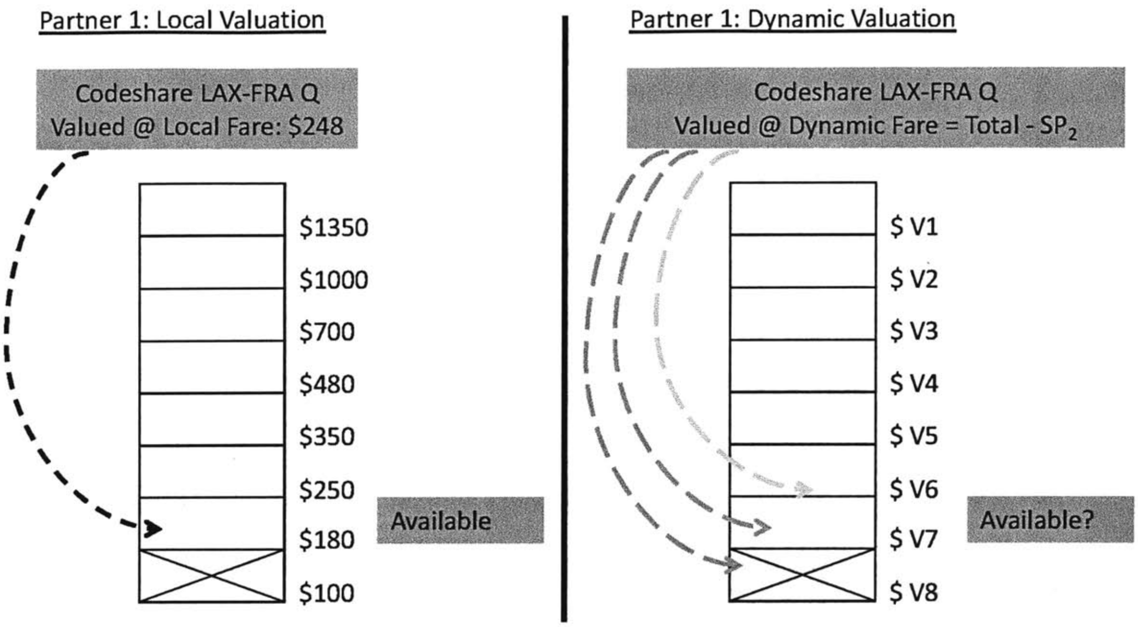

Figure 5.3: Effects of Local Fare Valuation vs. Codeshare Valuation

The difference between effects of local fare valuation and dynamic valuation of codeshares used in partner 1's optimizer is illustrated in Figure 5.3. With local fare valuation scheme, partner 1 values the codeshare itinerary LAX-FRA/Q at its local fare of \$ 248. Similarly the other codeshare itineraries are valued at their local fares and partner 1 runs the deterministic linear program (see DAVN, section 3.2.2.1) to calculate the shadow prices of its legs and construct the nested virtual buckets, as shown in Figure 5.3. Further the LAX-FRA/Q is mapped to an appropriate virtual bucket based on its local valuation of \$ 248 and the itinerary is available for booking if this virtual bucket is still open which is the case in Figure 5.3.

In the case of dynamic valuation, partner 1 uses the difference of total codeshare fare and partner 2's bid price on ORD-FRA leg, in order to calculate the valuation of LAX-FRA/Q (Figure 5.3). Thus the valuation may change in each time frame depending on the conditions of ORD-FRA leg of partner 2. For a given set of fare values, if the demands of paths traversing this leg are low, then its bid price is relatively low. This will result in a higher valuation of the codeshare path LAX-FRA/Q by partner 1 in its optimizer and vice versa.

For a given set of bid prices of partner 2's codeshare legs and upon its sharing, partner 1 calculates the dynamic valuation of codeshare paths and then runs the deterministic linear program to calculate the shadow prices and construct the nested virtual buckets. Note that the bucket fare ranges will be different in this case than local valuation and will depend on the set of values used in dynamic valuation. Further, the codeshare itinerary LAX-FRA/Q is mapped to an appropriate virtual bucket based on its dynamic valuation and it remains available for booking if that assigned virtual bucket is still open, as shown in Figure 5.3.

5.2 Revenue Sharing and Sum of Airlines' Codeshare Valuations

The process of sharing revenues, obtained from codeshare bookings, among the alliance partners is called revenue sharing. It is commonly handled through a contractual agreement between alliance carriers. It should allow for a fair distribution between them and provide incentives to pursue a strategy which is optimal for the combined alliance rather than just own airline. The revenue to be shared is the total fare received from a codeshare passenger while the airlines value this passenger, in their own optimizer, as per the codeshare valuation scheme being used by them. We will compare the total fare with *sum of airlines' codeshare valuations* under different schemes and see how dynamic valuation can provide a basis for developing a fair revenue sharing scheme.

Sum of airlines' codeshare valuations is defined as sum of the valuations of a codeshare path used by alliance partners in their own optimizers. In Chapter 3 (section 3.3), we have seen equations for the *sum of airlines' codeshare valuations* for each static valuation scheme. Equation 5.3 states the order followed by static schemes with regard to the value placed by an airline on a codeshare path:

$$Total\ Valuation \geq Local\ Valuation \geq Y\ Prorate\ Valuation \tag{5.3}$$

In fact, this is also the order with regard to the *sum of airlines' codeshare valuations.* In the total valuation scheme, both partners value the codeshare path in their optimizers at its total fare and thus the sum of valuations is twice the total fare. Whereas in the local valuation scheme both partners value the codeshare path at the local fares of the corresponding legs traversed by the codeshare path. The sum of local fares is always less than or equal to twice the total fare and hence the sum of valuations in total valuation. However, the sum of local fares on any two flight legs is usually greater than a connecting or codeshare fare which traverses those two legs. Thus, the sum of valuations under local valuation scheme is greater than or equal to that in Y-Prorate valuation in which the valuations sum-up exactly to the total fare.

