

Expansion of Point-to-Point Routes by Low-Cost Carriers in Hub Networks:
Traffic and Revenue Impacts

By

Gregory Zerbib

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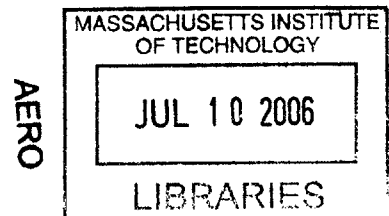
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Signature of Author.....
International Center for Air Transportation
Department of Aeronautics and Astronautics
May 20th, 2006

Certified by
Dr Peter P. Belobaba
Principal Research Scientist
Department of Aeronautics and Astronautics
Co-Thesis Supervisor

Certified by
Dr Amedeo Odoni
Professor of Aeronautics and Astronautics
Department of Aeronautics and Astronautics
Co-Thesis Supervisor

Accepted by
Jaime Peraire
Professor of Aeronautics and Astronautics
Chair, Committee on Graduate Students



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ABSTRACT

Legacy carriers developed hub networks to achieve a high concentration of operations, increase frequency, and serve multiple Origin-Destination markets with maximum efficiency. By contrast, the rapid emergence of low-cost carriers (LCCs) is mainly based on a low-fare entry strategy in point-to-point markets competing with the traditional connecting paths offered by the legacy carriers via their hubs. This thesis examines the traffic and revenue impacts of an LCC developing a point-to-point network in a legacy hub network environment. To this purpose, we use the Passenger Origin-Destination Simulator (PODS) to perform all quantitative evaluations. Modeling the choice of travelers with regard to flight schedules and fares, as well as the airlines' revenue management systems, PODS allows one to investigate the changes in aggregate and disaggregate airline statistics following the introduction of low-fare service on point-to-point routes.

The first goal of the thesis is to review and update models of passenger choice between connecting legacy and non-stop low-cost paths. The review of the literature on air traveler choice provides parameters and benchmarks critical to the calibration of PODS. We then simulate a LCC entry case, and calibrate the Passenger Decision Model (PDM) embedded in PODS through sensitivity analysis. In the second part of the thesis, we analyze the introduction of LCC operations in two legacy hub networks, a theoretical symmetric and a more realistic asymmetric network. Two different LCC strategies were considered. In the first case, LCC routes are added to the legacy network with one daily frequency, while the second strategy is characterized by two daily flights in each market entered by the low-fare airline.

For both networks and strategies, the analysis reveals that legacy revenues are greatly reduced whereas the decrease in legacy traffic is limited even with extended and aggressive low-cost competition, allowing the legacy carriers to maintain their network load factors at high levels. The lower fares implemented by the LCC and matched by the legacy airlines lead to the reduced legacy revenues. However, legacy carriers can rely on demand stimulation, as well as great demand in local hub markets and connecting markets not served by the LCC, to replace traffic captured by the new entrant.

Thesis Co-Advisor: Dr Peter P. Belobaba
Title: Principal Research Scientist of Aeronautics and Astronautics

Thesis Co-Advisor: Dr Amedeo Odoni
Title: Professor of Aeronautics and Astronautics

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I did not hesitate long before choosing the first person to mention on this page. For those familiar with Revenue Management, Peter Belobaba is an expert praised by airlines all around the world. To me, he is also a fantastic teacher and advisor. His knowledge of the airline industry inspired me and I almost thought about working for an airline. Given these tumultuous times for the industry, you can imagine how good he must be! His support was limitless, and I must say that my stay at MIT would not have been as enjoyable without his funny sarcastic comments.

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TABLE OF CONTENTS

TABLE OF CONTENTS	7
LIST OF FIGURES	9
LIST OF TABLES	11
INTRODUCTION	13
1.1. Thesis Goal	13
1.2. Thesis Structure	14
LITERATURE REVIEW	17
2.1. The Post-Deregulation Expansion of Hubs	17
2.2. The Low-Cost Era	20
2.3. Passenger Disutility Costs	22
PODS SIMULATION	27
3.1. PODS Overview	27
3.2. Passenger Decision Model	29
3.3. Networks, Fare Structure, and Revenue Management Systems	37
3.4. Calibration of Critical Parameters	44
IMPACTS OF LCC ENTRY IN A SYMMETRIC LEGACY NETWORK	59
4.1. Calibration of Base Case	59
4.2. 1 LCC Hublet with Single Frequency	66
4.3. LCC Frequency Analysis	76
4.4. 1 LCC Hublet with Double Frequency	79
4.5. Multiple LCC Hublets	88
4.6. Conclusion	90

IMPACTS OF LCC ENTRY IN AN ASYMMETRIC LEGACY NETWORK	93
5.1. Calibration of Base Case	93
5.2. 1 LCC Hublet with Single Frequency	97
5.3. 1 LCC Hublet with Double Frequency	104
5.4. Multiple LCC Hublets	111
5.5. Conclusion	116
CONCLUSION AND FUTURE RESEARCH DIRECTIONS	119
6.1. Summary of Findings	119
6.2. Future Research Directions	122
TABLE OF REFERENCES	125

LIST OF FIGURES

Figure 1: Hub System.....	19
Figure 2: Multi-Hub System.....	19
Figure 3: PODS Architecture (Courtesy of Hopperstad)	28
Figure 4: Passenger Choice Model Process	30
Figure 5: Arrival Curves by Passenger Type	31
Figure 6: Willingness-to-Pay Curves with Initial Fares.....	33
Figure 7: Willingness-to-Pay Curves with Decreased Fares	33
Figure 8: Legacy Network.....	38
Figure 9: Example of LCC Network.....	39
Figure 10: Legacy Network.....	40
Figure 11: LCC Network in Calibration Environment	47
Figure 12: Market Shares by Competitor in S01-S21 Market.....	49
Figure 13: Daily Number of Passengers by Competitor in S01-S21 Market.....	50
Figure 14: Comparison of Market Shares by Competitor in S01-S21 Market (Replanning Disutility Costs).....	52
Figure 15: Comparison of Market Shares by Competitor in S01-S21 Market.....	54
Figure 16: Comparison of Market Shares by Competitor in S01-S21 Market (Airline Preference Disutility Costs).....	56
Figure 17: Comparison of Market Shares by Competitor in S01-S21 Market (LCC schedule).....	57
Figure 18: LCC Network with 1 Hublet S01	66
Figure 19: Legacy and LCC Revenues.....	67
Figure 20: Legacy and LCC Network Load Factors	68
Figure 21: Legacy Traffic by Market ex-S01	69
Figure 22: Legacy Average Fare for Legs Ex-S01	70
Figure 23: Legacy Revenue and Load Factor for Legs Ex-S01.....	71
Figure 24: LCC Network Average Fare.....	71
Figure 25: Legacy Statistics for S01-S21 Market.....	73
Figure 26: Legacy Statistics for S01-S30 Market.....	74
Figure 27: Legacy Statistics for S01-S25 Market.....	75
Figure 28: Legacy and LCC Revenue	77
Figure 29: Legacy and LCC Load Factor.....	79
Figure 30: Legacy and LCC Revenues.....	81
Figure 31: Legacy Average Fare for Legs Ex-S01	82
Figure 32: Legacy Revenue and Load Factor for Legs Ex-S01.....	83
Figure 33: Legacy Statistics for S01-S30 Market.....	84
Figure 34: Fare Class Mix in S01-S21 Market	85
Figure 35: Legacy Fare Class Mix in S01-S21 Market.....	86
Figure 36: LCC Fare Class Mix in S01-S21 Market.....	87
Figure 37: Legacy and LCC Revenues.....	89
Figure 38: Legacy and LCC Load Factor.....	90
Figure 39: Legacy and LCC Revenues.....	99
Figure 40: Aggregate Legacy Revenue and Traffic for Legs ex-S16.....	100
Figure 41: LCC Average Fare and Traffic.....	101
Figure 42: Aggregate Legacy Average Fare and Traffic in S16-S22.....	102
Figure 43: Aggregate Legacy Average Fare and Traffic in S16-S21.....	103
Figure 44: Legacy and LCC Network Revenue.....	106
Figure 45: Aggregate Legacy Revenue and Traffic for Legs ex-S16.....	107
Figure 46: LCC Average Fare and Traffic.....	108
Figure 47: Aggregate Legacy Average Fare and Traffic in S16-S22.....	109

Figure 48: Aggregate Legacy Average Fare and Traffic in S16-S21110
Figure 49: Legacy and LCC Revenues.....112
Figure 50: Legacy and LCC Load Factors113
Figure 51: Legacy and LCC Load Factors115
Figure 52: Legacy and LCC Load Factors116

LIST OF TABLES

Table 1: Estimated Value of Schedule Delay by Hour.....	23
Table 2: Estimated Value of Frequent-Flyer Membership.....	23
Table 3: Business Trip Disutility Costs Distributions for Basic Service Variables	24
Table 4: Leisure Trip Disutility Costs Distributions for Basic Service Variables	24
Table 5: Generalized Cost Computation Passenger Travel Choice Example.....	36
Table 6: Air Travel Potential Demands in the 2 Types of O-D Markets	37
Table 7: Fare Restrictions Applied to 6 Fare Class Structure	41
Table 8: Set of Air Fares of Symmetric Network.....	41
Table 9: Set of Air Fares of Symmetric Network.....	41
Table 10: Connecting Flight Value Linear Fit Results.....	46
Table 11: Connecting Flight Value Non-Linear Fit Results	46
Table 12: Expected Market Shares in LCC Entry Base Case	46
Table 13: Legacy and LCC Schedules (Central Time)	47
Table 14: Disutility Costs Distributions for Number of Connections	48
Table 15: Connection Disutility Costs by Passenger Type by Test Case.....	49
Table 16: Replanning Disutility Costs by Passenger Type by Test Case.....	51
Table 17: Legacy and LCC Schedule.....	53
Table 18: Airline Preference Disutility Costs by Passenger Type by Test Case.....	55
Table 19: Legacy and LCC Schedules with 1 LCC Flight per Day	57
Table 20: Summary Table of Calibrated Parameters	58
Table 21: Air Travel Demands at Base Fare.....	60
Table 22: Initial Fare Structure in S01-S21 Market.....	61
Table 23: Traffic and Revenue Statistics for the S01-S21 Market.....	61
Table 24: Initial Fare Structure in S01-S21 Market.....	61
Table 25: Traffic and Revenue Statistics for the S01-S21 Market.....	62
Table 26: Initial Fares Decreased by 20% in S01-S21 Market.....	62
Table 27: Traffic and Revenue Statistics for the S01-S21 Market.....	63
Table 28: Initial Fares Decreased by 40% in S01-S21 Market.....	63
Table 29: Traffic and Revenue Statistics for the S01-S21 Market.....	63
Table 30: Summary Chart of Low-Cost Entry Case in S01-S21.....	64
Table 31: Decrease in Average Fare and Demand Surge	65
Table 32: Legacy and LCC Market Statistics in S01-S21	78
Table 33: Air Travel Demands at Base Fare.....	94
Table 34: Initial Fare Structure in S02-S22 Market.....	94
Table 35: Traffic and Revenue Statistics for the S02-S22 Market.....	94
Table 36: Initial Fare Structure in S02-S22 Market.....	95
Table 37: Traffic and Revenue Statistics for the S02-S22 Market.....	95
Table 38: Initial Fares Decreased by 30% in S02-S22 Market.....	96
Table 39: Traffic and Revenue Statistics for the S02-S22 Market.....	96
Table 40: Summary of Traffic and Revenue Results.....	118
Table 41: Summary of Changes in Total Network Statistics for the Legacy Carrier	120
Table 42: Summary of Changes in Aggregate Network Statistics for both Legacy Carriers	121

1. INTRODUCTION

Because of the emergence of numerous and rapidly growing low-cost carriers (LCC), legacy airlines are currently facing a very competitive environment. A significant amount of traffic is diverted from legacy carriers as passengers are no longer reluctant to book a flight with minimal or even no onboard service. Moreover, most LCCs are building up their networks by operating point-to-point routes. While virtually all legacy carriers rely on networks with at least one hub, point-to-point operations represent a threat that may force legacy carriers to re-estimate the economic viability of exclusively hub-oriented strategies.

Over the last decade, the performance of the legacy carriers has been affected by the expansion of LCC operations benefiting from the competitive advantage of point-to-point networks and a low-cost structure. First, operational efficiency and customer convenience are enhanced by point-to-point routes, which tend to minimize turn-around times, and maximize aircraft utilization and customer satisfaction driven by shorter travel time. Second, the cost structure of LCCs provides them with pricing power that led to a tremendous decrease in fares within the US air network since the 90's. **Geslin**¹ (2005) estimated the decrease in fares between 2000 and 2004 in markets entered by low-cost carriers. She showed that fares decreased on average by 31% in US markets where LCC operations reached the 10% market share level between 2000 and 2004. Legacy carriers, who generally match fares to protect their initial market shares, are put under the pricing pressure of LCC competitors.

The goal of this thesis is to determine the impacts of the entrance of an LCC in a hub network operated by a legacy carrier. The effects of the entrance will be examined both in terms of traffic and revenue. From a micro perspective, it will be determined to which extent passengers prefer non-stop service to a legacy carrier offering higher frequency in an Origin and Destination market (O-D market²), and evaluate the financial losses of the legacy carrier on the routes operated by the LCC as compared to the initial level of legacy revenue. From a macro perspective, the analysis will focus on the effects of an extended LCC entrance and their dependence on the characteristics of the legacy and LCC networks. For instance, in the case where LCC operations are limited to a small number of cities, one would expect the legacy carrier to report smaller traffic losses in the O-D markets entered if the initial demand for air travel is greater. As passengers book non-stop flights in certain O-D markets, the negative impact on legacy traffic will be reduced if this decrease is partially compensated by more bookings in other monopoly O-D markets served by the same legs of the legacy hub network.

All quantitative evaluations will be performed by the Passenger Origin-Destination Simulator (PODS) first developed by **Hopperstad**³ at the Boeing Company. The use of this simulator will not only allow us to obtain aggregate and disaggregate results on traffic and revenues, but also to calibrate the decision of passengers facing a

¹ Geslin, *Pricing and Competition in US Airline Markets: Changes in Air Travel Demand Since 2000*, 2006, MIT Thesis

² An O-D market is a city-pair composed of an Origin and a Destination on which passengers choose between airlines and products (non-stop vs. connecting flight, restrictions)

³ *Boeing PODS*, developed by Hopperstad, Berge and Filipowski, 1997

choice between two radically different options, a low-cost non-stop flight vs. a legacy connecting flight.

1.1. Thesis Goal

In this thesis, we will use simulation in order to investigate the potential impacts of the further expansion of LCC non-stop operations on the viability of traditional hub networks. As demand for air travel will surely increase in the future, hubs will remain in the US air system at least to consolidate local demands. However, the legacy strategy mainly focused on connecting operations may not remain as attractive as originally in the context of fierce non-stop LCC competition.

By successively adding non-stop routes to a simulated hub network operated by a legacy carrier, our objective will be to determine the impacts of LCC competition both in terms of traffic and revenue. All simulations will be performed by PODS. After some required calibration of the passenger decision model embedded in this simulation tool, we will analyze the changes in traffic and revenue reported by both carrier types as the number of markets entered by the LCC is modified. Since this analysis intends to model the future expansion of LCC operations, we will emphasize sensitivity analysis on some parameters such as the global air travel demand within the network in order to account for variability in the future characteristics of the US air transportation system.

1.2. Thesis Structure

The thesis consists of 5 main parts: the Introduction, the Literature Review, the PODS Calibration, the Impacts of LCC Entry in a Symmetric Legacy Network, and the Impacts of LCC Entry in an Asymmetric Network.

Chapter 1 includes an overview of the challenges faced by legacy carriers which are struggling against the fierce competition of LCCs developing point-to-point operations. We present the objectives of the thesis as well as the structure of this analysis based on airline network simulations provided by PODS.

In Chapter 2, we present a literature review related to the historical and economical factors that shaped the US airline industry from the 80's, and how the current rivalry between LCCs and legacy carriers affects passenger travel choices in the 21st Century. While most LCC operations are point-to-point and sustain low fares thanks to a competitive cost structure, legacy networks remain hub-centered and struggle to match fares without sacrificing profitability. As customer behavior is greatly correlated to the level competitiveness and the products offered by the airline industry, we will refer to recent scientific analyses that investigated passenger choice with regard to air travel. This review will provide crucial parameters required to calibrate the PODS simulator.

In Chapter 3, we will first describe PODS in detail. Both the Passenger Decision Model and the Seat Inventory Control System will be emphasized and will shed light on the need for calibration in the context of this analysis. Then, we will present the characteristics of the networks used in the thesis. In order to gradually increase the

complexity of the networks tested, two networks were developed. The first is symmetric in terms of demand between spoke cities whereas the second is composed of a greater number of cities served with non-homogeneous demand levels. Finally, the PODS passenger decision parameters are calibrated to realistically model the passenger choice between connecting legacy flights and non-stop LCC operations. The modifications will be based on simulation runs and a literature review providing estimates for crucial passenger disutilities, e.g. the disutility associated with airline preference.

Chapter 4 presents simulation results related to LCC entrance in a symmetric network. Based on the initial literature review on LCC entrance, we will describe a base case defined as a reasonable scenario in terms of overall demand within the network and fare decrease in the routes entered by the LCC. Then, the traffic and revenue changes due the expansion of non-stop LCC operations will be analyzed under these base case assumptions. As we intend to provide some insight on the future of LCC competition against hub networks, we will also consider alternative scenarios with different levels of air travel demand and LCC frequency to evaluate the importance of these factors in the outcomes of the LCC entrance.

The structure of Chapter 5 is similar to Chapter 4 as it relates to the simulation results for LCC entrance in an asymmetric network. The base case will be used as a starting point of investigation and we will then modify these assumptions with regard to air network characteristics and LCC frequency. Finally, we will assess the performance of Revenue Management algorithms that may be implemented by the legacy carrier to protect its market share more effectively. In the base case, both carriers use the same optimization algorithm and we will determine to which extent results change when this assumption is challenged.

Chapter 6 summarizes the findings of the LCC entrance analysis and suggests directions for future research work.

2. Literature Review

From the late 70's onward, a wave of deregulations has spread to the airline industry worldwide, most notably in the US, Australia, Japan and the western countries in Europe. The elimination of regulations in domestic markets and the more open-market for international services is a continuing trend and two thirds of air travel worldwide is expected to be liberalized by the end of the next decade⁴.

In Chapter 2, we present a literature review that first illustrates the reshaping of the US airline industry following the deregulation in 1978, and how the new regulatory environment led to the expansion of hub networks in the 80's. Then, we will analyze the recent evolution of the industry and emphasize the factors involved in the surge of LCC operations over the last decade. Finally, we will focus on the current behavior of travelers to understand how their decisions are influenced by the airline and the product characteristics (flight time, connections, and departure time). Indeed, a thorough customer behavior analysis is required to any modeling effort related to passenger choice between LCC and legacy carriers, which will be a key stone of our simulation environment presented in Chapter 3.

Following the 1978 deregulation, legacy airlines put a very strong emphasis on developing their hubs for operational and economical reasons described in the next section. Yet, for 10 years, legacy carriers have been facing the rapidly increasing competition of LCCs expanding non-stop service within the US. Fares plummet and a significant proportion of traffic is diverted from the traditional carriers which struggle to break even. Indeed, 25% of the domestic US air traffic was carried by LCCs in 2004. In Section 2.2, we present the fundamentals of the LCC competitiveness, and the future orientations of the US airline industry that will affect our modeling assumptions in the next chapters.

2.1. The Post-Deregulation Expansion of Hubs

The Airline Deregulation Act of 1978 led to profound changes in the structures of the US airline industry. Prior to deregulation, the Civil Aeronautics Board acted under the provisions of the Civil Aeronautics Act that limited de facto the competition between incumbent airlines and the entrance of new competitors. To be granted a new route award, an airline had to prove that its operations would benefit the public and would not affect its competitors adversely. Moreover, the applicant had to provide the CAB with good records of operations on other routes, which prevented most entrepreneurs from starting a new airline. These restrictions were designed to build a stable business environment for airlines that would as a result invest in high-quality service and safety, and to ensure the financial profitability of these companies. Indeed, fares were fixed by the CAB on a route distance criteria, and new route awards were used as a mean to help financially weak carrier.

⁴ The Boeing Company, *2002 Annual Report*

Not surprisingly, rationalization and integration did not occur in the industry before airlines were free to define their strategy by modifying their operations and achieving economies of scale that one would expect from companies of significant size. Most networks were linear, i.e. air carriers provided non-stop service between city pairs. Some connecting flights were offered to travelers but these flights were not the focus of the airlines in this period. The public would benefit from numerically many direct services⁵. However, large air travel service was often limited to major cities, flight frequency was often low, and fares were very high due to monopoly control.

Following the Deregulation Act of 1978, the CAB changed its policy and procedures to comply with the new law within only a few months. The new rules allowed the CAB to grant an airline authorization unless incumbents could prove that new operations would not benefit the public. This policy reversal led to a surge in applications and new route awards. While only 24 000 authorizations were given by the CAB during the regulated period, there were 106 000 city-pair authorizations within eighteen months after the act became law.

As shown by the tremendous number of new route applications, airlines started to reshape the organization of the American air network immediately. The industry as a whole oriented its strategy toward the expansion of mega-centers of air transportation where partial consolidation took place in the regulated period but coordination lacked.

Kenneth Button⁵ presents the evolution of the networks developed by the US airline industry from the 1950's onward. After deregulation, linear networks were quickly modified and the Hub-and-Spoke structure was recognized as the best model to achieve efficient allocation of resources, enhanced revenue flow, and better level of service through higher frequency and increased capacity. Although networks were rarely perfect examples of this hub model due to market specificities and remaining regulation within the industry, hubs expanded and coordination was enhanced to face growing traffic flows.

A key element of traffic flow coordination consisted of the introduction of bank times. A bank time is defined as a period time, typically one hour, in which great numbers of inbound and outbound flights are operated at a hub. The objective is thus to maximize feasible connections for travelers. After deregulation, the wide use of connecting banks improved quality of service due to increased frequency and a greater number of routes served, which stimulated air travel demand and boosted the development of hubs. In the 1990's, international air traffic met with a previously unseen growth period fostered by airline strategic alliances. National flag carriers were then willing to build networks in which all cities of the partner countries were interconnected, which led to the inevitable creation of multi-hub networks.

⁵ Kenneth Button, *Airline Network Economics*, Handbook of Airline Economics, 2nd Edition

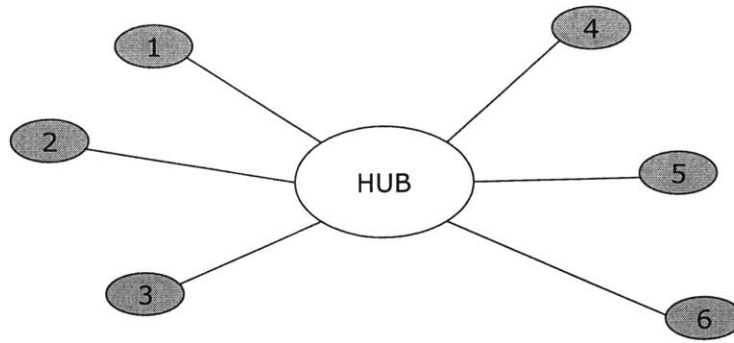


Figure 1: Hub System

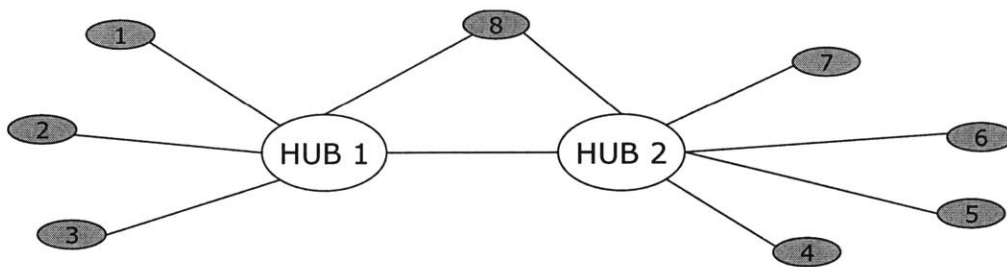


Figure 2: Multi-Hub System

Source: Kenneth Button, *Airline Network Economics*

The economic and operational advantages of Hub-and-Spoke networks have been extensively investigated in the literature. In 1989, **McShan and Windle**⁶ estimated the reduction in costs resulting from the concentration of operations at hub airports between 1979 and 1984. First, they developed a new measurement of hub-and-spoke routing by considering the proportion of an airline's most utilized (domestic and foreign) leaving from the 3% most utilized airports (points served) in that airline's network. For instance, consider a network consisting of 100 points served by airline A, the hub-and-spoke routing measure will be the number of airline A departures leaving its 3 most utilized airports divided by the total number of airline A departures in a given year. Then, McShan and Windle analyzed cost reports of US legacy carriers and concluded airlines costs diminished by 0.1% for every 1% increase in hub routing.

⁶ McShan and Windle, *The Implications of Hub-and-Spoke Routing for Airline Costs and Competitiveness*, *Logistics and Transportation Review*, Sep 1989, 25

Besides, airlines took a great advantage of quasi-monopoly markets at dominated airports. **Borenstein**⁷ explored the impact of hubs on market power in the US airline industry and his regression analysis showed that hub structures result in higher fares for travelers who want to fly to or from these airports. In a subsequent article, **Borenstein**⁸ confirms these conclusions by an analysis of fare changes following the wave of mergers in the mid-1980, focusing on the TWA/Ozark and Northwest/Republic acquisitions.

Although hub networks might seem to benefit airlines primarily, they also led to an increase in passenger welfare. On one hand, passengers originating and departing from hubs experience higher fares but benefit from higher frequencies, greater capacity and an extended network allowing them to reach a high number of destinations on non-stop flights. On the other hand, connecting traffic benefits from an extensive choice of destinations, lower connection time, and lower fares. Indeed, **Brueckner and al.**⁹ analyzed the changes in fares due to higher traffic densities in an air network. Exploratory regressions showed that hub-oriented airline strategies were far from collusive in O-D markets where connections via several hubs were available. On the contrary, major airlines passed the cost reduction resulting from hub concentration along to passengers, which raises passenger welfare.

In the end, hub operations increased both airline productivity and customer welfare by rapidly extending airline networks and fostering competition for connecting O-D markets. As a result, legacy hubs met with an expansion phase that remained unchallenged for almost 15 years.

2.2. The Low-Cost Era

Whereas the expansion of hub operations was the keystone of US airline networks in the 80's and early 90's, the competition of low-cost carriers is arguably the most important factor shaping the present and the future of the airline business in the 21st Century. While CEO's of legacy carriers are struggling with cost-cutting plans in many countries, the low-cost airline sector is booming in emerging markets like China and India, as well as in North America with JetBlue, Southwest, AirTran, and the imminent run-up of Virgin America. In this section, we describe the key factors involved in the success story of the LCCs, and the plausible scenarios for the future of the US airline industry likely to remain the battle arena between legacy carriers and LCCs.

⁷ Borenstein, *Hub and high fares: dominance and market power in the US airline industry*, the RAND Journal of Economics, Vol. 20, No. 3

⁸ Borenstein, *Airline Mergers, Airport Dominance, and Market power*, The American Economic Review, Vol. 80, No. 2

⁹ Brueckner and al., *Economies of Traffic Density in the Deregulated Airline Industry*, the RAND Journal of Economics, Vol. 23, No. 3

a. The Low-Cost Model

The business model of LCCs is far from a recent innovation. Southwest considered as a pioneer in the “no-frills” airline industry was launched in 1971. **Gillel and Lall**¹⁰ presents an excellent synthesis of the sustainable competitive advantage of Southwest against its legacy rivals. Operational simplicity is the *credo*, and the force of this company that enhances productivity and sustains low prices.

First, the onboard amenities are reduced to a minimum, which reins in costs but also alleviate the workload of crew staffs and speeds up turn-arounds at airports. The expenses related to booking procedures are drastically limited by the extensive use of online and internal website-based reservation systems. For instance, 80% of the seats sold by Southwest were ticketless and 70% were sold directly by Southwest website in 1999. Finally, the structure of the low-cost airline is also a key element of its cost-controlled efficiency. Most LCCs including Ryanair in Europe use uncongested airports of small cities or less congested airports of large cities. Thus, landing fees are less of a burden, turn-around time is reduced and ontime performance is improved. Connecting traffic is not emphasized but rather considered as a bonus due to non-optimized network effects¹¹. Indeed, 70% of Southwest traffic was point-to-point in 2000¹⁰.

For the last decade, LCCs have used this cost advantage to attract customers with low fares and boost their growth rate. A recent analysis performed by the Air Transportation Association showed that US air fares decreased on average by 18% from 2000 to 2004. These results corroborate the findings of Geslin with regard to fare decrease in markets entered by LCCs in the same period¹. In these markets, she showed that fares were reduced by 31% between 2000 and 2004.

b. Scenarios for the Future of the US Airline Industry

Sustained by a surge in air traffic demand and customer demand for low fares, the number of non-stop routes operated by low-cost carriers has grown at a quick pace over the last decade and is likely to continue. The future entrance of Virgin America that announced significant operations on the New York-San Francisco route from 2007 onwards confirms such a trend. Considering a significant fraction of O-D markets in the US, **Ito and Lee**¹² estimate the proportion of legacy carrier revenues that may ultimately be exposed to LCC competition. By using probit entry models, they found that the penetration rate could exceed 55% while the current revenue exposure to LCC was only 32%.

¹⁰ Gillel and Lall, *Competitive advantage of low-cost carriers: some implications for airports*, Journal for Air Transportation, Vol.10 (2004), 41-50

¹¹ Perry Flint, “What’s wrong with the airlines?”, Air Transport World, May 1993

¹² Ito and Lee, *Low-Cost Carrier Growth in the US Airline Industry: Past, Present, and Future*, April 2003

Moreover, the continuous growth of LCC operations will certainly be combined with a change in the nature of markets entered by low-fare airlines. Until the mid-90's, Southwest was exclusively focused on short and medium-haul routes between uncongested airports leading to increased productivity. **Boguslaki, Ito, and Lee**¹³ analyzed the strategy of the most successful American LCC and showed that Southwest re-oriented its entrance moves toward long-haul markets with a distance greater than 1200 miles. As JetBlue serving many long-haul markets from New York and Boston, Southwest modified its initial strategy, which consisted in entering short and medium-haul markets served by legacy carriers only. As the number of these markets diminished significantly in the 90's, Southwest now considers long-haul markets as potential targets.

2.3. Passenger Disutility Costs

In the first sections of Chapter 2, we presented the respective characteristics of legacy carriers and LCCs, which offer significantly different products but compete for the same passengers in O-D markets. The preliminary literature review indicates the level of LCC exposure in the US airline industry for the foreseeable future as well as the magnitude of the fare decrease in markets entered by LCCs. Eventually, these values will be integrated in our model to build realistic LCC entrance cases.

Besides network characteristics and airline strategies, the passenger behavior related to our specific competition case needed to be addressed by a complementary literature review. Indeed, we will perform all quantitative evaluations with the Passenger Origin-Destination Simulator (PODS). In Chapter 3, the structure of this simulator will be described, and we will see that it relies on two major components, which are the passenger decision model and the seat inventory control system. Because the PODS environment requires any disutility cost attributed by passengers to booking characteristics to be an input, such as the number of connections or the airline associated with the booking, the review of previous estimates of these disutility costs will allow us to calibrate these parameters consistently.

In 1999, **Prousaloglou and Koppelman**¹⁴ conducted a customer survey and built a three-dimensional choice context designed to evaluate the passenger choice of carrier, flight and fare class. The data collection based on air traveler's reported choices allowed Prousaloglou and Koppelman to determine the values attributed by air travelers to schedule delay and frequent-flyer membership. In the literature, schedule delay refers to the difference between the preferred departure time of a passenger and the actual flight departure time. It is defined as a measure of schedule convenience and can be attributed a monetary value. Indeed, a passenger is willing to pay an extra amount of money if the flight departure time is closer to his preferred time. In Table 1, the results show that business and leisure passengers are respectively willing to pay \$60 and \$17 to book on a flight with a departure time one hour closer to their preferred time.

¹³ Boguslaki, Ito, and Lee, *Entry Patterns in the Southwest Airlines Route System*, Review of Industrial Organization, Vol.25 (2004), 317-350

¹⁴ Prousaloglou, Koppelman, *The Choice of Air Carrier, Flight and Fare Class*, 1999

	Value of Schedule Delay
Business Travelers	\$60
Leisure Travelers	\$17

Table 1: Estimated Value of Schedule Delay by Hour

Then, Proussaloglou and Koppelman estimated the values attributed by air travelers to frequent-flyer membership. Indeed, any passenger participating in such a program will be willing to pay an extra amount of money for flying his preferred airline to earn frequent-flyer miles. Table 2 summarizes the findings of the analysis and shows that the value of frequent-flyer membership depends on both the passenger type and his level of commitment. For instance, a business passenger who travels frequently will be willing to pay an extra \$72 for a flight operated by the airline running the frequent-flyer program he participates in. These values are particularly relevant to traveler's choices between LCC and legacy flights and will be used to calibrate the passenger decision model embedded in the PODS simulator.

	Business	Leisure
Member	\$21	\$7
Active member - all travelers	\$52	\$18
Active member - frequent travelers	\$72	\$26

Table 2: Estimated Value of Frequent-Flyer Membership

Adler, Falzarano and Spitz¹⁵ also provide estimates of a wide range of disutility costs including the effects of flight time, on-time performance, aircraft type, schedule time difference, airline ranking and number of connections. Unlike the analysis of Proussaloglou and Koppelman, this research project is based on a mixed logit approach using stated preference survey data for the development of an itinerary choice model, which can determine all values of service attributes. Compared to the logit model created by **Ben-Akiva and Lerman**¹⁶ in the 80's and its further developments that are incorporated into the GEV family of discrete models, a mixed logit model accounts for variations in individual and context preferences. Thus, the researcher has the possibility to consider a disutility cost either as a fixed parameter or as a variable with a given distribution, usually normal or lognormal for fixed-sign parameters. The mixed logit model provides estimates for the mean and the variation of these pre-defined distributions.

¹⁵ Adler, Falzarano and Spitz, *Modeling Service Trade-offs in Air Itinerary Choices*, 2004

¹⁶ Ben Akiva M.E., Lerman S. R., *Discrete Choice Analysis: Theory and Application to Travel Demand*, 1985, MIT Press, Cambridge

The analysis is based on an annual online survey of US domestic travelers conducted from 2000 to 2002. The survey was administered to approximately 600 individuals and collected detailed information on the traveler such as his membership level in frequent flier programs and his travel preferences. The traveler was then presented a scenario and a set of choices that would be analyzed to estimate the values attributed to flight characteristics such as the associated number of connections. Tables 3 and 4 presents the estimates that will affect the calibration of the passenger decision model embedded in PODS.

	Mean (\$)	Standard Deviation
Flight time (/hr.)	69.7	39.2
Number of Connections	53.7	48.5
Schedule Delay (/hr.)	30.3	22.9
Airline Preference <i>Preferred Airline vs. Lowest Ranked</i>	96.1	55.9

Table 3: Business Trip Disutility Costs Distributions for Basic Service Variables

	Mean (\$)	Standard Deviation
Flight time (/hr.)	31.2	23.2
Number of Connections	18.8	23.3
Schedule Delay (/hr.)	4.8	5.7
Airline Preference <i>Preferred Airline vs. Lowest Ranked</i>	37.8	36.4

Table 4: Leisure Trip Disutility Costs Distributions for Basic Service Variables

The schedule convenience model adopted by Adler and al. is similar to the Prousaloglou and Kopelmann model, i.e. each passenger has supposedly a preferred departure time and is willing to pay an extra amount of money for a flight departing closer to his optimal time. On average, a business traveler is willing to pay \$30.3 more for a flight departing one hour closer to his preferred time. Then, travelers attribute values to the total amount of flight time and the number of connections, which are both proportionally related to flight inconvenience. In Table 4, the results show that a leisure passenger is willing to pay on average an extra \$31.2 for a flight with a one hour shorter duration and \$18.8 for a flight with one less connection. Finally, Adler and al. confirmed that travelers are willing to pay more for flying on their preferred airline. Several factors including frequent-flyer programs, and brand image that may also be related to safety, affect the value of this disutility cost. Table 3 shows that a business passenger is willing to pay on average \$96.1 more for a ticket on his favorite airline as opposed to his least preferred airline.

In Chapter 3, we will use the values of disutility costs estimated by the previous analyses both directly and indirectly. We will directly implement some of these values as input in PODS. Indirectly, we will use these scientific estimates to fix the ratio of the disutility costs between leisure and business demand, and check the consistency of our values determined by sensitivity analyses as explained in the next chapter.

3. PODS SIMULATION

Chapter 3 describes the Passenger Origin-Destination Simulator (PODS) that was used to obtain statistical reports on traffic and revenue generated by the carriers in the network, as well as the calibration of the simulator. The thesis is focused on the specific LCC entrance scheme involving non-stop flights, which requires calibrating the behavior of passengers accordingly.

The first two sections will be a review of the concepts and subtleties related to PODS as it was described in detail by **Zickus, Gorin and Carrier**¹⁷. The reader should refer to these materials for a complete description of the simulator.

In the third section, we will focus on the calibration process. These adjustments are primarily based on the literature review of Chapter 2 that will provide direction with respect to realistic scenarios to be tested in the thesis, and parameters such as disutility costs. Moreover, we will present the results of a previous analysis that give some benchmarks in terms of market shares that can be expected from a LCC entrance scenario. Indeed, benchmarks will play a key role in the calibration process as it requires adjusting subtle parameters for which data cannot easily be found and estimated values are too reliant on the airline competition case chosen for the sake of the analysis.

3.1. PODS Overview

In the thesis, all simulation results will be performed by the Passenger Origin-Destination Simulator (PODS) that was originally developed by Hopperstad, Berge and Filipowski³ at the Boeing Company in the mid 90's. Further development was then initiated by the PODS Consortium, a partnership between MIT and seven international airlines. The objective of the PODS Consortium is to use a realistic simulator environment to test revenue management (RM) systems in different competitive configurations, as well as to assess the performance of innovative methods related to demand forecasting and RM algorithms.

