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Proposition of a mathematical model for selecting possible low-cost airlines routes

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Abstract. This paper examines the effects that low-cost carriers (LCC's) produce when entering new routes operated only by full-service carriers (FSC's) and routes operated by low-cost carriers in competition with full-service carriers. A mathematical model has been developed to determine what routes should be operated by a low-cost carrier with better possibilities to subsist, as a first step towards reaching the most convenient route; additional factors must be considered after running the proposed model, such as route passenger demand and aircraft characteristics not took into account in this paper. The proposed model was set up by analyzing The United States domestic air transport market. Distance is the only variable taken into account by the model. This model analyses the relation between the real fare data ($) and the distance (miles). The model generates three lines that includes amongst them 68% of the approximately 18,000 routes by calculating a standard deviation and estimates the minimum, maximum and average fare for a low-cost carrier given the distance the model determines in which routes a low-cost carrier could be successful by comparing, route by route, different airline fares against the low-cost minimum, maximum and average fare estimated per distance.

Keywords: Airline competition, full-service carrier, low-cost carrier, airfare pricing determinants, airline-airport relationship

1. Introduction

Since the beginning of 19th century, the development of the air transport system has shown an exponential growth [18] and the United States air transportation system has been in continuous state of evolution.

The deregulation and privatization of the air transport have increased the number of new airline business models. After the liberalization of the air transport, new airlines companies appeared and have improved their business models applying new strategies to reduce cost operations, lower fares and maximize their profits mainly based on two business models, full-service and low-cost carriers. While some of the airlines have succeeded most of them have failed to be able to compete and widen their air traffic market.

The low-cost airline business model is having a profound effect on the airline fares because of the very low operating cost and aggressive expansion that these types of airlines have implemented as strategy [3]. This business model has increased the competition between airlines [11] and routes with presence of low-cost carriers have lower average fares compared with routes dominated by full-service carriers explaining why airlines fares are an important factor to dominate routes, increase airline market share

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and number of passengers. The different fares that low-cost airlines charged compared to full-service carriers appears to be the main reason why they grow and are so competitive against other airline business models.

In a non-competing airline scenario the interest for FSC's to minimize operations cost is very low or does not exist showing little dispersion between fares. When an effective price competitor enters a high fare market, the FSC's previous fare premium diminishes or disappears altogether.

Today, FSC's have been forced to put attention in the minimization of airline operation costs and lower fares to compete against LCC's. FSC's have recognized the advantages of the LCC business model trying to be more competitive. Some of them, such as Freedom Air (Air New Zeland) [11] Click Mexicana (Mexicana de Aviacion) and Aeromexico Connect (Aeromexico) have invested in a low-cost subsidiary carrier to operate shorter regional routes, lower costs and reduce fares. The FSC's have developed strategies to contra rest the LCC's strategies such as offering business and economy class, be compatible with long-haul flights for connect and concentrate passengers at a major hub [5].

The high stress in the airlines market produced by sudden fluctuations of economic conditions during the last years has supported the low-cost business model [1]. The LCC concept has provided more accessibility to travel offering lower prices. The basic strategy is to provide short-haul point-to-point routes. As they grow, some LCC's networks have converted into a quasi hub-and-spoke system, with only one way fare. This allows LCC's to increase the number of routes making independent flights (point-to-point) to a hub. The LCC business model main characteristic is to reduce cost and lower fares as much as possible [12]. The LCC's main customers are leisure passengers whilst the FSC's are predominantly business passengers.

1.1. Statement of problem

It is not easy to enter into new routes, but it is even more difficult to gain a significant market share, keep it and then survive in an industry that has become extremely competitive, making it very difficult to study the dispersion caused by different airlines operating different airports in same city-pair markets. Different researches have been carried out on airfare pricing determinants and most of them have found travel distance between origin and destination airports as the most significant parameter determining route fares in the air transportation system.

A mathematical model that allows airlines to determine what routes should be operated by a low-cost carrier with better possibilities to subsist, it is very helpful for airlines to make a decision whether or not to enter or exit routes. The mode calculates airline fares depending on the market competition. This enable airlines to decide for themselves; what fares to charge, which markets to serve, estimate their potential revenues, profits, and the advantages and disadvantages in routes with a lot of competition.

1.2. Literature review

Perhaps the most important strategy applied by LCC's has been the introduction of cheap one way fares. It has undermined the price discrimination power of the FSC's [20]. LCC's have forced FSC's to look into their processes to identify which operations costs can be reduced by new strategies to compete against low-cost airlines in the short-haul market and to minimize costs in long-haul operations. If FSC's do not minimize operation costs and drop fares, they will probably not be able to compete against LCC's on short-haul markets, which have won an important piece of the market during the last years and have caused airline fares dispersion between same travel distance routes from different origins and destinations.

The air transport business has a very dynamic and complex pricing system. A number of studies document the subject of airfare pricing. In this section, basic description of different studies about airline pricing models and determinants are reviewed.

According with Morrison and Winston's [13] approximately 50% of the variation in airfares in the United States might be due to routes travel distances, routes passenger demand, and the competition between airlines and airports operating same routes. Vowles [22] developed an econometric model to study different airfare pricing determinants concluding that Southwest Airlines (WN) is a significant determinant of fares apart from the distance. Vowles [21] studied pricing in hub-to-hub markets using different determinants such as a definition of different route types, low fare carriers, competition in hub to hub markets and a classification between tourism and non-tourism cities. His results show that low-fare carriers have a high influence in airfares determinants in the US. Windle and Dresner [23, 24] looked at the role of the low fare carrier's entrance into air transportation markets. Their results show that the presence of LCC's in the air transport markets was significant, while market concentration was not (Windle and Dresner, 1995). They also studied the reaction of Delta Airlines to the entrance of ValueJet in some routes. Their results show that fares on routes where both airlines compete went low, but Delta did not increase fares on other routes without competition to compensate revenues [24].

Pels and Rietveld [17] have developed some models to estimate fares for different airlines. First, they have found that FSC's do not follow the fare movements of LCC's; second, some carrier appears to lower fares when competitors raise ticket prices; and third, all airlines increase fares as the departure date gets closer. These results show how difficult it is to estimate airfares.