Now let us evaluate the *sum of airlines' codeshare valuations* under the dynamic valuation scheme. Consider an alliance involving two partners, both using ProBP. The total amount in dynamic valuation is the sum of the two valuations used by the partners and is given by equation 5.4. For a codeshare booking request, partner 1 can accept the booking only if it satisfies equation 5.5. Similarly, partner 2 can accept a codeshare booking request provided that it satisfies equation 5.6. The parameters δ_1 and δ_2 represent the alliance **revenue surplus** which is the amount by which the dynamic valuation of a codeshare booking exceeds the leg bid price of that airline. In the case of a lag of one time frame it is different for a booking made by each airline.

$$(T - BP_2^{t-1}) + (T - BP_1^{t-1}) \tag{5.4}$$

$$\delta_1 = (T - BP_2^{t-1}) - BP_1^t \geq 0 \tag{5.5}$$

$$\delta_2 = (T - BP_1^{t-1}) - BP_2^t \geq 0 \tag{5.6}$$

where,

$$T = Total\,fare\,for\,the\,codeshare\,path$$
$$BP_i^j = Bid\,Price\,of\,partner\,i's\,codeshare\,leg\,in\,time\,frame\,j$$
$$\delta_i = Alliance\,revenue\,surplus\,for\,a\,codeshare\,booking\,accepted\,by\,partner\,i$$

Assuming that the bid prices are approximately the same in the two consecutive time frames (for partner 1 or 2), as stated in equation 5.7 for partner 1, the sum defined previously by equation 5.4 becomes $T + \delta_1$ as shown in equation 5.8.

$$BP_1^{t-1} \approx BP_1^t \tag{5.7}$$

$$(T - BP_2^{t-1}) + (T - BP_1^{t-1}) \approx (T - BP_2^{t-1}) + (T - BP_1^t) = T + \delta_1 \tag{5.8}$$

In the case of real time bid price sharing between partners, the approximation in equation 5.7 is not needed. Then the two parameters δ_1 and δ_2 representing revenue surplus become equal and the relationship in equation 5.8 holds exactly.

Thus, from equation 5.8, dynamic valuation can exceed the total available fare by a value equal to revenue surplus which is greater than or equal to zero. This can provide a basis for further research on revenue sharing between alliance partners. The operating carrier of a codeshare leg must receive at least the bid price of that leg from the marketing carrier and the revenue surplus can be further divided in a ratio mutually agreed upon. This ratio may depend on bid prices of the codeshare legs involved.

Note that in the case of bid price sharing control in the availability, the *sum of airlines' codeshare valuations* is dependent on the valuation schemes used by partners in their optimizers and is not affected by the bid price sharing mechanism which acts in the later stage of availability control as shown in Figure 5.1. Thus, it can be greater than that of dynamic valuation in the cases of local and total valuation schemes while equal to or slightly lower than that of dynamic valuation in the case of Y-Prorate valuation.

5.3 PODS Simulation Results

This section presents the PODS simulation results for dynamic valuation scheme. The simulation setup remains the same as described in Chapter 4 (section 4.2). We will focus on the performance of alliance partners, i.e. AL 2 and AL 4 and will compare it with the baseline statistics presented in section 4.2. It should be kept in mind that cascading, O-D control and bid price sharing (as described in Chapter 3) are important prerequisites for dynamic valuation. We present the dynamic valuation results for the two O-D seat allocation optimizers, DAVN and ProBP under separate sections.

5.3.1 Dynamic Valuation in DAVN Environment

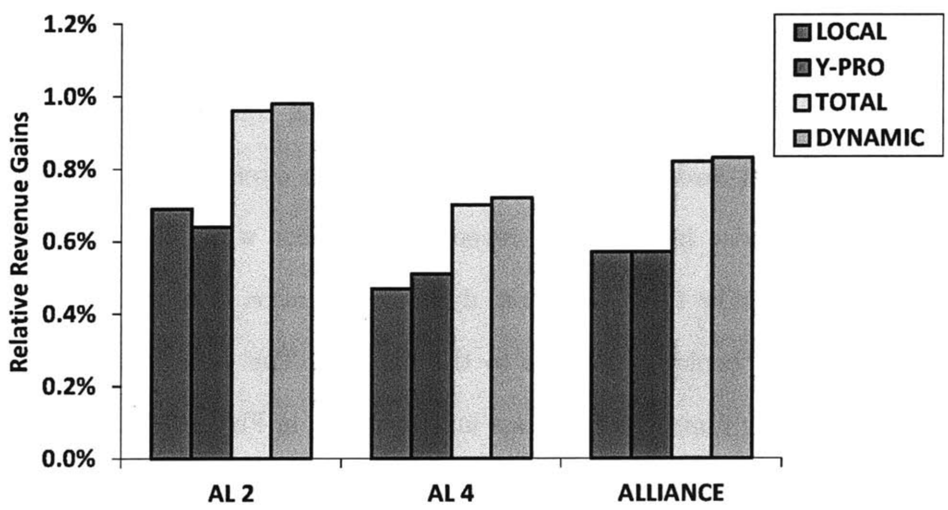

Figure 5.4: Revenue Gains with Different Valuation Schemes

If both partners are using DAVN, they share the shadow prices on their codeshare legs with each other and use equation 5.1 to calculate the dynamic valuation inputs of codeshare paths. In Figure 5.4, we compare the revenue gains relative to the baseline for the three static valuation schemes and dynamic valuation scheme. It is observed that the dynamic valuation yields substantially higher gains compared to the local and Y-Prorate valuation schemes. The gain for total valuation is close to that of dynamic valuation. Figure 5.5 compares the revenue components of these four schemes for Airline 2.

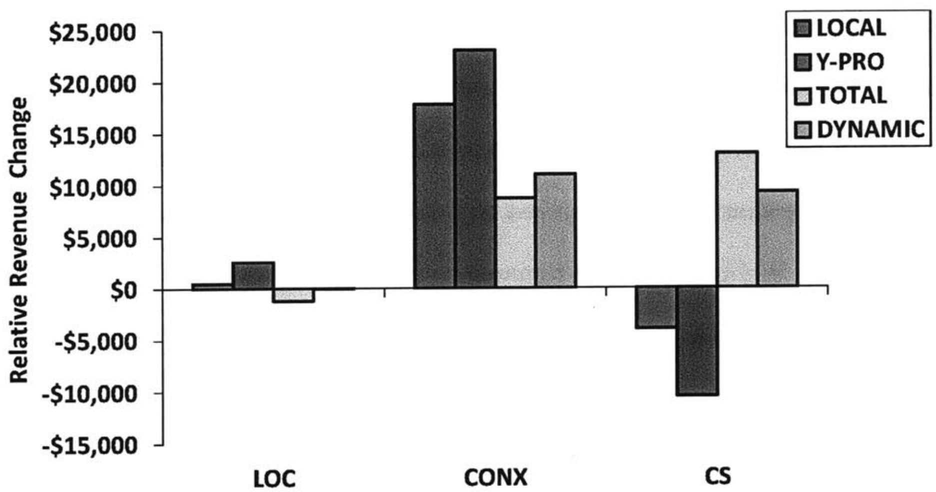

Figure 5.5: Changes in Revenue Components of Airline 2

Dynamic valuation increases both codeshare revenues and connecting revenues compared to the baseline which lead to a substantial increase in overall revenues. Compared to total valuation, the rise in codeshare revenues is smaller while the rise in connecting revenues is larger. Unlike total valuation, dynamic valuation does not increase the total number of codeshare bookings relative to the baseline. The gain in codeshare revenues rather comes from the improved fare class mix as shown in Figure 5.6. Also in the case of connecting and the local traffic components, the fare class mix improves with dynamic valuation (Figure 5.7 and 5.8). Thus in spite of a lower amount of traffic, the overall revenues go up in dynamic valuation.