¹⁷ Zickus, *Forecasting for Airline Network Management; Revenue and Competitive Impact*, 1998

Gorin, *Airline Revenue Management: Sell-up and Forecasting Algorithms*, June 2000

Carrier, *Modeling Airline Passenger Choice: Passenger Preference for Schedule in the Passenger Origin-Destination Simulator (PODS)*, 2003

PODS simulates an air transportation network composed of airlines interacting with passengers willing to travel from an origin to a destination. The simulator models the booking process associated with each flight operated within the network on a same departure day. The process starts 63 days before the scheduled departure and is divided into 16 timeframes that are used by the airlines to update their seat inventory strategy. In each O-D market served, a daily demand is generated and given characteristics such as its distribution over the booking period (63 days). Based on this demand, passengers are generated and given individual characteristics, e.g. the value they attribute to a non-stop as compared to a connecting flight. Finally, the same passengers request bookings and cancellations, and airlines interact with travelers by accepting or rejecting these requests.

PODS runs as an iterative process by performing the simulation described in the previous paragraph multiple times. Indeed, a PODS run consists of several "trials" which are composed of hundreds of booking simulations called "samples" corresponding to one same departure day. Because seat inventory control relies on historical bookings, PODS reiterates all these booking processes for the same departure day numerous times. Moreover, iterations are divided into "trials", i.e. independent groups of iterations, so that all simulation results are not correlated. Under the current settings, a PODS run consists of 5 trials, each composed of 600 successive simulations for the same departure day.

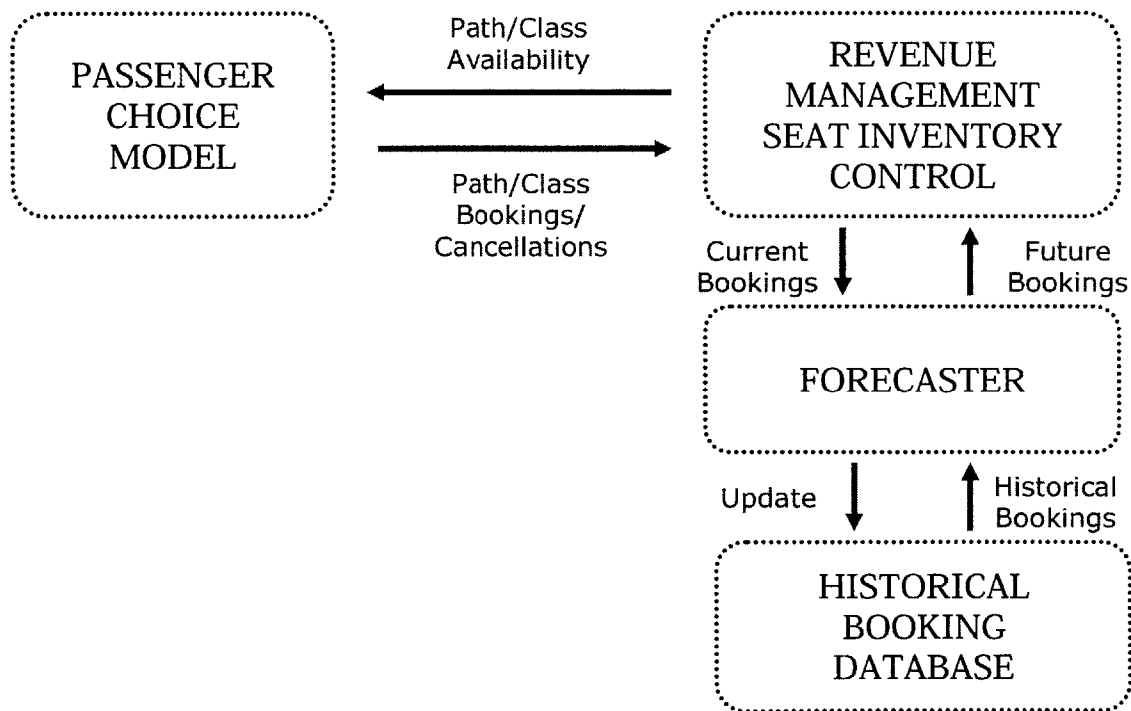


Figure 3: PODS Architecture (Courtesy of Hopperstad)

Figure 3 shows the PODS architecture which consists of 4 main parts. For each sample, demand is generated and passenger decision processes are simulated by the Passenger Choice Model, which determines the preferred paths and classes of each passenger according to his personal criteria. Then, the RM Seat Inventory Control system of the airline will accept or reject the requests of passengers, which always have the alternative to book no flight. The airline decision is based on optimization algorithms embedded in the RM system that will be detailed in Section 3.2.c, and the forecasts provided by the Forecaster. These booking forecasts by fare class are estimates of future bookings, and depend on several variables including the current number of bookings in each class, updated at each timeframe, and the historical bookings for this flight provided by the Historical Booking Database.

PODS modules can be divided into two separate groups respectively related to passenger choice and airline decision. We will dedicate Section 3.2 to specifically describing the Passenger Choice Model generating demand and customer preferences. In Section 3.3, we will present the networks, fare structures, forecasting methods and RM algorithms specific to the thesis.

3.2. Passenger Choice Model

a. Network Inputs

Passenger booking requests will depend on the characteristics of the network implemented in PODS, which are as follows:

- Number of airlines
- Airline Preference Index¹⁸ of each airline
- Number of Origin-Destination markets
- Departure time, Arrival time, and Capacity of each leg
- Path Quality Index (PQI¹⁹) of each path
- Number of fare classes with associated fares, base fares²⁰, advance purchase requirements and other restrictions (i.e. Saturday Night Stay requirement, non-refundability and change fee)

b. Passenger Choice Model

For each sample, the Passenger Choice Model will simulate traveler choices with regard to path preferences by following the process presented in Figure 4.

¹⁸ Disutility costs associated with airline preference may be implemented in PODS (see Section 3.2.d)

¹⁹ PQI refers to the number of connections associated with a given path. The higher the PQI, the greater the number of connections and the higher the disutility costs associated with this path (see Section 3.2.d)

²⁰ Base fares determine demand as demand inputs are defined at base fares (see Section 3.2.c)

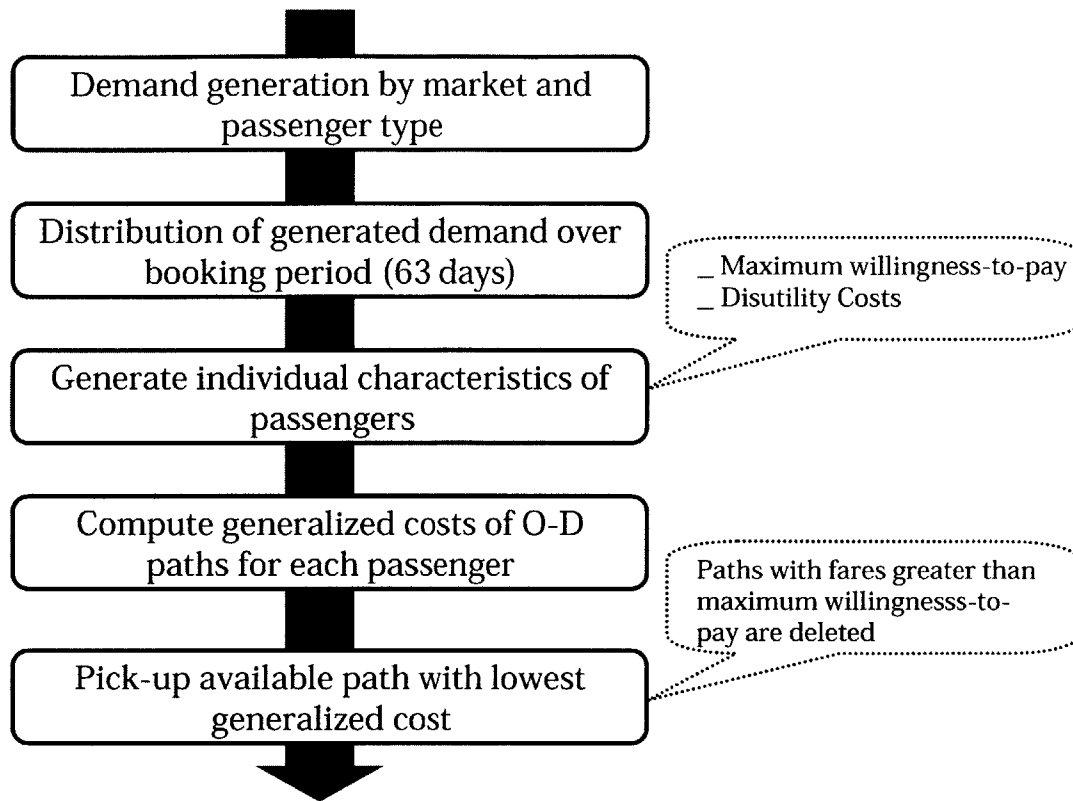


Figure 4: Passenger Choice Model Process

The Passenger Decision Model requires a specific set of inputs related to demand. Mean market demands and passenger characteristics can be customized according to the researcher preferences. Since PODS takes into account the stochasticity of air travel demand, all parameters required to calibrate passenger choices are defined by a mean value and a standard deviation. These inputs include:

- Average demand by O-D market and passenger type
- Arrival curves by passenger type. They are required to distribute generated demand over the booking period, and translate the fact that leisure passengers generally book earlier than business travelers. Arrival curves are presented in Figure 5
- Parameters involved in passenger willingness-to-pay
- Average disutility costs associated with connections, airline preference, restrictions, and replanning. These disutility costs allow the Passenger Decision Model to compare all flights in a given O-D market from the passenger perspective and pick up the path minimizing his disutility

The modeling of randomness in passenger choice is a key achievement in PODS. While mean values of demand and disutility are chosen by the researcher, standard deviation are computed assuming these variables follow normal distributions with a 0.3 k-factor²¹, typical of air transportation demand according to marketing research conducted by Boeing.

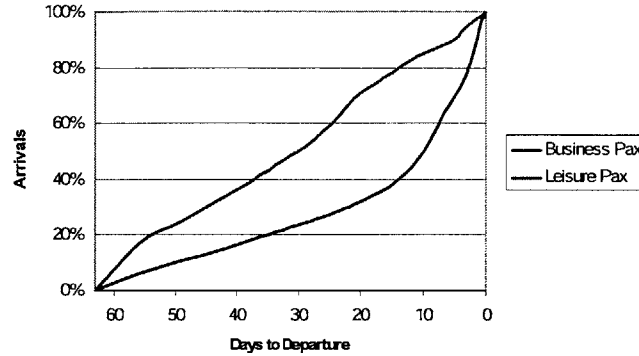


Figure 5: Arrival Curves by Passenger Type

c. Demand Generation

For each sample, the first step performed by the Passenger Choice Model is to generate a demand for each market and each passenger type. These demand levels change between samples to account for the stochasticity of air travel demand. The mean demand values are PODS inputs set by the researcher and actual demand follows a Gaussian distribution with a 0.3 k-factor.

Air travel demand is not a pure function of macroeconomic factors such as the size of the cities served by the route, and the average income in these cities. Demand modeling must also take into account the elasticity of the demand with regard to price levels, which PODS simulates. Indeed, market demand is defined at “base fares”. For each market, the input includes a set of two base fares (one by passenger type) that define the fares at which respectively 100% of business and leisure passengers are willing to buy a flight ticket.

Usually, the lowest fare available in a given market is very close to the leisure base fare, and the business base fare is equal to 2.5 the leisure base fare. In this case, actual demand is equal to the number picked up by the Passenger Choice Model for each sample based on the mean demand input value. Indeed, the lowest available fare class will always be equal or greater than base fares. However, a decrease in fares will result in a demand increase as more passengers are willing to pay for very low fares (see Section 3.2.d). Therefore, we will refer to mean demand level as “mean base fare demand”.

²¹ k-factor refers to a normal distribution with the following relation between the mean value μ and the standard deviation σ , i.e. $\sigma = (\text{k-factor}) * \mu$

d. Passenger Characteristics

1) Willingness-to-Pay

Each passenger entering the booking process gets assigned a willingness-to-pay which is defined as the maximum amount of money he will be willing to pay for a ticket. This willingness-to-pay refers only to fares and not to the generalized cost of a flight ticket, which is computed in PODS to simulate trade-offs between different travel options.

Willingness-to-pay is randomly assigned to any passenger by the Passenger Decision Model (PDM) but this assignment process reproduces aggregate willingness-to-pay curves embedded in the model. Since leisure and business have inherently different properties, two curves are implemented in the PDM. The equations of the willingness-to-pay curves are the following:

$$P(\text{pay at least } f, \text{ business passenger}) = \min\left[1, \exp\left(-\frac{.6931 * (f - \text{basefare})}{(emult - 1) * \text{basefare}}\right)\right]$$

$$P(\text{pay at least } f, \text{ leisure passenger}) = \exp\left(-\frac{.6931 * (f - \text{basefare})}{(emult - 1) * \text{basefare}}\right)$$

Where f = fare in question

Basefare = fare at which all travelers would travel (business basefare=2.5*leisure basefare)

$e\text{-mult}$ = elasticity multiplier (of the basefare where 50% of travelers are willing to travel). These parameters are respectively calibrated to 3.0 and 1.2 for business and leisure passengers

In the previous section, we explained how demand levels are input in PODS and defined with reference to the willingness-to-pay model and the base fares by passenger type. The two equations of willingness-to-pay curves reveal the implementation of demand stimulation in PODS. Indeed, more than 100% of leisure base fare demand will be willing to pay for a lower fare than the leisure base fare. This proportion reflects the increase in demand due to lower fares and may lead to simulation reports where the average number of bookings will be greater than the "mean base fare demand" for a given market and a passenger type.

Figures 6 and 7 illustrate the willingness-to-pay curves and the demand stimulation effect. Both charts refer to the same market operated by the same airline with different sets of fares. Fares are shown on the x-axis. The second chart presents a case where fares are decreased by 10% as compared to the price levels of Figure 6. As shown by Figure 7, the number of leisure passengers willing to pay for the lowest fare is equal to about 1.8 the mean base fare leisure demand when all fares are decreased by 10%.

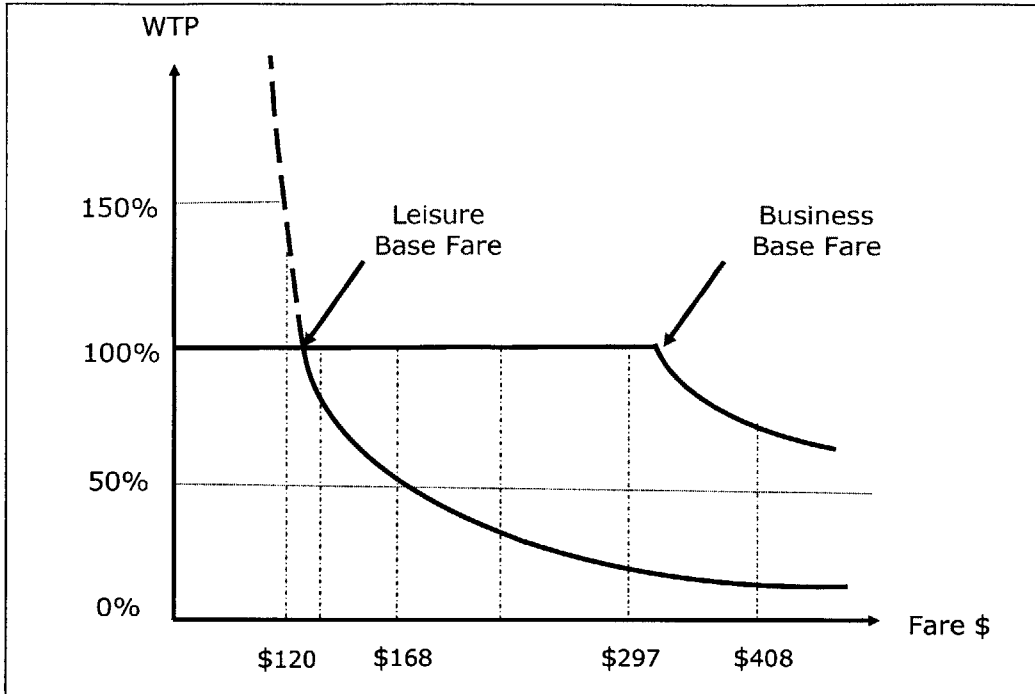


Figure 6: Willingness-to-Pay Curves with Initial Fares

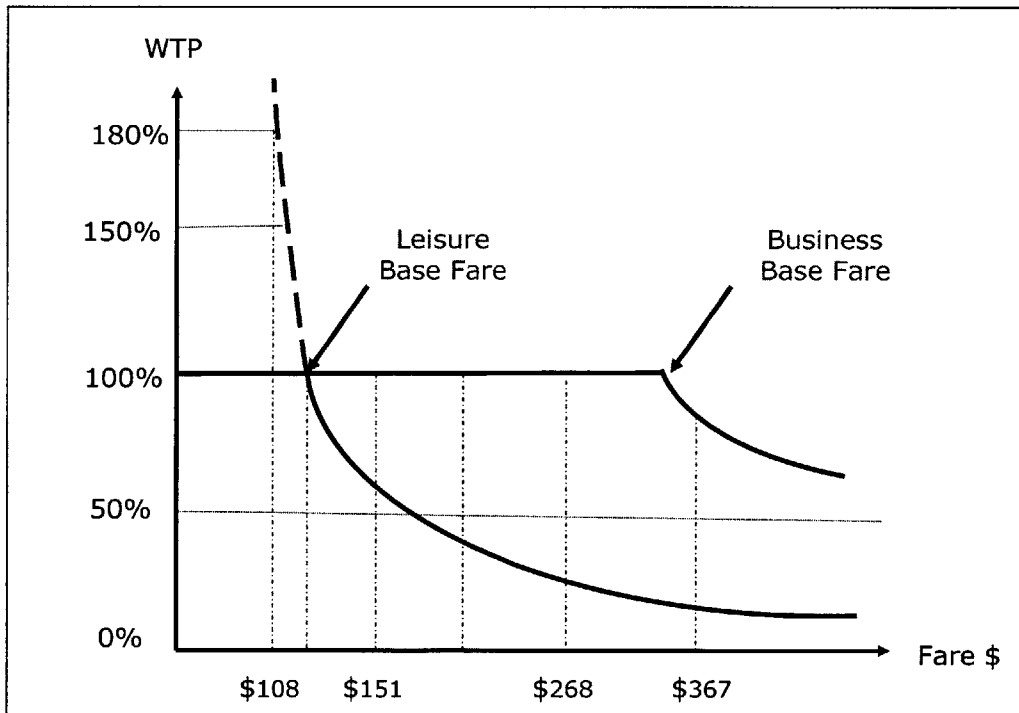


Figure 7: Willingness-to-Pay Curves with Decreased Fares (No Change in Base Fares)

Each passenger will be assigned a willingness-to-pay that will fix the maximum budget allocated to his travel. Then, the Passenger Decision Model will compute the generalized cost of each path for each fare class to simulate the trade-offs performed by the passenger while reserving his trip. The reader should refer to **Lee**²² to get more precise information on the calibration of disutility costs in PODS. In the end, the passenger will book the available fare-path combination with the lowest generalized cost and a fare lower than his willingness-to-pay, if any.

$$\text{Total Generalized Cost} = \text{OD Fare} + \sum_i (\text{disutility} \cdot \text{costs})_i$$

2) Passenger Decision Window

Besides his random willingness-to-pay, any passenger entering the booking process is assigned a preferred decision window. This model is directly inspired from the **Decision Window Model**²³, and refers to the passenger window which the customer would prefer to depart and arrive within. The position and the size of the decision window is a function of the flight elapsed time and the passenger type. For further reference, the reader should refer to Carrier¹⁷.

To account for passenger trade-offs related to schedule convenience, the "replanning disutility" was introduced in the PDM. Thus, a fare-path outside the passenger's decision window will be considered by this passenger as a reasonable travel option, but the associated generalized cost will be incremented by the replanning disutility costs specific to this passenger. Like all PODS disutilities, the mean value by passenger type is a PODS input with a Gaussian distribution and a 0.3 k-factor.

3) Restriction Disutility Costs

In PODS, 3 types of restriction are implemented: Saturday Night Stay requirement, non-refundability and change fee. A set of restrictions applies to each fare class in each market and the total generalized cost of the fare-path will be incremented by the disutility costs associated with the restrictions applying to the fare class, if any.

As replanning disutility costs, restriction disutility values are smaller for leisure passengers than for business passengers on average. Since the Saturday Night requirement is the most difficult requirement to meet for both business and leisure passengers, the associated disutility costs are greater than for the two other restrictions.

²² Lee, *Modeling Passenger Disutilities in Airline Revenue Management Simulation*, 1998, MIT Thesis

²³ The Boeing Company, *Decision Window Path Preference Model*, Copyright 1993

4) Disutility Costs Associated with a Connecting Path

The set of PODS network inputs includes a Path Quality Index (PQI) for each path that determines the number of legs associated with this path. Therefore, PQI is directly related to the number of connections of a path that is equal to (PQI-1). For instance, a path with a PQI equal to 2 must be a connecting path with one connection between the two corresponding legs. As passengers prefer non-stop as opposed to connecting paths, a disutility cost associated with the number of connections was introduced in the PDM. For each fare-path, the generalized cost is incremented by the connection disutility cost multiplied by PQI. This disutility cost is specific to the traveler, but the mean disutility value is a PODS input and the distribution is Gaussian with a 0.3 k-factor.

5) Utility Costs Associated with Airline Preference

The airline preference disutility was introduced in PODS to model the competition between airlines with different level of service, which is particularly relevant to our analysis investigating the expansion of low-cost carriers in a legacy environment.

The set of network inputs includes an Airline Preference Index (API) for each airline operating within the network. This coefficient is a constant across the network, and is either equal to 1 or 0. The preferred airline is designated by 1 while the other carrier is designated by 0. In the end, the generalized costs of all fare-path of the preferred airline will be reduced by the airline preference utility value specific to the passenger. On average, airline preference disutility costs are much greater for business than for leisure passengers. Like all PODS disutilities, the mean value by passenger type is a PODS input with a Gaussian distribution and a 0.3 k-factor.

6) Example

Let X be a passenger willing to travel from LAX to JFK. Mr. X is a leisure passenger with a low willingness-to-pay (\$150) so we will consider only the lowest existing fares on this route. Given the network implemented in PODS, X has two travel options. Both paths are connecting flights since the two airlines are legacy carriers exclusively operating major hubs. These two airlines have recently decided to remove the Saturday Night Stay requirement from all their fare classes, but non-refundability and change fee apply to the fare class Mr. X is interested in. The first option would be to fly his preferred airline, airline 1, but unfortunately the flight is outside his decision window between 10am and 6pm (LAX local time). The alternative would be to fly airline 2 with a flight within his decision window.

Table 5 shows the computation of the generalized costs associated with the two different paths. Finally, airline 1's option has the lower generalized cost, which means that this passenger will prefer to reschedule his trip and fly his preferred airline. Given his willingness-to-pay, Mr. X can afford both fares which are lower than \$150. However, this traveler is not assured to book on airline 1 as his booking request is still subject to availability. Indeed, he must first meet the advance purchase requirement applying to this ticket, if any, and then request the booking to airline 1 that has booking limits for each fare-path combination as calculated by its RM system. If his booking request is rejected, the passenger will request another booking among the remaining options with the lowest generalized cost, if any. Eventually, Mr. X will either buy the available ticket with the lowest generalized cost, or will not book.

	Option 1			Option 2		
	Mean Disutility Value (Leisure Traffic)	Mr. X's Disutility Cost	Generalized Cost	Mean Disutility Value (Leisure Traffic)	Mr. X's Disutility Cost	Generalized Cost
Fare			\$130			\$145
Replanning Disutility	\$30	\$40	\$40	\$30	\$40	\$0
Airline Preference Utility ²⁴	(\$20)	(\$30)	(\$30)	(\$20)	(\$30)	\$0
Connection (PQI=2)	\$20	\$46	\$92	\$20	\$46	\$92
Saturday Night Stay Requirement	\$90	\$67	0	\$90	\$67	0
Non-Refundability	\$30	\$42	\$42	\$30	\$42	\$42
Change fee	\$30	\$28	\$28	\$30	\$28	\$28
Total			\$302			\$307

*Table 5: Generalized Cost Computation
Passenger Travel Choice Example*

²⁴ Parentheses indicate negative numbers

3.3. Networks, Fare Structures and Revenue Management Systems

a. Networks

The PODS network used in this study consists of the following:

- 1 hub
- 2 sets of Spoke cities (East and West Coast)
- O-D markets with mean base fare demands
- 1 set of legs operated by the legacy carrier via its hub
- 1 set of legs operated by the LCC

Two networks were developed in order to highlight the effects of the LCC entry both at the leg and network levels. These networks were then modified to account for changes in the number of markets entered by the LCC.

Along with the set of legs operated within the air transportation system, O-D demand levels for air travel are key parameters determining the properties of a network. In the PODS environment, demand is divided into 2 categories, i.e. business and leisure demand. These values are defined for each O-D market served and correspond to the mean daily demands at base fare.

Network 1: Symmetric Network

The first network is the simplest and is relevant to theoretical analysis only. Indeed, it is a fully symmetric case, i.e. demands for O-D markets between spoke cities are all equal. However, demand between hub and spoke cities are much higher as presented in Table 6.

	Business Base Fare Demand	Leisure Base Fare Demand	Total
Between Spoke Cities	4.66	8.66	13.32
Between Spoke City and Hub	25	50	75
Base Fare	\$325	\$130	

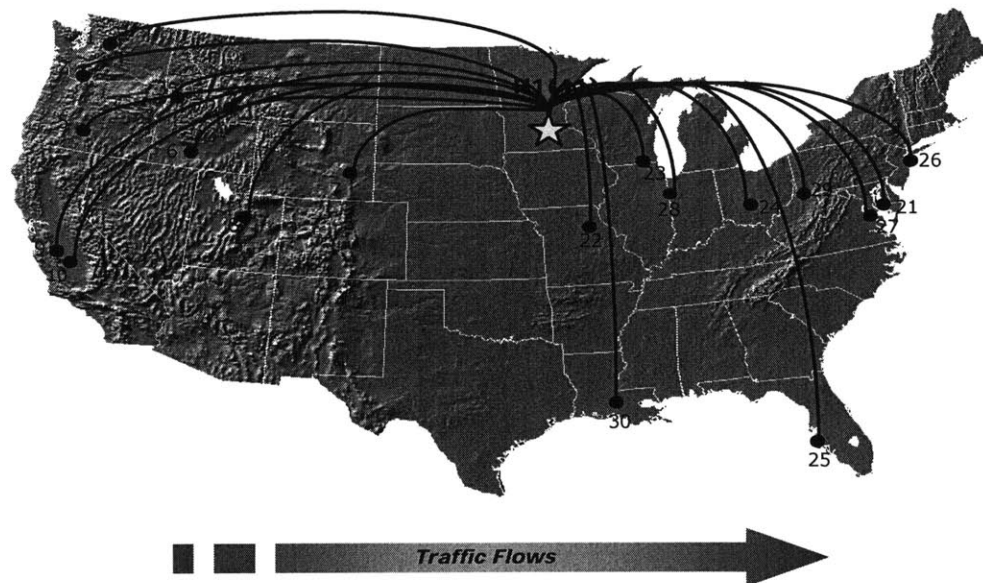
*Table 6: Air Travel Potential Demands in the 2 Types of O-D Markets
(Symmetric Network of Chapter 3 only)
Daily Number of Passengers at Base Fare*

These demands were not arbitrarily determined. They were extracted from the network D6 developed by the PODS airlines consortium, which is based on recent traffic statistics reported by US legacy carriers. Absolute numbers do not reflect actual demand between major cities in the US, but the ratios of business vs. leisure demand and local vs. connecting demand are realistic and consistent with the capacity of legacy airplanes, i.e. 100 seats.

In PODS, a day of operations is modeled by one eastbound flow of aircraft. Figures 8 and 9 show the spoke cities served by the legacy carrier as well as the flows of legacy and LCC aircraft across the network. While the LCC network will change as O-D markets are added to its operations, the characteristics of the symmetric legacy network are constant and given below:

- 1 legacy carrier
- 1 hub (H1 located in the North)
- 20 spoke cities
- 60 legs in 3 banks
- 120 O-D markets

All spoke-to-spoke legacy flights are connecting in H1. The legacy carrier operates the 20 routes between spoke cities and H1 three times per day, i.e. 60 legs in total. The legacy network is composed of three banks that correspond to coordinated eastbound flows of aircraft serving all 120 O-D markets with 20 legs.



*Figure 8: Legacy Network
Symmetric Network*

The LCC adopts a different strategy and operates non-stop flights between spoke cities. In the thesis, we will assume that the LCC concentrates its operations in pre-determined spoke cities on the east coast. The LCC will focus on expanding non-stop service from a limited number of cities, called "hublets". For instance, the cities number 1 and 5 are LCC hublets in Figure 9. In the spoke-to-spoke markets served by the LCC, the low-cost airline will operate one to three flights per day. In Chapters 4 and 5, we will analyze the impact of the expansion of LCC operations whose strategy follows the guidelines stated in this paragraph.

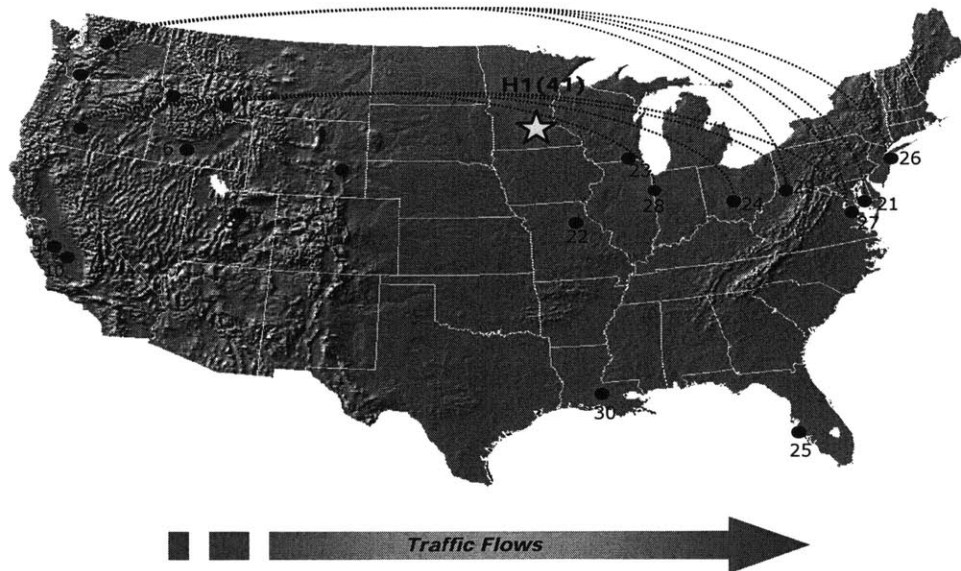


Figure 9: Example of LCC Network

Network 2: Asymmetric Network (Network D6)

The second network used in the thesis is the framework of a more realistic case as it accounts for differences in demand between O-D markets. This network is the network D6 developed by the PODS consortium with the help of the airline partners who provided real data and participated in the design of this network originally including two hubs operated by two legacy carriers. The characteristics of the asymmetric legacy network are given below (see Figure 10):

- 2 legacy carriers
- 2 hubs (H1 located in the North, H2 in the South)
- 40 spoke cities
- 482 O-D markets
- 42 sectors in 3 banks by legacy carrier

The definition of a sector is a route that can be operated multiple times per day. In this case, legacy aircraft carry passengers in 42 sectors 3 times a day, which implies that each legacy network is composed of 126 daily flights.

LCC flights will be successively added to the original legacy carrier network to model the LCC entrance in non-stop markets between spoke cities in the asymmetric case, similarly to the first symmetric network.

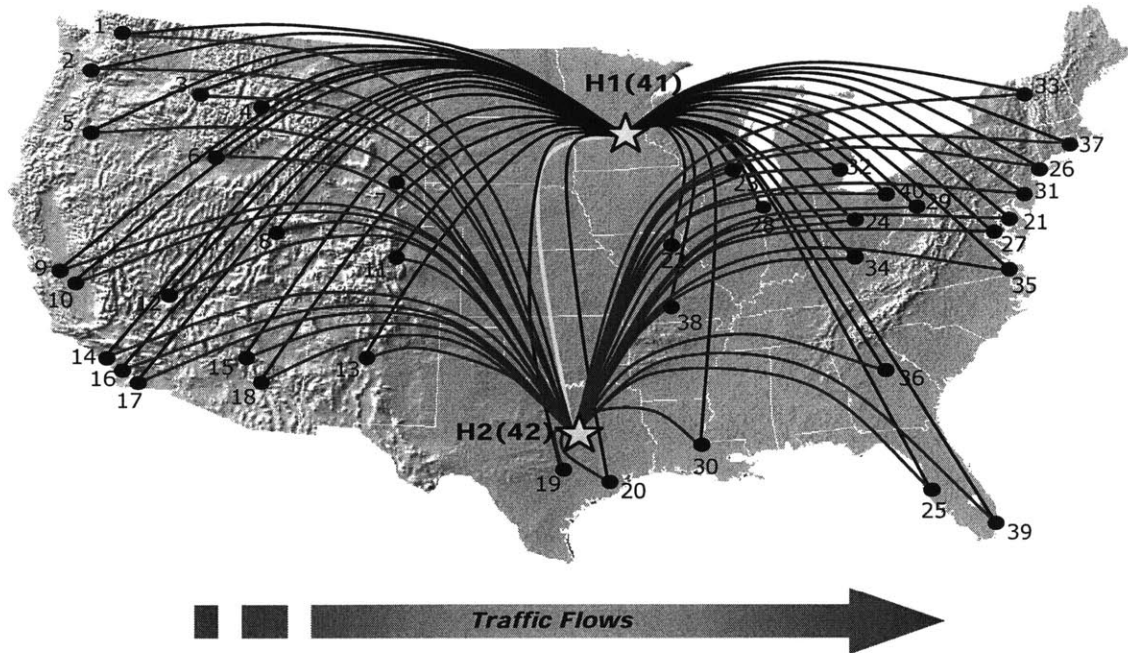


Figure 10: Legacy Network
Asymmetric Network (Network D6)

Finally, the characteristics of the aircraft operated by the two types of carriers are different. On one hand, the legacy carrier operates 100-seat aircraft between the spoke cities and the hub whose significant demand makes the use of wide-body jets sustainable. On the other hand, the LCC focusing on smaller demand point-to-point O-D markets operates 30-seat aircraft.

b. Fare Structures

Fare structures rely on two components in the PODS environment, which are respectively the set of restrictions associated with each type of fare, and the set of prices applied to each fare product. In terms of restrictions, the networks presented in this thesis will be uniform. The fare structure in both symmetric and asymmetric networks is classified as semi-restricted and the following set of restrictions applies to the 6 fare classes implemented in each O-D market as shown in Table 7:

Class	Advance Purchase requirement (in days)	Saturday Night Stay	Non-Refundability	Change Fee
1	0	0	0	0
2	3	0	1	0
3	7	0	1	1
4	10	0	1	1
5	14	0	1	1
6	21	0	1	1

Table 7: Fare Restrictions Applied to 6 Fare Class Structure

In the PODS environment, fare structure is similar across the entire network. However, ticket prices may differ between O-D markets and the researcher is free to implement any set of fares to any O-D market. In the first symmetric network, two sets of fares are implemented as shown in Tables 8 and 9. These sets of fares were implemented respectively in "Spoke-to-Spoke" and "Spoke-to-Hub" markets.

Class	1	2	3	4	5	6
Fare	408	297	192	168	144	120

Table 8: Set of Air Fares of Symmetric Network "Spoke-to-Spoke" Markets

Class	1	2	3	4	5	6
Fare	329	231	136	115	94	72

Table 9: Set of Air Fares of Symmetric Network "Spoke-to-Hub" Markets

In the second asymmetric network, fares vary to a great extent. For a given route, fares are primarily based on the route distance. Then, randomness is introduced by the use of a gravitational model to build a realistic network with asymmetries between O-D markets. In terms of fares, a network can then be characterized by its average fare ratio. In a given O-D market, the fare ratio is defined as the ratio of the highest fare over the lowest fare. For instance, the fare ratio of the fare structure presented in Figure 8 is equal to \$408 divided by \$120 which is 3.4. In the second asymmetric network, the average fare ratio is equal to 4.1 across the network.

c. Revenue Management Systems

In PODS, the Revenue Management system simulates that of an airline. The objective is to maximize revenue by setting booking limits by path and fare class. The limits are updated at each timeframe, i.e. 16 times during the 63 day-booking process, and are based upon two RM components, the booking forecasts and the optimization algorithm. Booking forecasts are output by the Forecaster specific to the airline and fed into the Seat Inventory Control System in which the optimization algorithm is embedded. Based on current and expected bookings provided by the Forecaster, booking limits are computed by the algorithm.

Because revenue management systems are not the primary focus of the thesis, Section c is a short overview of forecasting methods and optimization algorithms available in PODS. For a complete description of all PODS functions related to revenue management methods, the reader should refer to Gorin¹⁷ and Cleaz²⁵.

1) Forecasting and Detruncation

One major assumption of the traditional revenue management systems tested in the thesis is the independence of demand by fare class. As a result, the Forecaster determines booking forecasts by:

- Itinerary i
- Timeframe TF_i
- Fare class j

The Forecaster use historical bookings to predict future bookings. However, the fare class j in question may have been closed before departure. In this case, the Forecaster will perform detruncation to estimate the number of passengers that would have booked this flight on fare class j if it had remained opened until departure.

The detruncation method used is called *Booking Curve Detruncation*. This method extrapolates the curve of total bookings in class j as a function of timeframe, and then estimates the unconstrained demand by picking the value of this extrapolated function at flight departure.