Obeng [14] developed a model to study airlines fares in a medium size market using on-line daily information fares on, plane, flight and trip characteristics collecting data using ORBITZ Internet search engine. The results of this study show large differences in fares among the airlines, large variation in daily fares offered, and fare differentiation. Fare dispersion can be originated from price discrimination (airlines that segments their customers and charges each segment different fares), Edgeworth cycles (period of time or seasonal), peak load pricing (airport charges different cost according to peak operation times) and cost differentials (different airline and airport costs).

Giaume and Guillou [8] developed a model to study the phenomenon of multiple prices offered in the intra-European routes gathering data on ticket prices in all routes from Nice Airport to European destinations. The results showed that concentration and price discrimination are negatively related.

Borenstain [2] and Oum [15] have studied the case of airlines monopolies at airlines hubs. The results show that consumers pay higher fare and concluded that hubs are detrimental to low fares for consumers because there is no competition between airlines. Borenstain [2] found that an airline with a dominant position in an airport charges higher fares than in other airports operated by the airline.

There are many airfare pricing determinants apart from the airline operation cost and airport cost factors when pricing a fare route. Borestein and Rose [4] found that the difference between airline cost, competition and willingness of consumer to change to another carrier are main factors that cause different route fares. City and airport's location between airports seems to be significant, especially together with measures of market concentration and low-fare competition [6]. Fuellhart [6] also found, similar results as Vowles [22] that the presence of significant low-fare competition can have important effects on the airfares paid by passengers. According with Fuellhart [6] the influence of low-fare competition from a specific airport can have important effects on routes fares in other airports in the same region.

Finally, [9] reported that fares from hub airports without a significant presence of LCC's are higher than other hubs with substantial LCC's service.

1.3. Research question

The aim of this paper is to develop a simple model that select, from the complete air transport market, those routes that represent an opportunity to open new services with better possibilities to succeed or subsist just based on airlines fares competition. Using the mode, it has been possible to simulate the competition between different airlines business models, determine the lowest fare and select those routes that represent a possibility to subsist or succeed. Chapter 2 shows an analysis of the United States domestic air transportation market. Chapter 3 explains the design of the mathematical model. Chapter 4 is an analysis of the results. Chapter 5 is an analysis of the possible routes that could be operated by low-cost airlines using the proposed model. Finally, chapter 6 is a conclusion of this paper.

2. Database analysis, airline business models and airport types definition

The U.S. Department of Transportation Office of Aviation Analysis releases a Domestic Airline Fares Consumer Report that includes information of approximately 18,000 routes operated by different airlines inside the United States. The reports include non-directional market passenger number, revenue, nonstop and track mileage broken down by competitor. Only those carriers with a 10 percent or greater market share are listed.

The air transportation market 2005 data average weight distance flown by airlines from airport to airport in the US domestic market is 1088 mi with an average fare of $146.81 and 1,108,826 passenger per day (pax per day), as Table 1 shows. Twenty-six airlines were providing air transportation passenger service during 2005 in the US air transport domestic market routes and three hundred and seventeen airports as an origin or destination.

FSC's transported twice as much pax than LCC's. The average weight fare for the FSC business model ($162.80) is more expensive than LCC business model ($109.28). The average weight fare for the FSC model is higher also because the average weight distance is longer than the LCC model. Even though, the unit price average weight fare per mi shows that FSC's are in general more expensive than LCC's. Almost 90% of the US domestic market routes are operated by FSC's which means that the market is dominated by FSC's. The number of pax transported by FSC's is approximately 70% of the domestic US air transport market. On the other hand, the number of pax per mi transported by LCC's is more than 4 times the number of pax per mi transported by FSC's meaning that LCC's routes are shorter than FSC's routes.

In this research, to measure and understand the competition between airline business models, full-service against low-cost, all the routes have been divided into three different groups FSC-FSC, FSC-LCC and LCC-LCC. The FSC-FSC routes are those where no presence of LCC's are. The LCC-LCC routes

Table 1
FSC and LCC business models characteristics

Market	Ave. dist (mi)	Number of pax per day	Ave. fare ($)	Pax/dist (pax/mi)	Ave. fare/ dist ($/mi)	Number of airlines	Number of routes
Total	1,088	1,108,826	$147	17	$0.21	26	17,636
FSC's	1,180	775,434	$163	14	$0.21	17	15,574
LCC's	873	330,558	$109	51	$0.16	9	2,062

are those where no FSC's have operations. Finally, the LCC-FSC routes are the routes where at least one LCC and one FSC have operations, and they are in direct competition.

The FSC-FSC competition routes are the most expensive and the most common. Table 2 shows that LCC's are competing in just one third of the US domestic market. The LCC-LCC competition routes transport 169 pax per mi what is almost 8 times more than the FSC-LCC routes and approximately sixteen times more than the FSC-FSC routes. The LCC-LCC routes are also the cheapest competition routes and their average weight travel distance is 752 mi what is shorter than in the other markets, which was expected since the LCC model mainly operates short-haul routes. The number of LCC-LCC routes is small and shows clearly that LCC's provide service with lower fares and more aircraft passenger load.

To measure and understand the influence that airport fees have on airline fares the database has been classified into five types of airports according with the number of US domestic pax per day using the airport, as Table 3 explains. The average weight fare per mi is almost the same for all the airport types instead of type E, finding these airports as the most expensive. Airports type B have the longest average weight travel distance from airport to airport whilst airports E have the shortest what might be because airports D and E are feeding airports A and B. Airports type A have shown the biggest number of pax per mi whilst for airports D and E the number is very small.

Table 4 shows that FSC's fares are more expensive than LCC's fares, Table 5. The number of pax per mi for LCC's are bigger than FSC's meaning that an LCC flight is expected to bring more passengers to the airport. These might be a reason for lower airport fees to FSC's because airports can increase revenues and reduce operation costs due to economy of scales.

Table 6 shows that most of the routes are connecting airports type D with airports type B and C. Routes connecting big airports, such as AA, BB, AB, AC and CC, are expecting to have cheap fares. Opposite, routes connecting small airports type E are expected to be very expensive. It is clear that the number of pax per mi have a positive relation with fares per mi, what means that the bigger the number of pax per mi, the cheapest fare per mi will be.