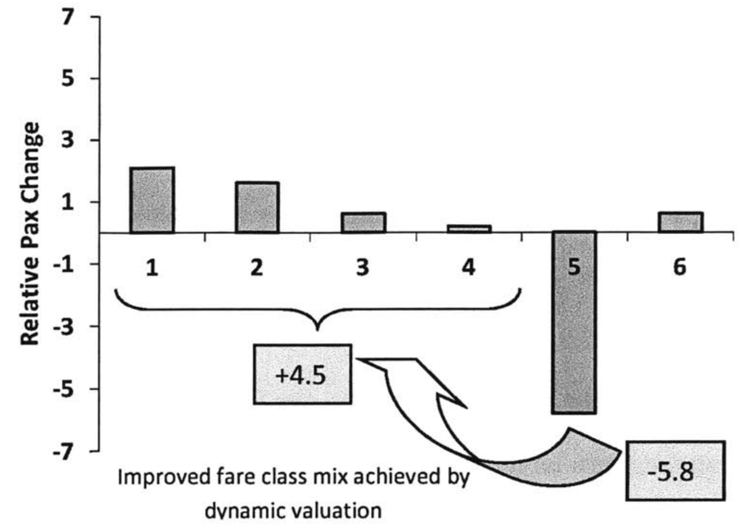

Figure 5.6: Changes in Codeshare Traffic Mix of Airline 2 (different scale)

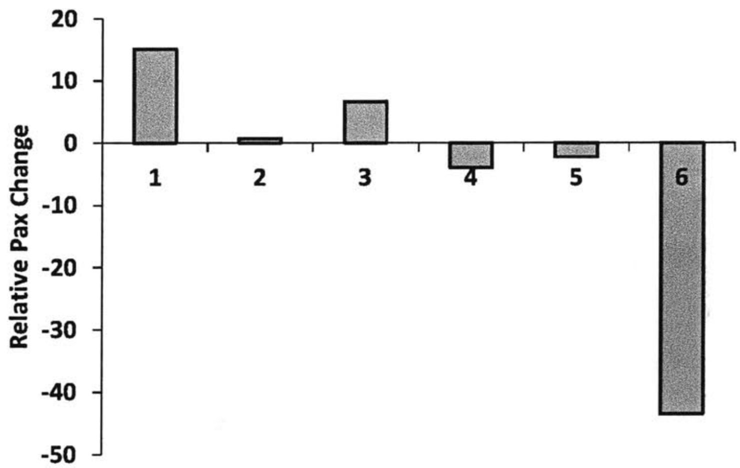

Figure 5.7: Changes in Local Traffic Mix of Airline 2

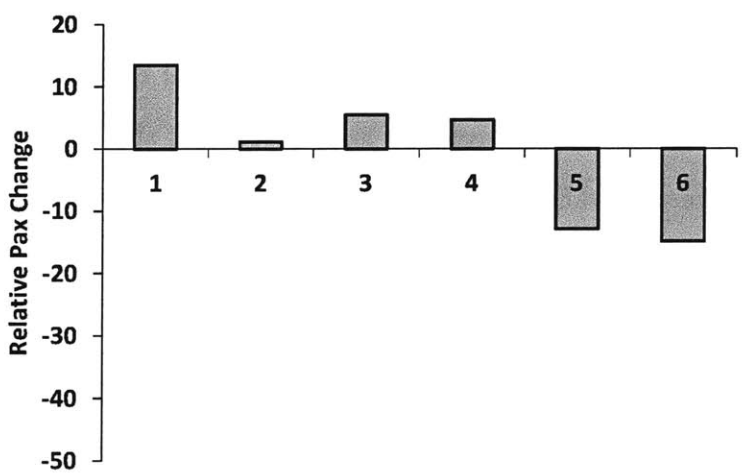

Figure 5.8: Changes in Connecting Traffic Mix of Airline 2

5.3.2 Dynamic Valuation in ProBP Environment

If both partners are using ProBP, they share the bid prices on their codeshare legs with each other and use equation 5.2 to calculate the dynamic valuation inputs of codeshare paths. It is observed in Figure 5.9 that, in the same manner as in DAVN, dynamic valuation yields substantially higher gains compared to the local and Y-Prorate valuation schemes. The absolute numbers are larger in the case of ProBP compared to DAVN. The gain for total valuation is again close to that of dynamic valuation but the traffic mix is quite different under the two schemes as explained through Figure 5.10.

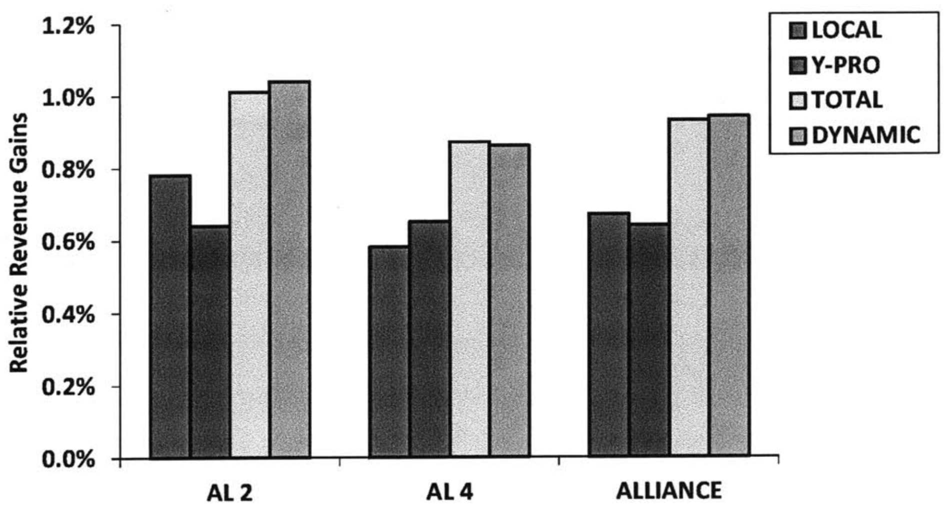

Figure 5.9: Revenue Gains with Different Valuation Schemes

Figure 5.10 provides a deeper insight by comparing the individual revenue components for Airline 2 under the four valuation schemes. It is observed that all the three revenue components go up in dynamic valuation. The only other scheme which exhibits this property is total valuation, Compared to total valuation, the rise in the codeshare revenues is lower but the rise in local and connecting revenues is higher with dynamic valuation. This is because total valuation overvalues the codeshare traffic and takes much more codeshare bookings (see section 4.5) than in dynamic valuation. In fact, the total number of bookings goes down in dynamic valuation relative to the baseline. The rise in revenues comes through the improved fare class mix as shown in Figure 5.11.