Once the unconstrained demand is obtained, the Forecaster uses the *Pick-Up Moving Average* (PUMA) method to estimate the number of "Bookings-To-Come" for class j from TF_i . This method takes the average over the previous samples of occurrence of additional bookings between TF_i and the departure date.

²⁵ Cleaz, *Airline Revenue Management Methods for Less Restricted Fare Structures*, 2005, MIT Thesis

2) Optimization Algorithm

Given the booking forecasts, the Seat Inventory Control System will compute booking limits using an optimization algorithm. The family of revenue management algorithms is very large and we present only the method tested in the thesis.

EMSR

The "Expected Marginal Seat Revenue" method was first introduced by **Belobaba**²⁶ and then used by a large number of airlines for revenue management purposes. This method requires the implementation of nested booking limits, i.e. the booking limits apply to a group of contiguous fare classes including the lowest fare class. As a result, no booking limit apart from total capacity applies to the highest fare class, and no booking limit protecting a given class will ever prevent a passenger from booking in a higher fare class.

The principle is based on the expected revenue of a seat in a given class, equal to the associated fare multiplied by the probability of selling this seat. As long as this expected revenue in class j is greater than the expected revenue of the first seat sold in the next lower class $j-1$, the algorithm will protect this seat from class $j-1$ and all other classes lower than j .

²⁶ Belobaba, Air Travel Demand and Airline Seat Inventory Control, 1987, MIT Thesis

3.4. Calibration of Critical Parameters

The first three sections of this chapter described the underlying structure of PODS, which relies on a passenger decision model and a seat inventory control system. The former is inherent to microeconomic characteristics of travelers within the air transportation network studied, while the latter is specific to an airline as it depends on the revenue management method implemented within its booking reservation system. This section presents the methodology developed to define the base case of the new LCC entry analysis.

The calibration addresses the most important criteria with regard to passenger choice between a non-stop and a connecting flight, and network characteristics that will affect the outcomes of the entry. The following parameters were calibrated:

- Disutility costs associated with connections
- Disutility costs associated with replanning
- Elapsed time of LCC flight
- Disutility costs associated with airline preference
- LCC schedule

All parameters will be described and intuitively justified in the relevant section. As for the second parameter that is not self-explanatory, it results from the implementation of the Decision Window Model²¹ in PODS. Before entering the booking process, each passenger is pre-assigned a decision window that corresponds to his tolerance relative to departure and arrival time. If a path is outside this window, the passenger will consider the path as a relevant travel option but replanning disutility costs will be added to the generalized cost of this path.

Several categories of parameters can be defined according to the type of calibration they require. Disutilities associated with connections and replanning are inputs for which estimates can be found in the literature. Yet, their implementation might be challenging given the specificities of the passenger choice models embedded in PODS. Therefore, we will use the literature review performed in Chapter 2 to check the consistency and the order of magnitude of these parameters.

The elapsed time of LCC flights can be inferred from the characteristics of the routes operated in the network. The elapsed time of a flight is the absolute amount of time between departure and arrival, i.e. time zones are not taken into account. We will estimate the reduction in elapsed time achieved by a non-stop flight over a connecting flight on spoke-to-spoke routes. We will assume that this potential time advantage remains constant across the O-D markets between spoke cities. This assumption simplifies reality as each O-D market has specific geographic characteristics, but still confers a significant competitive advantage to the LCC competitor.

Finally, airline preference disutility and LCC schedule are parameters that require calibration as they are very reliant on the business case chosen for the purpose of the analysis. A preliminary literature review will provide benchmarks in terms of market shares to expect when 2 competitors provide flights with different levels of service (i.e. connecting vs. non-stop) in the same market. Airline preference

disutility will then be adjusted to reach these goals expressed in market shares. The LCC schedule will eventually be optimized so as to maximize LCC revenues.

a. Expected Market Shares

In introduction, it was shown that the calibration process will ultimately require a model that will determine the market shares of competitors offering different types of service in the same O-D market. **Clarke and Melconian**²⁷ developed a model that takes into account the heterogeneity of service offered in a given market as well as the preference of travelers for airlines with high frequency shares. The model was then calibrated by performing regression analyses on US airline markets served by non-stop and connecting flights.

The model is motivated by the most common market share model that gives markets shares as a function of frequency shares

$$MS_i = \frac{Freq_i^\alpha}{\sum_j Freq_j^\alpha}$$

where MS_i is the market share of airline i ; $Freq_i$ is the number of non-stop flights of carrier i in the market; and α is a coefficient accounting for the non-linear impacts of frequency shares on market shares

This initial model was extended to account for connecting and one-stop flights. A one-stop flight is a flight that makes one stop at an airport and then departs to its final destination. While a passenger on a one-stop flight does not have to change aircraft between departure and arrival, a traveler on a connecting flight must transfer to another aircraft at the hub. Hence, these lower quality flights were counted as a fraction of a non-stop flight according to the following formula:

$$Freq_i = Freq_{i\text{non-stop}} + a \cdot Freq_{i\text{one-stop}} + b \cdot Freq_{i\text{connecting}}$$

Historically, the formula has been used with coefficients $a=0.4$ and $b=0.1$. In order to check the relevance of these values, Clarke and Melconian performed two regression analyses on a set of selected markets. The main selection criterion was the removal or the gain of non-stop service between 1995 and 1999. Eventually, they obtained two models via a linear and a non-linear regression. The linear regression implies to assume that α is assumed equal to 1. The results are presented in Tables 10 and 11.

²⁷ Melconian, Clarke, *Effects of Increased Nonstop Routing on Airline Cost and Profit*, 2001

	Value	Standard Error	t-statistic
a (one-stop)	0.1748	0.0063	27.7
b (connection)	0.0129	0.0003	43

Table 10: Connecting Flight Value Linear Fit Results

	Value
a (one-stop)	0.1748
b (connection)	0.0129
α	1.107

Table 11: Connecting Flight Value Non-Linear Fit Results

The LCC entry into an O-D market originally served by a legacy carrier only is particularly adapted to these models. The condition of heterogeneity in service offered is indeed respected. Assuming legacy flights are one-stop flights, our base case consists of one O-D market originally served by 3 one-stop flights that gained one non-stop flight operated by the LCC. The following results are obtained from the two models previously presented in Table 12:

	Legacy Carrier	LCC
Linear Model	34.4%	65.6%
Non-linear Model	40.3%	59.7%

Table 12: Expected Market Shares in LCC Entry Base Case

b. Calibration Environment

The symmetric network is the framework used for calibration purposes. The initial case consists of the original legacy network where the LCC enters only the S01-S021 O-D market with one flight a day (see fig.11). The initial LCC schedule was determined based on results provided by the Decision Window Model and is shown in Table 13. LCC market coverage was maximum when the LCC flight was departing at the same time as the second daily legacy flight. Ultimately, the schedule will be optimized so as to maximize LCC revenues with the complete set of parameters previously calibrated.

Operator	Bank Number	Departure Time	Arrival time
Legacy Carrier	1	7:07	14:05
	2	10:36	17:35
	3	14:06	21:05
LCC	1	10:36	16:20

Table 13: Legacy and LCC Schedules (Central Time)

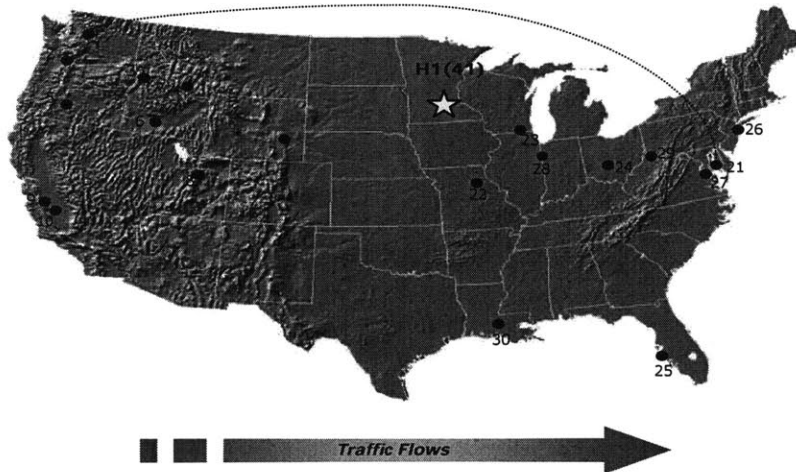


Figure 11: LCC Network in Calibration Environment

Because any asymmetry in Revenue Management systems could introduce bias in the calibration process, both legacy carrier and LCC are assumed to use the same standard optimization algorithm EMSRb coupled with time series forecasting (see Section 3.3). Over the last decade, these forecasts and algorithm have become standard across the airline industry worldwide. Nevertheless, the assumption of symmetry will be challenged in chapter 5.

Replanning disutility costs are set to their initially calibrated value, i.e. to \$73.50 for business travelers and \$14.9 for leisure passengers on average.

Airline preference utility costs are set to \$21 (business) and \$7 (leisure) in favor of the legacy carrier. These values are based on results provided by Prousaloglou and Koppelman¹⁴.

As a first conservative approximation, the elapsed time of the LCC flight is 1 hour and 15 minutes shorter than legacy flights on the same route. This value will be modified to be consistent with previous analyses of flight duration (see Section 2.3.e) and analyze the sensitivity of the results to this time advantage.

In the PODS environment, demand can be calibrated with a demand multiplier. In chapter 4, we will see the large impact of the total air travel demand on the outcome of LCC entrance. Therefore, the choice of the average load factor reported at the

network level is important and must be consistent with the calibration methods used. In his Master's thesis, **Strina**²⁸ analyzed the recent evolution of airline operational and econometric measures. He showed that the load factors reported by both the US Majors and the whole US airline industry were equal to 76%. Since our calibration process relies on the market share model which was updated based on airline statistics from the late 90's²¹, the PODS demand multiplier was modified to achieve a 70% load factor at the network level, i.e. for the legacy carrier. Moreover, this relatively low network load factor removes from the analysis all bias that is related to capacity constraints. Thus, the attractiveness of the LCC will not be boosted by the limit in capacity offered by the legacy carrier, which defines a better calibration basis.

Finally, we mention that load factors and revenues of the LCC are unreasonably low in the calibration process. Indeed, the calibration process is performed disregarding the demand stimulation due to the large fare decrease that will eventually be introduced by the LCC in Chapters 4 and 5.

c. Disutility costs associated with one connection

As stated in the section presenting the PODS simulator, the disutility costs associated with connection and replanning were calibrated by Lee²¹. As the environment of the US airline industry has significantly been modified since then, a review of the disutility costs associated with connections will be performed to check the consistency of this parameter with the most up-to-date estimates found in the literature.

As presented in Chapter 2, Adler, Falzarano and Spitz¹⁵ provide estimates of a wide range of disutility costs including the effects of number of connections. These estimates are summarized in Table 14. Thus, the next step will be to test these values and assess the accuracy of these coefficients in the PODS environment.

	Mean (\$)	Standard Deviation
# of connections (business trip)	69.7	39.2
# of connections (leisure traveler)	53.7	48.5

Table 14: Disutility Costs Distributions for Number of Connections

²⁸ Strina, *US Airline Industry Trends and Performance 1999-2204: Analysis of Form 41 Data*, 2006 (MIT thesis)

Calibration

Table 15 presents the connection disutility configurations tested. These cases were defined so as to fulfill two requirements:

- Business and non-business disutility costs are greater than the intercept value (See PODS Presentation section)
- Ratio of business over non-business disutility costs is constant and equal to the ratio computed with values found in the literature

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Business Trip	\$64.30	\$57.70	\$54.50	\$48.00	\$44.80	\$41.50	\$38.30	\$38.30
Leisure Trip	\$22.00	\$20.30	\$18.60	\$17.60	\$16.30	\$15.00	\$12.40	\$9.80

Table 15: Connection Disutility Costs by Passenger Type by Test Case

As stated in the first section of this chapter, the objective is to obtain a reasonable distribution of market shares as a function of the service offered by the airline, i.e. connecting vs. non-stop service, as well as a base case that corresponds to the present characteristics of the airline industry. In the case tests, global demand for air travel was first calibrated so that the average load factor over the original network was 70%. Then, the LCC flight was introduced and the effects of the entry were estimated in terms of market shares and number of carried passengers in the S01-S021 market.

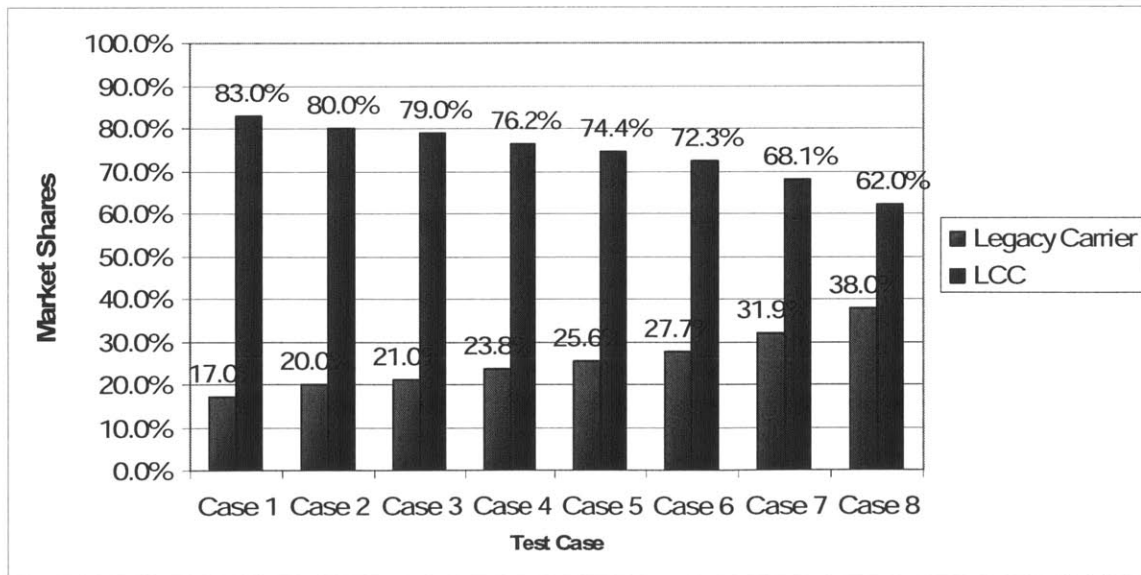


Figure 12: Market Shares by Competitor in S01-S21 Market (Connection Disutility Costs)

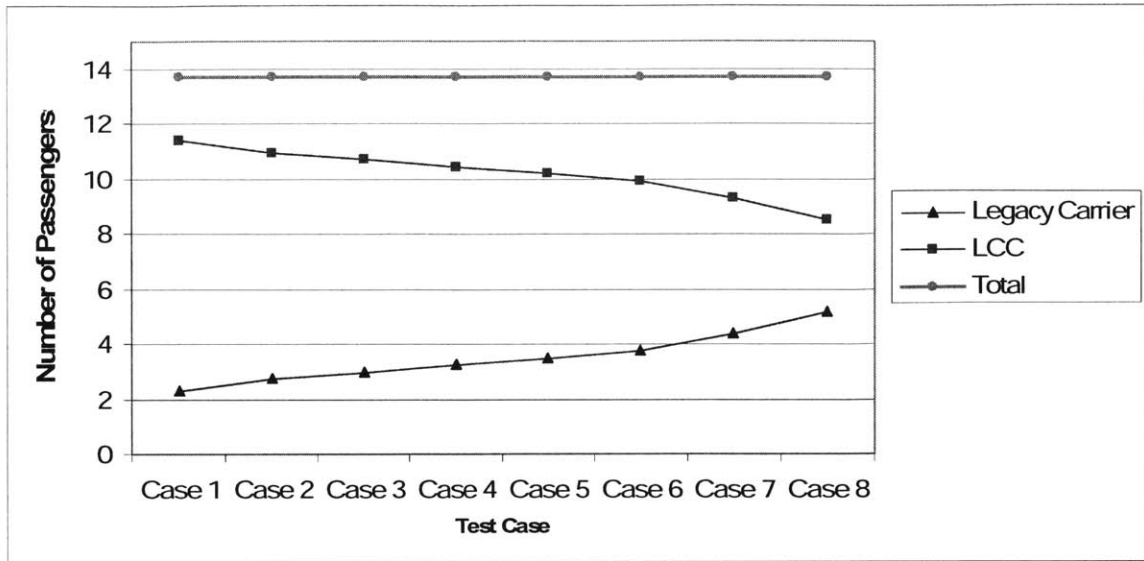


Figure 13: Daily Number of Passengers by Competitor in S01-S21 Market

As shown in Figures 12 and 13, the traffic performance of the legacy carrier is strongly affected by the disutility costs associated with connections. As one would expect, the percentage of passengers booking a ticket on a legacy flight decreases as connection disutility costs increase. In case 1, only 17% of the total number of S01-S21 passengers is carried via its hub while this share increases to 38% in case 8. The disutility cost estimates of Adler, Falzarano and Spitz were based on fares observed in the US airline industry between 2000 and 2003. Since 2000, fares have decreased by 18% on average. Moreover, Geslin (2005) showed that fares decreased by more than 30% in markets entered by LCCs between 2000 and 2004. Case 5 which corresponds to a 20% decrease as compared to disutility cost estimates of the literature seems to be the most appropriate value.

d. Effects of Replanning Disutility Costs

In the PODS environment, a decision window is assigned to each passenger entering the booking process. The decision window is the period of the day preferred by the traveler willing to depart and arrive within this window. In the PODS booking process, a path that does not fit into the passenger decision window is still considered as a relevant travel option but a replanning disutility cost is added to the total generalized cost of the associated ticket.

Unfortunately, the literature does not provide any estimate of the replanning disutility costs as most models presented in scientific articles assume the existence of an ideal departure time. A disutility associated with schedule time difference accounts for the costs of departing earlier or later than the ideal departure time. This disutility cost is estimated by hour of displacement. For instance, the results of the Adler, Falzarano and Spitz analysis with regard to schedule time difference disutility are presented in Tables 3 and 4. Their estimates for the mean disutility costs associated with schedule time difference are about \$30 and \$5. In Chapter 2, we

present the results of Proussaloglou and Koppelman who conducted a customer survey and determined that one hour of displacement cost \$60 for a business and \$17 for a leisure passenger.

As PODS is based on a different travel time decision model, these previous references could not be directly implemented in the base case input. Even though the initial replanning disutility costs had been calibrated by the PODS consortium originally (see Lee²¹), the objective of the calibration was to check the relevance of these initial values.

The ratio of business over leisure replanning disutility was the first point of investigation. While the Proussaloglou and Koppelman ratio was 3.5, the Adler, Falzarano and Spitz ratio was 6. The data used by these two groups of researchers were not contemporary, which may explain the gap in the values they determined. With an initial ratio of 5, the initial PODS settings seemed to be a reasonable and conservative choice. Then, an analysis was performed in order to determine the sensitivity of market shares to replanning disutility. The base case was similar to the first one used to calibrate disutility costs associated with a connection. However, the disutility costs associated with one connection were set to \$44.80 and \$16.30 respectively for business and leisure traffic as a result of the first calibration step. The cases tested are presented in Table 16.

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Business Trip	\$54.00	\$60.50	\$67.00	\$73.50	\$80.00	\$86.50
Leisure Trip	\$11.00	\$12.30	\$13.60	\$14.90	\$16.20	\$17.50

Table 16: Replanning Disutility Costs by Passenger Type by Test Case

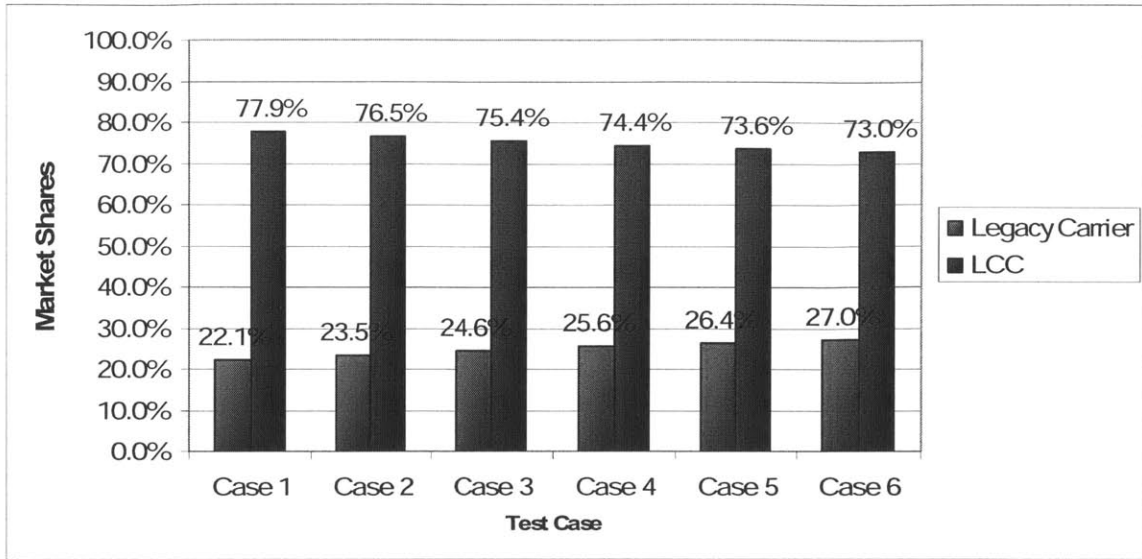


Figure 14: Comparison of Market Shares by Competitor in S01-S21 Market (Replanning Disutility Costs)

The range of values tested was selected to be consistent with the estimates of schedule time difference disutility found in the literature. Indeed, both ideal departure time and DWM models are correlated and a relation between the disutilities of these models must exist. If we estimated the average schedule displacement time of a passenger considering travel alternatives outside his preferred decision window in the DWM environment, the schedule time difference multiplied by this displacement should give the DWM replanning disutility cost. Hence, the test cases are equivalent to an average schedule displacement between 1.8 and 2.8 hours for business passengers, and between 2.3 and 3.6 for leisure travelers²⁹. In the base case, the legacy carrier operates flights departing at regular intervals of 3 hours and the elapsed time between the first and the last daily flight is 6 hours. The range of values tested is therefore appropriate to the case analyzed.

As compared to connection disutility, the sensitivity of the results to replanning disutility costs is smaller. Based on Figure 14, market shares change to a greater extent when leisure connection disutility is increased by \$1 than leisure replanning disutility.

The initial replanning disutility cost setting, i.e. case 4, was selected for two reasons. First, the equivalent schedule displacement equal to 2.5 hours for business passengers and 3 hours for leisure passengers seemed reasonable based on the legacy carrier schedule and the time position of the LCC flight, which departs at the same time as the second daily legacy flight. Then, the relatively low sensitivity of results to replanning costs dissipated the need for a very precise replanning disutility cost estimate that could have significant negative impacts on the final results.

²⁹ In this case, schedule time difference disutility referred to the Adler, Falzarano and Spitz analysis

e. Effects of Reduction in LCC Flight Duration

Initially, the flight duration of the LCC flight was set equal to the sum of the two flight durations of the legs S01-H1 and H1-S21, minus 15 minutes. This overestimated value must be adjusted to reflect the real operating advantage of non-stop flights over connecting flights.

Three factors play a key role in the reduction of flight duration. First and foremost, non-stop flights do not experience connecting time at hub. Second, the aircraft on a non-stop route performs one take-off and one landing while a connecting airplane performs two of each of these operations. Because speed is reduced in the initial climb after take-off and the final descent, the non-stop aircraft requires less time to travel the same distance. Finally, the routing of the aircraft can be optimized and flight distance can be reduced as the hub cannot lie on the shortest path joining the spoke cities of its network. The second factor will result in a significant decrease in flight duration as well.

The calibration tests were performed with the following set of parameters:

- Optimized connection disutility costs set to \$44.80 (business), \$16.30 (leisure)
- Optimized replanning disutility costs set to \$73.50 (business), \$14.90 (leisure)
- Airline preference utility costs set to \$21 (business) and \$7 (leisure) in favor of the legacy carrier
- Initial LCC schedule

Operator	Bank Number	Departure Time	Arrival time
Legacy Carrier	1	7:07	14:05
	2	10:36	17:35
	3	14:06	21:05
LCC	1	10:36	15:50

*Table 17: Legacy and LCC Schedule
(LCC Flight Duration 5h15)*

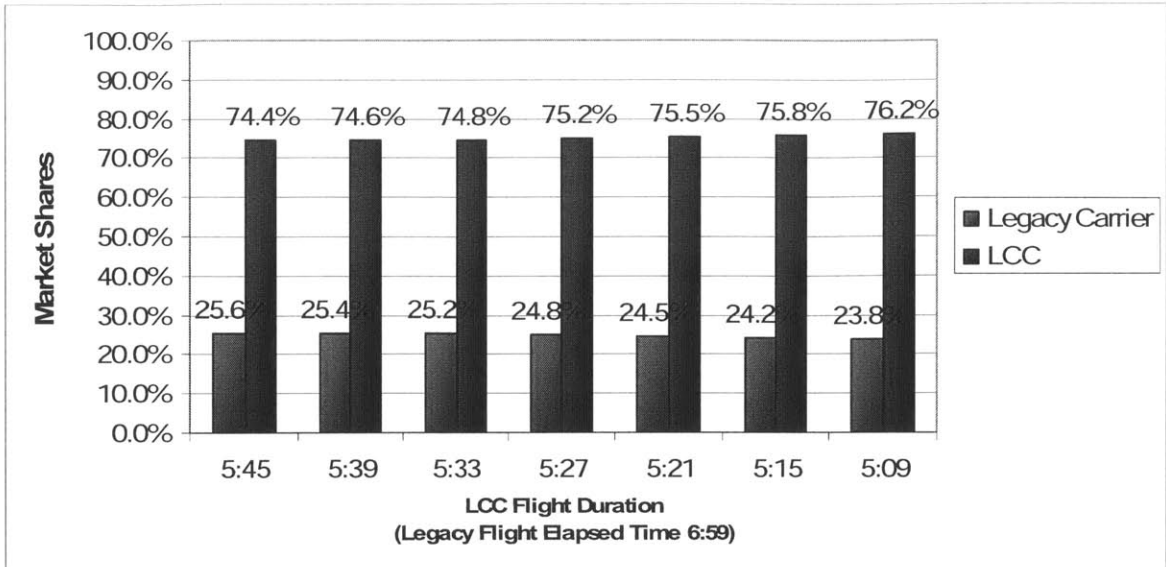


Figure 15: Comparison of Market Shares by Competitor in S01-S21 Market

Results presented in Figure 15 show that market shares are not very sensitive to flight duration. However, this factor might be crucial for further steps of the calibration process, including the optimization of the LCC schedule.

Based on the schedule of the legacy carrier, the determination of the time gain due to connecting time at the hub is simple. In the base case, this gain is equal to 1 hour. Estimates related to take-off and landing durations can be found in the literature. In his PhD thesis, **Schorr**³⁰ performed a regression analysis using published schedule data in order to relate scheduled block time with aircraft speed and flight distance. Letting d be the flight distance and v the cruise speed, the following formula was established:

$$BlockHours(d,v) = 0.5944 + 1.0562 \cdot \frac{d}{v}$$

The intercept can be interpreted as the BlockHour time due to the performance of take-off and landing operations. Thus, 0.5944 hour or roughly 35 minutes is then a satisfactory approximation of what one could expect from the reduction in LCC flight duration due to one less take-off and one less landing. In the third and fourth chapter of this thesis, most of the markets entered by the LCC are aligned with the legacy hub H1. Therefore, a reduction of 1 hour and 45 minutes in LCC flight duration appeared to be conservative but reasonable given the structure of the air networks used.

³⁰ Schorr, *Aviation Infrastructure Pricing*, 2006 (MIT Thesis)

f. Effects of Airline Preference Disutility Costs

The airline preference disutility regroups a string of factors that will affect the traveler decision process but do not refer to the previously calibrated parameters such as flight times, flight duration, connections and price. Given the recent large reductions in costs of the US airline industry following 9/11, onboard service offered by legacy carriers in coach class cannot be viewed as a persuasive sales argument. However, legacy airlines continue to make big investments in their loyalty programs, and increase the distribution channels via websites like Orbitz in order to attract customers to their systems. Indeed, these marketing strategies have met with a significant success over the last decade.

All travelers are not familiar with the plethora of websites offering air tickets. As customers tend to focus their web search on a limited number of websites, legacy carriers sell tickets on the best known ones, which must stimulate demand for legacy flights. Moreover, Frequent Flyer programs have been very successful in enhancing customer loyalty. This commercial success led to the expansion of air alliances enabling travelers to accumulate miles and increase loyalty further.

On one hand, Adler, Falzarano and Spitz estimated utility costs related to the size of the carrier in the market considered. Their results are presented in Tables 3 and 4 and show that these costs are very significant. On the other hand, Proussaloglou and Koppelman looked at the problem from a different perspective and considered the effects of loyalty programs only. The results are consistent with the more recent analysis of Adler as the ratio between business and leisure disutility costs is close to 3. Therefore, we decided to perform the sensitivity analysis with regard to airline preference disutility by choosing a constant ratio of 3 between business and leisure disutility, and determine the value for which the market shares of the legacy carrier will be consistent with the results given by the formula developed by Clarke and Melconian. The cases tested are presented in Table 18.

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Business Trip	\$21.00	\$25.00	\$30.00	\$35.00	\$40.00	\$45.00	\$50.00
Leisure Trip	\$7.00	\$8.30	\$10.00	\$11.70	\$13.30	\$15.00	\$16.70

Table 18: Airline Preference Disutility Costs by Passenger Type by Test Case

The calibration tests were performed with the following set of parameters:

- Optimized connection disutility costs set to \$44.8 (business), \$16.3 (leisure)
- Optimized replanning disutility costs set to \$73.5 (business), \$14.9 (leisure)
- Initial LCC departure time
- 1h45 reduction in LCC flight duration

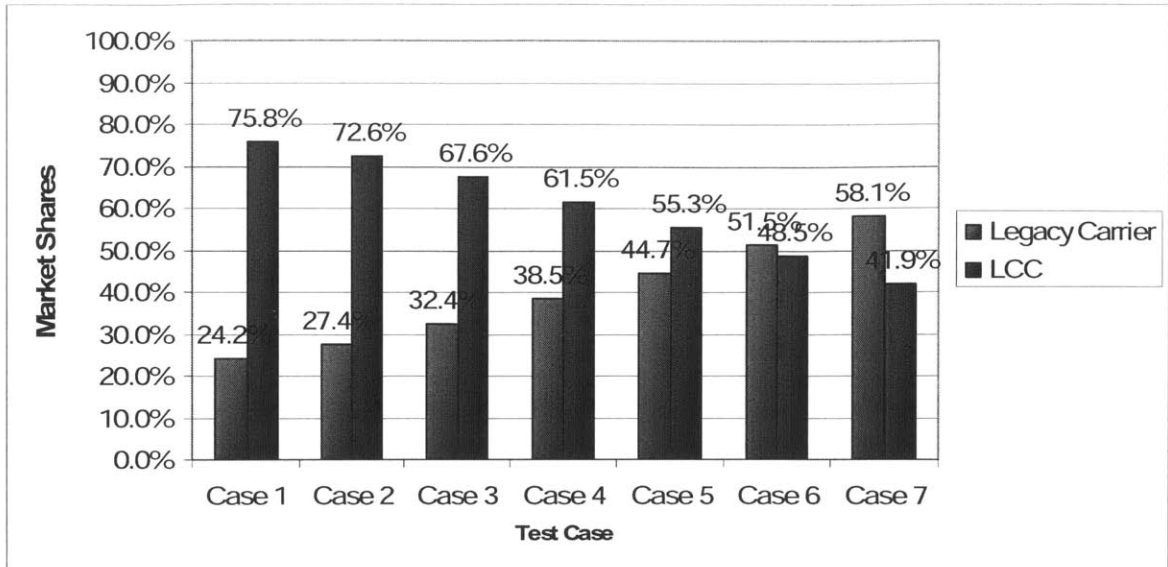


Figure 16: Comparison of Market Shares by Competitor in S01-S21 Market (Airline Preference Disutility Costs)

As shown in Figure 16, the sensitivity of results to airline preference disutility is greater than for other input parameters calibrated previously. In fact, airline preference disutility is the last most important parameter slightly adjusted in order to be consistent with the objective in market shares set by the Clarke and Melconian analysis. LCC market shares are expected to be between 34.4% and 40.3%. Based on Figure 11, an airline preference disutility of \$35 for business travelers seems to be the most appropriate setting (case 4).

The magnitude of this disutility cost can be intuitively justified. Assuming that frequent flyer programs are the biggest incentives for business travelers to choose their preferred airline, and that these programs usually require the purchase of five tickets to get one for free, the disutility value means that business passengers are willing to pay 44% of the "free" ticket since a one-way Y business fare costs about \$400 (see 2.2.b).

g. LCC Schedule

The final step of the calibration consists of determining the LCC schedule defined as revenue-maximizing for the LCC. The initial settings were determined by maximizing the market coverage of the LCC flight with the Decision Window Model given the legacy schedule. The subsequent simulation results show that the initial schedule, i.e. with the LCC flight departing at the same time as the second daily legacy flight, was indeed maximizing LCC revenues in the PODS environment.

The calibration tests were performed with the following set of parameters:

- Optimized connection disutility costs set to \$44.80 (business), \$16.30 (leisure)
- Optimized replanning disutility costs set to \$73.50 (business), \$14.90 (leisure)
- Optimized airline preference utility costs set to \$35 (business) and \$11.70 (leisure)
- 1h45 reduction in LCC flight duration

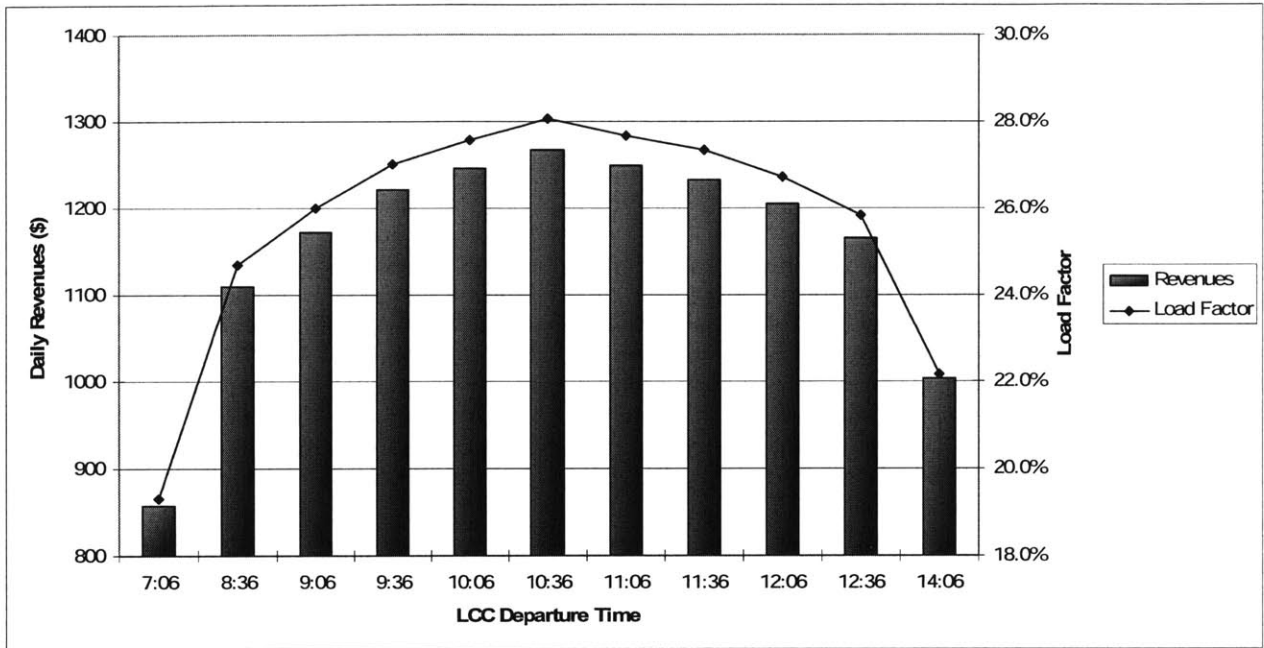


Figure 17: Comparison of Market Shares by Competitor in S01-S21 Market (LCC schedule)

Figure 17 shows that a LCC flight departing at the same time as the second daily legacy flight maximizes LCC revenues peaking at \$1267 per day. In the rest of the thesis, the LCC flight will therefore depart at the same time than the second daily legacy flight when only one LCC flight is operated in the O-D market. Table 19 gives an example of appropriate legacy and LCC schedules.

Operator	Bank Number	Departure Time	Arrival time
Legacy Carrier	1	7:07	14:05
	2	10:36	17:35
	3	14:06	21:05
LCC	1	10:36	15:50

Table 19: Legacy and LCC Schedules with 1 LCC Flight per Day Example in S01-S21 Market

h. Summary

The findings of Chapter 3 are summarized in Table 20. All required parameters were calibrated to build a realistic model of passenger behavior with consistent disutility costs, and achieve the objective in terms of market shares set by the Clarke and Melconian analysis.

In PODS, connection disutility costs can refer to two factors involved in the connecting process. The first is the disutility associated with the inconvenience related to the connection, i.e. a passenger must move from an aircraft to another, turn off his laptop and carry his bags across the terminal. The second is the risk of losing his luggage and missing the connecting flight. The magnitude of the calibrated connection disutility values, which have means of \$44.80 and \$16.30 respectively for business and leisure passengers, is reasonable given the potential risks and inconvenience enhanced by congestion in the US air network and the numerous alternatives offered by expanding non-stop service.

In Chapters 4 and 5, the initial values of replanning disutility costs calibrated by Lee will remain unchanged. The consistency of these values can be checked by order of magnitude calculations as well. Assume a business traveler whose salary is \$75 000, this passenger works 50 weeks a year and about 40 hours a week. Therefore, an hour of his working time is worth about \$37.50. Setting replanning disutility costs to \$73.50 for business passengers is equivalent to fixing a penalty of 2 hours of work to a flight that is located outside the passenger decision window. Given the legacy schedule with flights spaced every 3.5 hours, the magnitude of replanning disutility costs is correct.