Table 2
Competition markets characteristics

Market	Ave. dist (mi)	Number of pax per day	Ave. fare ($)	Pax/dist (pax/mi)	Ave. fare/ dist ($/mi)	Number of of routes
FSC-FSC	1,211	509,017	$173	11	$0.22	12,346
FSC-LCC	1,048	465,492	$132	27	$0.17	4,973
LCC-LCC	752	131,093	$101	169	$0.19	317

Table 3
Airport type classification characteristics

Airport type	Pax per day (1000)	Airports	Ave. fare ($)	Ave. dist (mi)	Total pax per day	Fare/dist ($/mi)	Pax/dist (pax/mi)
A	≥ 65	5	143	1,136	378,118	0.20	43
B	50–65	23	150	1,162	966,020	0.19	27
C	20–50	33	139	981	552,338	0.20	16
D	50–20	117	154	996	299,704	0.21	7
E	0–50	139	187	948	16,136	0.26	4

Table 4
Airport type classification characteristics, FSC market

Airport type	Ave. fare ($)	Ave. dist (mi)	Total pax per day	Fare/dist ($/mi)	Pax/dist (pax/mi)
A	155	1,228	276,088	0.21	35
B	165	1,236	689,749	0.20	21
C	159	1,119	347,980	0.21	12
D	170	1,057	221,459	0.22	6
E	188	941	15,926	0.26	4

Table 5
Airport type classification characteristics, LCC market

Airport type	Ave. fare ($)	Ave. dist (mi)	Total pax per day	Fare/dist ($/mi)	Pax/dist (pax/mi)
A	109	886	102,031	0.15	107
B	112	976	276,271	0.15	77
C	105	746	204,359	0.16	41
D	110	826	78,246	0.18	23
E	135	1,476	211	0.17	9

Table 6
Airport relationship classification characteristics

Airport relationship	Ave. fare ($)	Ave. dist (mi)	Total pax per day	Fare/dist ($/mi)	Pax/dist (pax/mi)	Number of routes
AA	142	1213	21,731	0.16	216	27
AB	132	1014	89,064	0.17	163	146
AC	135	998	62,801	0.17	68.0	227
AD	151	977	33,490	0.22	14	647
AE	180	928	1,901	0.25	4	165
BB	156	1,285	191,994	0.17	76	518
BC	139	1,021	149,665	0.16	35	849
BD	150	933	79,932	0.21	9	2,389
BE	192	981	3,820	0.26	4	343
CC	134	903	66,937	0.16	13	1,246
CD	145	748	36,488	0.25	6	2,257
CE	186	826	460	0.30	4	49
DD	172	971	5,546	0.24	3	587
DE	196	547	750	0.43	37	13

Tables 7 and 8 show the airport relationship route classification characteristics for the FSC and LCC models respectively. Again it is clear that LCC routes are cheaper than FSC and the aircraft load pax factor are higher for the LCC's. The FSC's provide service to all type of airport connections, whilst the LCC's do

Table 7
Airport relationship classification characteristics, FSC market

Airport relationship	Ave. fare ($)	Ave. dist (mi)	Total pax per day	Fare/dist ($/mi)	Pax/dist (pax/mi)	Number of routes
AA	149	1323	17,896	0.16	223	21
AB	145	1119	60,957	0.17	145	105
AC	151	1153	40,279	0.17	53	174
AD	168	1036	24,056	0.22	12	582
AE	180	927	1,898	0.25	4	164
BB	172	1356	134,839	0.19	66	396
BC	153	1107	102,859	0.16	28	686
BD	162	918	60,859	0.21	7	2,212
BE	194	960	3,694	0.27	4	340
CC	162	1,157	35,706	0.17	9	966
CD	169	855	23,319	0.25	5	1,999
CE	185	826	460	0.30	4	49
DD	178	991	4,997	0.24	3	544
DE	196	547	750	0.43	38	13

Table 8
Airport relationship classification characteristics, LCC market

Airport relationship	Ave. fare ($)	Ave. dist (mi)	Total pax per day	Fare/dist ($/mi)	Pax/dist (pax/mi)	Number of routes
AA	106	701	3,835	0.17	188	6
AB	105	787	28,107	0.15	225	41
AC	105	721	22,522	0.18	150	53
AD	109	825	9,434	0.17	51	65
AE	157	1,372	–	0.11	1	1
BB	116	1,116	57,154	0.13	125	122
BC	107	832	46,807	0.14	81	163
BD	115	980	19,074	0.18	40	177
BE	136	1,594	127	0.15	14	3
CC	102	613	31,231	0.15	33	280
CD	102	557	13,170	0.20	21	258
CE	–	–	–	–	–	–
DD	122	789	549	0.21	5	43
DE	–	–	–	–	–	–

not provide services connecting the smallest airports, type E. The majority of the US domestic passengers fly between airports type A, B and C meaning that airports have a direct impact on the passenger demand and fares. These tables also prove that small airports are expensive and big airports are cheap because as the aircraft load factor increase (pax/mi), average weight fares per distance decrease.

The airports with more LCC's passenger's traffic are in high populated and tourism cities or nearby, Fig. 1. Las Vegas is the airport with more LCC's passenger's traffic and it should be because Las Vegas

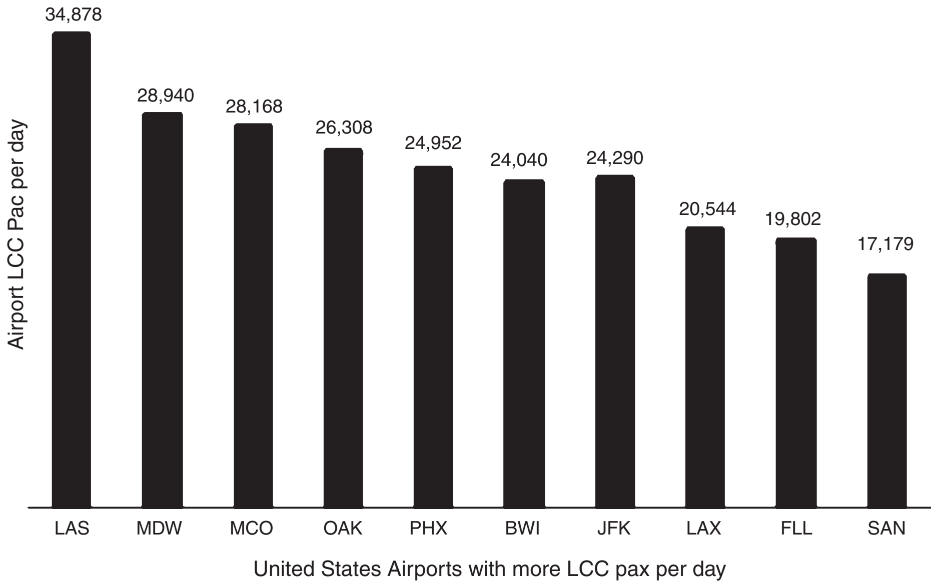

Fig. 1. United States Airports with more LCC domestic passengers.