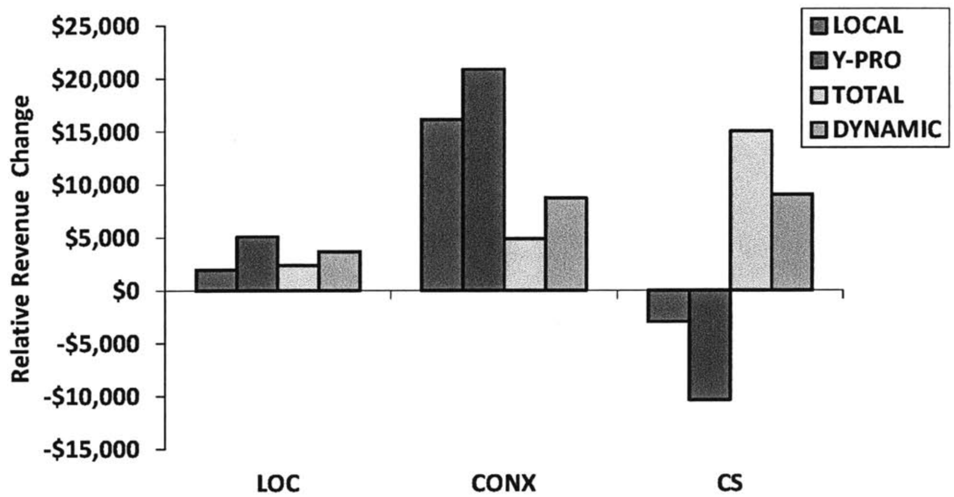

Figure 5.10: Changes in Revenue Components of Airline 2

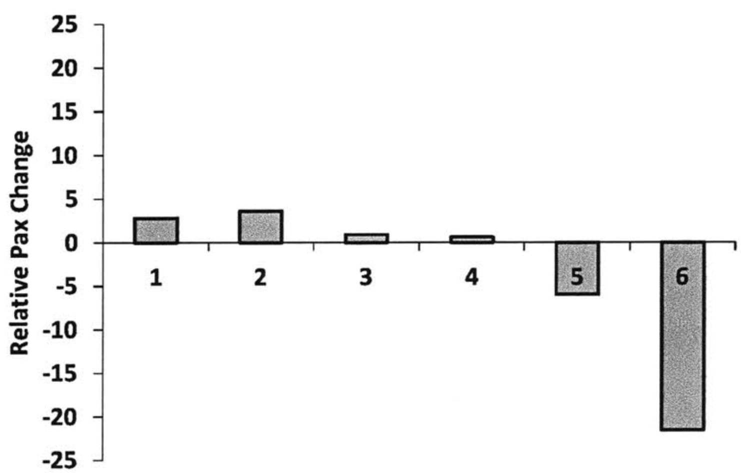

Figure 5.11: Changes in Codeshare Traffic Mix of Airline 2 (different scale)

In ProBP, the changes in codeshare fare class mix due to dynamic valuation are similar to those in DAVN. However, the local and connecting traffic behave in a little different manner (Figure 5.12 and 5.13). Unlike DAVN, ProBP cuts down heavily on class 6 connecting traffic while replacing it with an increase in class 6 local traffic. This may happen due to higher bid prices of certain legs in the airline's network.

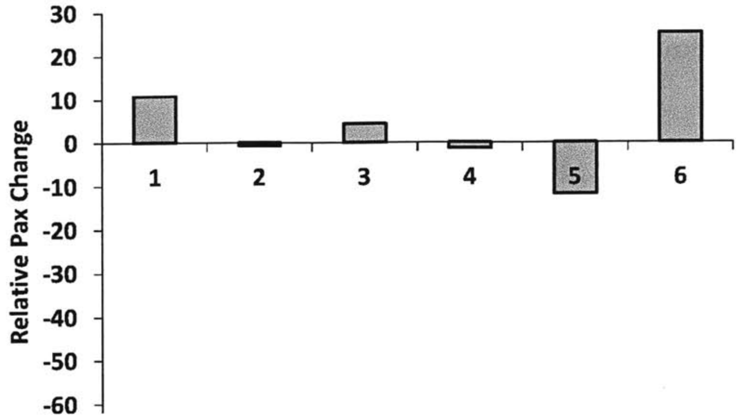

Figure 5.12: Changes in Local Traffic Mix of Airline 2

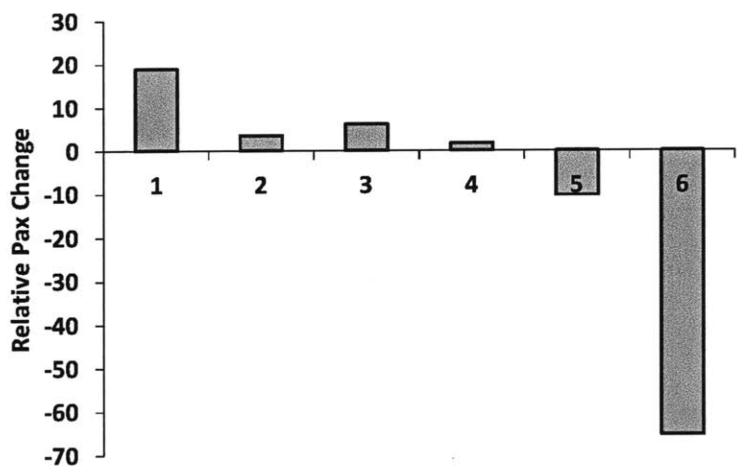

Figure 5.13: Changes in Connecting Traffic Mix of Airline 2

5.4 Comparison of Dynamic Valuation with Bid Price Sharing Control

Both dynamic valuation in the optimizer and bid price sharing control in the availability are similar in that they require the alliance partners to share bid prices (or shadow prices) of codeshare legs between each other. However, there are key differences between the two in the use of these shared bid prices. Bid price sharing control uses the partner's bid prices in the last but one step of availability control. The seat allocation optimizer still uses the arbitrary and fixed valuation inputs for codeshare paths i.e. local, Y-Prorate or total valuation, while in the case of dynamic valuation the information of partner's bid prices is used in the seat optimizer itself. Figure 5.14 shows a matrix of the use of bid prices during the two different steps of valuation and availability under dynamic valuation and bid price sharing control.