In Section 3.3.e, we showed that airline preference disutility costs solely due to frequent flier programs means that business passengers are willing to pay 44% of the "free" ticket offered after 5 purchases, which is realistic of the current marketing attractiveness of these programs.

Finally, LCC flight time and schedule were determined by following scientific methodologies that do not cast any doubt on the consistency of these results.

	Business Passengers	Leisure Passengers
Connection Disutility Costs	\$44.80	\$16.30
Replanning Disutility Costs	\$73.50	\$14.90
Airline Preference Disutility Costs	\$35.00	\$11.70
Reduction in LCC Flight Time	1:45	1:45
LCC Departure Time	10:36	10:36

Table 20: Summary Table of Calibrated Parameters

4. Impacts of LCC Entry in a Symmetric Legacy Network

In Chapter 3, we developed and used a methodology to calibrate the Passenger Decision Model embedded in PODS so that it will simulate passengers' choices between LCC non-stop flights and legacy connecting flights realistically. Chapter 4 presents the results associated with LCC entry in the symmetric legacy network described in Section 3.3.a. The analysis will focus on the amount of traffic captured by the LCC, the average fare in the markets entered by the LCC, and the aggregate statistics of both carriers including revenue and load factor.

First, we will define a base case of LCC entry. Indeed, the introduction of LCC operations must be combined with a significant decrease in fares stimulating demand. We will perform sensitivity analysis by gradually decreasing fares in one market entered by the LCC, check the consistency of PODS demand stimulation with real LCC entry cases, and select the most appropriate fare decrease. In fact, each O-D market of a real airline network has its own specificities as demand elasticity varies between markets and changes across time as well. In this thesis, we will focus on *LCC entry cases with high demand stimulation*.

Then, we will analyze the impact of a LCC entering multiple legacy markets with one non-stop flight per day. The LCC strategy will be described and we will examine the statistics at several levels, including the market and the network level. Finally, we will increase the frequency of LCC operations in the markets entered by the low-cost airline and determine to which extent the results differ from the entry scenario with single LCC frequency.

4.1. Calibration of Base Case

a. Demand Stimulation Analysis

In Chapter 3, we defined a symmetric network with specific demand levels so that the legacy network load factor would be approximately 70%. The objective was to remove bias related to capacity constraints from the calibration process. However, such a load factor is unrealistic (see Strina²⁸) and underestimates the current load factor within the US. Indeed, the average load factor for the entire US air network is 77.5%³¹. As the increase in the average load factor of the US airline industry is also likely to continue in the foreseeable future, we modified the demand levels of the symmetric network to achieve an 87% load factor on the network level. Table 21 presents the base fare demands between spoke cities and between spoke city and hub, as well as the associated base fares.

³¹ U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information, *Airline Industry Traffic Statistics*, January 2006

Although the network load factor chosen may seem high, the order of magnitude is not only justified by recently reported load factors in some markets of the US airline industry, but also necessary due to the use of a symmetric network as a base case in which each spoke-to-spoke market is a potential target for the LCC. The base case must define a framework where LCC operations are sustainable against legacy competition in each market, which implies that all markets between spoke cities must be of significant size.

	Mean Business Base Fare Demand	Mean Leisure Base Fare Demand	Total
Between Spoke Cities	6.52	12.12	18.64
Between Spoke City and Hub	35.00	70.00	105
Base Fare	\$325.00	\$130.00	

Table 21: Air Travel Demands at Base Fare

The base case will be calibrated by introducing LCC operations in the S01-S21 market (see map in Section 3.3.a). As in the conclusion of chapter 3, the LCC enters the S01-S21 market by operating one flight a day departing at the same time as the second legacy flight. The associated schedule is presented in Table 19 and shows that the total LCC flight time is 1h45 shorter than for the legacy connecting flights. All parameters involved in the passenger decision process are set to the values previously calibrated in Chapter 3.

The initial fare structure and statistics for the S01-S21 market without LCC operation are presented in Tables 22 and 23. The fare structure is composed of six booking classes with a fare ratio of 3.4. As the legacy carrier operates three flights a day between each spoke city and its hub H1, we define *new aggregate load factor measures*, i.e. the load factors associated with the legs S01-Hub and the legs Hub-S21, to analyze the impact of LCC operations at the S01-S21 market level. The load factor of the legs S01-Hub is defined as the average of the load factors reported by the legacy carrier for the 3 daily legs between S01 and H1. Similarly, the load factor of the legs Hub-S21 is the average of the load factors for the 3 daily legacy legs between H1 and S21.

Unsurprisingly, the load factors of both legs S01-Hub and legs Hub-S21 are very close to the 87% network load factor reported by the legacy carrier since the network is symmetric. The average fare in the market equals \$163, which is 34% greater than the lowest fare. Indeed, the revenue management system of the legacy carrier limits the bookings of potential S01-S21 passengers by closing low fare classes to improve revenue. As a result, the reported traffic is 14% lower than the base fare demand of 18.6 passengers.

Class	1	2	3	4	5	6
Fare	407.59	297.30	191.81	167.83	143.86	119.88

Table 22: Initial Fare Structure in S01-S21 Market

	S01-S21 Market Traffic	Average Fare S01-S21 Market	Load Factor Legs S01-Hub	Load Factor Legs Hub-S21
Legacy Carrier	16.1	\$163.10	86.12%	86.28%
LCC	/	/	/	/
Total	16.1	\$163.10	/	/

Table 23: Traffic and Revenue Statistics for the S01-S21 Market

In a second case, one daily LCC flight is introduced with no change to the initial fare structure. As the legacy carrier is assumed to match the competition, both carriers apply the same set of fares to their products presented in Table 24. The associated statistical results are shown in Table 25. A large proportion of the S01-S21 traffic is now carried by the LCC whose market share is 71%. This value is higher than the market share obtained by the LCC after the final calibration step in chapter 3. Indeed, the network load factor of the legacy carrier is greater, which allows the legacy revenue management system to continue to close low fare classes of the S01-S21 flights early in the booking process even in presence of the LCC. As the legs S01-Hub and Hub-S21 are used to serve other markets than S01-S21, the loss of traffic due to the LCC competition in S01-S21 can be partially compensated by travelers booking in other markets. Thus, the legacy carrier can remain aggressive in closing low fare classes. This hypothesis is corroborated by the increase in the legacy average fare from \$163 to \$168 as compared to the previous case with no LCC operation.

Since the load factor reported by the LCC is only 45%, the new competitor has a weaker pricing power than the incumbent which benefits from the shared utilization of its legs serving multiple markets. Indeed, load factors for both the legacy legs S01-Hub and legs Hub-S21 are still close to 86% even with a reduced 29% market share in S01-S21. This structural difference causes the LCC average fare to be \$19 lower than its competitor's.

The total number of passengers in the S01-S21 market is slightly greater than the total base fare demand. This result is due to the lowest fare in S01-S21 that is lower than the base fare (see Section 3.2.d). However, the 45% load factor reported by the LCC confirms that a low-cost operation is not realistic if not combined with a significant fare decrease triggering demand stimulation.

Class	1	2	3	4	5	6
Fare	407.59	297.30	191.81	167.83	143.86	119.88

Table 24: Initial Fare Structure in S01-S21 Market
Legacy Carrier and LCC

	S01-S21 Market Traffic	Average Fare S01-S21 Market	Load Factor Legs S01-Hub	Load Factor Legs Hub-S21
Legacy Carrier	5.6	\$168.40	86.15%	85.79%
LCC	13.5	\$149.30	44.88%	/
Total	19.0	\$154.90	/	/

Table 25: Traffic and Revenue Statistics for the S01-S21 Market

The third case corresponds to a 20% decrease in the initial set of fares. The new set is presented in Table 26 and applied to the products of both carriers. Table 27 includes the associated traffic and fare statistics. As compared to the first case with no LCC operation, the total market average fare decreases by 24% while total traffic increases by 82% in the S01-S21 market. These first results show that the PODS demand model with the current e-mult parameters results in substantial demand stimulation, which is the objective stated in the introduction of Chapter 4.

As compared to the previous case with higher fares, the reported traffic of both carriers increases. The LCC load factor is close to 67%, which is more realistic for sustainable operations than the 45% load factor without price stimulation. However, the number of S01-S21 passengers carried by the legacy airline does not reach its initial level when LCC did not compete in the market.

The average fares of both the LCC and the legacy carrier are greatly reduced as compared to the previous case with no fare decrease. The legacy average fare is down from \$168 to \$138, which is equivalent to an 18% decrease. Similarly, the LCC average fare decreased from \$149 to \$119, or 31%. The difference between LCC and legacy average fare remains constant at \$19, which is significant and related to the shared use of legacy legs by multiple markets as in the previous case.

In terms of market share, the legacy carrier reports a greater proportion of S01-S21 bookings than in the previous case. Indeed, the legacy market share is about 32%. As the LCC load factor increases, we observe a greater number of simulated days in which the LCC flight is full. Consequently, the legacy carrier takes advantage of limited LCC offer on these days with high demand, which leads to a higher market share in S01-S21.

Class	1	2	3	4	5	6
Fare	326.00	238.00	153.00	134.00	115.00	96.00

Table 26: Initial Fares Decreased by 20% in S01-S21 Market Legacy Carrier and LCC

	S01-S21 Market Traffic	Average Fare S01-S21 Market	Load Factor Legs S01-Hub	Load Factor Legs Hub-S21
Legacy Carrier	9.4	\$138.40	86.37%	86.17%
LCC	19.9	\$119.20	66.49%	/
Total	29.3	\$125.40	/	/

Table 27: Traffic and Revenue Statistics for the S01-S21 Market

Finally, Tables 28 and 29 present the results associated with a 40% decrease in fares. The total number of passengers carried in S01-S21 is up to 48.2, which represents a 200% increase as compared to the initial case with no LCC operation. This increase is great and close to the upper bound of one would expect from a 40% decrease in fares. In the conclusion of this section, we will see that such an increase in demand is uncommon but realistic, and has been observed in the US and Europe when low-cost flights were introduced.

The surge in demand pushes the LCC load factor up to 88%. As a result of this limited LCC capacity, more S01-S21 passengers turn to the legacy carrier to book a flight. As compared to the previous case with a 20% fare decrease, the LCC traffic increases by about 6 passengers only whereas the legacy carrier reports on average 12 more passengers per simulated day. The legacy market share is 45%, which is a significant shift from the initial 29% legacy market share with the initial fare structure.

The decrease in fares in the S01-S21 market is reflected in the average fares reported by both the LCC and the legacy carrier. These fares are respectively 40% and 46% lower than the values in the initial fare structure. In the end, the introduction of LCC operations combined with a 40% fare decrease results in a 40.4% decrease in average fare on the market level.

Class	1	2	3	4	5	6
Fare	245.00	178.00	115.00	101.00	86.00	72.00

Table 28: Initial Fares Decreased by 40% in S01-S21 Market Legacy Carrier and LCC

	S01-S21 Market Traffic	Average Fare S01-S21 Market	Load Factor Legs S01-Hub	Load Factor Legs Hub-S21
Legacy Carrier	21.8	\$107.10	87.27%	87.59%
LCC	26.4	\$89.10	88.16%	/
Total	48.2	\$97.20	/	/

Table 29: Traffic and Revenue Statistics for the S01-S21 Market

b. Conclusion

In the PODS environment, demand stimulation is primarily determined by the e-mult multiplier inputs to the Passenger Decision Model (see Section 3.2.d). As shown in the previous section, the calibrated parameters lead to a great increase in demand when LCC flights are introduced and fares are decreased. Indeed, a 23.1% decrease in average fare results in an 82% increase in traffic, and a 40.4% decrease triples traffic of the S01-S21 market. Table 30 summarizes the results of the demand stimulation analysis.

	Mean LCC Traffic	LCC Average Fare	LCC Market Share
No Fare Decrease	13.46	\$149.28	71%
10% Fare Decrease	16.67	\$133.44	70%
20% Fare Decrease	19.95	\$119.21	68%
30% Fare Decrease	23.66	\$104.46	63%
40% Fare Decrease	26.45	\$89.05	55%

Table 30: Summary Chart of Low-Cost Entry Case in S01-S21

The intent of the thesis is to build a framework of analysis for LCC entry cases with high demand stimulation. The demand stimulation analysis performed in Section *a* showed that demand is elastic in the markets of the symmetric network. However, the definition of a base case requires us to check the consistency of the demand stimulation magnitude with real entry cases. In her analysis, **Perry**³² provides benchmarks for traffic stimulation following the introduction of low-fare airline service. She selected O-D markets in the US where LCC service was introduced between 1993 and 1994, and determined the decrease in average fare as well as the increase in the annual number of passengers. Table 31 includes a summary of these results, which shows that demand elasticity is very heterogeneous across O-D markets in the US.

³² Linda J. Perry, *The Response of Major Airlines to Low-Cost Airlines*, The Handbook of Airline Economics, 2nd Edition

Low-fare Airline Market	Annual Origin-Destination Passengers Percent Increase	Average One-Way Airline Fare Percent Decrease
Salt Lake City to San Diego	281%	45%
Phoenix to Burbank	121%	30%
Seattle to Spokane	86%	45%
Atlanta to Orlando	75%	44%

*Table 31: Decrease in Average Fare and Demand Surge
In selected US Markets between 1993 and 1994*

Based on the benchmarks provided by the Perry analysis, the demand stimulation observed in PODS with the current settings and 40.4% decrease in average fare is aggressive but plausible. As we intent to simulate entry cases with high demand stimulation, we will select the case where the initial set of fares is decreased by 40% as the base case for further investigation.

4.2. 1 LCC Hublet with Single Frequency

In the previous section, we determined a base case specifying the decrease in fares implemented in the markets entered by the LCC. As the legacy carrier is assumed to match the fares offered by any competitor, the fare decrease will always be applied to both the legacy carrier and the LCC in the markets where low-fare service is offered. This major assumption will never be changed in the rest of the thesis, which will focus on investigating the impact of expanding LCC operations in terms of traffic and revenue.

The first LCC strategy will consist of entering spoke-to-spoke markets with one flight a day departing from a single spoke city called "hublet". Figure 18 illustrates this strategy with a LCC operating 6 non-stop flights from the hublet S01. As for the order of entrance, S01-S21 will be entered first, S01-S22 second, etc... The S01-S30 will therefore be the last market entered. At the network level, O-D demands are based on the values presented in Table 21. As in the previous section, the initial network load factor of the legacy carrier will be 87%. In all LCC markets, the flight operated by the low-fare airline will depart at the same time as the second daily legacy flight. The Passenger Decision Model will remain calibrated to the values determined in Chapter 3, which includes the 1 hour 45 minute reduction in the travel time associated with LCC. Finally, a 40% decrease in the initial set of fares will be implemented in the markets entered by the LCC.

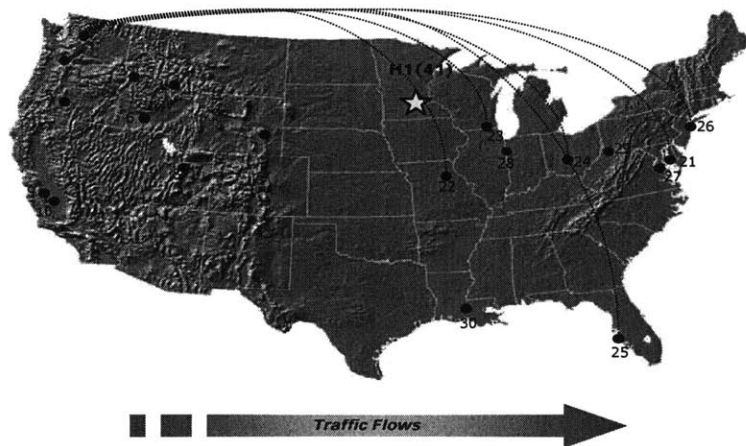


Figure 18: LCC Network with 1 Hublet S01

In this section, the statistics with regard to traffic and revenue will focus both on the market and the network level. To analyze statistics at an *intermediate level*, we introduce two measures referring to the load factor and the average fare of the group "legacy legs ex-S01". The load factor of the legs ex-S01 is defined as the average of the three legacy legs between S01 and H1. The average fare of the legs ex-S01 is defined as the total revenue generated by all markets with origin S01, including S01-H1 (11 markets in total), divided by the corresponding number of passengers.

a. Network Statistics

Following the LCC entry strategy described in the previous section, we gradually introduced up to ten LCC flights departing from S01 to ten different spoke cities. Figure 19 shows the revenue of the legacy carrier and the LCC at the network level.

On one hand, the increase in LCC revenue is quasi-linear. As the network is totally symmetric in terms of demand between spoke cities, this result is unsurprising. On the other hand, the changes in legacy network revenue are uneven and reflect network effects due to hub operations. In this configuration, a carrier operating legs serving multiple markets may use available seats in multiple ways. Further analysis at the market level will show that revenue and traffic associated with all markets ex-S01 both decrease when a LCC flight is added to the network. Thus, irregular changes in legacy network revenue indicate that the revenue management system of the legacy carrier takes advantage of these extra seats for supplying other markets than O-D pairs with origin S01.

In the end, low-fare operations affect legacy network revenues negatively although legacy revenue may sporadically increase or remain stable when another LCC flight is introduced. After the introduction of 10 LCC flights from S01, the legacy carrier reports a 1.2% drop in revenue.

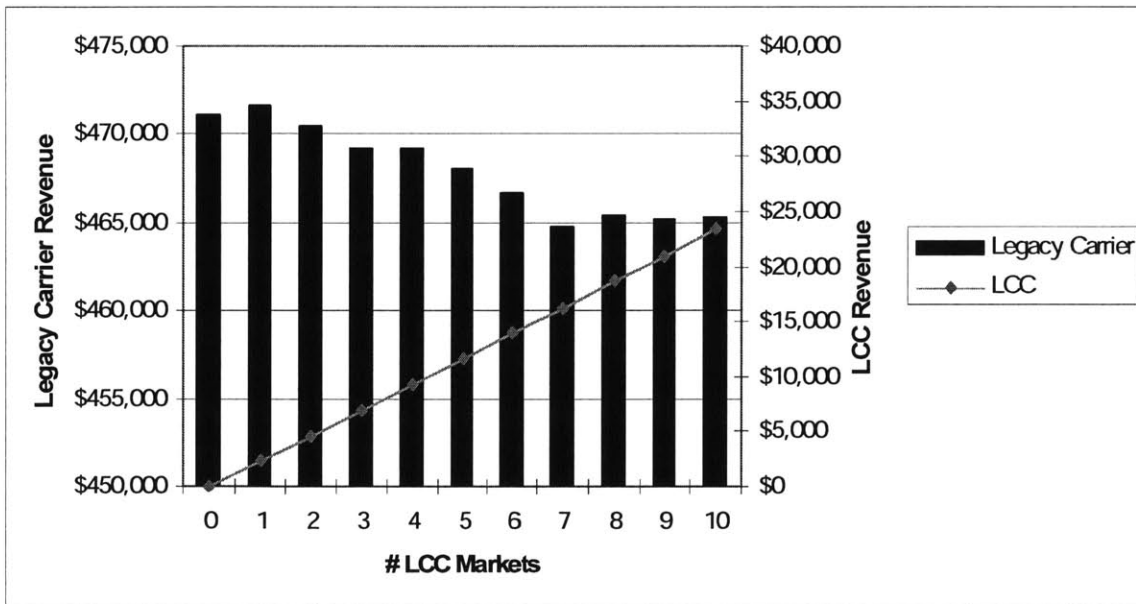


Figure 19: Legacy and LCC Revenues

In terms of load factor, Figure 20 shows that load factor changes greatly differ between the legacy carrier and the LCC. While the legacy airline reports a load factor approximately constant around 87%, the LCC seems to benefit from some extra demand as it expands its network to all markets served from S01.

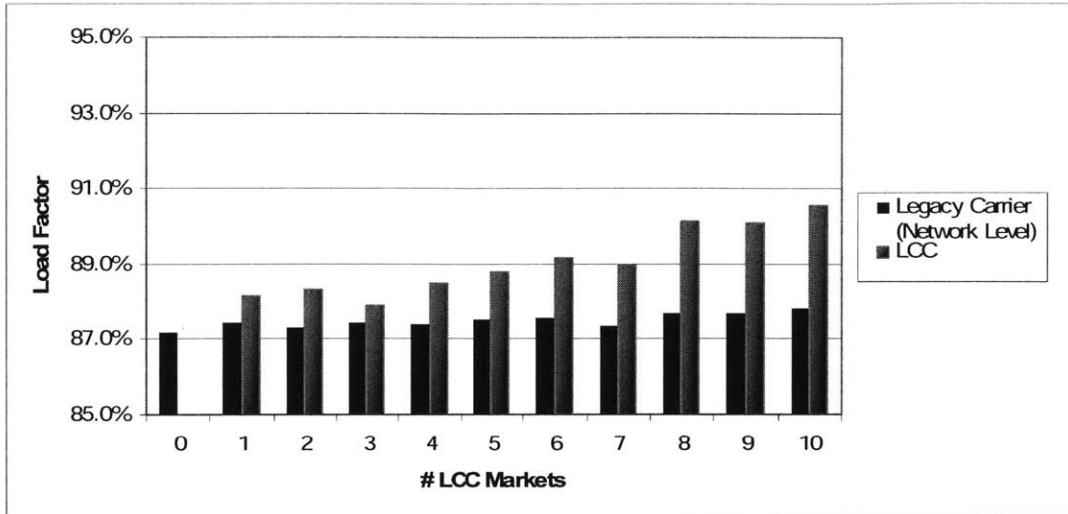


Figure 20: Legacy and LCC Network Load Factors

An intuitive explanation of the LCC increase in load factor may seem challenging as the legacy network is symmetric in terms of demand between spoke cities. In fact, this trend is caused by interactions between markets ex-S01 served by the legacy carrier. The analysis at the market level reveals that the introduction of one LCC flight per day combined with a 40% decrease in fares results in a significant increase in the demand for both carriers. This increase is illustrated by the initial leap in legacy load factor when the first LCC flight is introduced. As the LCC network expands, the aggregate legacy demand for the markets served by the three legs between S01 and H1 increases. However, seat inventory control is managed by the revenue management system of the legacy carrier, which achieves an approximately constant load factor to enhance revenues. When a new market is introduced by the LCC, the legacy carrier is therefore forced to spill an increasing number of passengers in the other markets departing from S01 in order to accommodate the soaring demand in the market newly entered. In the other markets, the passengers spilled by the legacy carrier confer a competitive advantage to the LCC because they can book on LCC flights only. As a result, the LCC load factor increases slightly as the low-fare network grows.

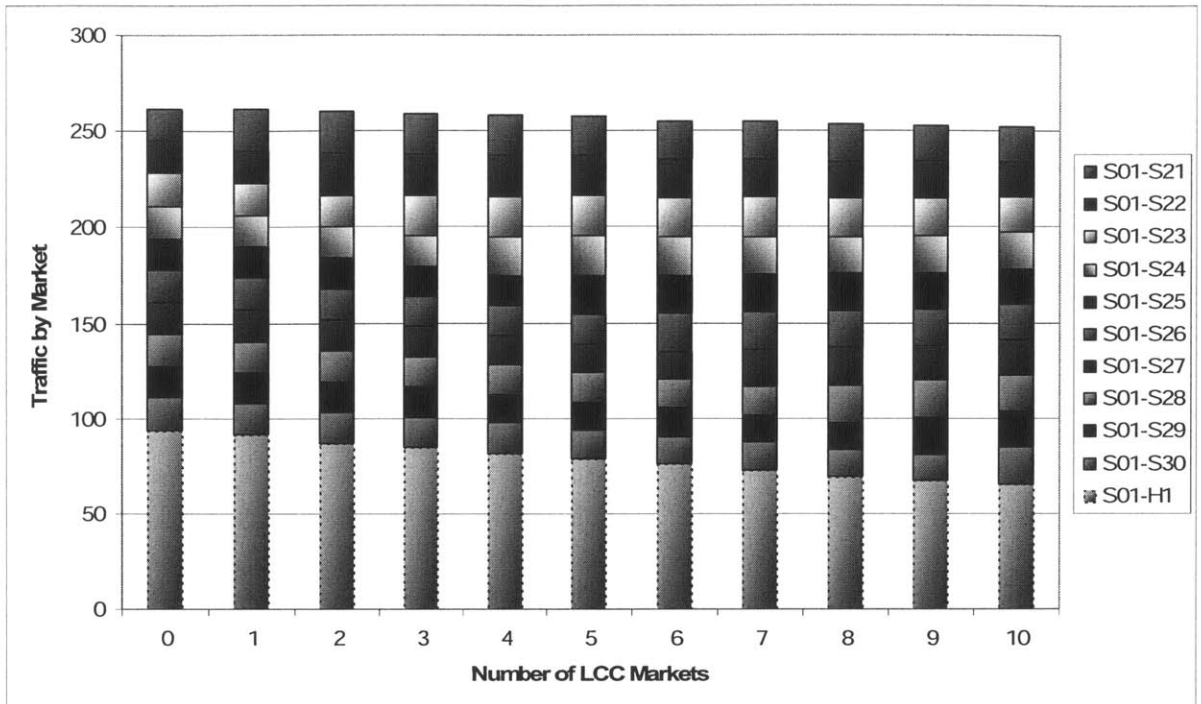


Figure 21: Legacy Traffic by Market ex-S01

Figure 21 illustrates the interactions between markets ex-S01 served by the legacy carrier when LCC flights are introduced and demand soars in the corresponding markets. In S01-S21, the legacy carrier traffic is about 22 passengers after the first LCC entry in this market. As the LCC network expands, the demand for legacy flights increases in the new spoke-to-spoke markets operated by the LCC. With a constant capacity and a revenue management achieving a constant load factor, the legacy carrier ultimately reports lower bookings in the S01-S21 markets when the LCC operates ten flights a day from S01. In the end, the legacy airline carries about 18 passengers in S01-S21 when the LCC operates in all spoke-to-spoke markets from S01. As the demand of the S01-S21 market has not changed since the first LCC introduction, more passengers book the LCC flight in this market, which affects the LCC aggregate load factor positively.

b. Statistics at Intermediate Level

As previously stated, we introduce two measures related to the "legacy legs ex-S01". The load factor of the legs ex-S01 is defined as the average of the three legacy legs between S01 and H1. The average fare of the legs ex-S01 is defined as the total revenue generated by all markets with origin S01, including S01-H1, divided by the corresponding number of passengers. These measures will allow us to investigate more aggregate impacts of expanding LCC operations.

Based on Figure 22, the analysis of the average fare for the legs ex-S01 shows that the legacy carrier reports an intuitive and continuous decrease as LCC flights are gradually introduced. Once the LCC competes in all spoke-to-spoke markets with origin S01, this average fare is down from \$142 to \$122. This 14% change is much smaller than the 40% fare decrease implemented in these markets, and is partially due to the protection of the S01-H1 market against the LCC, which competes only on spoke-to-spoke routes.

Then, the number of ex-S01 passengers decreases slightly as LCC flights are added to the network. In the previous section, we saw that market demand soars for both the legacy carrier and the LCC when one LCC flight is proposed in the market and fares are decreased by 40%. Therefore, the decrease in ex-S01 passengers can only be interpreted as a reaction of the legacy revenue management system to the increase in demand.

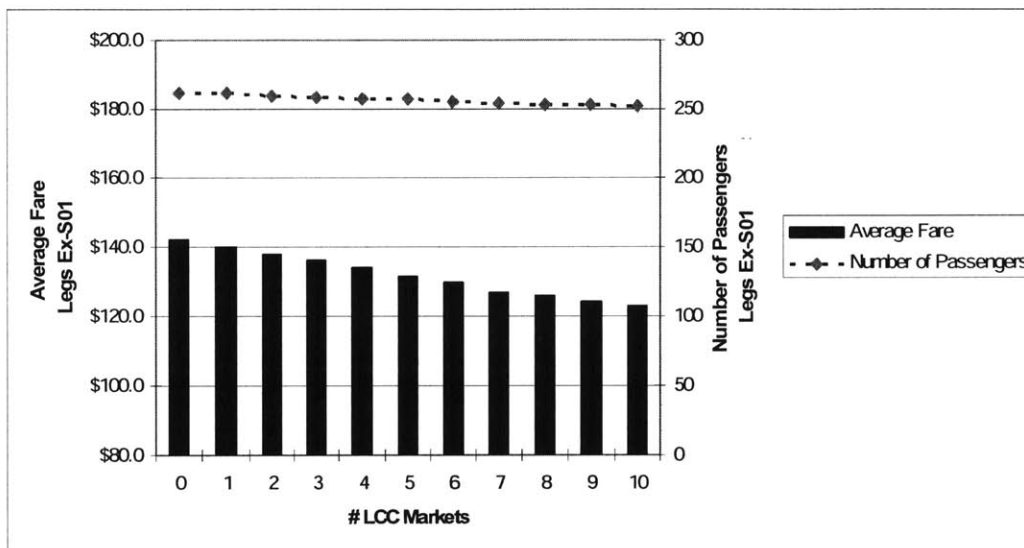


Figure 22: Legacy Average Fare for Legs Ex-S01

Since both the average fare and the traffic for the legs ex-S01 decrease, aggregate revenues for the corresponding markets must be reduced as well. Figure 23 shows to which extent legacy revenues in the markets with origin S01 are affected by the LCC entries. Overall, the trend in revenue is continuously downward. If we limit the analysis to the markets with origin S01, LCC operations finally cost \$6,237 to the legacy carrier. As compared to the \$5,805 decrease in average network revenues experienced by the legacy carrier, the discrepancy in revenue losses confirms the assumption that hub structures can partially compensate for the lack of revenue opportunity in certain markets. This conclusion is a result of the shared utilization of legs by the legacy carrier to serve multiple markets.

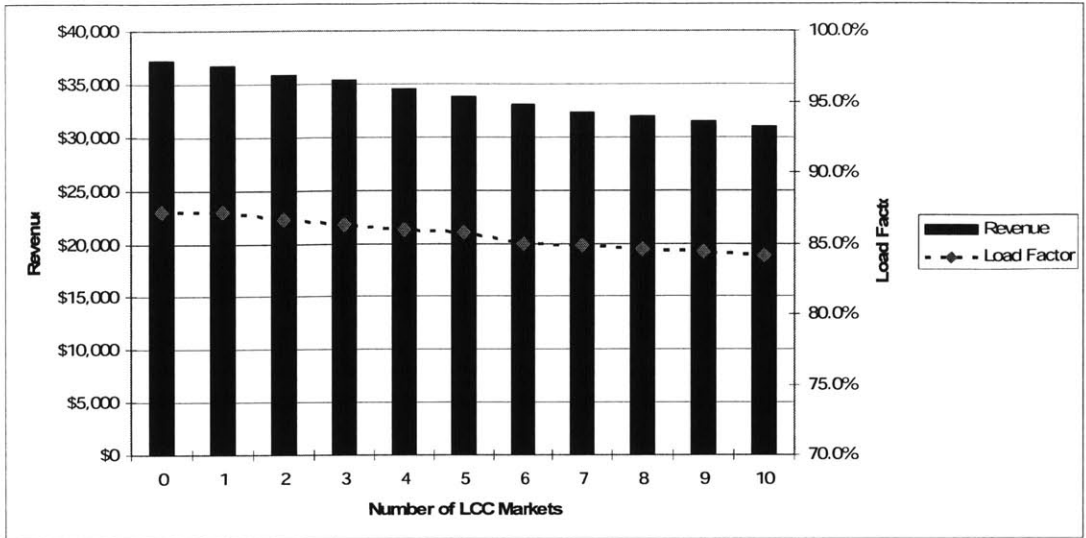


Figure 23: Legacy Revenue and Load Factor for Legs Ex-S01

Unlike the legacy carrier, the LCC average fare for the entire network remains approximately constant around \$88. Figure 24 illustrates the changes in both average fare and traffic reported by the LCC. Due to the symmetry of the legacy network, the LCC traffic increase is regular and the decrease in average fare insignificant. Slight irregularities are due to the downstream effects produced by the extra demand rejected by the legacy carrier when LCC flights are introduced, as explained in the previous section. For instance, when the LCC opens a new route, the absolute variation in the number of LCC passengers increases as the number of LCC flights grows.

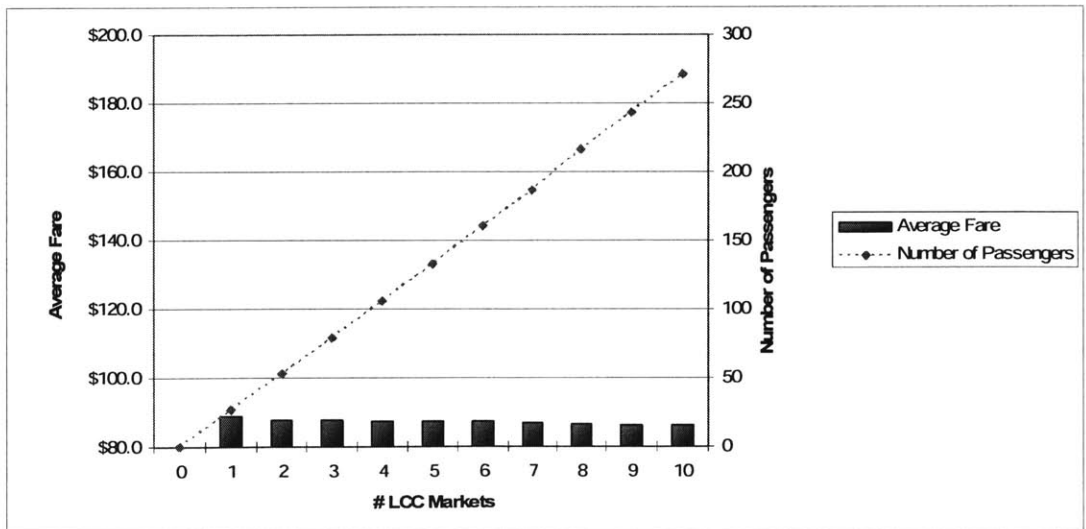


Figure 24: LCC Network Average Fare

c. Statistics at Market Level

On the intermediate level, the aggregate statistics with regard to legacy traffic and average fare show that these two performance indicators decrease continuously as the LCC network expands. However, the understanding of the mechanisms involved can be refined by an analysis at the market level. For a given market with its origin airport served by the LCC, two phases with very different properties can be distinguished in terms of changes in traffic and average fare. As expected, for a route that will eventually be operated by the LCC, the introduction of the LCC flight in this specific market is a turning point along the overall expansion of LCC operations.

The analysis of two specific markets will be emphasized:

- the first legacy market entered by the LCC S01-S21
- the last legacy market entered by the LCC S01-S30
- the fifth legacy market entered by the LCC S01-S25

First Legacy Market Entered S01-S21

Figure 25 presents the changes in legacy average fare and legacy traffic for the first market entered by the LCC. The LCC entrance results in a 37% drop in average fare, plummeting from \$171 to \$107. Simultaneously, the traffic reported for the S01-S21 market soars by 37%. The 40% decrease in the initial set of fares stimulates the market demand greatly, which results in demand surges for both carriers since the LCC capacity is limited to one flight a day. Overall, the introduction of the S01-S21 LCC flight causes the legacy carrier to sell more tickets at much lower prices in the market.

Then, as the number of LCC markets grows, the shift observed at the LCC entry is reversed. Following the introduction of the first LCC flight in S01-S21, the number of legacy passengers in this market is reduced significantly by each increment of LCC operations. Once all spoke-to-spoke markets with origin S01 are served by the LCC, the market traffic is down from a peak at 21.7 to 18.4 passengers on average.

As LCC operations expand, a surge in demand similar to the one observed in S01-S21 occurs in the other markets entered by the LCC. In Section *b* presenting the aggregate statistics at the intermediate level, the number of bookings for all markets with origin S01 is shown to remain approximately constant. As the LCC grows, this result implies that some passengers in the S01-S21 market will be rejected from the booking process to accommodate more passengers in other markets entered by the LCC. For instance, as the LCC enters the S01-S22 market, the demand for this market soars. Since the RM system caps the total number of passengers from S01, fewer S01-S21 bookings can be accepted, which is confirmed by Figure 25.

In the end, three main factors cause the number of S01-S21 passengers to decrease as the LCC expands:

- the surge in demand following any LCC entry
- the RM system capping the number of passengers departing from S01
- the symmetry of the legacy network

Indeed, the symmetry plays a great role as the RM system has no reason to favorite any particular spoke-to-spoke market from S01, which reduces the supply for S01-S21 when demand in other markets surges.

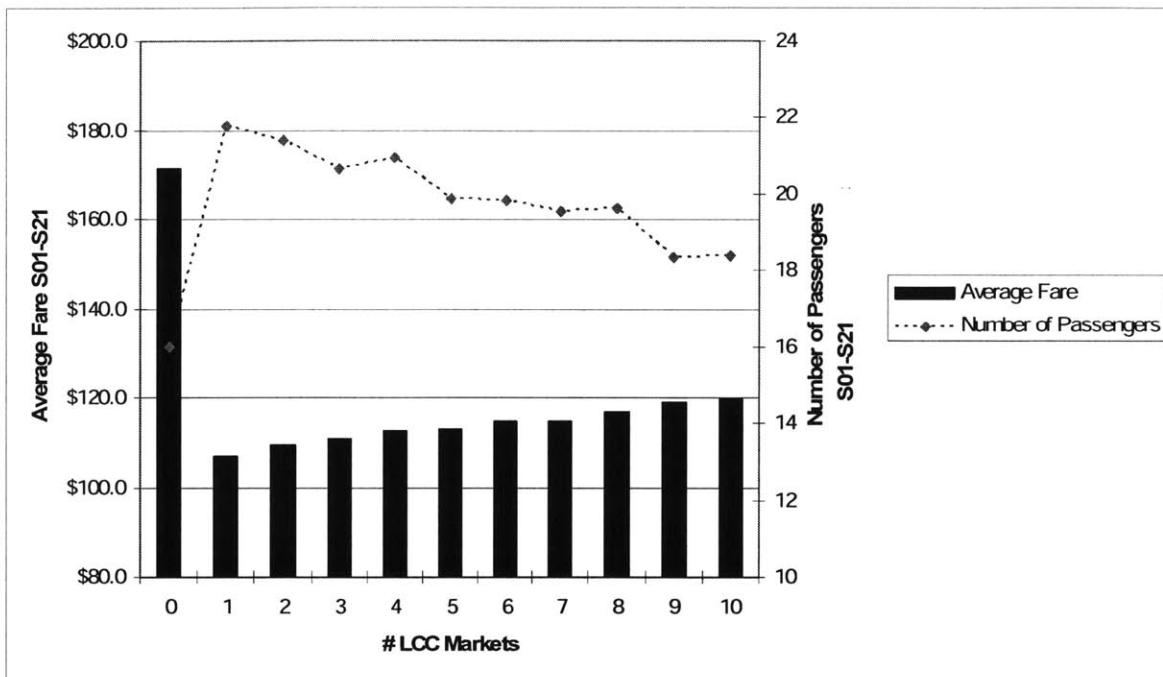


Figure 25: Legacy Statistics for S01-S21 Market

In the previous paragraph, we described the mechanism leading to a decrease in S01-S21 passengers and found it due to a shortage of supply. As opposed to a case where demand lowers, we would expect the legacy carrier to take advantage of the limited supply in S01-S21 by increasing fares and thus reducing the associated number of bookings. The assumption is confirmed by Figure 25 showing that the average fare increases from \$107 to \$119 when the number of LCC markets increases from 1 to 10.