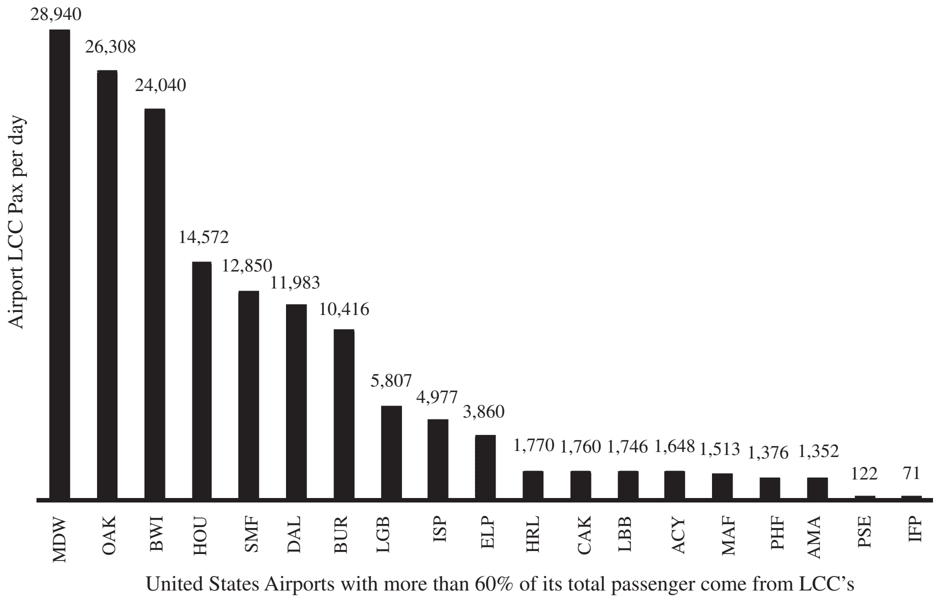

Fig. 2. United States Airports with more than 60% of LCC domestic passengers.

could be considered as Southwest Airlines (WN) hub since most of the flights are operated by WN. Some of these airports are considered as second city airports such as Chicago (MDW), Oakland (OAK) near San Francisco, Baltimore (BWI) near Washington D.C., etc.

The competition between airline business models (FSC against LCC) is also affected by the competition between airports. Figure 1 shows the US Airports with more LCC's pax traffic per day. The main characteristic of these airports is to be located near airline airports hub or in big cities. Figure 2 shows the US airports with more than 60% LCC passenger's traffic. These airports are located either in tourism cities or nearby airline airport hubs in big cities such as Chicago (MDW), Oakland (OAK), Baltimore (BWI), Houston (HOU) near Houston George Bush (IAH), and Dallas (DAL) near Dallas Fort Worth (DFW), etc. These airports are competing and bringing more passengers providing service to LCC's affecting fares on similar routes operated by other airports.

3. Research model design

From the analyses of the United States Domestic data, it turns out that distance between the origin and destination airports is the major factor that affects the prices level charged by airlines on the United States domestic market. In this model the only parameter to take into account is the *distance (D)*. This model makes an analysis of the relation between the real fare data depending on the route travel distance with a linear regression equation. The model generates three lines (min, max and average) that includes between 68% of the total market routes by calculating a standard deviation. The model divides the data in two groups: first group for distance shorter than D^* and second for distance longer than D^*.

$$F_{est} = \begin{cases} m_1 D + b_1 \\ m_2 D + b_2 \end{cases} m_1,\ b_1 \text{ if } D \geq D* \text{ and } m_2,\ b_2 \text{ if } D \leq D* \quad (1)$$

Where
F_{est} = Fare estimation using the model [$]
D = Distance [mi]
m_1, m_2 = slope [$\$mi^{-1}$]
b_2, b_1 = y-interceptions [$]

Constraint:
$b_2 = b_1 + D^* (m_1 - m_2)$ (2)

Where
D^* = Distance division group point
This constrain ensures the continuity of the straight lines in D^*.
D^*, m_1, m_2 and b_1 are calculated to minimize of the sum of square errors:

$$S = \sum_i e_{1_i}^2 \quad (3)$$

$$e_{1_i} = F_{est_i} - F_{real_i} \quad (4)$$

Where
F_{real} = Real route fare database [$]
Calculation of the standard deviation:

$$|e_{est}| = \begin{cases} \Delta m_1 D + \Delta b_1 \\ \Delta m_2 D + \Delta b_2 \end{cases} \quad (5)$$

Δm_1, Δm_2 = slope [$\$mi^{-1}$]
Δb_2, Δb_1 = y-interceptions [$]

Constraint:

$$\Delta b_2 = \Delta b_1 + D^* \ (\Delta m_1 - \Delta m_2) \quad (6)$$

This constrain ensures the continuity of the straight lines in D^*.
Δm_1, Δm_2 and Δb_1 are calculated to minimize of the sum square errors

$$S = \sum_i e_{2_i}^2 \quad (7)$$

$$e_2 = e_{est} - |e_1| \quad (8)$$

$$F_{\min} = F_{est} - e_2 \quad (9)$$

$$F_{\max} = F_{est} + e_2 \quad (10)$$

All the markets fares increase as distance increase. Depending on the market, fares start prices according with the value of b_1 and after D^* on b_2. Their increments depend on the slope m_1 after D^* on m_2 as distance increase. The standard deviation helps to measure the fares dispersion on the market. Thus, a market with high dispersion Δb_1 and after D^* on Δb_2 will be bigger than in a market with small dispersion.