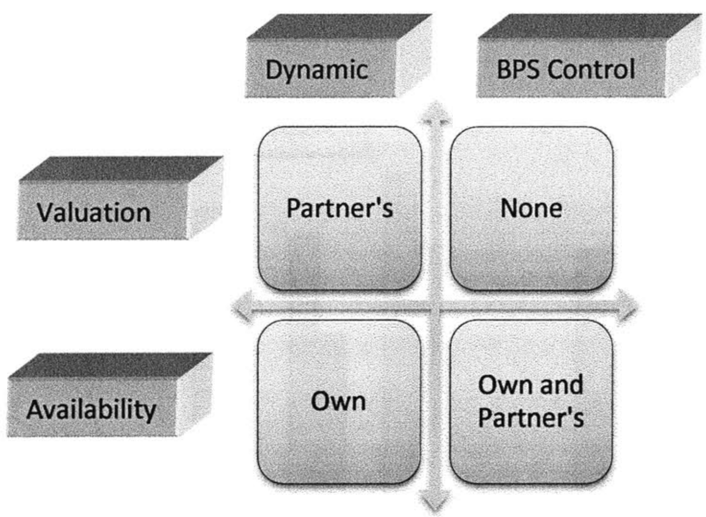

Figure 5.14: Bid Prices in Dynamic Valuation and Bid Price Sharing Control

In the case of dynamic valuation, partner's bid prices from previous time frame are used for the valuation of codeshares using equations 5.1 and 5.2. Thus the codeshare valuation may change in each time frame depending on the partner's bid prices. In the availability step, dynamic valuation just uses its own bid price and thus executes standard availability control while bid price sharing control uses both own and partner's bid prices. Thus dynamic valuation is theoretically more sound than bid price sharing control because it accounts for the opportunity cost of partner's leg in the valuation step itself and hence helps the airline in estimating optimal bid prices. The bid price sharing control leads to distorted bid prices because it does not fix the valuation step when own bid prices are calculated. More significantly, it affects the combined alliance in two ways—

not only own bid prices get distorted, but also it affects the partner when the own bid prices are shared and used for valuation or availability control by the partner. Thus it is critical to fix the valuation step and provide the correct valuation inputs to the seat allocation optimizer. This becomes evident from the poor performance of ProBP with bid price sharing control as shown in Figure 5.15. This impact can be overcome in more robust algorithms like DAVN in which bid price sharing control in availability performs as good as dynamic valuation in the optimizer.

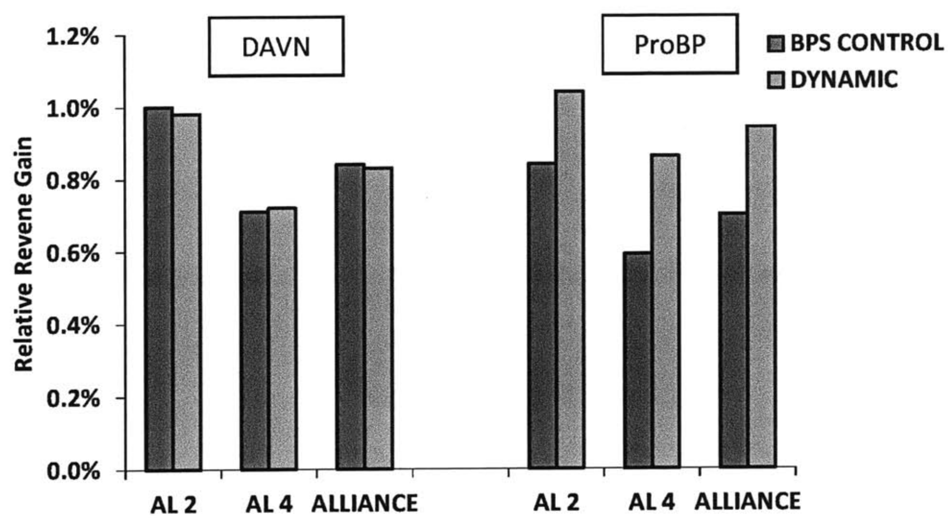

Figure 5.15: Revenue Gains with Dynamic Valuation and Bid Price Sharing Control

Figure 5.15 shows that the revenue gains with dynamic valuation are close to bid price sharing control in DAVN environment. In contrast to this, the revenue gains are substantially higher with dynamic valuation than bid price sharing control in ProBP environment. In addition, ProBP with dynamic valuation generates even higher revenue gains than DAVN thus keeping the order consistent across all valuation schemes. As discussed in section 3.2.2, DAVN is an algorithm which uses deterministic shadow prices for mapping fare classes into the appropriate virtual buckets and uses EMSRb heuristic on top of that to calculate the nested booking limits. This framework creates robustness in DAVN and reduces its sensitivity to the fare inputs used in the optimizer. This results in similar gains of dynamic valuation and bid price sharing control in DAVN environment. On the other hand, ProBP is an algorithm based on the optimal proration of total fares over the traversed legs. The valuation inputs affect the bid prices calculations and have a dominating impact in ProBP. To get a deeper insight into this, let us compare the average bid prices of AL 2 with dynamic valuation and bid price sharing control (Figure 5.16 and 5.17). The valuation inputs used with bid price sharing control are static local fare inputs while the dynamic valuation inputs change in every time frame.