Last Legacy Market Entered S01-S30

The analysis of the last market entered by the LCC corroborates the results associated with the first market served by the low-fare airline. As the number of LCC flights increases, the demand for both carriers on legs departing from S01 soars. As explained in the previous section, this surge is due to the fare decrease in the markets entered by the LCC and the limited offer of low-fare service. The legacy RM system capping the total number of passengers on the legs ex-S01, the shortage of

supply also affects the markets not served by the LCC. Indeed, the demand in these markets has remained constant while passengers in other markets served by the LCC rush to book legacy flights. As shown by Figure 26, it results in a decreasing number of S01-S30 passengers as the LCC increases its number of flights from 0 to 9. Simultaneously, the S01-S30 average fare increases as a response of the RM system to the shortage of supply in a market with constant demand.

As for S01-S21, the trend is abruptly reversed as the LCC enters the S01-S30 market. Following the LCC entrance, traffic report jumps from 13.5 to 19.1 passengers on average while the average fare drops by 35%.

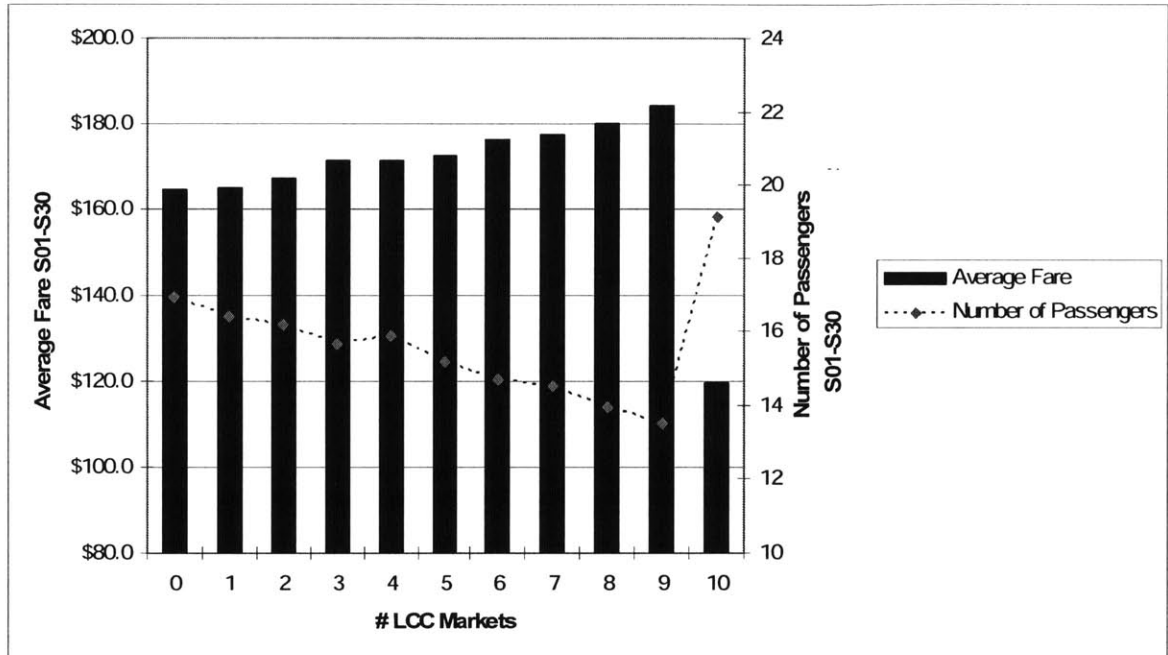


Figure 26: Legacy Statistics for S01-S30 Market

Overall, the LCC entrance in the ten spoke-to-spoke markets from S01 leads to a major decrease in the legacy average fare, dropping from about \$170 to \$120, and a rise in traffic from about 17 to 19 passengers in all these markets. Interestingly, as the total number of passengers departing S01 remains constant, we could expect the number of passengers in spoke-to-spoke markets served by the low-fare airline to return to its initial level. In fact, the equilibrium is achieved by a major decrease in the local traffic between S01 and H1. The number of local passengers between these cities is reduced by 30%, from 94 to 65 passengers on average. As for the spoke-to-spoke markets entered by the LCC, the traffic decrease is due to limited legacy capacity as opposed to weak demand. Consequently, the average fare in S01-H1 rises from \$104 to \$129, or 24%.

Fifth Legacy Market Entered S01-S25

The analysis of the fifth market entered by the LCC confirms the conclusions drawn from the two previous cases.

Based on Figure 27, the demand in spoke-to-spoke markets served by the LCC surges as the LCC starts to expand its network. As a result, the capacity available for the other markets departing from S01 is reduced, which drives the average fare up in these markets not served by the LCC including S01-S25. As expected, the introduction of LCC service in the market leads the average fare to a very significant drop while the number of passengers carried by the legacy airline increases. Finally, the gradual introduction of more LCC flights departing from S01 limits the capacity available for the S01-S25 market, which results in smaller traffic and greater average fare in the market.

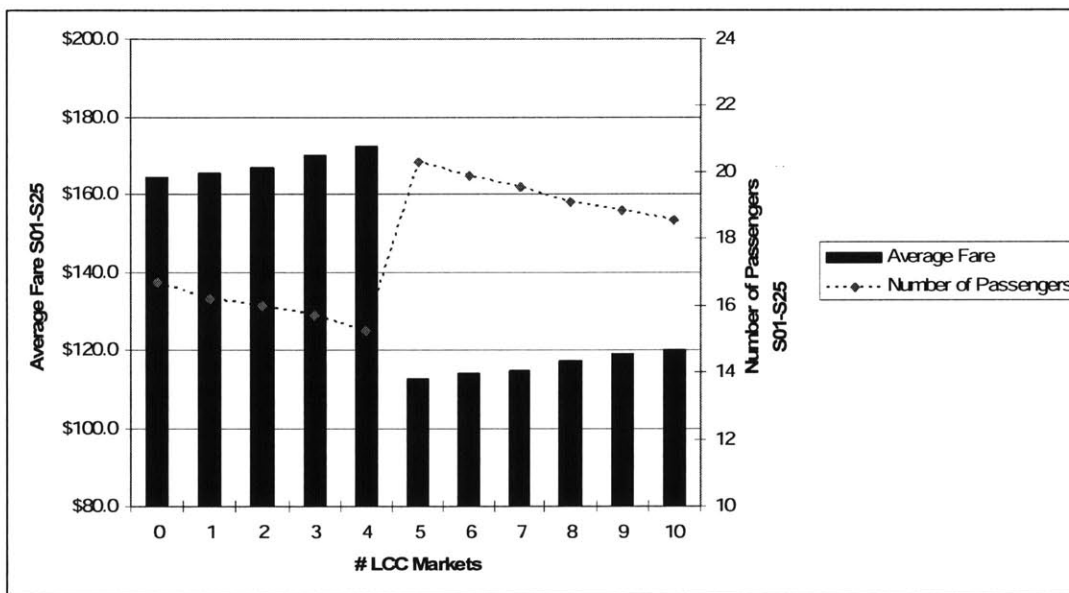


Figure 27: Legacy Statistics for S01-S25 Market

d. Conclusion

On the network level, the impact of LCC entry is significant on legacy revenues. Once the ten spoke-to-spoke markets from S01 are served by the low-fare airline, legacy revenues are reduced by 1.2%. However, the amount of traffic carried by the legacy carrier is slightly affected by the LCC in each market entered by the low-fare airline. Because the LCC operates only one flight a day in these spoke-to-spoke markets, the demand stimulation due to the 40% decrease in fares also causes the demand for legacy flights to increase. As a result, the number of passengers departing from S01 on legacy flights remains approximately constant, while the average fare for the leg group ex-S01 drops by 14%.

Due to the symmetry of the legacy network, the expansion of the LCC is very regular, i.e. increases in revenue and traffic are approximately constant for each increment of LCC operation. By operating ten flights per day, low-fare service generates \$25,000. As compared to the total decrease of \$5,800 in legacy revenue, we conclude that aggregate revenues at the network level are enhanced by LCC operations, which is consistent with the implementation of lower fares stimulating demand.

On the market level, the introduction of only one LCC flight in a market boosts the demand for both the legacy and the low-fare carrier on this route. As the legacy carrier shares the utilization of its legs to serve multiple markets, the increasing traffic in the market entered by the LCC limits the number of seats available for other markets with the same origin airport. When a LCC flight is added to the network, the limited supply of legacy seats leads to a decrease in traffic for all other markets with the same origin airport as the new LCC flight, and an increase in the average fare of this market. This side-effect is the achievement of the revenue management system of the legacy carrier taking advantage of a constant demand and a smaller supply in the market. Eventually, the LCC operating one flight in all spoke-to-spoke markets from S01 leads to a significant decrease in the average fare of these markets, i.e. about 30%, while stimulating the associated demands and traffic.

4.3. LCC Frequency Analysis

In Section 4.2, the analyses at the market level confirmed that the LCC entrance combined with a major fare decrease leads to great demand stimulation. As the base case characteristics were determined to define an aggressive entrance scheme in terms of fares, the LCC expansion with single frequency results in a LCC load factor greater than 88%. Because the legacy load factor is similar, the demand in the markets entered by the low-fare airline is likely to sustain increased LCC capacity. In this section, the objective will be to assess the impact of increased LCC frequency at the market level.

a. Increased LCC Frequency in S01-S21

The frequency analysis is based on the same set of assumptions used to perform the LCC entrance analysis with single frequency. In the markets entered, fares are decreased by 40% and applied to the products of both the low-fare and the legacy carrier. The initial legacy network load factor is about 87%, and the Passenger Decision Model remains calibrated to the values determined in Chapter 3. In this section, S01-S21 is the only market in which customers benefit from LCC competition.

LCC frequency was gradually increased from one to three flights per day. For the three frequency levels tested, an optimization process was followed to determine the most appropriate LCC schedule maximizing LCC revenues. To reduce the number of cases to test, we added one constraint to the optimization process, which states that

a LCC flight must depart at the same time as a legacy flight. Given the results of Section 3.4.g, this assumption is indeed the most likely to maximize LCC revenues.

First, the Decision Window Model²³ was used to find the schedule maximizing the LCC market coverage given the legacy schedule. Then, series of tests were performed to confirm that the LCC schedule was indeed revenue-maximizing. In the end, the following schedules were found optimal:

- single LCC frequency: LCC flight departs at the same time as the second daily legacy flight
- double LCC frequency: LCC flights depart at the same time as the first and the second daily legacy flight
- triple LCC frequency: LCC flights depart at the same times as the legacy flights

Figure 28 presents the results of increased LCC frequency in S01-S21 in terms of revenue. When the first non-stop low-cost flight is introduced in the market, the increase in LCC revenues is the greatest. Further LCC expansion provides customers with more non-stop travel options but the impact on LCC revenues is smaller. Similarly, the drop in legacy revenue due to the expansion of LCC operations decreases in magnitude when LCC frequency is higher. After the introduction of three daily LCC flights, the legacy carrier reports a \$1446 decrease in revenue for all markets with origin S01, while low-fare flights generate \$4206 in S01-S21. This competition game with non-zero sum confirms that demand and traffic are largely stimulated by reduced fares and increased capacity in the market.

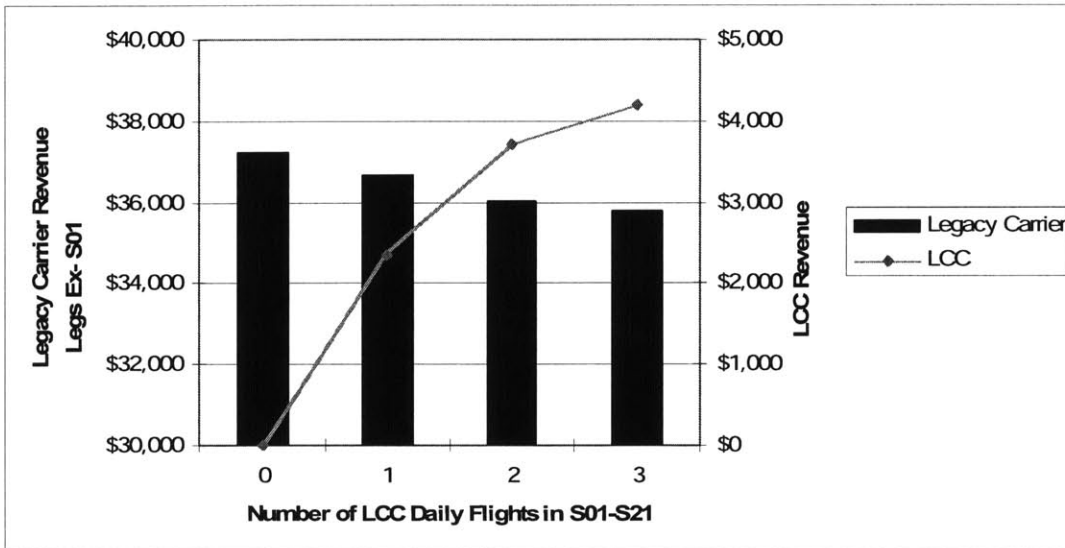


Figure 28: Legacy and LCC Revenue

	Total Legacy Traffic	Total LCC Traffic	Total S01-S21 Traffic	Legacy Average Fare	LCC Average Fare	Total S01-S21 Average Fare
No LCC Flight	16.8	/	16.8	\$163.1	/	\$163.1
1 Daily LCC Flight	21.8	26.4	48.2	\$107.1	\$89.1	\$97.2
2 Daily LCC Flight	10.9	41.1	52.0	\$106.2	\$90.1	\$93.5
3 Daily LCC Flight	6.8	46.1	52.9	\$103.6	\$91.3	\$92.9

Table 32: Legacy and LCC Market Statistics in S01-S21

Table 32 includes the results related to both traffic and average fare statistics, and provides some insight into the competitive mechanisms involved when LCC frequency is increased. As described in Section 4.1, the introduction of the first LCC flight drives traffic up to 48.2 passengers on average whereas average fare decreases by 40.4%. Then, total traffic statistics for the S01-S21 market show that demand is only slightly stimulated by increased capacity beyond one daily LCC flight. Indeed, the increase in total traffic is only 0.9 passenger on average when the low-fare airline switches from two to three daily flights. Thus, the increase in LCC revenues beyond one daily flight is mainly due to the capture of market shares from the legacy carrier, which is illustrated by the changes in legacy and LCC traffic as LCC flights are added. Because a core of passengers always finds more attractive to fly the legacy carrier for various reasons such as airline preference, the capture of market shares becomes less and less efficient as the LCC frequency is already high. Therefore, the increase in LCC revenues by increment of LCC frequency is smaller when the LCC operates more flights, as shown by Figure 28.

Figure 29 presents the network load factors of the legacy carrier and the LCC. Since the total demand for the S01-S21 market reaches a plateau when the LCC increased frequency from one to three daily flights, the LCC load factor would be stable if the amount of legacy traffic captured could fill the new aircraft operated in the market. However, the sharp drop in LCC load factor along the gradual introduction of LCC flights shows that captured market shares are not high enough to fill the extra LCC capacity available. Indeed, the LCC load factor with three daily flights is down to 50% while the initial value was 88%.

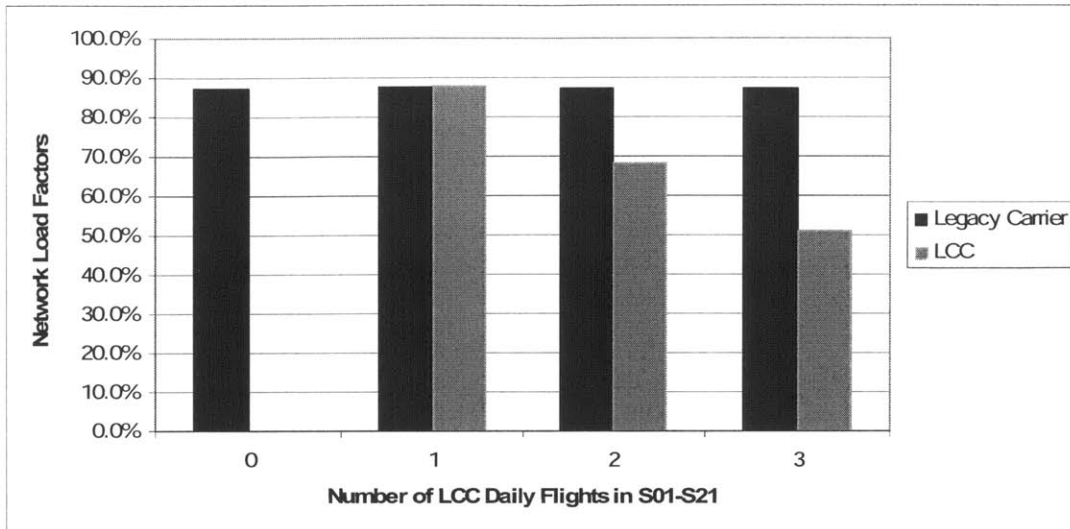


Figure 29: Legacy and LCC Load Factor

b. Conclusion

On the market level, the LCC frequency analysis shows that the legacy load factor is stable while the LCC load factor is greatly affected by the increase in frequency. If the low-cost airline operates one or two daily LCC flights, its load factor stays above 69%. However, the LCC load factor is around 50% when three daily flights are introduced in the S01-S21 market. Therefore, the double frequency case was chosen for the frequency analysis detailed in the next sections. Indeed, the double frequency scenario is more realistic than a LCC entering markets with a capacity leading to a 50% load factor for the new entrant airline.

4.4. 1 LCC Hublet with Double Frequency

The previous analysis of LCC expansion in Section 4.2 relied on the assumption that only one daily LCC flight was operated in each market newly entered. Although our base case of LCC entrance defines an aggressive LCC strategy in terms of fare decrease, the results of Section 4.3 showed that demand stimulation was so great that the LCC capacity could be increased to two daily flights per market.

In this section, we will again investigate the impact of a growing LCC point-to-point network in an environment dominated by a legacy carrier, but each market entered by the low-fare airline will be operated by two daily LCC flights. The assumptions with regard to the initial legacy network and the entrance scenario will be the same as in the two previous sections. The initial legacy load factor is equal to 87%, the Passenger Decision Model is set to the same calibrated values, and a 40% decrease in fares is implemented in all markets entered by the low-fare airline. The LCC strategy still consists of entering spoke-to-spoke markets departing from a single

spoke city called "hublet". However, two daily flights will be introduced in each spoke-to-spoke market operated by the LCC.

a. Network Statistics

From the LCC hublet S01, we introduced up to twenty flights operated in ten spoke-to-spoke markets. Figure 30 presents the revenue results of both the legacy carrier and the LCC following the gradual introduction of LCC flights.

First, the revenue curve of the low-fare airline is quasi-linear. As in the single LCC frequency case, this characteristic is due to the symmetry between spoke-to-spoke markets in the network. However, the slope of the revenue curve differs from the entrance cases presented in Section 4.2. Indeed, the increased LCC capacity allows the LCC to gain more market share and also stimulates total market demand slightly. With 20 daily flights in ten markets, the low-fare airline generates about \$36,300 as compared to \$23,400 with 10 daily flights in ten markets.

Second, legacy revenues are shown to be greatly affected by LCC operations. Except for the first market entered by the LCC, the impact of low-cost entrance on legacy revenues is always negative. In the single LCC frequency case, the legacy carrier could take advantage of network effects due to the shared utilization of legs to serve multiple markets. In the end, legacy revenues were reduced by 1.2% when all ten spoke-to-spoke markets from S01 were served by the LCC, but the introduction of one LCC flight resulted in slight increases in total legacy revenue for some markets entered. In the double LCC frequency case, legacy revenues almost always decrease when the LCC network is expanded. Once a market is entered by the LCC, the number of passengers carried by the legacy carrier plummets in this market. Even with extra seats available for other markets, the legacy carrier can hardly compensate for the losses in the market entered. Finally, legacy revenues are reduced by 2.6% when the LCC operates 20 flights in the ten markets from S01.

As in the single frequency case, the legacy carrier achieves to maintain network revenue when the LCC introduces its first flight in S01-S21. In fact, the first LCC entry results in significant losses for ex-S01 leg group of the legacy carrier, but legacy revenues increase in the local markets linking H1 with S01 and S21, as well as in the other spoke-to-spoke markets arriving at S21. These extra revenues compensate for the losses experienced at the S01 intermediate level. However, as the LCC continues to add flights departing from S01, the legacy carrier is unable to increase revenues in the S01-H1 market as in the first entry case. Therefore, legacy network revenues decrease following the introduction of new LCC flights.

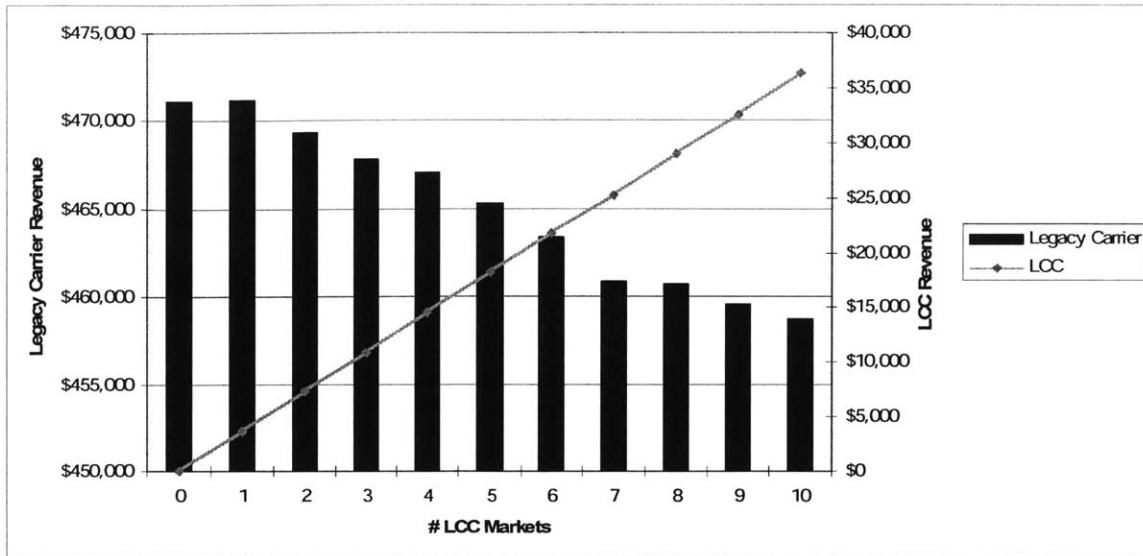


Figure 30: Legacy and LCC Revenues

b. Statistics at Intermediate Level

As previously defined, the average fare of the legs ex-S01 is the total revenue generated by all markets with origin S01, including S01-H1, divided by the corresponding number of passengers. Then, the load factor of the legs ex-S01 is defined as the average of the three legacy legs between S01 and H1. These measures allow us to investigate the direct impacts of LCC operations in the markets entered by the low-fare airline and analyze the network effects within the legacy network.

Figure 31 presents the legacy average fare of the legs ex-S01 as well as the total number of legacy passengers in the corresponding eleven markets. Unlike the single LCC frequency case, both reported statistics decline sharply as the LCC network expands. The average fare and the total traffic decrease respectively by 29% and 13%, as compared to 14% and 3% when markets are entered by only one LCC flight. Obviously, the LCC takes more passengers away from the legacy carrier, which is consistent with the increase in LCC frequency. The total LCC capacity available in the markets entered is much greater than in previous entry cases with single frequency, which leads a greater proportion of passengers from S01 to book on low-cost flights. In terms of average fare, the associated decrease is still smaller than the 40% decrease applied to fares proposed in the markets with LCC competition. However, the average fare decrease is much closer to the 40% reduction applied to nominal fares. The discrepancy is here mostly due to the protection of the S01-H1 market from low-cost competition.

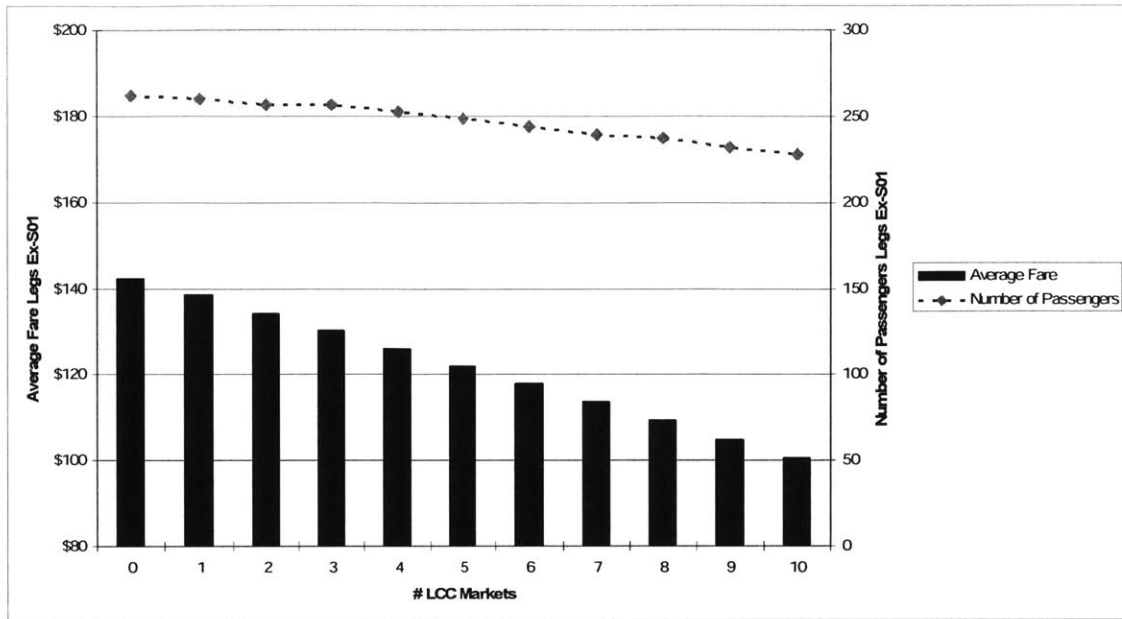


Figure 31: Legacy Average Fare for Legs Ex-S01

As the LCC increases the number of markets operated from S01 with two daily flights, the legacy carrier sees a continuous decrease in the load factor for the legs ex-S01. Figure 32 illustrates the changes in this load factor and the revenue losses in the markets with origin S01. The LCC entrance in all spoke-to-spoke markets from S01 results in the load factor dropping from 88% to 76%. As an increasing number of passengers book on low-cost flights, the revenues associated with the markets from S01 are greatly affected. In the end, the legacy carrier reports a revenue decrease of \$14,300 for the markets ex-S01. In relation with the \$12,300 decline in total network revenue, the discrepancy shows that the legacy carrier takes advantage of its hub structure to generate extra revenues from the seats made available by passengers flying on LCC flights instead. In the single LCC frequency case, these extra revenues totaled \$400 while they reach \$2000 in the double frequency case. This sharp increase is consistent with the traffic statistics in the markets entered with two daily LCC flights, which show that the aggregate load factor for the legs ex-S01 decreases more significantly. However, this compensation remains partial as total revenue losses for the legacy carrier more than double as compared the case where markets are entered with one LCC flight only.

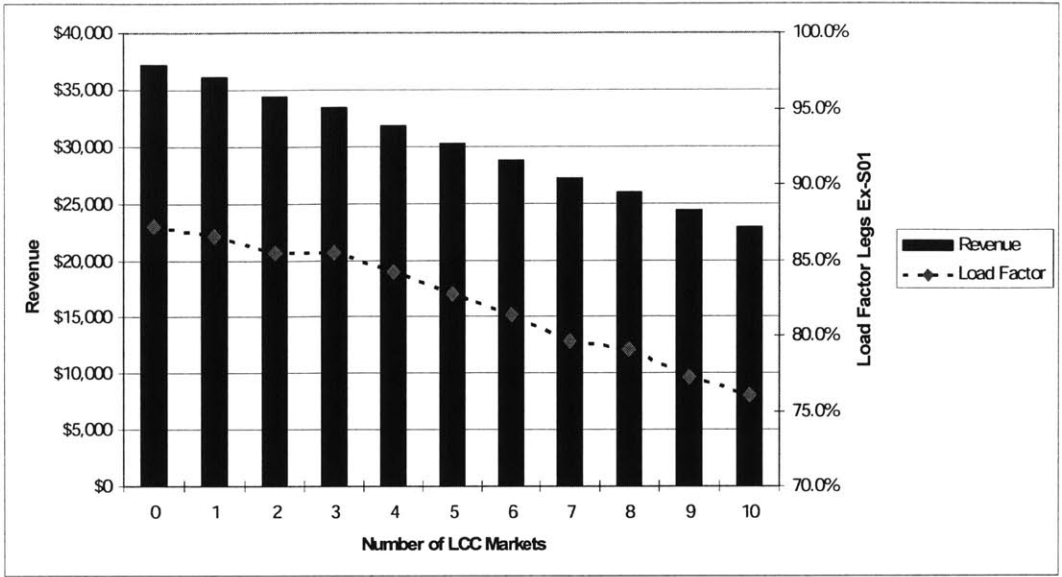


Figure 32: Legacy Revenue and Load Factor for Legs Ex-S01

c. Market Statistics

At different aggregate levels, the two previous analyses show that the legacy carrier experiences a decrease in both traffic and revenue as the LCC expands its network with two daily flights in each spoke-to-spoke market targeted. In fact, the market analysis shows that the legacy carrier does not seem to benefit from demand stimulation due to the 40% drop in nominal fares, as opposed to cases with single LCC frequency. Thanks to increased capacity, the LCC captures most of the traffic and increases its market shares in the markets entered as shown in Section 4.3.

Figure 33 presents the average fare reported in the S01-S30 market, as well as the associated number of passengers. This market is the last spoke-to-spoke market entered by the LCC expanding operations from the hublet S01. In the case with single LCC frequency, S01-S30 statistics were greatly affected by the introduction of LCC flights in all markets with origin S01. LCC entrance resulted in a traffic boost for both carriers in the market entered since LCC capacity was limited. This increase in traffic put pressure on the markets not entered by the LCC and served by the same legacy legs. In these non-entered markets including S01-S30, traffic was reduced and the average fare increased until the LCC entered the market.

In the case with double LCC frequency, the markets with origin S01 are very stable in terms of traffic and average fare until they are entered by the LCC. As shown by Figure 33, the number of passengers in S01-S30 slightly oscillates around the initial value, i.e. 17. The associated average fare presents very small changes that do not exceed 2% about the initial average fare of \$164. Once the market is operated by the LCC, the legacy carrier reports a sharp decline of 39% in average fare and 24% in traffic. As expected, these values are greater than the changes following the

entrance of S01-S30 by only one LCC flight. Indeed, S01-S30 average fare decreased by 27% while traffic increased by 12% (see Section 4.2.c).

The analysis of other markets with origin S01 eventually operated by the LCC would present the same characteristics of stability. For instance, the S01-S25 would report approximately constant traffic and average fare until the number of markets entered by the LCC reaches five. Then, the two market statistics would drop by 39% and 24% respectively, and remain approximately constant as the LCC continues the expansion of its first hublet.

As compared to the single LCC frequency case, network effects are less complex at the market level with increased LCC frequency. In a simple way, the LCC entrance results in traffic and average fare decreases in all markets entered, which affects the network performance of the legacy carrier negatively.

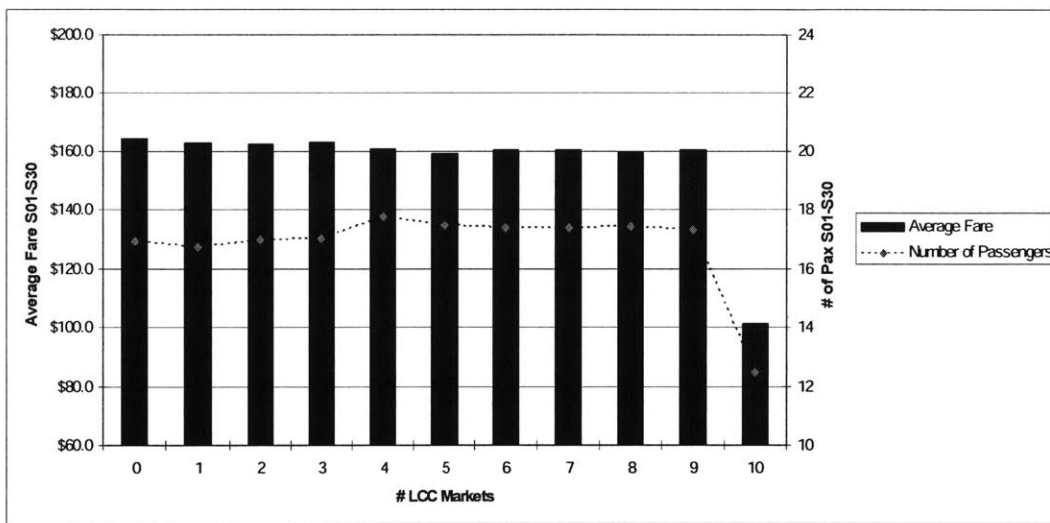


Figure 33: Legacy Statistics for S01-S30 Market

Since a major drop in traffic was shown to occur when a spoke-to-spoke market was entered by the LCC, a fare class mix analysis was performed to determine which legacy fare classes were most affected by the LCC entrance, and what type of passengers were carried by the low-fare airline. All fare class mix analyses were performed at the market level to emphasize the abrupt changes following the LCC entrance. As stated in Section 3.3.b, fare class 1 is the most expensive unrestricted class while fare class 6 is the cheapest class.

First, Figure 34 presents the aggregate fare class mix related to the passengers carried by both carriers in the S01-S21 market. The daily number of passengers is reported by fare class and by LCC penetration level. The four groups of colored columns present the results associated with four cases in which the number of LCC markets differs. As soon as the LCC starts operating in S01-S21, demand stimulation results in traffic surges for only two booking classes, class 1 and 6. Indeed, the number of class 6 passengers increases from 8.8 to 24.4 and class 1 bookings almost triple from 1.3 to 3.5. On the contrary, statistics for other fare classes show

that the associated numbers of passengers are either stable or decrease significantly, e.g. in class 2. Thus, demand stimulation is shown to have a great impact on passenger types, i.e. leisure and business. On one hand, the significant decrease in the class 1 must encourage business travelers to book in the highest fare class, which now benefits from an unrestricted status, no advance purchase requirement, and a smaller price. On the other hand, the increase in class 6 bookings is consistent with the demand model implemented in PODS. In Section 3.2.d, demand stimulation was shown to be mostly due to travelers with a very low willingness-to-pay that would not have bought a ticket if fares had been higher.

As the LCC enters new spoke-to-spoke markets from S01, the aggregate fare class mix does not change to a great extent. In all fare classes, the number of passengers is approximately stable. This result corroborates the previous conclusion drawn from the analysis at the market level, i.e. network effects between markets with the same origin S01 do not play a great role in the scenario with double LCC frequency.

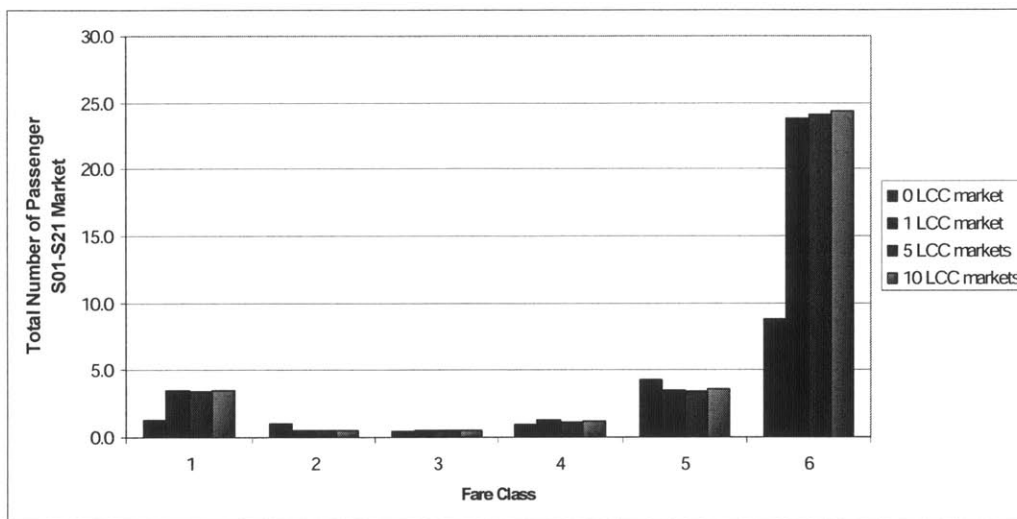


Figure 34: Fare Class Mix in S01-S21 Market
All Carriers

In Figure 35, the number of passengers carried by the legacy carrier is reported by fare class and by LCC network penetration. The four groups of columns present the results associated with four cases in which the number of LCC markets differs. Once S01-S21 is served by the LCC, the number of passengers decreases in all fare classes, except class 1. Indeed, the fare class mix analysis of the LCC will show that the 40% fare decrease in S01-S21 leads to a surge in the aggregate class 1 ticket demand for the market. As compared to the initial legacy network with no LCC competition, class 1 tickets are much less expensive and still benefit from no restrictions. Consequently, class 1 is very appealing to the business demand in S01-S21. However, all business demand cannot be accommodated by the LCC as most business travelers book at a very late stage in the booking process when many LCC flights are already booked up. Moreover, airline preference disutility confers a significant advantage to the legacy carrier especially for business passengers. As a

result, the number of legacy passengers paying the highest fare increases by 23% following the LCC entry.