The model can be used to study different markets such as the complete US domestic market, the FSC and the LCC market separately. The model can study also more specific markets such as FSC-LCC, FSC-FSC and LCC-LCC classification routes market or airport markets such as A, B, C, D and E airport classification, see section 3, and the relationship between the airport types such as AA, AB, AC, etc. Finally, the model can be used to study and compare specific airlines markets such as American Airlines (AA), Southwest Airlines (WN), Continental (CO), Delta (DL), etc.

4. Model results at different markets

In order to examine the effects that low-cost carriers produce when entering routes, operated by FSC's incrementing the competition, routes without LCC competition and routes without FSC competition, the mathematical model developed in section 3 has been used to analyze the relation between the real fare data and the distance in different markets classified according to the analysis of the database developed in section 2.

The Figs. 3–5 show three examples of how the model generates the min, max and average lines to include 68% of the total routes depending on the markets by calculating a standard deviation for the US 2005 market, LCC and FSC market.

Table 9 shows the model results for the US 2005, LCC and FSC market. The FSC market is approximately \$8 more expensive than the US 2005 market, whilst the LCC market is approximately \$50 cheaper than the FSC market. After crossing the D^*, LCC and FSC fares per mi get close and fare dispersion between both markets reduce as distance increase.

The LCC market average linear regression (Fig. 4) is approximately the same line as the US 2005 market Min linear regression (Fig. 3) what shows that the LCC routes fares have the lowest fares on the market. The LCC market shows the lowest average dispersion around \$25 compering with the \$37.55 for the FSC market and the \$40.00 for the complete US 2005 market, Table 9.

In the case of the FSC market the average linear regression (Fig. 5) is approximately the same line as the US 2005 market linear regression. This market shows also very low fares as much as the LCC market what means that FSC airlines have the possibility to low fares as much as the LCC airlines in some routes.

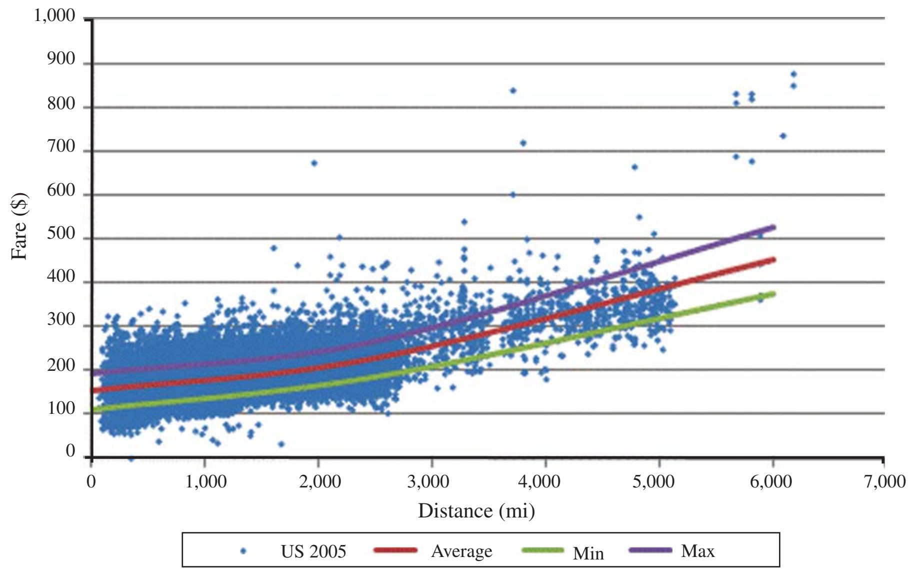

Fig. 3. US 2005 market model result.

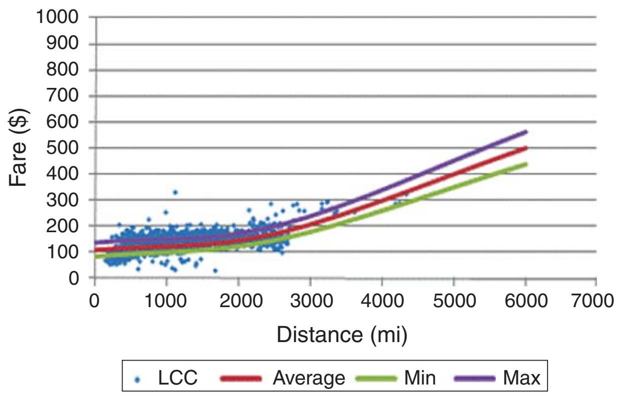

Fig. 4. LCC market model result.

Table 10 shows the model results for the competition classification markets FSC-FSC, LCC-LCC and FSC-LCC. The FSC-FSC market is approximately \$80 more expensive than the LCC-LCC market, whilst the routes under competition of both business models FSC-LCC market is approximately \$40 cheaper than the FSC-FSC market and \$40 more expensive than the LCC-LCC market. FSC-FSC market dispersion is greater than the other competition markets around \$35.30 and after D^* around \$12.52. The LCC-LCC market show an average dispersion over \$29.25 and after the D^* the dispersion becomes negative, thus more dispersion between fares are expected for the LCC-LCC market than for the others at long distance. The model is not really accurate after D^* because the LCC-LCC market does not have enough routes to simulate the market behavior for long-hauls.

The Figs. 6–8 show that the FSC-FSC market has a more relax increment on fares after D^* comparing with the LCC-LCC market and also for the competition between different airlines business models FSC-

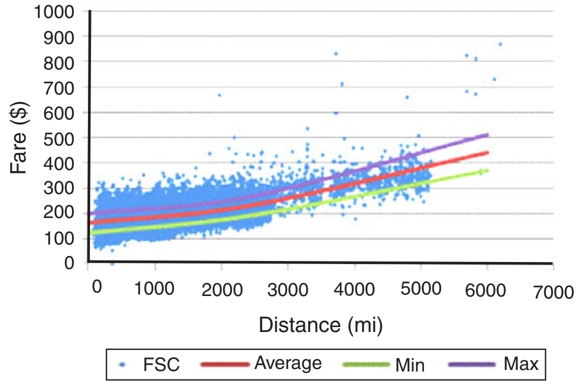

Fig. 5. FSC market model result.