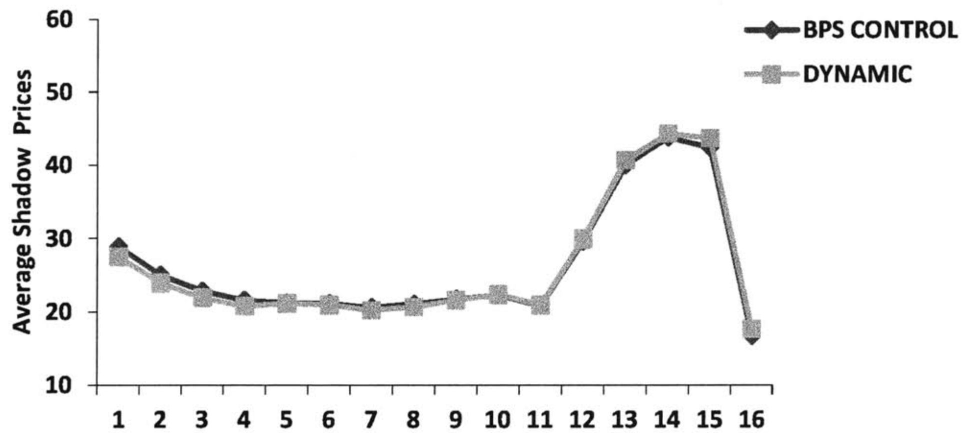

Figure 5.16: Average Shadow Prices in DAVN

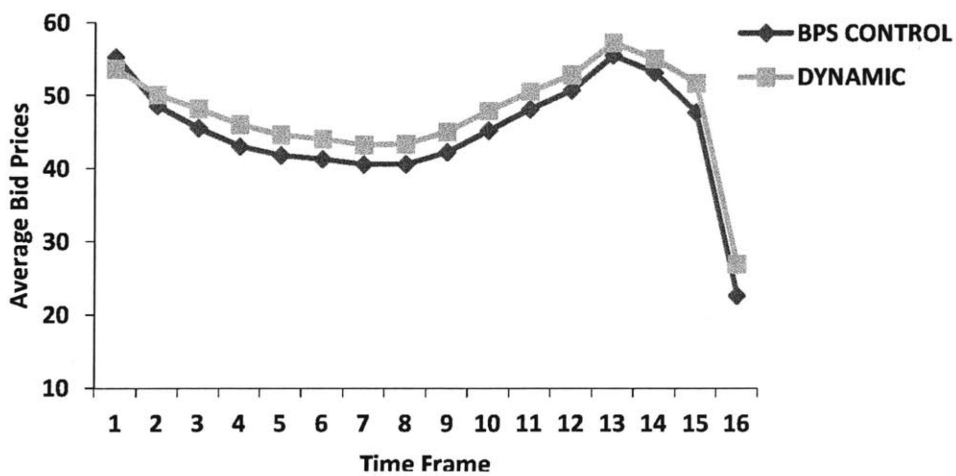

Figure 5.17: Average Bid Prices in ProBP

It is observed that the average shadow prices are not very different in DAVN environment, while there is a marked difference between the bid prices in ProBP environment. In ProBP, the bid prices are higher with dynamic valuation compared to bid price sharing control except in the first time frame. The distortion of bid prices under bid price sharing control leads to lower gains compared to those with dynamic valuation. It should be noted that the curves in Figure 5.16 and 5.17 show bid prices averaged over all the legs in the network and the difference will be larger on legs which carry a high proportion of codeshare traffic.

5.5 Implementation of Dynamic Valuation: Challenges and Risks

The implementation and use of dynamic valuation at airlines will depend on their needs, capabilities and revenue sharing agreements. Dynamic valuation requires the following three key techniques of revenue management as prerequisites. Each of them requires additional efforts and costs on part of the alliance carriers as explained below:

- Cascading: It is required for separating codeshare bookings from local bookings in the historical database and then forecasting the demand for the two separately. Cascading is dependent on the degree of information sharing between alliance carriers and requires information of the full codeshare itinerary booked by the partners. The common challenges in this regard include insufficient technical capabilities at airlines, incompatibilities among different bookings reservation systems and Global Distribution Systems (GDS).
- O-D Seat Allocation Control: In order to treat the codeshare itineraries differently from local itineraries and also differently from each other, O-D control or network revenue management for seat allocation is required. In addition,

dynamic valuation requires O-D control to calculate the bid prices or shadow prices on codeshare legs and share them with partner. O-D control is technically advanced, complicated and expensive for airlines to implement. It requires path/class forecasts and is more sensitive to the accuracy of inputs provided to the optimizer. Currently, with the exception of several larger carriers in the world, most of the airlines still use leg based RM control only.

∞ Bid price sharing: It is required to gather information on partner's codeshare legs and can be subjected to legal regulations. An antitrust immunity from concerned regulatory authorities like Unites States Department of Justice and European Union allows the airlines to share bid prices. Another issue is the frequency of sharing bid prices. It can be real time, every time frame or with a lag of few time frames. Darot (2001) also proposes a mechanism called bid price inference which can guess the partner's bid prices on a codeshare leg using the lowest publicly available fare on that leg. This can be useful to some extent in the case when bid price sharing is not allowed.

An airline can face challenges on one or more of the above three technical fronts. It would conduct a cost-benefit analysis of implementing dynamic valuation in their system. For airlines with a smaller proportion of codeshare revenues, the gains from implementing dynamic valuation may not justify the costs involved.

Apart from the technical issues, the codesharing and revenue sharing agreements can become the biggest hurdles in implementing any alliance revenue management technique like dynamic valuation. The codesharing agreement may entail sharing some minimum seats on a leg and not allow optimal allocation of seats. In addition, the revenue sharing agreement may be structured in a way such that in spite of dynamic valuation benefitting the combined alliance, it hurts an individual airline. In that case the airline will not implement the dynamic valuation and risk a loss of own revenues.

5.6 Chapter Summary

This chapter describes a new valuation scheme for codeshare paths called dynamic valuation. Dynamic valuation in the optimizer provides inputs which incorporate the opportunity cost of occupying a seat on the partner's legs of codeshare paths by using the information available through bid price sharing. It is based on calculating an estimate of the actual contribution of a codeshare booking for the alliance. The difference technique which uses the difference of the total O-D fare and partner's bid price is used in this chapter to estimate the dynamic valuation of codeshare paths in the optimizer. Unlike the static valuation schemes, the dynamic valuation may change in each time frame depending on partner's bid prices from previous time frame.

The *sum of airlines' codeshare valuations* is solely dependent on the valuation scheme used by alliance partners in their optimizers. It exceeds the total O-D fare in local and total valuation schemes while it is exactly equal to the total O-D fare in Y-Prorate valuation. In the case of dynamic valuation, it can exceed the total O-D fare by a value equal to the revenue surplus which is greater than or equal to zero.

PODS simulation results of the implementation of dynamic valuation are presented and explained for DAVN and ProBP environments separately in this chapter. In the network A4 setting, it is found that dynamic valuation significantly improves the revenue gains over the local and Y-Prorate valuations for both DAVN and ProBP. In DAVN, dynamic valuation increases the codeshares and connections revenues compared to the baseline. It improves the fare class mix of all the three traffic components, particularly codeshares, thus leading to substantial revenue gains. In ProBP, the revenues go up in all the three components compared to the baseline. It should be noted that the total number of passengers carried is lower under dynamic valuation scheme compared to total valuation scheme and baseline; the revenue gain is derived from an improved fare class mix instead.

Both dynamic valuation in the optimizer and bid price sharing control in the availability require sharing of bid prices between partners but they differ from each other in the manner these shared bid prices are used. Bid price sharing control uses partner's bid prices in the last but one step of availability control. The seat allocation optimizer still uses the arbitrary and fixed valuation inputs while in the case of dynamic valuation the information of partner's bid prices is used in the RM optimizer itself to dynamically value the codeshare paths. Compared to bid price sharing control, the revenue gains with dynamic valuation are similar in DAVN environment but they are significantly higher in the case of ProBP. DAVN is based on a heuristic framework which makes it less accurate but more robust than ProBP which is based on optimal proration of itinerary fares over traversed legs.