The legacy carrier sells fewer tickets in all other classes including class 6. The significant drop in reported class 6 bookings shows that a large part of the stimulated demand due to the 40% decrease in nominal fares is carried by the LCC. With a relatively small increase in class 1 bookings whose fares have been reduced by 40% and significant drops in bookings for all other classes, these changes are fully consistent with decreases in traffic and revenue reported by the legacy carrier at the network level.

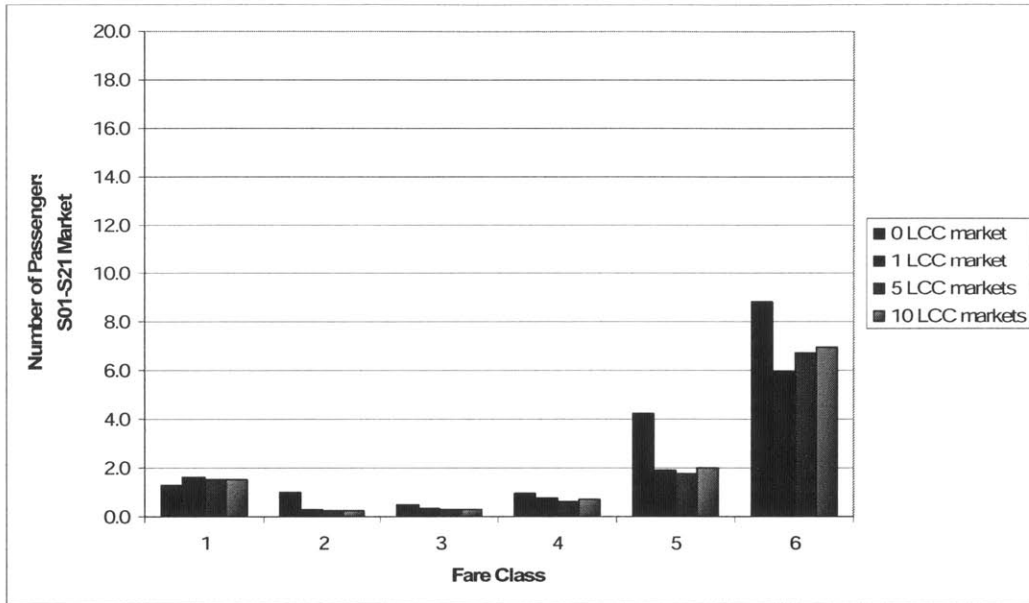


Figure 35: Legacy Fare Class Mix in S01-S21 Market (First Market Entered)

In Figure 36, the fare class mix analysis of the LCC confirms that the low-fare airline fills a great proportion of its capacity with passengers booking in the lowest fare class. As a large part of these low revenue bookings must come from demand stimulation, the LCC seems to be appealing to and willing to accept bookings from travelers with low willingness-to-pay. On the other end of the fare structure, the LCC reports a great number of class 1 bookings as well. Obviously, the business demand benefits from low-cost operations by booking on the non-stop flights newly offered in the market. Even though many business travelers have a preference for the legacy carrier (see airline preference disutility), more than half the passengers booking in the highest fare class opt for one LCC flight offering non-stop service and fare classes with no restrictions.

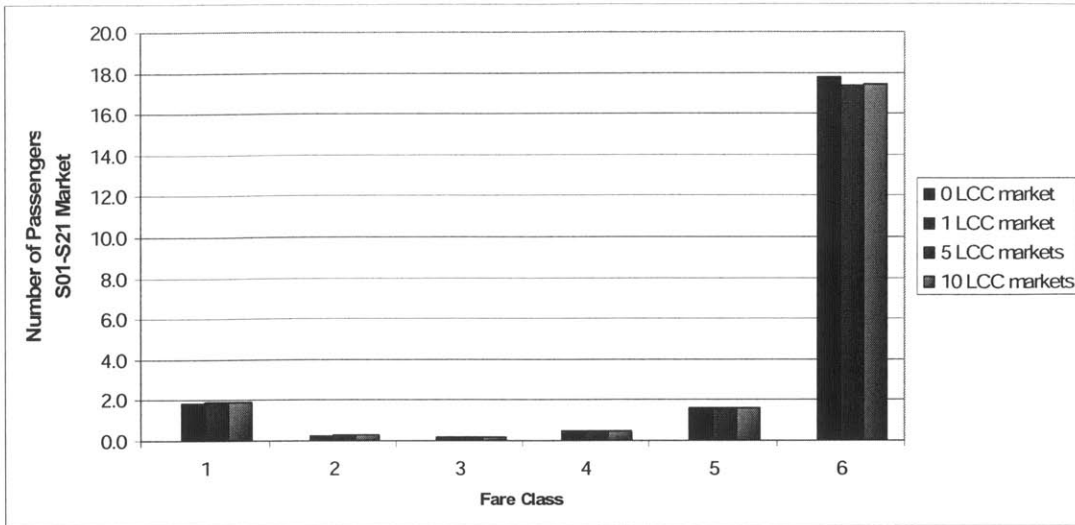


Figure 36: LCC Fare Class Mix in S01-S21 Market (First Market Entered)

d. Conclusion

In Section 4.2, we focused on the analysis of an entrance scenario with one non-stop flights operated in each spoke-to-spoke market targeted by the LCC. In Section 4.4, as the low-fare airline steps up the aggressiveness of its expansion strategy, the double LCC frequency defines a realistic scenario where the LCC diverts a large part of the traffic from the legacy carrier in the markets entered.

On the market level, the total capacity of 60 seats offered by the two daily low-cost flights accommodates a large proportion of the demand in the markets entered. Indeed, the LCC reports market shares close to 80% in these O-D markets. The fare class mix analysis shows that demand stimulation due to the passengers with a low willingness-to-pay benefits primarily the LCC whose load in class 6 is great. Low-fare non-stop service diverts demand from the legacy carrier which reports fewer bookings in almost all its fare classes. As soon as the LCC launches service in a market originally dominated by the legacy carrier, the market average fare and traffic of the legacy carrier decrease respectively by 39% and 24%, and then remain approximately stable as the low-fare airline expands further.

As the market statistics are affected to a greater extent than in the scenario with single LCC frequency, the negative impacts of LCC operations on the legacy network performance are expected to be more dramatic. Indeed, the introduction of non-stop flights results in a continuous decrease in legacy traffic and revenue. Once the ten markets with origin S01 are operated by the LCC, legacy revenues are reduced by 2.6% while the load factor for the legs ex-S01 has decreased from 88% to 76%. In terms of capacity, the introduction of ten LCC flights leads the low-fare airline to offer 1.2 million ASM while the legacy carrier offers about 5.7 million ASM in the network. As in the previous scenario, the legacy carrier takes advantage of its hub structure to serve other markets with capacity not booked by passengers in the

markets entered by the LCC. Yet, if we compare the losses experienced in the markets served by LCC flights and the total revenue losses of the legacy carrier, this network effect can generate only about 15% of total losses reported in the markets targeted by low-fare service. Although these extra revenues are significant, the cost paid by the legacy carrier remains very high as a result of low-cost competition in only ten markets.

4.5. Multiple LCC Hublets

In the last phase of the symmetric network analysis, we will investigate the impact of a LCC network operating multiple hublets. In Section 4.4, legacy revenue was shown to decrease by 2.6% once all spoke-to-spoke markets departing from one single hublet were served by the low-fare airline. In this section, the objective is to assess the existence of "cascade effects" following further LCC expansion. For instance, the impact of LCC operations on legacy revenues could prove to be non-linear or exponential on a greater LCC expansion scale.

As in the previous section, the LCC will be assumed to opt for an aggressive strategy and each market entered by the low-fare airline will be operated by two daily LCC flights. The assumptions with regard to the initial legacy network and the entrance scenario will be the same as previously. The initial legacy load factor remains at 87%, the Passenger Decision Model is set to the same calibrated values, and a 40% decrease in fares is implemented in all markets entered. In terms of LCC expansion strategy, the emphasis will be put on developing a low-cost network with multiple hublets. As a starting point, the first ten markets entered by the LCC will depart from S01. Then, the LCC will start operations in markets originating from S02 until all spoke-to-spoke markets are served, i.e. the number of LCC markets will be equal to twenty. S03 will be the third hublet where the low-fare airline will expand from. In the end, we fully simulate LCC operations from five different hublets.

Figure 37 presents the revenue statistics of both the legacy carrier and the LCC as the number of markets entered increases. Given the symmetry of the network, the revenue growth of the LCC airline is approximately linear as it expands operations. This result is fully consistent with the revenue reports shown in Section 4.4 where the progressive development of the LCC hublet S01 led to a linear progression of LCC revenues. However, the revenue losses reported by the legacy carrier have different characteristics. Indeed, network revenues decreased from \$471,000 to \$404,000, or by 14.2%, following the introduction of 50 LCC flights in the original legacy network. First, the proportion of network losses as compared to the initial legacy revenues is greater than five times the legacy losses experienced by the legacy carrier when only markets departing from S01 are entered. This result is the first indication that the negative impact of LCC entrance may increase non-linearly as the number of markets already served by the low-fare airline increases. Then, the comparison of the legacy losses caused by the successive LCC hublets corroborates the preliminary conclusion. Indeed, the incremental losses caused by the LCC hublets are as follows:

- hublet S01-\$12400 *in losses*
- hublet S02-\$13200 *in losses*
- hublet S03-\$12900 *in losses*
- hublet S04-\$13100 *in losses*
- hublet S05-\$15400 *in losses*

Based on the network losses reported by the legacy carrier, we identify an upward trend that suggests the existence of cascade effects. However, these side effects remain small in magnitude as shown by Figure 37. As the LCC network expands, legacy revenues decrease almost linearly. These effects result from the shared utilization of legs by the legacy carrier to serve multiple markets. In the previous sections, we saw that the hub network operated by the legacy carrier allows it to partially compensate for losses incurred in the markets entered by the LCC. Indeed, the legacy airline can focus on serving other markets that do not face low-cost competition (see Section 4.4). As the LCC expands further by developing multiple hublets, the opportunities for such compensation diminish rapidly. We saw that market demand for legacy flights is greatly affected by the introduction of LCC flights. Therefore, the greater the number of LCC markets, the smaller the demand for legacy flights and the fewer the passengers willing to book legacy seats left empty by travelers flying the LCC. Eventually, the incremental damage caused by one extra LCC flight on legacy revenues increases as the size of the low-cost network increases.

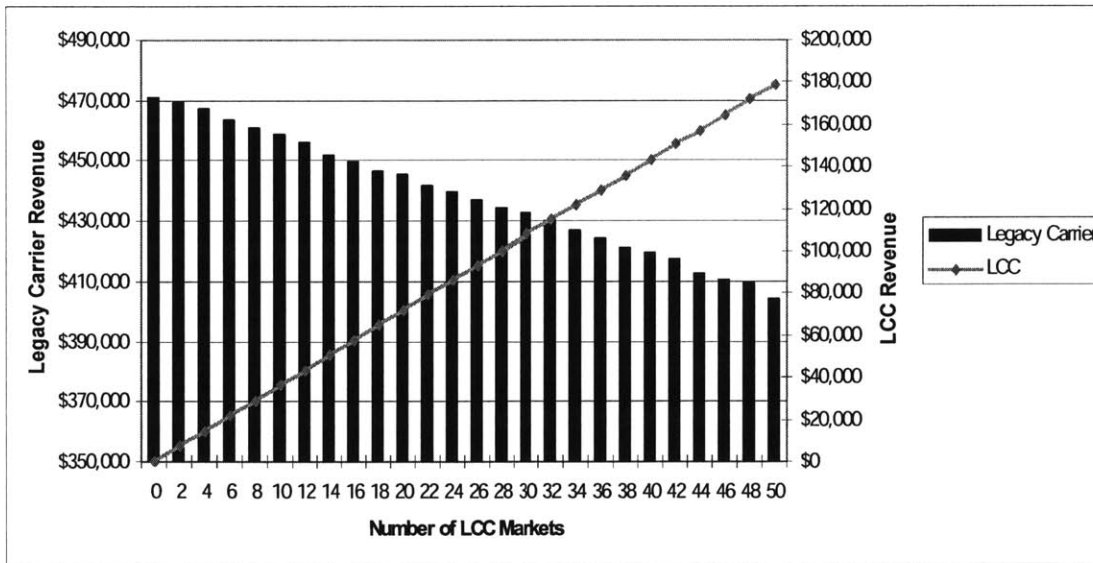


Figure 37: Legacy and LCC Revenues

In Figure 38, the load factor of both the legacy carrier and the low-fare airline are given as a function of the number of LCC markets. As in Section 4.4, the legacy traffic reports a continuous and significant decline along the gradual LCC expansion. Once the LCC operates in the 50 spoke-to-spoke markets originating from five different hublets, the legacy load factor is indeed reduced from 87% to 83%. Unlike the revenue statistics presented in Figure 37, the traffic reported by the legacy

carrier is not characterized by an increase in traffic decline as the LCC network increases in size. As for the LCC, the associated load factor slightly decreases from 68% to 65.5% as the number of LCC markets increases. This result is consistent with the correlated decrease in the legacy load factor. As the traffic reported by the legacy carrier diminishes, the capacity constraint on the legacy capacity is partially released, i.e. the legacy carrier will be able to accommodate more passengers as the number of full flights is reduced. Thus, a greater proportion of demand will prefer booking a legacy flight rather than an LCC flight. Therefore, the low-fare airline reports a slight decrease in load factor.

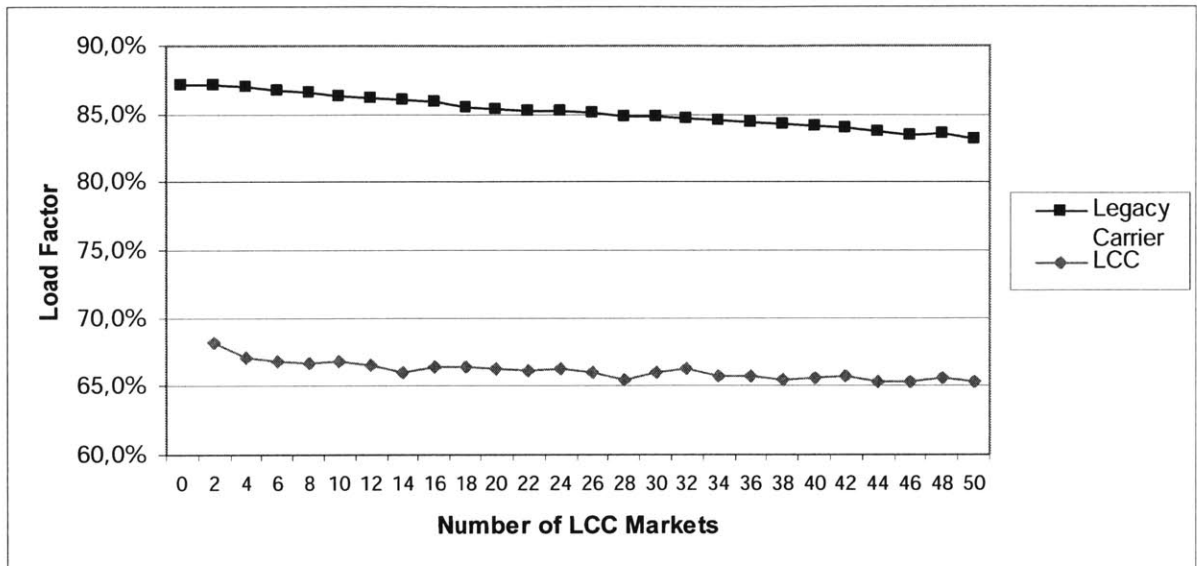


Figure 38: Legacy and LCC Load Factor

4.6. Conclusion

In Chapter 4, we developed and analyzed an LCC entrance case adapted to the symmetric network where demand stimulation was strong on the market level. Based on a sensitivity analysis with the discount applied to nominal fares as input, we estimated the associated increase in traffic and decrease in average fare. As our objective was to model an entrance case with significant demand stimulation, a 40% decrease in nominal fares was chosen as the base case. We showed that it resulted in 40.4% decrease in average fare and a 200% increase in traffic in the markets entered by the LCC.

Throughout the entry analysis, we evaluated one LCC strategy focused on the development of hublets. The low-fare airline operated routes from a limited number of cities on the West Coast, thus concentrating its operations in a theoretically efficient way. Then, we modified the frequency offered by the LCC in the markets entered and estimated the impact on reported traffic and revenues for both carriers.

In the single LCC frequency case, the combination of strong demand stimulation and low LCC frequency resulted in various network effects actually enhancing the expected performance of the legacy carrier. Both carriers reported load factors greater or equal to 87%, which suggested that LCC frequency could still be increased to higher sustainable levels. On the market level, the introduction of one LCC flight led to a sharp drop in average fare but also an increase in legacy traffic. As the LCC expanded its operations from the hublet, the proportion of legacy traffic associated with the markets with LCC competition increased as compared to the total legacy traffic from the hublet. Consequently, the LCC entrance in a given market departing from the hublet resulted in a legacy traffic decrease and an average fare increase in other markets departing from the hublet. Once all ten spoke-to-spoke markets from the hublet were entered by the LCC, the legacy traffic for the group of legs from the hublet was approximately equal to the initial level, whereas the associated average fare decreased by 14%. In the end, LCC operations in ten markets caused the legacy revenues to decrease by 1.2% but did not affect the legacy load factor significantly.

In the case where the LCC doubled its frequency, the greater total capacity offered by the low-fare airline resulted in its gaining of about 79% of market share with a 68% load factor. As a result, traffic and average fare reported by the legacy carrier dropped respectively by 24% and 39% in the markets served by the LCC. The large majority of new demand for low fares stimulated by the 40% nominal fare decrease was shown to be carried by the LCC. Although the number of high fare class bookings reported by the legacy carrier increased in the markets entered, the fare decrease combined with fewer total bookings led to a 2.6% drop in network revenues once all ten markets from the hublet were operated by the LCC. As in the single LCC frequency case, the legacy carrier was shown to take advantage of the hub structure of its network by serving other markets with seats that remained empty due to passengers booking LCC flights. However, this compensated for only 15% of the revenue losses reported for the group of legs departing from the hublet, i.e. directly affected by LCC operations.

Finally, we investigated scenarios involving greater LCC expansion with multiple hublets. In this case, we assumed that the LCC would be aggressive by entering targeted markets with two daily flights. As expected, the results showed that the impact of LCC entrance on legacy revenues was greater as the size of the LCC network increased. Indeed, the presence of LCC competition in many markets weakens the ability of the legacy carrier to compensate for the revenue losses incurred in the new markets entered by the LCC. Once the LCC operated 50 spoke-to-spoke routes from five hublets, the legacy load factor decreased from 87% to 83% while its revenue dropped by 14.2%. In this case, the low-fare airline offered 6.0 million ASM while the legacy carrier offered about 5.7 million ASM throughout the network.

In the symmetric network, the analysis of aggressive LCC entrance cases showed that the legacy performance estimated both in terms of revenue and traffic was greatly affected by low-cost operations. Moreover, network effects were shown to play a great role in the final outcomes. As a market was offered low-cost service, the legacy carrier reported greater revenue and traffic from passengers in markets with no LCC competition. The objective of Chapter 5 will be to verify these preliminary results by implementing these base cases into a more realistic and asymmetric environment, the Network D6.

5. Impacts of LCC Entry in an Asymmetric Legacy Network

In Chapter 5, we will perform various LCC entry analyses in the asymmetric Network D6 that defines a more realistic environment. As in the previous chapter, we will gradually introduce LCC flights in spoke-to-spoke markets and analyze the traffic and revenue changes experienced by the carriers on the market and the network level.

As described in Section 3.3.a, the Network D6 is a generic model for airline systems with two legacy carriers operating hubs. A total of forty spoke cities are served by legacy flights connecting at the two hubs. Between the spoke cities, each legacy airline operates three daily connecting flights. These flights are scheduled so as to maximize the interconnectivity of flights arriving and departing at the hubs, which implies the existence of three banks. In terms of fares and demand levels, the O-D markets have very different characteristics, which simulate a realistic business environment including numerous disparities.

First, we will calibrate a base case of LCC entry. Unlike the LCC entry assumptions of Chapter 4, we will be more conservative with regard to the global demand for air travel within the network, the fare decrease induced by the LCC entry, and the demand stimulation due to low-fare service in the markets entered. Then, we will analyze the impact of the expanding LCC network on the revenue and traffic performance of the legacy carriers. To this purpose, we will investigate two LCC entry cases, the first with single and the second with double daily LCC frequency in the spoke-to-spoke markets entered by the low-fare airline.

5.1. Calibration of Base Case

a. Demand Stimulation Analysis

As stated in the introduction, the Network D6 is a more realistic model of real-world air travel demand. The two legacy carriers report load factors very close to 82% which is comparable to the 81.2% average load factor for the entire North America air network in March 2006³³. Unlike the symmetric network developed for the purpose of the thesis, business and leisure demand vary between O-D markets in the Network D6. However, the demand level between a spoke city and a hub always exceeds the demand between two spoke cities. Then, the sets of fares differ greatly between markets but result in a 4.1 average fare ratio across the entire network. In a given market, the initial sets of fares offered by the two legacy carriers are the same. As in the previous chapters, the legacy carriers are assumed to match the fare structure offered by the new entrant in the markets served by the LCC. Finally, the parameters related to the Passenger Decision Model remain calibrated to the values determined in Chapter 3.

³³ IATA Economics, *Monthly Traffic Analysis, March 2006*, www.iata.org/economics

The base case will be calibrated by introducing LCC operations in the S02-S22 market (see map in Section 3.3.a). This market was randomly chosen but had to be reasonably big in terms of demand to be sustainable for one daily LCC operation. The mean demand levels at base fare are presented in Table 33. As compared to the spoke-to-spoke market implemented in the symmetric network, demands for both leisure and business travelers are greater while the associated base fares are lower. To analyze the demand stimulation in this market, one daily LCC flight is introduced and the associated departure time is the same as the second daily flight of the first legacy carrier. Similar to the previous chapter, the total LCC flight time is 1h45 shorter than the legacy connecting flight with the minimum flight time in the market.

	Mean Business Base Fare Demand	Mean Leisure Base Fare Demand	Total
S02-S22	8.42	15.65	24.07
Base Fare	\$243	\$97	

Table 33: Air Travel Demands at Base Fare

The initial fare structure and statistics for the S02-S22 market without LCC operation are presented in Tables 34 and 35. First, the 4.5 fare ratio associated with this market is greater than the 4.1 mean value across the entire network. Then, the load factors of the leg groups one and two are above the 82% average load factor of the network, which indicates that the demands in the O-D markets from S02 and to S22 are relatively high. Based on the market traffic of the legacy carriers, both legacy carriers limit the number of S02-S22 bookings as compared to the potential demand in the market. This behavior is driven by the high load factors reported by the legacy carriers on the flights from S02 and to S22 as shown in Table 35. As a result, the legacy average fares which are respectively \$139 and \$134 are much greater than the leisure base fare and so limit the number of passengers that can obtain a flight ticket in the market.

Class	1	2	3	4	5	6
Fare	393.77	276.31	163.96	138.43	112.90	87.36

*Table 34: Initial Fare Structure in S02-S22 Market
Both Legacy Carriers*

	S02-S22 Market Traffic	Average Fare S02-S22 Market	Load Factor Legs S02-Hub	Load Factor Legs Hub-S22
Legacy 1	9.9	\$139.2	87.21%	87.14%
Legacy 2	7.9	\$134.0	86.95%	86.61%
LCC	/	/	/	/
Total	17.8	\$136.9	/	/

Table 35: Traffic and Revenue Statistics for the S02-S22 Market

In a second case, one daily LCC flight is introduced in the S02-S22 market with no change to the initial fare structure. The fare structure applied by the three carriers is presented in Table 36, and the market statistics associated with this LCC entry case are included in Table 37. As indicated by the respective market traffic, a significant number of passengers book the LCC flight which represents a 71% market share. A large part of the S02-S22 traffic is diverted from the two legacy carriers which report much smaller loads as compared to the previous case with no LCC competition. Simultaneously, both the legacy average fares increase in the market even though the number of legacy passengers decrease. As in the previous Chapter, the legacy carriers can remain aggressive in closing low-fare classes in S02-S22 early in the booking process because they benefit from the shared use of the legs from S02 and to S22. In fact, the load factors for the legs S02-Hub and Hub-S22 even increase as the LCC enters its first market. The loss of legacy traffic due to LCC competition is compensated by travelers booking in other markets departing from S02 and arriving at S22. The hub structure allows both the legacy carriers to achieve greater average fares in the market entered, which are respectively \$40 and \$32 higher than the \$105 LCC average fare.

On the S02-S22 market level, the LCC entry increases the capacity offered in the market to a great extent. As expected, this leads to a significant increase in the total number of bookings and a drop in the average fare based on the three carriers' statistics. Total market traffic is 24.6 on average which is slightly greater than the total mean demand at base fare. This result is explained by the class 6 fare lower than the leisure base fare and therefore stimulating demand to a small extent. Then, the market average fare is down from \$137 to \$116 as compared to the previous case. As opposed to the legacy average fares in S02-S22, the LCC reports a much smaller average fare in the market. The LCC has a much weaker pricing power than its competitors benefiting from the hub structure. Indeed, the low-fare airline has a 58% load factor which limits the opportunities for the LCC to close the lowest fare classes early in the booking process, and thus increase the average amount of money paid per passenger.

Class	1	2	3	4	5	6
Fare	393.77	276.31	163.96	138.43	112.90	87.36

*Table 36: Initial Fare Structure in S02-S22 Market
Legacy Carriers and LCC*

	S02-S22 Market Traffic	Average Fare S02-S22 Market	Load Factor Legs S02-Hub	Load Factor Legs Hub-S22
Legacy 1	4.1	\$144.7	87.46%	87.61%
Legacy 2	3.2	\$136.7	87.70%	87.45%
LCC	17.4	\$105.0	58.01%	/
Total	24.6	\$115.6	/	/

Table 37: Traffic and Revenue Statistics for the S02-S22 Market

Then, we simulated the introduction of one LCC flight in the S02-S22 market with respectively a 20%, 30%, and 40% decrease in fares. Tables 38 and 39 present the set of fares and the statistics associated with a 30% fare decrease that was determined to be most relevant to further analysis. The criteria are based on sufficient and realistic traffic stimulation due to fare decrease, as well as the consistency of the fare decrease with observations of LCC entries within the US air network over the past few years¹.

As compared to the first case with no LCC competition, the average fare is reduced by 41%, which leads to a 157% increase in traffic. The demand stimulation is smaller than in the symmetric network, but still significant and consistent with the results of the Perry analysis³². With one single daily offered by the low-fare airline, the LCC load factor is about 87% up from 58% in the previous case with no fare reduction. In terms of traffic, the legacy carriers benefit from both the demand stimulation and the limited LCC capacity, thus reporting greater loads than in the initial case. As the LCC load factors increase, the number of days for which the LCC flight is booked up increase, thus reducing the market share of the low-fare airline down to 57%. The legacy average fares in the S02-S22 are significantly reduced to respectively \$100 and \$96. However, they still far exceed the LCC average fare thanks to the shared use of the legacy legs from S02 and to S22 within the two hub systems.

Class	1	2	3	4	5	6
Fare	275.80	193.20	114.80	96.60	79.10	60.90

Table 38: Initial Fares Decreased by 30% in S02-S22 Market Legacy Carriers and LCC

	S02-S22 Market Traffic	Average Fare S02-S22 Market	Load Factor Legs S02-Hub	Load Factor Legs Hub-S22
Legacy 1	10.9	\$99.6	87.02%	87.07%
Legacy 2	8.7	\$96.0	87.15%	86.73%
LCC	26.1	\$68.5	86.98%	
Total	45.7	\$81.1	<i>/</i>	<i>/</i>

Table 39: Traffic and Revenue Statistics for the S02-S22 Market

b. Conclusion

In the asymmetric Network D6, the demand stimulation analysis is consistent with the results obtained in the symmetric network. As the LCC introduces its first flight, the total traffic carried in the market increases due to the increased capacity available. A large part of the travelers book the LCC flight which has a significantly lower average fare than its legacy competitors. As opposed to the LCC, the legacy carriers take advantage of the hub structure to maintain their average fares at a high level in the market entered. When the LCC combines the entry with a 30% decrease

in fares, the demand stimulation affects the traffic statistics of the three carriers. All carriers report greater loads but the LCC market share decreases as its capacity is limited in the market served. Simultaneously, the average fares of all three carriers plummet. However, the legacy average fares remain higher than the LCC average fare as many passengers in different markets with no LCC competition are competing to book the same legacy flights serving the market entered by the low-fare airline.

In this analysis, we show that fare decreases have different impacts in the symmetric and the asymmetric network. While a 40% decrease in the set of nominal fares leads to a 40.4% decrease in total average fare in the symmetric network, the 30% decrease in nominal fares results in a 40% decrease in total average fare in the more realistic Network D6. Then, the 40% fare decrease does not stimulate market demand in Network D6 as much as in the symmetric network. These conclusions should not be generalized as the demand stimulation analysis was performed on a market that differs from all the others in the Network D6. However, the results show that the modelization of demand stimulation is more conservative in the Network D6, which was the objective stated in the introduction of Chapter 5.

Based on the results given by the sensitivity analysis with the fare decrease as variable, and the benchmarks provided by LCC entry analyses³², we will select the case where the initial set of fares is decreased by 30% as the base case for further investigation.

5.2. 1 LCC Hublet with Single Frequency

In this section, we will investigate the traffic and revenue impact of a LCC entering spoke-to-spoke markets with one daily flight. The LCC will start to expand its operations from a single city S16 located on the West Coast (see map in section 3.3.a). As in the symmetric network, the "hublet" strategy is assumed to be the most efficient by achieving a significant degree of operational concentration for the low-fare airline.

The departure city S16 is the primary LCC target since the largest number of the spoke-to-spoke markets with the greatest demand depart from this city. As for the order of entrance, the spoke-to-spoke markets originating from S16 were entered based on their demand level. LCC operations were first introduced in the market with the greatest demand, followed by the market with the second greatest demand, and so on. In the end, the LCC offers service in fifteen out of the twenty spoke-to-spoke markets departing from S16. As in the previous section, the two initial legacy load factors are about 82% and the Passenger Decision Model remains calibrated to the values determined in Chapter 3. In the markets provided with low-fare service, the LCC flight departs at the same time as the second daily flight of either the first or the second legacy carrier, which differ only slightly. Finally, nominal fares are reduced by 30% as calibrated by the demand stimulation analysis.

Even though the Network D6 is asymmetric and demand levels differ between each O-D market, the network is consistent with a business reality that sees the greatest demand levels concentrated in the biggest cities. Thus, the spoke-to-spoke market with the greatest demand will always have S22 as destination for any departure city considered. In fact, the ranking of the arrival cities according to their respective

travel demands is the same for all departure cities. This remark also applies to the hub-to-spoke markets departing from H1 and H2.

a. Network Statistics

In the initial Network D6, we gradually introduced up to fifteen LCC flights departing from S16 to fifteen different cities. Figure 39 presents the total revenues of the three carriers operating in the network.

As opposed to LCC entry simulated in the symmetric network, the increase in LCC revenue is not quasi-linear, which is consistent with the entry pattern followed by the low-fare airline. Indeed, the markets with the greatest demands are entered first. As these high demand markets generate the most revenues for the LCC, the increase in revenue is reduced as the number of cities already served by the LCC increases. When fifteen markets are provided with low-fare service, the LCC reports total revenues of \$35,350. In this case, the legacy carriers produce about 12.5 million ASM while the low-fare airline only 892,800 ASM.

Then, the interpretation of the revenue changes reported by the legacy carriers is less straightforward than for the LCC. Overall, LCC operations in fifteen markets result in a \$10,000 decrease in aggregate legacy revenues that initially totaled \$1.88 million. However, the revenues of both legacy carriers go up and down as the LCC gradually expands its network. On the intermediate level, the analysis presented in the next section will show that the aggregate revenues for all markets departing from S16 continuously decrease as the number of markets entered increases. In fact, the irregularities of legacy revenue changes are due to the interaction of the entered markets with the O-D markets departing from the two hubs. All these markets are served by the same legs departing from the hubs and all passengers willing to book a flight in these markets compete for the same seats. As a result, the LCC introduction in a spoke-to-spoke market also affects the revenue performance of both legacy carriers in the markets with H1 and H2 as origin.

Along the LCC expansion, the analysis of the legacy revenues associated with the markets departing from the hubs does not reveal any particular pattern. In some entry cases, the revenues in the hub-to-spoke market with the same arrival city as the market entered increase. In other cases, the associated revenues decrease. However, the variation of the revenues for all markets departing from the hub is always much greater than the change affecting the hub-to-spoke market with the same arrival city as the market entered. From these observations, we infer that the interactions are complex and involve the entire set of markets departing from the hubs. Moreover, the revenue management systems of both legacy carriers also play a great role in these revenue changes. Indeed, the market analysis will show that the LCC introduction results in a slight increase in the traffic for both legacy carriers in the market entered. Paradoxically, LCC introduction with a single flight in markets with high demand does not free seats for other markets in the legacy networks due to the significant demand stimulation. However, the associated extra demand affects the revenue management systems which achieves higher average fares in some markets served, thus changes the overall revenue performance of the legacy carriers.

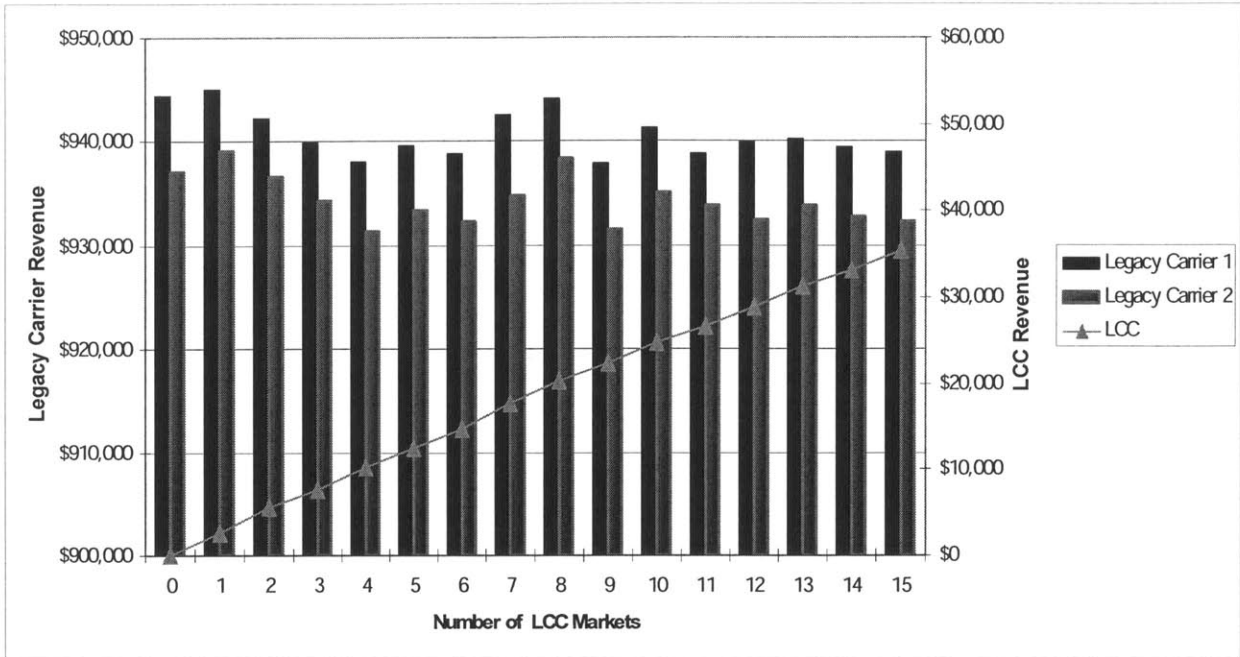


Figure 39: Legacy and LCC Revenues

b. Statistics at Intermediate Level

As in section 4.2, we introduce one measure related to the “legacy legs ex-S01” which is slightly adapted to the Network D6. The aggregate legacy average fare of the legs ex-S01 is defined as the total revenues of both legacy carriers generated by all markets with origin S01, including S01-H1 and S01-H2, divided by the corresponding number of passengers. This measure will allow us to investigate more aggregate impacts of expanding LCC operations.

Based on Figure 40, the legacy carriers report an intuitive decrease in the aggregate legacy average fare for the legs ex-S16. When all fifteen markets are served by the LCC, the legacy average fare is reduced by 9% from \$168 to \$153. This decrease is small but consistent with the entry scheme taken by the LCC entering markets with only one flight a day. The market analysis will show that it results in a slightly greater number of bookings for both legacy carriers in these markets. This allows the legacy carriers to reduce the drop in the average fare of the market entered due to the discount applied to nominal fares. It also allows the revenue management systems of the legacy carriers to maintain an equivalent pricing pressure on the other markets served by the same legs since the associated load factors do not decrease.

In terms of traffic, the number of bookings reported by the two legacy carriers slightly decrease with the number of cities entered. Once the fifteen biggest markets from S16 are served by the LCC, the number of bookings is reduced by 4% from 519 passengers initially. As stated in the previous paragraph, the LCC entry with only one

daily flight leads to a slight increase in the traffic for both legacy carriers in the market entered. Therefore, the slight decrease in traffic reported at the intermediate level must be the achievement of the legacy revenue management systems limiting the number of bookings in the markets from S16 to maintain the associated average fares at a high level.