Table 9
US 2005 market results

Market	D^* (mi)	m_1	b_1	m_2	b_2	Δm_1	Δb_1	Δm_2	Δb_2
US 2005	2,508	0.03	152.33	0.06	66.30	–0.0001	40.00	0.01	14.06
FSC	2,455	0.03	160.19	0.06	83.30	–0.0004	37.55	0.01	13.71
LCC	2,576	0.03	110.29	0.09	65.91	–0.0001	25.00	0.01	–1.65

Table 10
US Air business model competition classification market results

Market	D^* (mi)	m_1	b_1	m_2	b_2	Δm_1	Δb_1	Δm_2	Δb_2
FSC-FSC	2,442	0.03	165.65	0.06	103.01	–0.0001	35.30	0.01	12.52
LCC-LCC	2,828	0.04	84.93	0.07	–7.38	–0.0001	19.65	0.01	–6.74
FSC-LCC	2,549	0.03	128.64	0.09	–40.14	–0.0020	29.25	0.02	–20.85

LCC market. As it can be noticed on Fig. 7, there are few routes after D^*, so the increment is produced because fares after D^* are expensive. The model does not really have enough routes to make a simulation of this market because LCC-LCC routes are in general short-haul.

Distance is the only variable taken it into account by the model. Figure 9 shows the model fare estimation accumulative probability error for the markets under analysis for 200 mi travel distance. The LCC effect is shown by Fig. 9. The presences of LCCs reduce the average fare dispersion and lower fares.

The model predicts the cheapest routes to be those where LCC's dominate the route market and no presence of FSC's exists (LCC-LCC). The FSC-LCC market shows that the presences of LCC's make FSC's lower fares. Even though, these routes are more expensive than the LCC market. The FSC-FSC market is the most expensive and the market with most dispersion between fares, followed very close by the complete market and the FSC markets.

The average maximum fares are \$220.78, \$190.41 and \$151.41 for the FSC-LCC, LCC and LCC-LCC markets respectively for a 200 mi route. The average minimum fares are \$47.10, \$40.57 and \$33.56 for the FSC-LCC, LCC and LCC-LCC markets respectively.

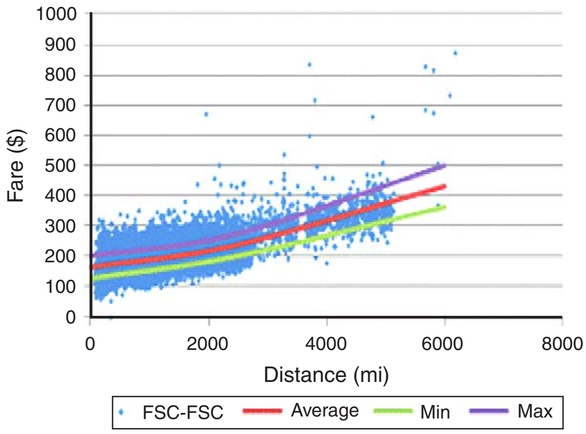

Fig. 6. FSC-FSC market model result.

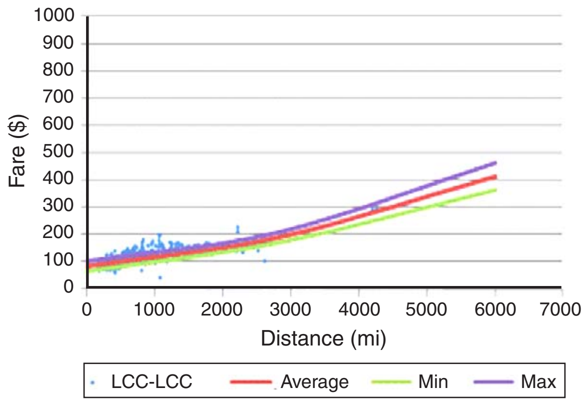

Fig. 7. LCC-LCC market model result.

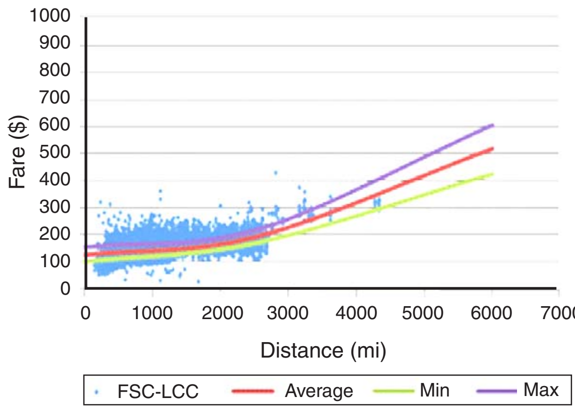

Fig. 8. FSC-LCC market model result.

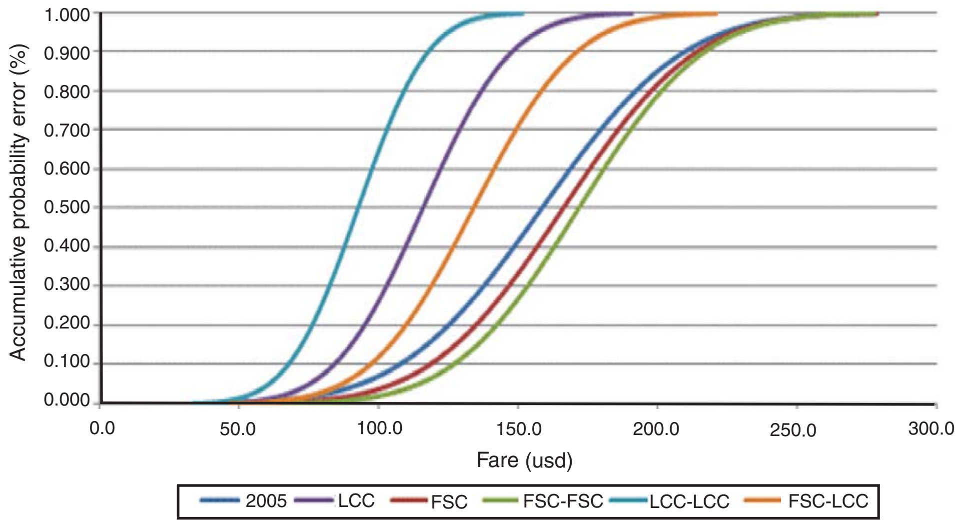

Fig. 9. Accumulative probability error all markets 200 mi distance.