Airlines that are using seat allocation algorithms which are less sensitive to valuation inputs, like DAVN, can benefit substantially from using bid price sharing control in availability which performs as good as using dynamic valuation in the optimizer. On the other hand, algorithms which are based on estimation of optimal bid prices, like ProBP, are more sensitive to valuation inputs. Airlines using such algorithms cannot benefit much from using bid price sharing control in availability because it uses the static and arbitrary valuation inputs in the optimizer, distorting the bid prices and resulting in lower revenue gains. Dynamic valuation improves these valuation inputs provided to the optimizer by estimating the actual contribution of a codeshare booking for the alliance and hence leads to higher revenue gains. Due to the probabilistic nature of ProBP which makes it more accurate, ProBP with dynamic valuation is able to yield higher revenue gains than DAVN, which aligns with the typical order found with individual network carriers.

6. Chapter 6

Conclusion

Recalling from Chapter 1, the goal of this thesis is to first identify the challenges and critical issues involved in revenue management for airline alliances and then propose innovative and feasible solutions to increase revenue gains for the combined alliance. This goal is achieved by analyzing the four key dimensions of the alliance revenue management problem: recording & forecasting, seat allocation method or optimizer, codeshare valuation in the optimizer and availability control of codeshare bookings. The performances of different techniques, which are implemented in the industry or discussed in the literature, are quantified using the Passenger Origin-Destination Simulator (PODS). A new valuation scheme called **dynamic valuation** is developed which is found to yield significant revenue gains for both DAVN and ProBP, two common forms of network revenue management. Section 6.1 summarizes all the findings of this thesis with a brief supplementary discussion. Further, research contributions of this thesis are presented in section 6.2 while the last section describes future research directions.

6.1 Summary of Findings

The findings of this thesis are summarized under two headings. First, the challenges involved in alliance revenue management in practice are discussed and then the performance of different techniques in alliance revenue management is summarized.

Challenges involved in alliance revenue management in practice

Airline revenue management systems strive to maximize the revenue gains given an inventory of seats and a fare structure. The existence of codeshare paths in airline alliances presents challenges to the airline revenue management systems on many fronts, from getting itinerary information to making an availability decision. All codeshare itineraries (except in virtual codesharing) are unique in that they are connecting in nature and only a part of the itinerary is carried on a flight operated by each alliance partner. The recording & forecasting of codeshare bookings depends on the degree of information (full or partial) received from the alliance partner. Recording & forecasting is the first step in alliance revenue management which affects all further steps and can pose serious limitations in terms of what techniques can be used to optimize the revenues. The codeshare passengers can be recorded & forecasted only as local passengers[1] if the full information of an itinerary booked by a partner is not available. Cascading, which requires full itinerary information from the partner, is a prerequisite to use alternative valuation schemes other than local fare valuation. It is also needed for using advanced techniques for managing codeshare paths such as bid price sharing control in availability and dynamic valuation in the optimizer.

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[1] Local passengers are those whose origin-destination pair is the same as city pair of a flight leg (refer section 1.2)

The seat allocation methods become more critical in the context of airline alliances compared to an individual airline's network. Together with cascading, O-D seat allocation is necessary to provide a differential treatment to codeshare passengers from local passengers. Also it is a necessity in order to distinguish between different codeshare itineraries using the same flight leg. The two common O-D control methods are Displacement Adjusted Virtual Nesting (DAVN) and Probabilistic Bid Pricing (ProBP). DAVN is based on estimating the network revenue contribution of all itineraries using deterministic linear programming. It then uses the EMSRb heuristic to estimate the booking limits for the virtual buckets. This heuristic framework creates robustness in DAVN which is less sensitive to fare inputs than ProBP. ProBP is more sensitive to fare inputs because it relies on the optimal iterative proration of fares of all itineraries over the traversed legs which means the valuation inputs used for codeshares is very important for it. The valuation must take into account the stochastic nature of demand in order to reach the optimal proration.

Codeshare valuation in the optimizer can affect the amount of codeshare demand accepted and hence other traffic demands as well due to network effects. Static approaches to valuation of codeshare paths remain constant throughout the booking period and does not account for the stochastic nature of demand. Among the static valuation schemes, both total fare valuation and local fare valuation overvalue the codeshare bookings in that the sum of airlines' codeshare valuations exceed the total codeshare fare while static prorate valuation sums up to the exact amount of codeshare fare.

In estimating the actual contribution to the combined alliance network of accepting a codeshare itinerary by an airline, the opportunity cost of occupying a seat on partner's leg(s) needs to be accounted for. Here the challenge lies in getting the information on partner's codeshare legs and also in the technique of using it in own revenue management system. Bid price sharing is the mechanism of sharing bid prices or shadow prices, which represent the displacement costs, between the partners. It is the first step in accounting for the partner's information in one's own system. The partner's bid prices can be used in availability control to override the output from the optimizer and accept/reject based on the comparison of own bid price with the difference of total fare and partner's bid price. This is known as bid price sharing control in availability.

Though bid price sharing control accounts for the partner's opportunity cost in the availability control step, it does not use it in the optimizer. Dynamic valuation allows the airline to achieve that by valuing the codeshare paths dynamically depending on the information of partner's legs.

Performance of different techniques in alliance revenue management

The different techniques related to each aspect of alliance revenue management are tested using the simulation tool called the Passenger Origin-Destination Simulator (PODS). It is found that the revenue management in alliances becomes sup-optimal due to incomplete information of codeshare itineraries and using an arbitrary and fixed valuation for them in the optimizer. In an alliance, the gains with O-D control are lower by 0.6%-0.8 % as compared to the typical gains for individual airline networks.

Under the dimension of recording & forecasting, cascading benefits marginally over AVS in the range of 0.1% in total alliance revenue by separating the codeshare bookings from local bookings and improving the forecast. Nonetheless, the indirect benefits of using cascading are large since it enables the use of different techniques in the later steps of revenue management which can yield substantial revenue gains.

Under the dimension of codeshare valuation in the optimizer, it is found that compared to local valuation, the codeshare traffic increases significantly in the case of static total valuation while it goes down heavily in static Y-Prorate valuation. Since there is a tradeoff between different traffic components in the network, the number of local and connecting passengers goes down in total valuation while it increases in the case of Y-Prorate valuation. None of these static valuation schemes are optimal and one can outperform the other in terms of overall alliance revenues depending on the network structure of the alliance partners. In the current setting of alliance network tested in PODS, the codeshare traffic is highly valuable in terms of revenue per passenger resulting in higher overall revenues with total valuation. Compared to local and Y-Prorate valuation, the revenues are higher for total valuation in the range of +0.2% to +0.4%.