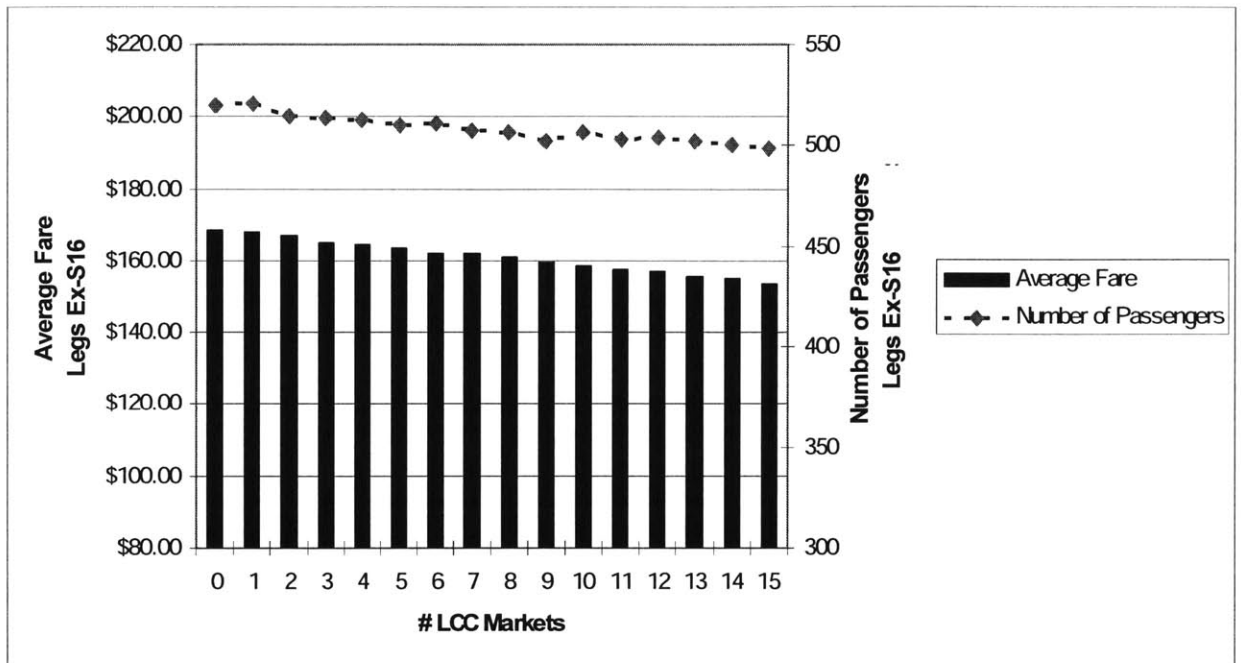


Figure 40: Aggregate Legacy Revenue and Traffic for Legs ex-S16

Figure 41 presents the LCC total revenue and traffic associated with the group of legs ex-S16. The LCC average fare slightly varies around \$91 as the low-fare network expands. In fact, the changes in the aggregate LCC average fare are due to the characteristics of the markets entered which have different average fares in the Network D6 with no low-cost competition. For instance, the second market entered by the LCC is S16-S26. As shown by Figure 41, this entry results in a significant increase in the aggregate LCC average fare from \$94 to \$101. In fact, the initial average fare of S16-S22 is \$209 whereas the initial average fare is only \$139 in the first market entered S16-S22. Then, the LCC traffic increase is regular but not linear, which is consistent with the entry pattern followed by the low-fare airline. Indeed, the markets with the greatest demands are entered first. As these high demand markets generate the most traffic for the LCC, the change in revenue is reduced as the number of markets already served by the LCC increases.

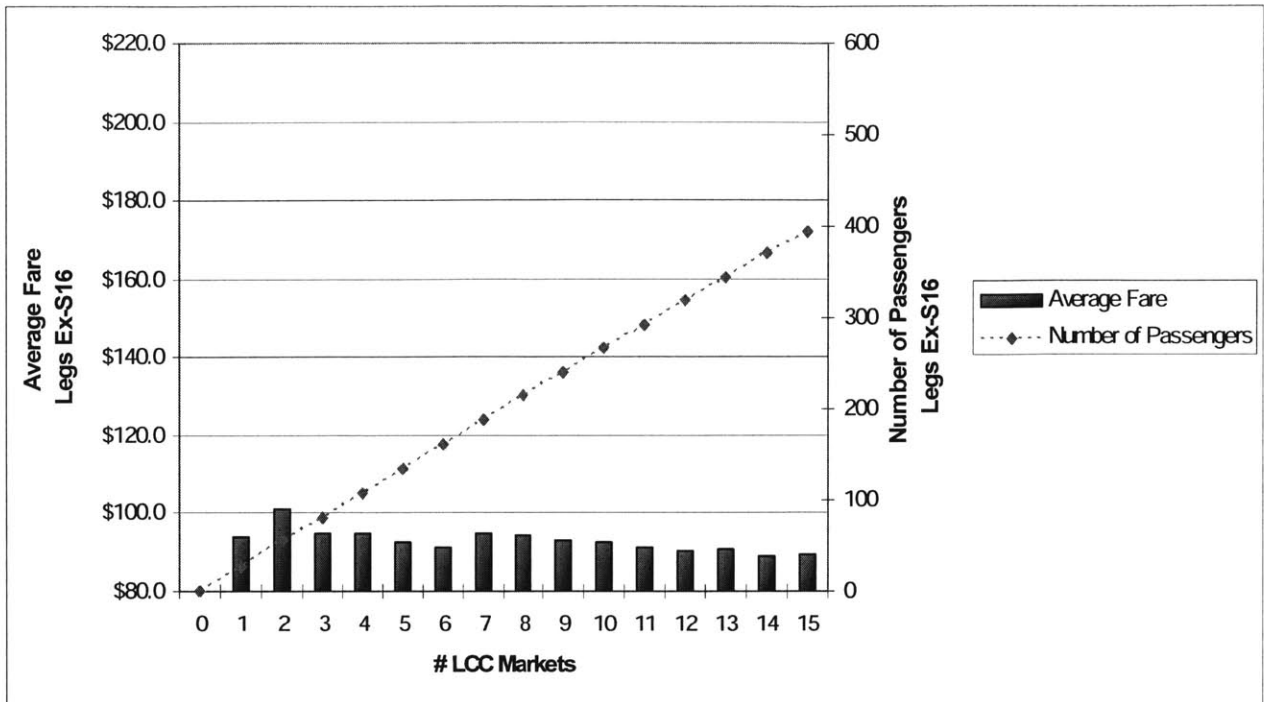


Figure 41: LCC Average Fare and Traffic

c. Statistics at Market Level

As in the symmetric network, the legacy statistics on the intermediate level are significantly weakened by the introduction of LCC service in the spoke-to-spoke markets departing from S16. Both the average fare and the load factor for the legs ex-S01 decrease as the low-fare network grows. The analysis of the legacy traffic and revenues on the market level will provide the keys to understand these trends. Moreover, LCC introduction in the symmetric network resulted in unexpected changes including the increase in the average fare of the markets not entered by the LCC but with the same origin as the markets with low-fare competition. In the Network D6, the market analysis will show whether these trends are observed in a different and more realistic environment.

First Market Entered S16-S22

Figure 42 presents the traffic and revenue statistics for both legacy carriers in the first market entered. Following the introduction of LCC service, the number of legacy bookings increases from about 21 to 25 daily bookings on average. This change is due to the great demand stimulation following the 30% decrease in nominal fares, combined with the limited capacity offered by the low-fare airline. The new entrant reports a 92% load factor when it operates only in S16-S22 with one flight a day, which gives the opportunity to both legacy carriers to maintain their loads in the market newly entered.

As for the market average fare reported by the legacy carriers, both airlines suffer from the 30% decrease in nominal fares following the LCC entry. The aggregate legacy average fare drops by more than 22% from \$171 to \$132. Even though the initial level of legacy traffic increases in S16-S22, the change in average fare affects the revenue performance of the legacy carriers to a great extent, which can be observed at the intermediate level (see Figure 40). At the market level, the total revenues can be estimated by multiplying the number of passengers in S16-S22 by the average fare. Similarly, this can be done at the intermediate level to estimate the revenues generated by all markets with origin S16 including S16-H1 and S16-H2. While the losses caused by the first LCC entry total \$290 at the market level, the revenues losses on the intermediate level are only \$190. As in the symmetric network, the shared use of legs in hub systems allow the legacy carriers to put some extra pricing pressure on the markets served by the same legs as the market entered, thus reduce revenue losses.

However, the further introduction of single daily LCC flights in additional markets departing from S16 led to a significant increase in the S16-S22 legacy average fare in the symmetric network. In the Network D6, this increase is barely noticeable. The average fare increases by less than 1% between the two cases with respectively one and fifteen LCC markets. As compared to the symmetric network, the increase in traffic is smaller in the markets entered by the low-fare airline in the asymmetric network. Therefore, the constraint on the available legacy capacity is less binding in Network D6, which puts less pricing pressure on the markets departing from the hublet developed by the LCC.

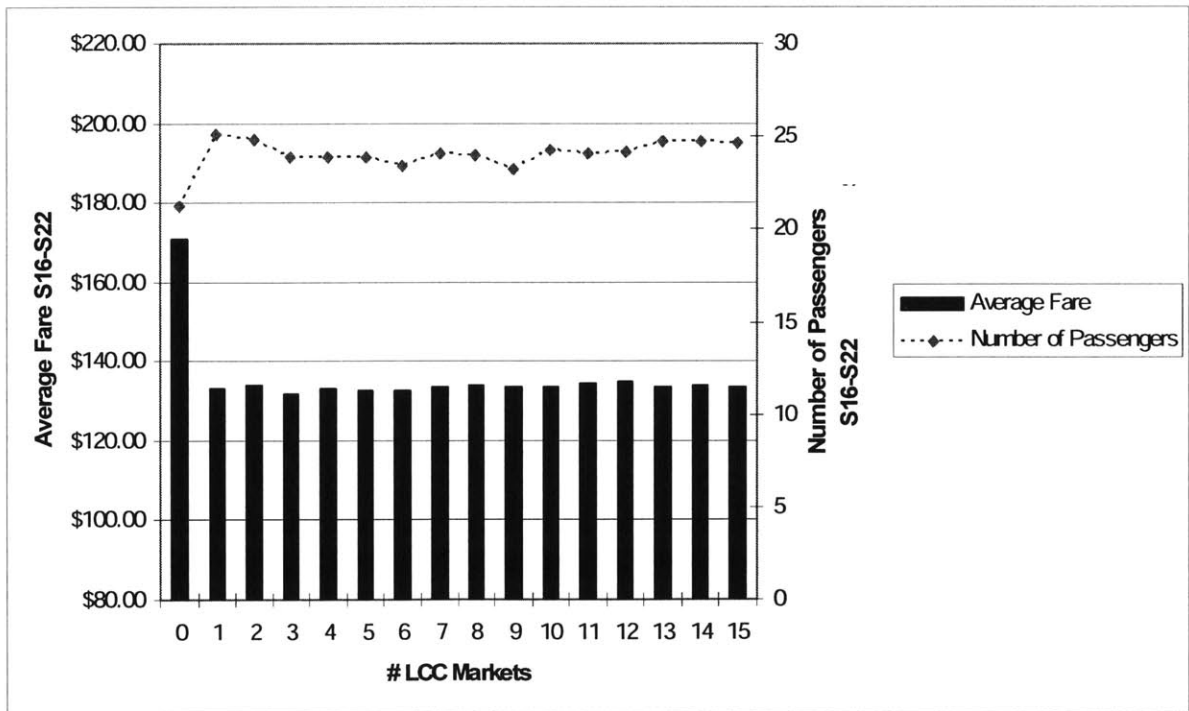


Figure 42: Aggregate Legacy Average Fare and Traffic in S16-S22 First Market Entered

Market Not Entered S16-S21

S16-S21 is the market with the fourth smallest demand among the spoke-to-spoke markets departing from S16. As the LCC enters only fifteen out of the twenty spoke-to-spoke markets from the hublet it develops, legacy operations never compete with low-fare service in S16-S21. However, the traffic and revenue statistics of the legacy carriers change when the LCC expands from its first hublet, as shown by Figure 43.

Based on the analysis of the S16-S22 market, legacy traffic in a market entered by the LCC increases slightly. As the low-fare network grows, these increments in legacy traffic are constrained by the limited capacity of the legacy carrier, however. This implies that all the potential demand cannot be accommodated by the two legacy carriers, which then use their revenue management systems to limit demand by increasing average fares. This trend is illustrated by figure 43 showing a slight decrease in the S16-S21 aggregate legacy traffic from 15.6 to 14.6 bookings on average. Simultaneously, the S16-S21 legacy average fare increases from \$193 to \$198. As compared to the results obtained in the symmetric network, the changes are much smaller in Network D6 but are consistent with the previous analyses in the symmetric network and the specifics of the asymmetric environment.

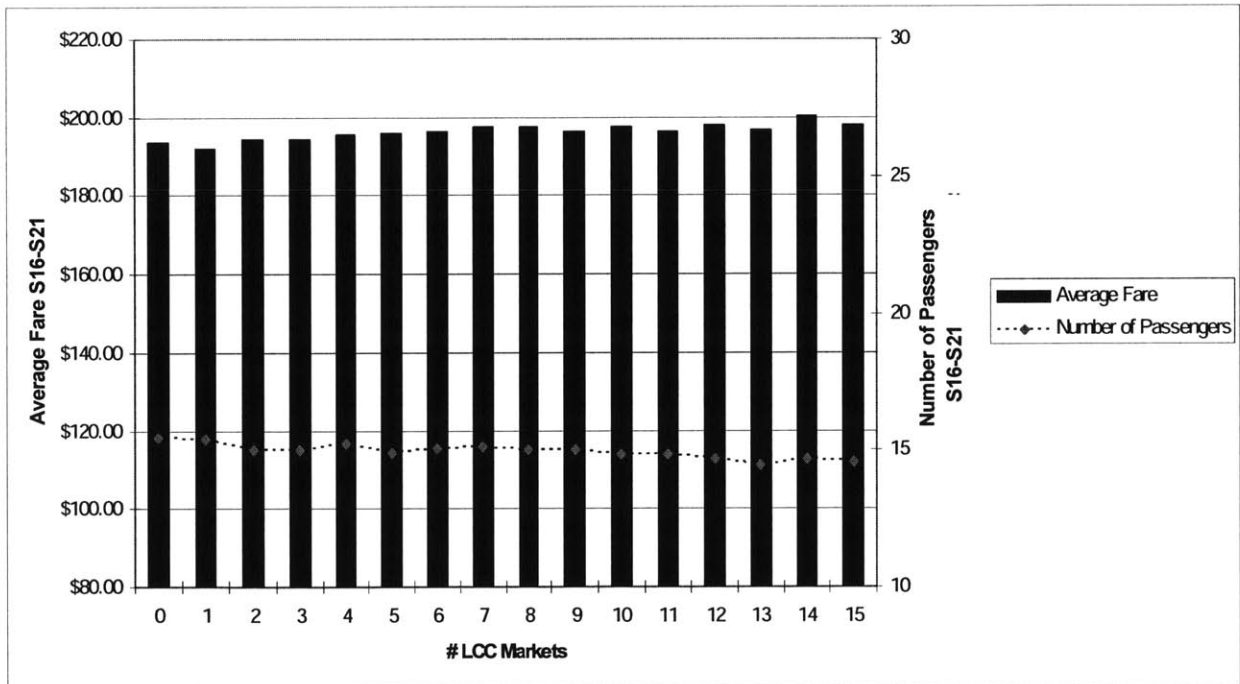


Figure 43: Aggregate Legacy Average Fare and Traffic in S16-S21 Market Not Entered

d. Conclusion

On one hand, the LCC entry in fifteen spoke-to-spoke markets from S16 has a significant impact on the aggregate revenue of the two legacy carriers. This aggregate revenue is reduced by 0.55% when all fifteen markets are served by the low-fare airline. The changes in total legacy revenue caused by each increment of LCC operations are variable and highly depend on the market entered. The analysis shows that network effects have a great impact on the final outcome in terms of revenue, specifically the changes affecting the markets departing from the two hubs. Overall, the LCC entry in the fifteen spoke-to-spoke markets results in reduced legacy revenues.

On the other hand, we infer from the analysis that the traffic levels of both legacy carriers are not threatened by the LCC offering only one daily flight in the markets entered. On the contrary, the market traffic statistics of the legacy carriers are even shown to increase in the markets where the low-fare airline starts its operations due to the significant demand stimulation. If the traffic of the two legacy carriers decreases for the group of legs ex-S01, this is only the result of the legacy revenue management facing an increased demand for legacy flights and reacting by limiting the number of bookings to rise the average fare as much as feasible. Therefore, the LCC entry scheme with one daily flight is a threat the revenue streams of the legacy carriers, but does not jeopardize the viability of the hubs in terms of traffic.

For the single frequency case, the conclusions drawn from the Network D6 analysis are similar to the LCC entry outcomes analyzed in the symmetric network. Although the changes are more difficult to identify within the increased noise produced by the size and the asymmetry of the Network D6, we determined common characteristics between the LCC entry cases in the two networks. The objective of the next section will be to determine whether the two networks present the same characteristics when the low-fare airline enters spoke-to-spoke markets with two daily flights.

5.3. 1 LCC Hublet with Double Frequency

In section 5.2, the entry analysis is based on the assumption that the LCC enters spoke-to-spoke markets from a single departure city with only one daily flight. In this section, we will investigate the traffic and revenue impacts of a different LCC strategy. As in the previous analysis, the LCC will enter spoke-to-spoke markets from a single departure city, S16, but the low-fare airline will introduce two daily flights in these markets.

The assumptions related to the initial legacy network, the Network D6, and the Passenger Decision Model will remain the same as previously calibrated. Initially, the legacy load factors are both close to 82% and all legacy flights connect at the two hubs, H1 and H2. In the markets entered, the set of nominal fares will be reduced by 30% as calibrated by the demand stimulation analysis in section 5.1. As for the schedule of the low-fare airline, the two LCC flights will depart at the same as the second and the third flight of either the first or the second legacy carrier. In a preliminary analysis, the results were indeed shown not to be very sensitive to the choice of either one of the legacy carriers. However, the LCC decision to pick up

departure times close to the second and the third legacy daily flights remains for the LCC one of the most revenue-enhancing schedule in Network D6 (see section 3.4.g).

a. Network Statistics

In the initial Network D6, we introduce up to thirty flights in markets departing from S16. As in section 5.2, the spoke-to-spoke markets with greatest demands are entered first. Figure 44 presents the revenue results of the three carriers operating in the network.

First, the decision made by the LCC to enter the markets with two daily flights results in increased LCC revenues as compared to the single frequency case. However, the increase is far from doubling its network revenues. With fifteen markets served by the low-fare airline, the double frequency leads to 45% increase in LCC revenue from \$35,500 to \$51,200. Thus, the increased LCC capacity must result in a decreased network load factor for the low-fare airline, which is only 60% when thirty flights are operated from S16 as compared to the 88% load factor obtained with fifteen flights.

Then, figure 44 shows that the changes in LCC revenue greatly rely on the demand of the market entered as the LCC expands its network. In the single frequency case, the LCC revenue curve was not linear but quite rectilinear. On the contrary, the increase in LCC revenue is greatly reduced in the double frequency case when the low-fare airline enters the last spoke-to-spoke markets with the lowest demands. While the first market generated about \$4,400, the incremental revenue associated with the last of the fifteen markets entered is only \$2,600.

Finally, the patterns of the legacy revenue curves are very similar to the single frequency case. In some entry cases, legacy revenues increase whereas they decrease when the LCC enters other spoke-to-spoke markets from S16. As described in Section 5.2, the interactions are complex and mainly involve the entire set of markets departing from the hubs. Overall, total legacy revenues are reduced by the LCC introduction in fifteen markets to a greater extent than in the single frequency case. As compared to the previous 0.55% decrease in aggregate legacy revenues with fifteen LCC flights, they are reduced by 0.8% when the fifteen markets entered are served with two flights operated by the low-fare airline.

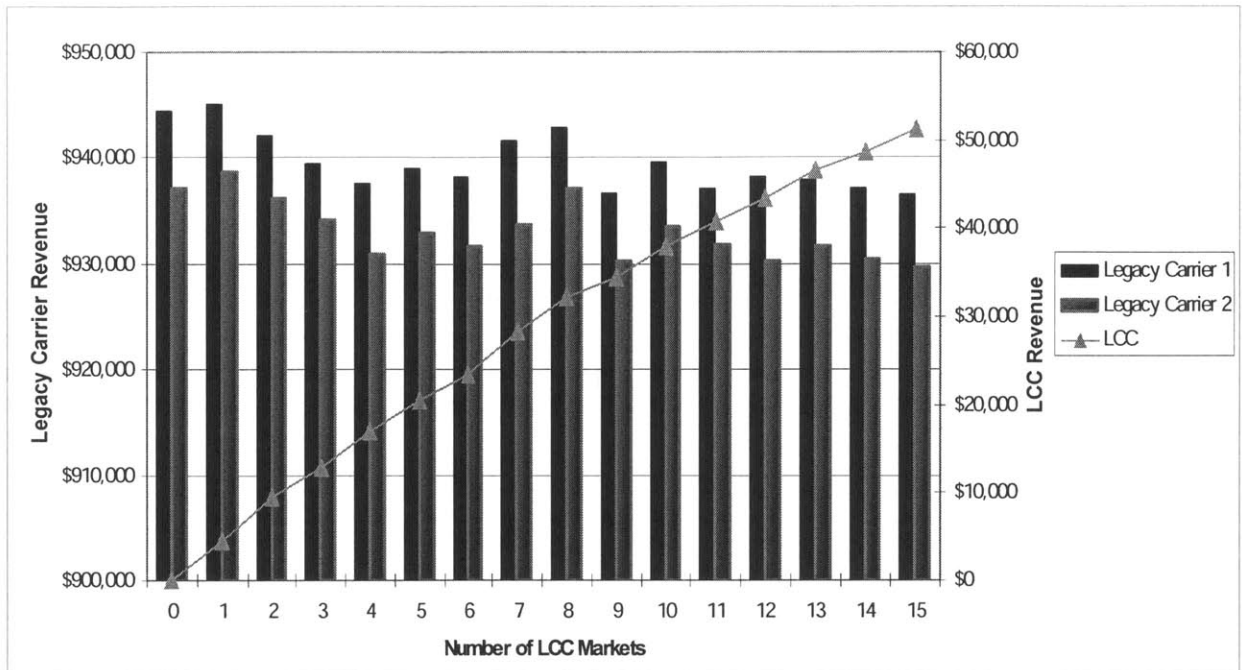


Figure 44: Legacy and LCC Network Revenue

b. Statistics at Intermediate Level

As in section 5.2.b, we introduce and analyze two measures related to the “legacy legs ex-S01”. The first measure, the load factor of the legs ex-S01, is defined as the average of the six legacy legs between S01 and the two hubs H1 and H2. The second, the legacy average fare of the legs ex-S01, is defined as the total legacy revenues generated by all markets with origin S01, including S01-H1 and S01-H2, divided by the corresponding number of passengers.

Figure 45 presents the aggregate legacy revenues and the traffic statistics associated with the legs ex-S16. As opposed to the single frequency case, the number of legacy passengers carried in the markets ex-S16 is approximately constant along the gradual introduction of LCC flights. In fact, the market analysis will show that traffic statistics are heavily reduced by the two daily LCC flights in the spoke-to-spoke markets entered. However, the extra seats left by passengers flying LCC are booked by passengers in the spoke-to-hub markets arriving at H1 and H2. Thus, the aggregate traffic levels reported by both legacy carriers are not affected by the LCC introduction although the mix of passengers across the markets ex-S16 changes.

While the aggregate legacy average fare was reduced by only 9% in the single frequency case, this measure decreases by about 20% from \$168 to \$134 in the double frequency case. Several factors are involved in the drop of the aggregate legacy average fare. In the markets entered, the nominal legacy fares are reduced by 30% as a matching response to the prices offered by the new entrant. Then, the introduction of two daily LCC flights captures a great market share, which leads to a

reduction in the loads carried by the two legacy carriers in the markets entered. This traffic decrease drives the average fare down even further. Finally, the traffic statistics at the intermediate level show that the total number of passengers carried from S16 is approximately constant. As explained in the previous paragraph, the legacy airlines maintain their loads in the markets ex-S16 thanks to more seats available to passengers traveling to the hubs. However, this increase in spoke-to-hub traffic can be only achieved by a decrease in the average fare paid by these passengers, which contributes to the decrease in the aggregate legacy average fare for the legs ex-S16.

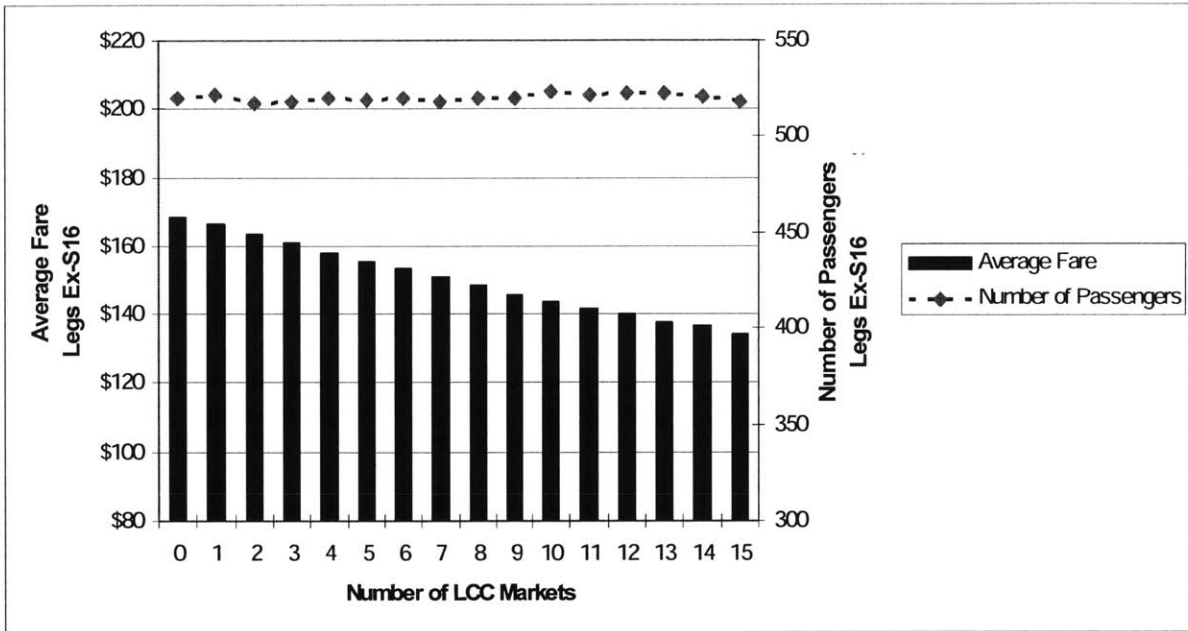


Figure 45: Aggregate Legacy Revenue and Traffic for Legs ex-S16

Figure 46 presents the LCC average fare and traffic for all the markets entered from S16. As expected, the increase in the LCC capacity leads to greater traffic levels. Thus, the total number of passengers carried by the low-fare airline is 532 on average while the total LCC traffic with fifteen spoke-to-spoke markets was only 394 in the single frequency case. In terms of average fare, the associated curve is characterized by the same pattern as observed in section 5.2.b. The average fare is approximately constant with some variations due to the specifics of the markets entered. For instance, the second market entered S16-S26 drives the LCC average fare up since the original average fare in the Network D6 with no LCC competition is very high. However, the LCC average fare is slightly greater than in the single frequency case. With two LCC flights operated in fifteen markets, the final LCC average fare is \$96.4 while it was \$89.6 in the previous analysis. We can infer that the revenue management of the LCC plays a great role in this average fare increase. Indeed, the LCC revenue management is designed to make trade-offs between decreasing the average fare which would increase the load factor, and increasing the average fare thus limiting the number of bookings. As we saw that the LCC load

factor is significantly reduced when markets are entered with two daily flights, Figure 46 illustrates the fact that increasing the load factor is not always sought by a revenue management system expected to maximize revenues.

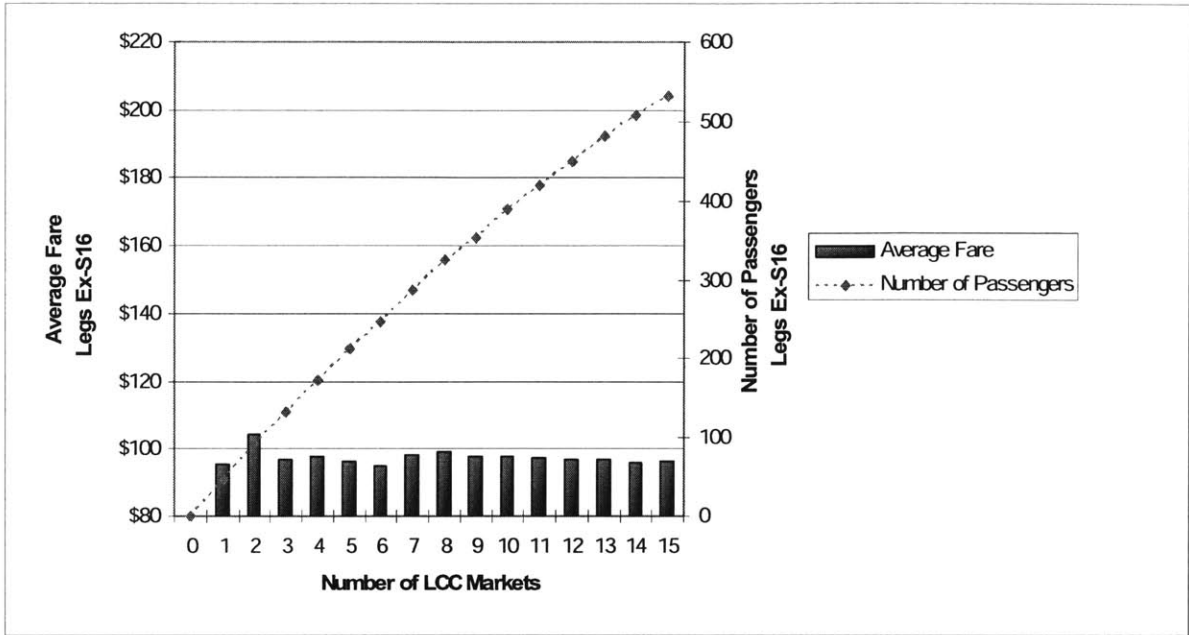


Figure 46: LCC Average Fare and Traffic

c. Statistics at Market Level

On the intermediate level, the analysis of the legacy statistics shows that the aggregate average fare is significantly reduced while traffic is approximately constant. As in the single frequency case, the analysis of the aggregate legacy average fare and traffic on the market level will allow us to understand the mechanisms driving the prices and the number of bookings in the markets entered. Moreover, the previous analyses revealed unexpected changes including the increase in the average fare of the markets not entered by the LCC but with the same origin as the markets with low-fare competition. In the double frequency case, the further investigation of the different types of markets will determine whether these trends are confirmed when the LCC pursues a more aggressive entry strategy.

First Market Entered S16-S22

Figure 47 presents the aggregate legacy average fare as well as the traffic in the first market S16-S22 entered by the LCC.

As compared to the single frequency case, the changes in legacy traffic are radically different. While the legacy traffic increased in the markets entered by the LCC with only one flight, the demand stimulation is not great enough to fill two LCC flights and

maintain the legacy loads in the markets served by the low-fare airline twice daily. As a result, the number of S16-S22 passengers carried by the two legacy carriers is reduced by 42% from 21.3 to 12.3 on average when the two LCC flights are introduced in the market. As the LCC network grows, the legacy traffic in this market increases slightly from 12.3 to 13.7 on average. In fact, this increase results from the cumulative effects of decreased traffic in the markets entered. On the intermediate level, we saw that the legacy revenue management systems achieve constant legacy traffic for the legs ex-S16. As any LCC entry with two daily flights results in decreased legacy traffic in the market, this means that the traffic in the other markets departing from S16 are managed so that the associated legacy traffic levels increase. This effect is illustrated by figure 47 showing an increase in the market traffic following the second LCC market entry.

Unexpectedly, the increase in legacy traffic is combined with a decrease in the aggregate legacy average fare for the market from \$142 to \$133 following the second LCC entry. Indeed, the average fare is the main means used by the legacy revenue management systems to regulate the demand for legacy flights in a given market. As the LCC network grows, the total demand for legacy flights departing from S16 decreases. To defend their market share, the legacy airlines are forced to put less pressure on fares, which leads to traffic increases and average decreases.

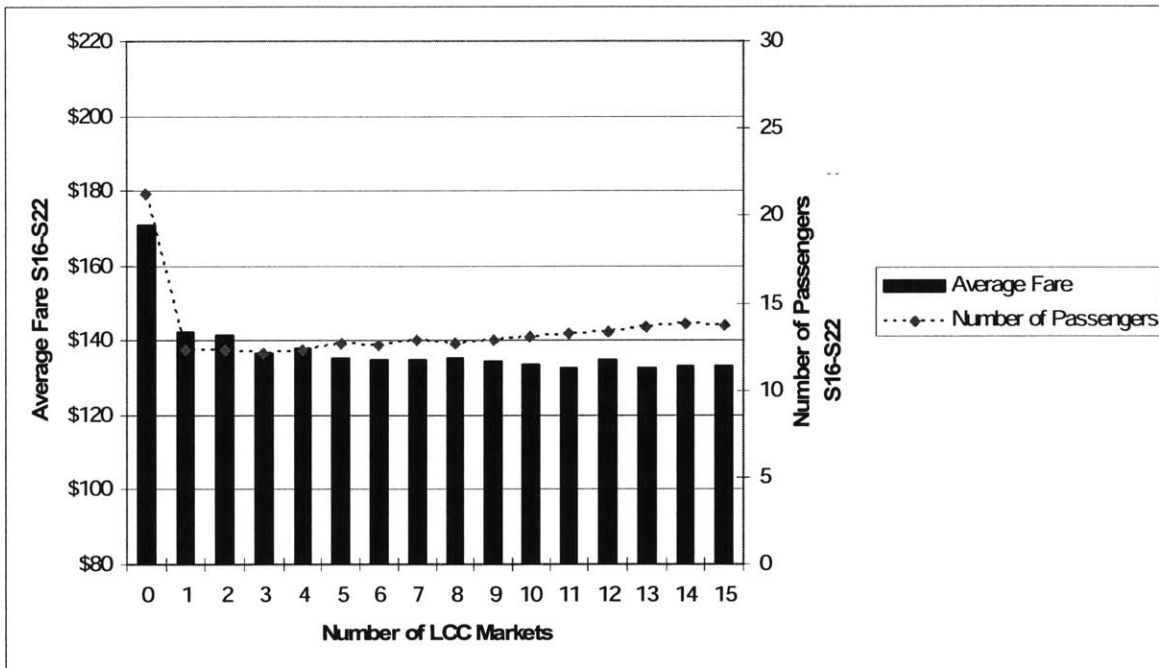


Figure 47: Aggregate Legacy Average Fare and Traffic in S16-S22
First Market Entered

Market Not Entered S16-S21

Unlike the S16-S22 market, S16-S21 is not entered by the LCC since it has one of the lowest demand levels among the spoke-to-spoke markets departing from S16. Figure 48 presents the traffic and aggregate legacy average fare associated with this market.

In the single frequency case, the traffic was shown to decrease and the legacy average fare to increase when the low-fare airline introduced new spoke-to-spoke markets from S16. In the double frequency case, the changes in the market legacy statistics are opposite. As the LCC network grows, the legacy average fare decreases by 10.3% from \$194 to \$174. In terms of traffic, the number of legacy passengers increases from 15.5 to 18.4 on average following the first LCC introduction. These changes are fully consistent with the changes observed in the S16-S22 market after the second LCC introduction. As the low-fare airline enters spoke-to-spoke markets, the legacy revenue management systems decrease the average fare in the other markets from S16 to increase the associated traffic and thus maintain the legacy traffic on the intermediate level.

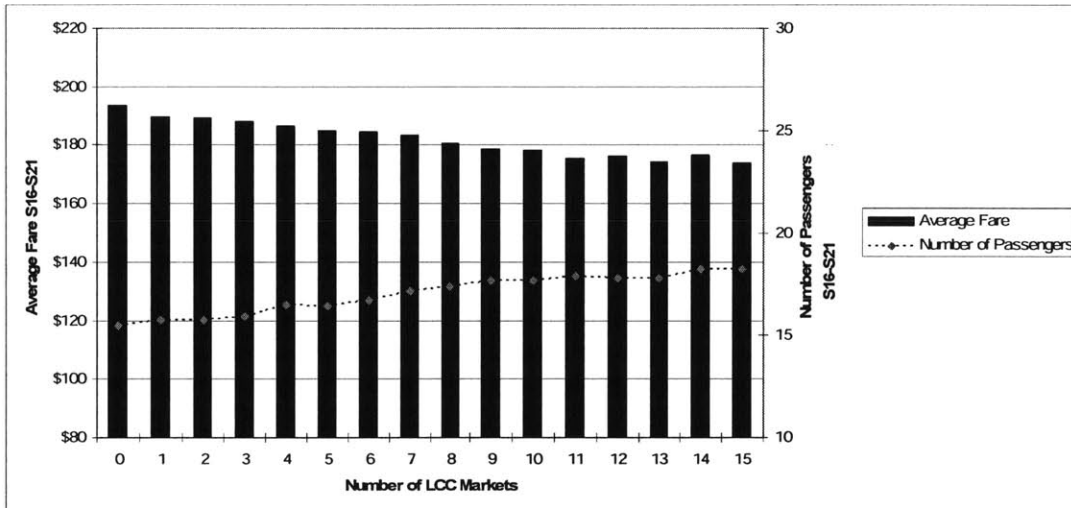


Figure 48: Aggregate Legacy Average Fare and Traffic in S16-S21 Market Not Entered

d. Conclusion

In section 5.3, the analysis of the double frequency case confirms the conclusions drawn from the LCC entry simulation in the symmetric market.