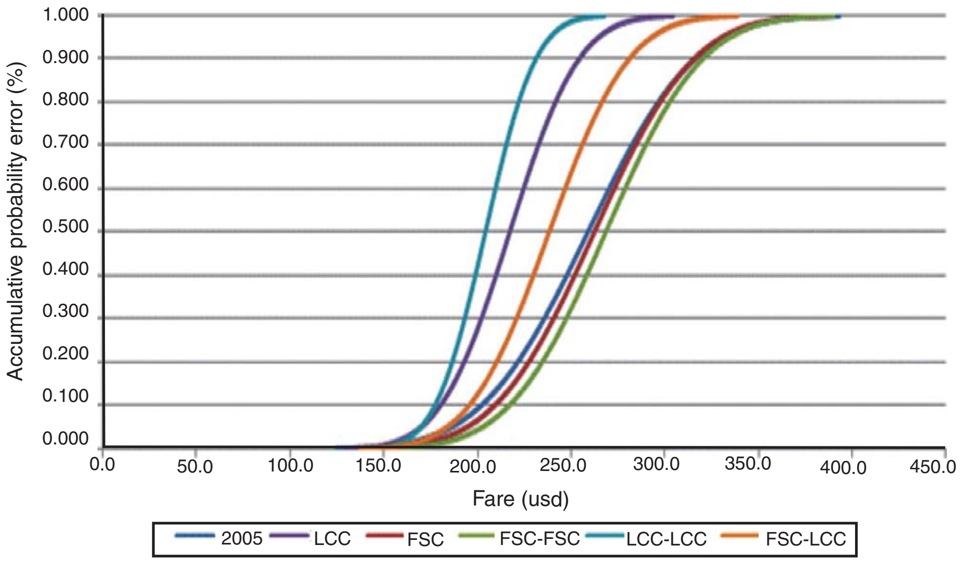

Fig. 10. Accumulative probability error all markets 3000 mi distance.

The average maximum fare for a 200 mi route is $277.43 for the FSC-FSC. For the complete market and in the case of the FSC markets are $278.30. The average minimum fares are $65.66, $38.38 and $53.43 for the FSC-FSC, FSC, and all the US market respectively.

Figure 10 shows the model fare estimation accumulative probability error for a 3000 mi distance for all the markets under analysis. The low-cost airline effect for long-hauls is shown by Fig. 10. As distance increase the dispersion in all the markets decrease and the difference between LCC's and FSC's markets fares decrease. Low-cost airlines find it more difficult to lower fares in long-haul routes because FSC's fares per mi are already low.

The model estimates the average maximum fare for the FSC-LCC, LCC and LCC-LCC markets at $338.67, $304.26 and $267.45 respectively for a 3000 mi route. The model estimates the average minimum fare for the FSC-LCC, LCC and LCC-LCC at $137.32, $130.23 and $140.31 respectively. The model estimates the average maximum fares for the FSC-FSC, FSC and all the US market at $389.71, $ 387.56 and $392.96 respectively. Finally, the model estimates the minimum average fares for the FSC-FSC, FSC and all the US market at $147.05, $137.02 and $124.71 respectively.

Figure 11 shows the model fare estimation accumulative probability error for a 250 mi distance for all the airlines operating the domestic US air transport. In general, the model estimates FSC's fares to be the maximum fares on the market. Continental (CO) and American West (HP) have shown the maximum average fare $302.31 but they also showed the minimum average fare $17.29. Table 11 shows the model average fare estimation maximum and minimum fares for five FSC's and five LCC's, for a short-haul distance (250 mi) and Table 12 for a long-haul distance (3000 mi).

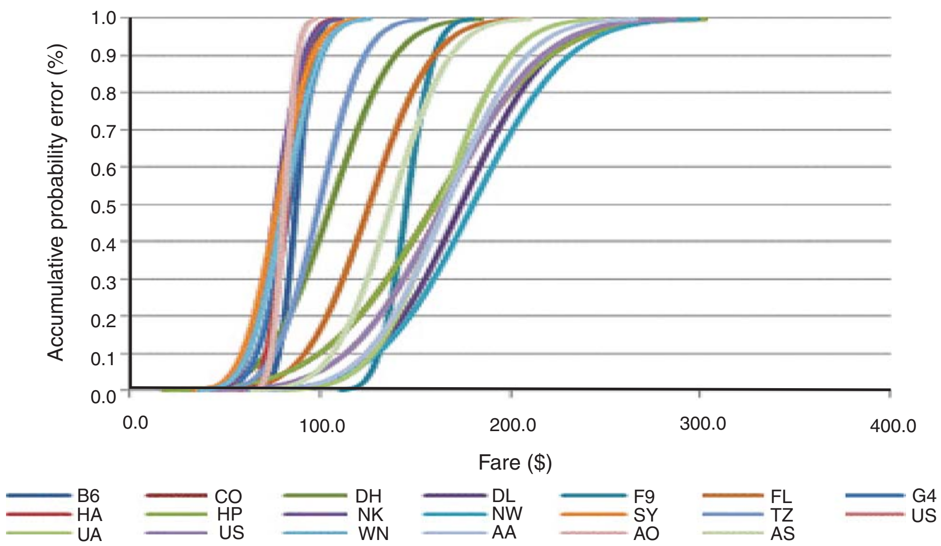

Fig. 11. Accumulative probability error all airlines 250 mi.