Under the dimension of availability control, it is observed that the two O-D control algorithms react differently to bid price sharing control. In DAVN environment, bid price sharing control benefits the alliance significantly, and the incremental revenue gains compared to standard availability control lie in the range of 0.2% to 0.3%. These gains come from an increase in the codeshare revenue component via an improved fare class mix. This is true for local and Y-Prorate valuation schemes while total valuation benefits only marginally using the bid price sharing control. With total valuation, the codeshare revenues rather go down because of the higher bid prices received from partner as compared to the local and Y-Prorate valuations.

In the ProBP environment, the incremental revenue gains from using bid price sharing control are marginal in the range of 0.05%. This is because the rise in codeshare revenue component is much lower in ProBP as compared to that in DAVN. The underlying reason is that bid price sharing control uses the static valuation schemes which feed arbitrary and fixed fare inputs to the optimizer. This results in a distortion of bid prices in ProBP whose performance is dominated by fare inputs because it relies on the optimal proration of itinerary fares over the traversed legs. This problem is addressed with the new valuation scheme of dynamic valuation.

Dynamic valuation benefits both DAVN and ProBP, with additional gains of 0.2% to 0.4% over the local and Y-Prorate valuation scheme. Though the overall revenue gains in dynamic valuation are similar to those in total valuation scheme for this network setting, the traffic mix is very different for the two. Total valuation overvalues the codeshare demand and takes much more codeshare passengers than in dynamic valuation. The benefits in dynamic valuation come from an improved fare class mix achieved across all the traffic components. Particularly, in codeshare traffic, the total passengers carried goes down compared to the baseline while the revenues go up significantly in both DAVN and ProBP. The average shadow prices under dynamic valuation and bid price sharing control are quite similar in the case of DAVN while they (bid prices) are different in ProBP. This provides a reason for the different performances of these advanced techniques under ProBP further leading into the exploration of underlying differences between DAVN and ProBP.

6.2 Research Contributions

Based on the findings summarized in section 6.1, the following conclusions can be drawn from this thesis on alliance revenue management:

∞ The existence of codeshare traffic in alliances generates sub-optimality in network revenue gains of alliance partners and the combined alliance. The magnitude of this impact increases with the proportion of codeshare traffic carried by the member airlines.

∞ There is a tradeoff between different traffic components in alliances and every codeshare passenger potentially replaces a local passenger or a connecting passenger in airline's individual network.

∞ Full information of codeshare itineraries booked by the partner and O-D control for seat allocation are necessary for treating codeshare demand differently than local demand in the optimizer of an airline and hence optimizing the alliance revenues.

∞ Static approaches to codeshare valuation are non-optimal for alliance revenue management. The relative performance of such schemes depends on the network characteristics of an airline because the traffic mix could be very different under each scheme. A particular scheme can perform better in the case of one alliance or airline while not for the other.

∞ Both bid price sharing control in availability and dynamic valuation in the revenue management (RM) optimizer account for the information of partner's legs using bid price sharing. Bid price sharing control uses it in the later step of availability control without improving the codeshare valuation inputs provided to the optimizer while dynamic valuation uses it in the optimizer itself.

∞ Airlines using heuristic and more robust O-D control algorithms like DAVN can benefit substantially by using bid price sharing control in availability. The revenue gains are as high as those obtained with dynamic valuation in RM optimizer.

∞ Airlines using more accurate and sensitive O-D control algorithms like ProBP can benefit substantially by using dynamic valuation in RM optimizer. Bid price sharing control does not help because it uses a fixed codeshare valuation scheme in RM optimizer resulting in distorted bid prices and lower revenues.

∞ Dynamic valuation in RM optimizer significantly increases the codeshare revenues for both DAVN and ProBP. It acts by improving the fare class mix, taking more passengers in higher classes with higher yield and rejecting passengers in lower classes. It accepts a lesser amount of codeshare traffic compared to the baseline and total valuation scheme.

6.3 Future Research Directions

The topic of alliance revenue management has generated tremendous interest in industry and academia and it certainly has a large scope for future research and development. As a follow up to this thesis, the following research directions can be explored:

Asymmetry in revenue management systems

Asymmetry in revenue management systems at different airlines in an alliance is common in the industry. The effects of asymmetry in different dimensions of alliance revenue management such as seat allocation optimizer and codeshare valuation can be studied. The pertinent questions which remain unanswered are: Are there any asymmetric gains to any one partner in the alliance by using asymmetric valuation? How are the techniques of bid price sharing control in availability and dynamic valuation in optimizer affected due to asymmetry? Since both techniques use partner's displacement costs, it is important to study their performance with asymmetric systems like one partner using DAVN and other using ProBP. Since the shadow prices for DAVN are on an average lower than the bid prices in ProBP, scaling techniques could be used while sharing them with partners.

Revenue sharing between partners

Sharing of revenues from codeshare bookings between alliance partners is a related problem which needs more research. Though the results presented in this research assume a static proration for distribution of revenues between partners (which does not affect the combined alliance revenues), the technique of dynamic valuation provides a basis to tackle this problem. The operating carrier of a codeshare leg must receive at least the bid price of that leg from the marketing carrier and the revenue surplus can be further divided in a ratio mutually agreed upon. This ratio may depend on bid prices of the codeshare legs involved. Different schemes can be tested for impacts on the alliance partners.

Sharing incorrect bid prices

Another interesting area which can be looked into is testing the impact of sharing incorrect bid prices, intentionally, during bid price sharing in order to increase one's own share of revenues. It can potentially increase or decrease the combined alliance revenues besides the impact on individual airline revenues. The effect will also depend on the valuation scheme used by the airlines and more prominently on the revenue sharing scheme. This is an area where the concepts and models from the field of game theory can be helpful.

Testing revenue management techniques in different network settings

This thesis tests the performance of different revenue management techniques for alliances in a single network setting in PODS which is described in Chapter 4. Other network settings should be created which are less complex, but realistic enough, to magnify the impacts of different techniques. Also, a different mix in terms of demand and revenue components for the alliance carriers should be created and tested to better understand the impacts of different valuation schemes and validate the fact that in the current network setting, total valuation performs well just because of *intelligent aggressiveness* it creates by valuing codeshares at higher values. This can be done by changing fares for the markets under consideration. In addition, virtual codesharing may also be tested in the new network settings.

Alliance composition and competition between alliances

The composition of alliance and competition between alliances can be studied under different dimensions. Research on the effects of number of members in an alliance, their network characteristics and their different combinations can be an interesting study not only from the point of revenue management but also from the broader view of overall business strategy of an airline. The competition effects between alliances can be studied as well.

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