First, the revenues of the two legacy carriers are more reduced when the low-fare airline enters spoke-to-spoke markets with two daily flights as opposed to only one. In section 5.2, we see that aggregate legacy revenues decreased by 0.55% while they are reduced by 0.8% when the LCC enters fifteen markets departing from S16

with two daily flights. As in the symmetric network, the network revenue losses experienced by the two legacy carriers are lower than the losses generated in the set of markets entered by the LCC. We show that the markets to and from the two hubs play a great role in compensation for the losses reported at the intermediate level. Overall, this revenue compensation remains partial as shown by the \$15,000 decrease in aggregate network revenue of the two legacy carriers when the LCC operates in fifteen spoke-to-spoke markets.

Then, we determine that the legacy average fare in the markets ex-S16 is much more affected by the LCC entries in the double frequency case as compared to the single frequency scenario. Indeed, the legacy average fare associated with all markets ex-S16 decreases by 20% while it is reduced by only 9% when the fifteen markets ex-S16 with the greatest demands are entered with only one daily flight. However, the results show that the traffic at the intermediate level does not decrease as the LCC network grows. The loss of bookings due to passengers booking LCC flights is compensated by legacy traffic carried in other markets departing from S16. In this case, the markets arriving at the two hubs again play a great role in maintaining the initial legacy traffic levels on the legs from S16.

Finally, the market level analysis shows that the two daily LCC flights capture too great a market share in the markets entered to allow the legacy traffic levels to remain constant. In the spoke-to-spoke markets served by the low-fare airline, the traffic carried by the two legacy carriers is reduced by between 30% and 40% depending on the market considered as compared to the initial legacy traffic level. This conclusion is although the demand is greatly stimulated by the 30% decrease in nominal fares.

5.4. Multiple LCC Hublets

As the last part of the Network D6 analysis, we will investigate the impact of a LCC operating multiple hublets. In Section 5.2 and 5.3, we determined that the aggregate revenue of the two legacy carriers decreased by 0.55% and 0.8% when the low-fare airline entered spoke-to-spoke markets from a single hublet with respectively one and two daily flights. The decrease in the legacy network traffic was negligible and could not lead to any conclusion since the low-fare airline operated only up to fifteen markets as compared to 482 O-D markets that compose the Network D6. In this section, the objective is to assess the existence of “cascade effects” following further LCC expansion. As the LCC network grows, the negative changes in legacy revenues and traffic could increase, i.e. the ability of the legacy carriers to replace connecting with local hub traffic would be limited.

a. Single Frequency Case

In Section 5.4.a, the LCC entry will be modeled as in section 5.2 but the number of spoke-to-spoke markets entered will be up to 150 departing from ten different hublets. The ten departure cities where the LCC expands its operations from have the greatest demands associated with the spoke-to-spoke markets of the Network D6. The low-fare airline will gradually enter these markets with one daily flight

departing at the same time as the second flight of alternatively the first and the second legacy carrier. The overall demand level in the Network D6 will be set up such that the initial load factors of the two legacy carriers are close to 82% (as in the previous sections), and the parameters of the Passenger Decision Model will remain as calibrated in section 3.

Figure 49 presents the revenues of the three carriers operating in the network as the LCC expands its operations. First, the LCC revenue curve is not linear. The positive change in LCC revenue is greater when the LCC network is small. The incremental revenue generated by the first five markets entered is \$12,500 while it is only \$5,100 for the last five markets. This decrease is consistent with the pattern of market entry adopted by the LCC. Indeed, the first markets entered have the greatest demand potential as compared to the last ones. Thus, the traffic and associated LCC revenues in the latter will be smaller than in the former. Then, the revenues of both legacy carriers are greatly affected by the LCC entries in 150 spoke-to-spoke markets within the network. The aggregate revenues associated with the two legacy carriers are reduced by 5.6% when 150 markets are served by the low-fare airline. As compared to the 0.55% decrease in aggregate legacy revenue determined in section 5.2, the multiple hublet analysis shows that there is no significant cascade effects in terms of legacy network revenue associated with the single frequency case. The decrease is indeed ten times greater than the revenue drop experienced by the legacy carriers when the size of the LCC network was ten times smaller.

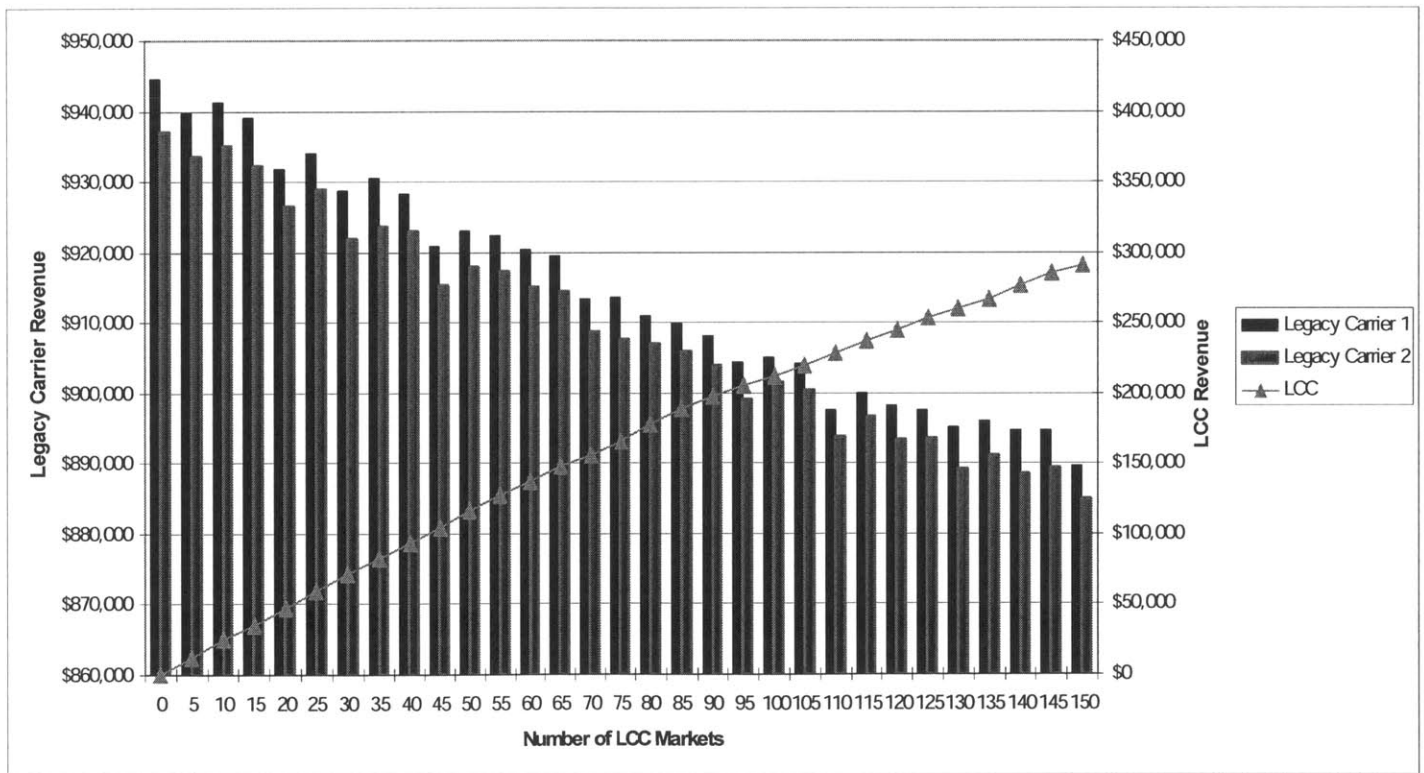


Figure 49: Legacy and LCC Revenues

In Figure 50, the load factors of respectively the two legacy carriers and the LCC are shown. The load factors of the two legacy carriers remain constant as the size of the LCC network increases. In section 5.2, we showed that the legacy traffic increased in the markets served by the low-fare airline. Therefore, the constant legacy load factors observed in this section are consistent with the results given by the previous analysis of LCC entry with single frequency. Moreover, the load factor of the LCC is shown to decrease from 90.4% to 77.1% as the size of its network increase from 5 to 150 markets. As was true for the decrease in the incremental LCC revenue, this observation is related to the pattern of market entry chosen by the LCC, which enters the spoke-to-spoke markets with the greatest demand first.

In conclusion, the multiple hublet analysis with single frequency shows that legacy revenues are greatly reduced by the expansion of LCC operations to 150 markets, but no significant cascade effects applied to legacy revenues are observed, and the traffic carried by the legacy airlines does not decrease as the low-fare airline grows.

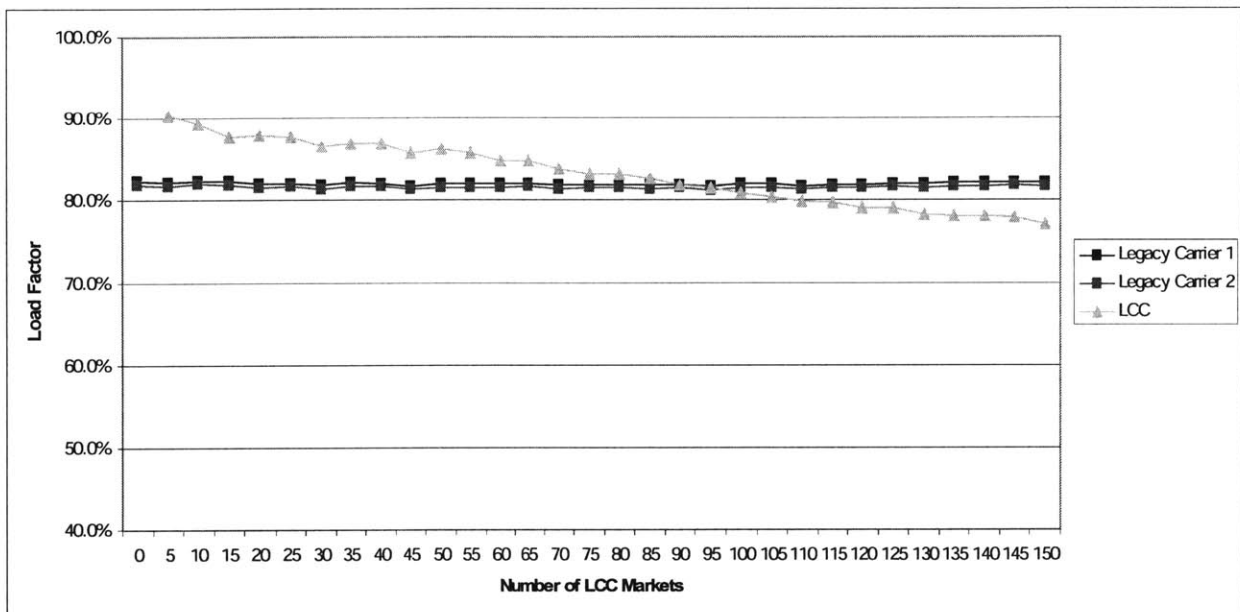


Figure 50: Legacy and LCC Load Factors

b. Double Frequency Case

In a second case, the LCC enters up to 145 spoke-to-spoke markets with two daily flights. Its strategy of expansion is still based on the development of hublets where the LCC concentrates its operations. As in the previous section, the low-fare airline will start service from the ten different departure cities with the greatest demand levels in the Network D6. The city with the greatest demand will be entered first, etc... In the end, thirty daily LCC flights will be operated in fifteen spoke-to-spoke markets from each hublet, except for the last hublet which will have LCC service in ten markets only. As for the schedule, the first daily LCC flight will depart at the

same time as the second flight of alternatively the first and the second legacy carrier. The second daily flight will depart at the same time as the third flight of alternatively the first and the second legacy carrier (see Section 5.3 for further explanation on schedule optimization). All other parameters will remain as calibrated in the previous section.

Figure 51 presents the revenues of the legacy carriers and the LCC operating within the Network D6. First, the increased LCC capacity results in greater revenues for the low-fare airline as compared to the single frequency case (see Section 5.4.a). When the LCC operates in 145 markets, its revenues are \$383,900 while total LCC network revenues were only \$285,000 with single daily frequency. In terms of ASM, the number is doubled from 7.5 million to 15 million between the single and the double frequency case. The LCC output level can be compared to the number of ASMs produced by the two legacy carriers, each of them reporting 12 million ASMs. As in the previous section, the incremental increase in LCC revenue due to new market entries is reduced as the size of the LCC network increases. This result is consistent with the LCC pattern of market entry focusing first on the markets with the greatest demand.

Then, the revenue curves of the two legacy carriers present similar characteristics as in the single frequency case. As the LCC expands its network by increment of five markets, the legacy revenues experience slight oscillations due to network effects. In section 5.3, we explained the great role played by the markets arriving and departing from the two hubs in regulating the traffic and revenues of the legacy carriers by providing extra traffic. The existence and the persistence of these effects are confirmed by Figure 51. However, the amplitude of the revenue oscillations tend to decrease as the size of the LCC network increases. The demand of the markets from and to the hubs being limited as in any other market, it must be more difficult for the legacy carriers to rely on local hub traffic to compensate for traffic and revenue losses due to LCC entry, which leads to a reduction of the oscillations.

As compared to the single frequency case, the revenues of the legacy carriers are affected to a greater extent. While the aggregate revenues of the two legacy carriers were reduced by 5.2%, the more aggressive LCC entry strategy results in a 7.4% decrease in these revenues. In the double frequency cases, the revenue decrease is equivalent to about \$490 in daily losses for both legacy carriers in each of the 145 markets entered by the LCC. This result is consistent with the market analysis performed in section 5.4.c where both traffic and average fare were shown to drop in the markets entered by two daily LCC flights. Although other markets including from and to the hubs can compensate for the losses experienced in these spoke-to-spoke markets, this can be only partial.

Then, the 7.4% decrease in aggregate legacy revenues shows the absence of cascade effects when the LCC enters up to 145 markets with two daily flights. The reduction in aggregate legacy revenues was already 0.8% when only fifteen markets were entered by the LCC (see section 5.4), which is about a tenth of the legacy revenue decrease when the LCC operates in 145 markets. Since the ratio of the revenue decreases and the number of markets entered are almost equal, no cascade effect plays a significant role in this scenario.

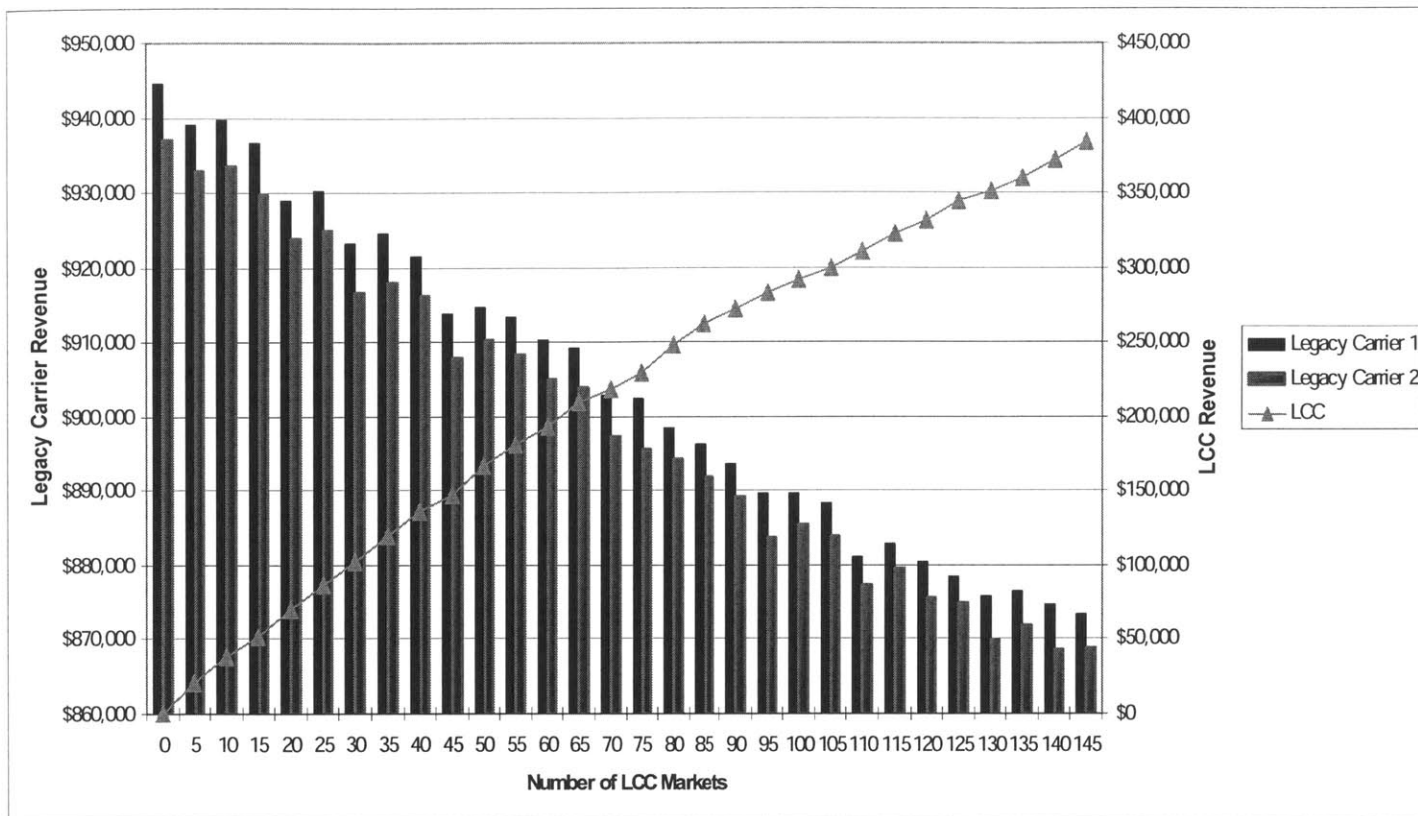


Figure 51: Legacy and LCC Load Factors

Figure 52 presents the load factors of the three carriers operating in the network. On one hand, the great capacity introduced by the LCC in every market entered results in a continuously decreasing load factor as its network expands. With operations in five markets, the LCC load factor is about 70% whereas the low-fare airline hardly reaches a 50% load factor with 145 markets operated. On the other hand, the load factors of the two legacy carriers are only very slightly reduced by the massive LCC entry. Both load factors decrease by less than 2% once the LCC serves the 145 markets targeted. As described in section 5.4.b, the extra demand available in the markets from and to the hubs, as well as demand stimulation in the markets entered allow the legacy carriers to maintain their loads. However, the legacy revenues are still greatly affected by the LCC entry.

In conclusion, the results of the double frequency case corroborate the findings of the analysis performed in the symmetric network. The more aggressive LCC strategy diverts more traffic from the legacy carriers, thus affects the legacy revenues to a greater extent and leads to greater revenues for the low-fare airline. However, the viability of the hub in terms of traffic does not seem to be threatened by this LCC entry scenario. The legacy carriers can rely on both the remainder of the customers in the markets entered by the LCC, and the great local demand from and to the hubs to feed their hubs.

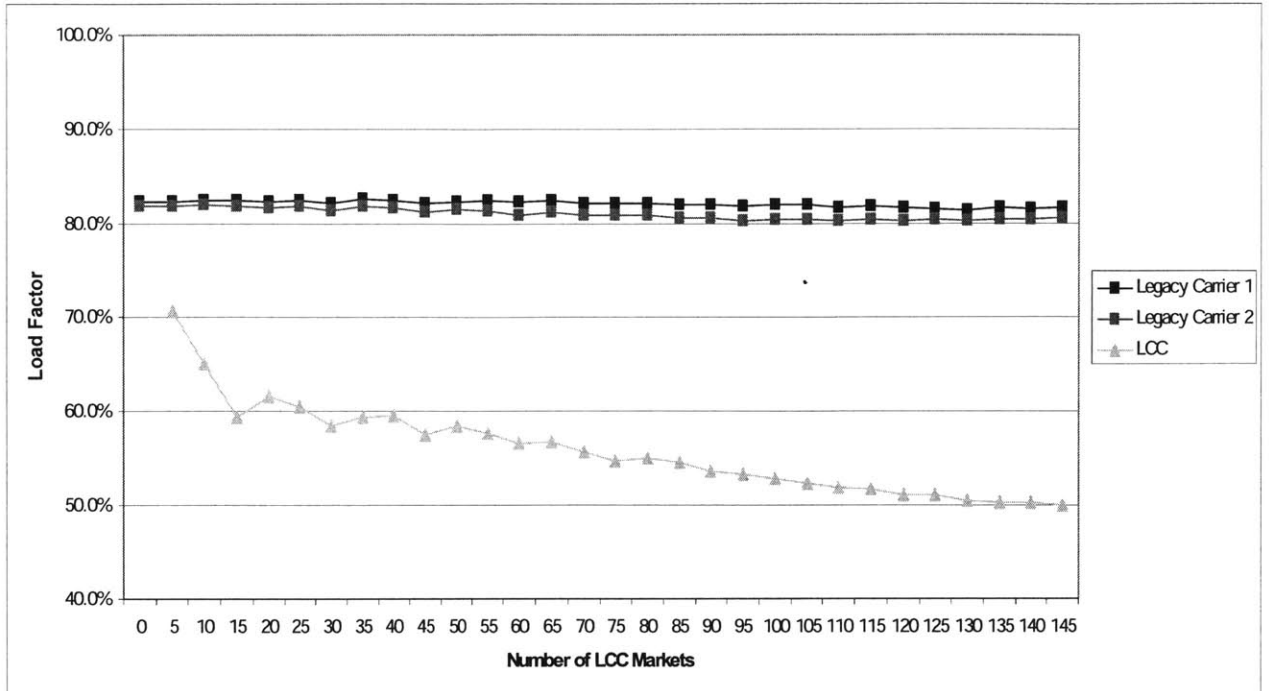


Figure 52: Legacy and LCC Load Factors

5.5. Conclusion

In Chapter 5, we analyzed the traffic and revenue impacts of a LCC entering point-to-point markets in a realistic environment, the Network D6. In this network, all markets have different characteristics with regard to both the fares implemented in the market and the demands, which defines an asymmetric network. Initially, the two legacy carriers operate two major hubs with load factors of 82% very close to the levels reported by the US airline industry recently. We developed a base case of LCC entry by analyzing demand stimulation and chose a 30% decrease in nominal fares following the introduction of low-fare service. In the market analyzed for demand stimulation purposes, the demand stimulation was shown to be smaller than in the symmetric network. After nominal fares were decreased in a market randomly selected, the average fare was reduced by about 40% while traffic increased by 157% as compared to about 200% in the symmetric network.

In the single frequency case, the findings related to the traffic and revenue impacts were very similar to the conclusions drawn from the analysis in the symmetric network. Overall, both legacy revenues were negatively affected by the LCC entries on the aggregate level, even though we observed significant oscillations in these revenues. Once the LCC operated in 150 markets departing from ten hublets, the aggregate revenues of the two legacy carriers were reduced by 5.6% while the associated load factors of the legacy carriers were still about 82%. On the market level, we showed that the LCC entry with only daily flight resulted in a significant

increase in both legacy carriers' traffic in the market entered. As in the symmetric network, this change had an impact on the other markets departing from the same hublet as the legacy capacity on the corresponding legs was limited. Therefore, we observed a slight increase in the legacy average fare and a moderate decrease in legacy traffic in these markets as the LCC expanded its network. However, the changes were smaller than in the symmetric network, which is consistent with the smaller demand stimulation modeled in the Network D6. The analysis of the multiple LCC hublet scenario showed that legacy revenues were greatly reduced by LCC competition in numerous markets, and the downward trend was regular and unaccelerated in spite of small oscillations due to network effects. Unlike the symmetric network where the negative changes in legacy revenues were shown to slightly increase as the LCC network size increased, the decrease in legacy revenues was very regular when the low-fare airline enters up to 150 markets with one daily flight in Network D6.

In the second frequency case, the results corroborate the findings of the analysis performed in the symmetric network as well. On the market level, the increased LCC capacity led to a greater LCC market share in the markets entered as compared to the single frequency scenario. The aggregate legacy traffic was reduced by between 30% and 40% in the markets served by the low-fare airline. Consequently, the revenue management systems of the two legacy carriers lost some power to manage high fares from the passengers willing to book in markets departing from the hublet developed by the LCC. On the intermediate level, these changes resulted in a significant reduction in the average fare for the legs ex the hublet. While the decrease in average fare was only 9% in the single frequency case, it was 20% when fifteen markets ex the hublet were operated by the LCC with two daily flights. In all the markets departing from the LCC hublets, the aggregate legacy average fare was eventually reduced. Overall, legacy revenues were greatly affected by the LCC entries with double frequency as shown by Table 40. With 145 markets entered, the LCC produced 15 million ASMs as compared to 12 million for each legacy carrier, and led to a 7.4% decrease in aggregate legacy revenues. Nevertheless, the load factors of the two legacy carriers were shown to remain approximately constant as the LCC expanded its operations. In fact, the traffic lost by the legacy carriers in the markets entered was compensated by local traffic from and to the hubs. This shift in the local vs. connecting traffic mix was done at the expense of the legacy revenues, but the traffic levels of both legacy carriers were thus stabilized. Finally, the revenue analysis of the multiple hublet scenario showed the lack of cascade effects as in the single frequency case.

Finally, the simulation of low-fare entry in the Network D6 shows that LCC competition threatens the revenues but not the traffic levels of the legacy carriers on the network level. Demand stimulation, legacy schedule convenience, the preference for legacy airlines, and local hub traffic are key factors enhancing legacy traffic in an environment where low-fare offer is increasing. However, the revenues of both legacy carriers are badly reduced by the overall expansion of the LCC. The "matching fares" assumption, as well as the traffic decrease in the markets entered by the low-fare airline with two daily flights contributes to the drop in legacy yield. Although the viability of the hubs in terms of traffic is unlikely to be comprised by increased LCC competition, the profitability of the legacy carriers will certainly be affected due to smaller revenues if their costs remain high. These conclusions are confirmed by the two LCC entry scenarios considered in Chapter 5, the single and the more aggressive double LCC frequency case.

		No LCC (Base Case)	15 Markets Entered Single LCC Frequency	15 Markets Entered Double LCC Frequency	150 Markets Entered Single LCC Frequency	145 Markets Entered Double LCC Frequency
Legacy Carrier 1	ASMs	12,267,966	12,267,966	12,267,966	12,267,966	12,267,966
	RPMs	10,102,966	10,101,275	10,117,039	10,074,327	10,010,645
	Load Factor	82.35%	82.34%	82.47%	82.12%	81.60%
	% Change vs Base Case	/	-0.01%	0.15%	-0.28%	-0.91%
	Revenues	\$944,457	\$939,033	\$936,524	\$889,704	\$873,461
	% Change vs Base Case	/	-0.57%	-0.84%	-5.80%	-7.52%
	Yield (\$)	9.35 cents	9.30 cents	9.26 cents	8.83 cents	8.73 cents
	% Change vs Base Case	/	-0.53%	-0.96%	-5.56%	-6.63%
Legacy Carrier 2	ASMs	12,739,530	12,739,530	12,739,530	12,739,530	12,739,530
	RPMs	10,433,881	10,426,247	10,423,433	10,416,971	10,256,303
	Load Factor	81.90%	81.84%	81.82%	81.77%	80.51%
	% Change vs Base Case	/	-0.07%	-0.10%	-0.16%	-1.70%
	Revenues	\$937,151	\$932,304	\$929,697	\$884,986	\$868,820
	% Change vs Base Case	/	-0.52%	-0.80%	-5.57%	-7.29%
	Yield (\$)	8.98 cents	8.94 cents	8.92 cents	8.50 cents	8.47 cents
	% Change vs Base Case	/	-0.45%	-0.67%	-5.35%	-5.68%
LCC	ASMs	/	892,580	1,785,160	7,626,828	15,087,037
	RPMs	/	783,320	1,061,418	5,880,432	7,555,499
	Load Factor	/	87.76	59.46	77.1	50.08
	Revenues	/	\$35,353	\$51,298	\$290,306	\$383,916
	Yield (\$)	/	4.51 cents	4.83 cents	4.94 cents	5.08 cents

Table 40: Summary of Traffic and Revenue Results

6. Conclusion and Future Research Directions

6.1. Summary of Findings

The objective of this thesis was to investigate the traffic and revenue impacts of a low-cost carrier (LCC) developing non-stop routes in a hub network system dominated by legacy carriers. Based on recent trends of the airline industry, we explained the relevance of such a competitive scenario. A literature review allowed us to determine the assumptions related to passenger choice between paths, fare classes, and airlines such that the LCC entry model would be realistic. Following a description of the mechanisms involved in the Passenger Origin Destination Simulator (PODS), we calibrated the simulator so it could integrate the assumptions defined earlier. We then developed two simulation environments, a symmetric and an asymmetric network. In both environments, we studied the traffic and revenue changes experienced by the incumbents and the new entrant as a result of the expansion of LCC operations.

In the first part of this thesis, we reviewed the development of hub systems. With the US airline industry as a case study, we showed that the schedule convenience, the concentration of operations, and the benefit of serving multiple O-D markets with legs connecting at the hub, were the main factors involved in the growth of hub operations. Then, we described the success of low-cost carriers that have experienced an exponential growth in the last ten years. The reshaping of the airline industry with new entrants coming in with extremely low fares changed the behavior of customers with regard to flight booking. We analyzed the most recent studies of passenger decision models based on disutility costs that could be implemented in the PODS simulator. Customer surveys showed that any kind of disutility cost was greater for business than for leisure traffic. Moreover, the analyses concluded that significant disutility costs were associated with flight connection, yet legacy carriers benefited from customer preference due to some perks such as the miles earned via loyalty programs. Thus, we were provided with the critical parameters necessary to model LCC entry in PODS.

In the second part of the thesis, we described the PODS environment including the two networks used for simulation purposes, the symmetric network and the asymmetric network (Network D6). We presented the concepts associated with airlines' booking systems and passenger decisions with regard to flight booking, both key elements of the PODS simulation. Since the Passenger Decision Model is based on a generalized cost function involving disutility costs associated with trip characteristics, we calibrated it to account for the specificities of LCC entry. In the symmetric network, we simulated an LCC entering a market with one daily flight. The literature review provided not only the order of magnitude of disutility costs, but also the expected markets share of the airlines in such a scenario. Based on these well defined constraints, all critical parameters were calibrated through a sensitivity analysis.

We then simulated LCC entry in the symmetric network and analyzed the associated traffic and revenue impacts. We performed a demand stimulation analysis that showed demand was significantly boosted when fares were reduced. Since our intent was to model LCC entry in a stimulated demand environment, we chose to

implement a 40% decrease in nominal fares in the markets entered by the low-fare airline. As a result, the average fare was shown to decrease by about 40.4% and the total traffic to increase by 200% in the spoke-to-spoke market operated by the LCC.

Table 41 summarizes the results associated with the two LCC entry scenarios tested, the single and the double LCC frequency case. When the LCC entered spoke-to-spoke markets with only one flight a day, demand stimulation was so strong that the traffic carried by the legacy carrier increased in these markets despite LCC competition, but the market average fares plummeted. We showed that other O-D markets were also greatly affected by the LCC entry when their origin was the departure city of the new LCC flights. Indeed, the traffic in these non-LCC markets was constrained by the legacy capacity due to the demand surge in the markets newly served by the LCC, which led to unexpected increases in some market average fares even in non-LCC markets. Overall, legacy revenues were shown to be greatly reduced by LCC operations although legacy load factor increased, and average fares increased in a limited number of markets. The introduction of fifty LCC non-stop flights resulted in a 7.9% decrease in legacy revenue while the legacy load factor increased by 1.7% from 87%.

In the double LCC frequency case, the greater capacity offered by the low-fare airline captured more traffic in the markets it entered, which prevented the legacy carrier from maintaining its load factor. Consequently, the negative impact on legacy revenue was strengthened by the significantly lower demand for legacy flights. No increase in legacy average fare was reported in any market as was observed in the single frequency case. In the spoke-to-spoke markets served by the LCC, the loss in legacy traffic was shown to be replaced by local hub demand, but this compensation was only partial and also led to average fare decreases in these local hub markets used to feed the hub. Eventually, legacy revenues were shown to be greatly affected by LCC double frequency operations in fifty markets as they were reduced by 14.2%. Simultaneously, the legacy network load factor decreased from 87% to 82.3%. This confirmed the LCC competition affected legacy traffic negatively, but was more a threat to the legacy revenue streams than the total number of passengers carried by the legacy airline.

	10 Markets Entered Single LCC Frequency	10 Markets Entered Double LCC Frequency	50 Markets Entered Single LCC Frequency	50 Markets Entered Double LCC Frequency
Change in Legacy Load Factor	0.71%	-0.99%	1.69%	-4.67%
Change in Legacy Yield	-1.90%	-1.58%	-9.39%	-10.02%
Change in Legacy Revenues	-1.23%	-2.63%	-7.94%	-14.24%

Table 41: Summary of Changes in Total Network Statistics for the Legacy Carrier Symmetric Network

Finally, the realistic Network D6 was used to corroborate the results obtained in the symmetric network. Based on a demand stimulation analysis, a 30% decrease in nominal fares was implemented in the markets entered by the LCC. In Network D6, demand stimulation depends on the characteristics of each market entered in which two legacy hub carriers compete originally. The level of stimulation was shown to be generally weaker as compared to the symmetric network, but significant and consistent with observations of real LCC entry cases.

Two LCC entry scenarios were tested, the single and the double LCC frequency case. In the former, the changes in the revenue and traffic of both legacy carriers were shown to have similar properties as in the symmetric network. In the markets entered, demand stimulation led to increases in legacy traffic while the average fare dropped. To a smaller extent, we observed the same unexpected increases in average fare for the markets not entered but departing from the new LCC hublets. Overall, the load factors of both legacy carriers were barely changed by the introduction of LCC service in up to 150 markets, fluctuating around the original 82% value as the low-fare airline expanded. Although partially compensated by network effects including average fare increases in local hub markets, aggregate legacy revenues were significantly reduced by up to 5.7%.

As expected, increased LCC capacity allowed the new entrant to gain a greater market share in the markets entered. However, both legacy carriers were shown to efficiently take advantage of demands in the markets to and from the hubs, thus replacing the traffic lost in the markets entered. As shown by Table 42, the aggregate legacy load factor decreased by only 1.3% when 145 markets were served by the low-fare airline. In the double frequency case, LCC entry caused the average fare to decrease not only in the market entered but also in all markets with the same origin or the same destination as the newly introduced LCC flights. As a result, aggregate legacy yield was shown to be reduced by up to 6.4%, which led to a 7.4% decrease in aggregate legacy revenues.

	15 Markets Entered Single LCC Frequency	15 Markets Entered Double LCC Frequency	150 Markets Entered Single LCC Frequency	145 Markets Entered Double LCC Frequency
Change in Aggregate Legacy Load Factor	-0.05%	0.02%	-0.22%	-1.31%
Change in Aggregate Legacy Yield	-0.50%	-0.88%	-5.46%	-6.38%
Change in Aggregate Legacy Revenues	-0.55%	-0.82%	-5.68%	-7.40%

Table 42: Summary of Changes in Aggregate Network Statistics for both Legacy Carriers Asymmetric Network (D6)

To conclude, all the results presented in the thesis demonstrate that hub systems are very resilient in terms of traffic load factors when facing extensive and aggressive LCC competition. As low-fare service is expanded in non-stop routes, legacy carriers can rely on connecting traffic in other markets and local demand departing and arriving at the hubs to replace the traffic captured by the new entrant. Nevertheless, this occurs at the expense of the average fare in these local hub markets, which adds up to the significant losses reported in the markets entered due to the traffic captured by the legacy carrier and the significant decrease in nominal fares. As a result, legacy revenues are greatly reduced in a massive LCC entry scenario, whereas legacy load factors are only slightly affected even in the most aggressive case with regard to LCC network size and frequency.

In the LCC entry scenarios tested, the size of the low-fare network was increased to a point where the new entrant offered more ASMs than any incumbent. In the real world, such cases are rare although Southwest reported the greatest number of domestic enplanements within the US in January 2006. In the thesis, the LCC entry analysis referred to only one low-fare airline. In fact, this approach was chosen to simplify the presentation of the results but not to exclusively model the competition of a unique LCC. The same framework of analysis could be applied to non-stop low-fare entry led by multiple LCCs simultaneously, and similar conclusions would be drawn as for the impact on legacy traffic and revenue.

6.2. Future Research Directions

The first suggestion for future research directions is to investigate the role of the Revenue Management systems in LCC entry. In this thesis, we assumed that legacy carriers and the low-fare airline used the same RM methods with regard to demand forecast and optimization algorithms, i.e. a traditional leg-based RM system based on EMSR controls. Recently, several more advanced methods have been developed and are currently used by network airlines to maximize their revenues even further. For instance, the Displacement Adjusted Virtual Nesting (DAVN) method is an O-D based optimization algorithm which discriminates local vs. connecting bookings. This method allows the airline to better select requests for bookings on connecting flights that may displace two non-connecting bookings usually generating more revenue. The implementation of these advanced RM systems is generally a long and expensive process, which explains why most low-fare airlines do not make use of these advanced RM systems. Therefore, it would be relevant to consider an LCC entry scenario in which the legacy airlines use more elaborate RM systems, and determine whether the traffic and revenue impact of LCC entry are significantly changed in this case.

Second, we assumed in the thesis that the legacy carriers matched the fare structure of the new entrant in all the markets entered. This assumption could be challenged especially for the highest fare classes. By testing LCC entry scenarios where the legacy carriers would keep the original fare structure, or reduce fares to a lower extent than the LCC, we would be able to better understand the legacy trade-off between higher fares and greater market share.

Finally, the resilience of legacy hub systems facing LCC competition was shown to greatly rely on strong demand in the markets from and to the hubs. The combination

of low-fare entry in spoke-to-spoke markets and spoke-to-hub markets may significantly change the outcomes of LCC entry. The analysis of such a scenario could show that hub networks might be weaker than assessed in this thesis.

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