Table 11
Airline model results maximum and minimum fares in US $ for 250 mi routes

Fare	AA	US	UA	DL	CO	WN	NK	FL	DH	B6
Min	66.74	43.89	78.54	64.15	17.29	36.81	42.37	45.46	26.30	65.56
Max	265.18	286.06	248.14	279.62	302.31	126.22	110.90	205.00	184.20	109.03

Table 12
Airline model results maximum and minimum fares in US $ for 3000 mi routes

Fare	AA	US	UA	DL	CO	WN	NK	FL	DH	B6
Min	140.09	133.63	172.83	125.99	128.44	113.50	159.41	122.74	143.87	128.73
Max	355.85	303.74	380.99	351.02	436.09	213.22	254.25	254.25	181.97	299.56

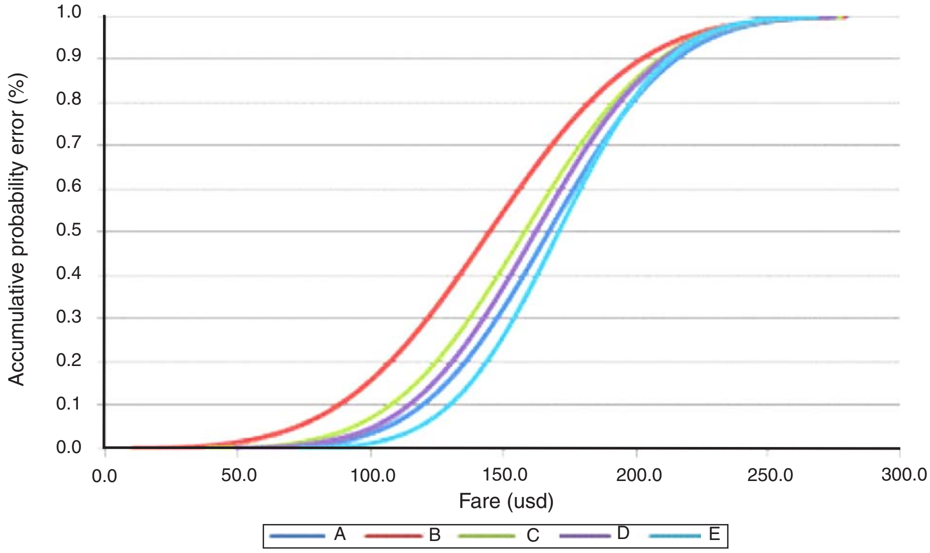

Fig. 12. Accumulative probability error airport type classification 250 mi.

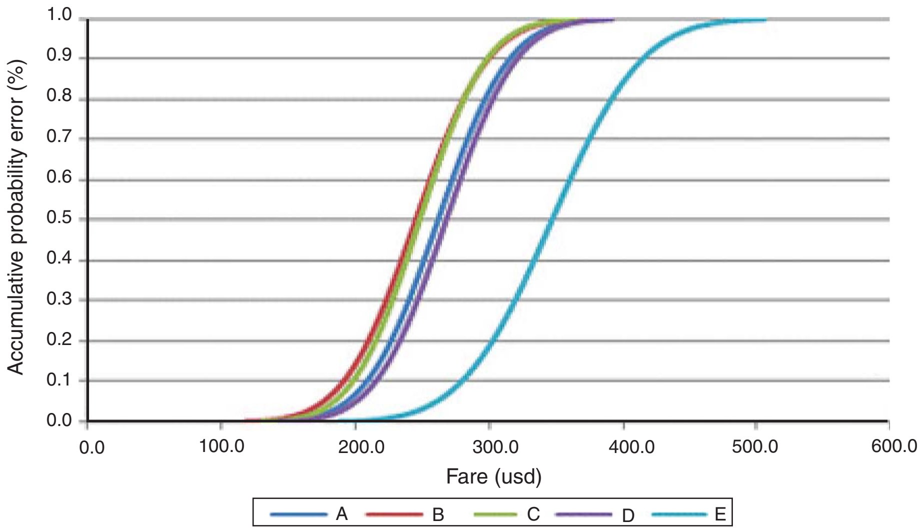

Fig. 13. Accumulative probability error airport type classification 3000 mi.

The model results show that FSC's can low fares in short-haul markets to contra rest the presence of LCC's. In long-haul markets LCC's fares are low making it difficult for LCC's to operate in those markets. Thus, few long-haul markets are operated by LCC's.

Figures 12 and 13 show how the model accumulative probability errors are for the different airport types in short-haul (250 mi) and long-haul (3000 mi) routes respectively.

The model results for a short-haul market (Fig. 12) show that in general all airports types' fares are close each other. The cheapest of all are airports type B, with maximum and minimum average fares, $278.22 and $10.56 respectively. The most expensive airports are the smallest ones (Type E), with maximum $267.59 and minimum $73.48.

The model results for long-haul markets show that dispersion does reduce as distance increase. Airports B and C show the lowest fares with very close average maximum and minimum fares for Airports A and D, with fares between $137.02 and $387.56 for 3000 mi routes. Small airports show very expensive route average fare in long-haul markets with average fares, minimum $188 and maximum $505.64 for 3000 mi routes.

5. Analysis

The mathematical model has been developed to help airline managers to determine what routes should be operated by a low-cost carrier with better possibilities to success according with the airline business model and strategies. The model select routes by comparing the behavior of the competition market (LCCs vs. FSCs) and the non-competitive market where FSCs do not face LCC routes fares. The model is the first step towards reaching the most convenient route; additional factors must be considered after running the proposed model, such as route passenger demand and aircraft characteristics. These factors have not been the subject of this paper. Thus they have not been taken into account but they are compulsory next steps to select what routes should be operated by LCCs or any airline.

To determine the possible routes that could be operated by a LCC with chances to be successful, the markets under study must be the FSC-FSC and the FSC-LCC. The FSC-FSC because this market has the routes that are not operated by any LCC's. The FSC-LCC market is used to simulate and describe the effects of the LCC's when entering new routes operated only by FSC's. This market is actually the market that describes better the competition between the full-service and low-cost airlines businesses models.

The model calculates the routes average fares per mi for any market. In this case, the model is calculating the FSC-LCC market routes average fares per mi at different standard deviations (1, 1.25, 1.5, 1.75, 2, 3, 4 and 5). Thus, the possible routes are those FSC-FSC market routes that are more expensive than the model average fares calculated at different standard deviations. Airline managers are responsible to determine after how many standard deviations the routes represent a possibility for the airline to compete in a specific route, according with the airline strategies and operations costs. Figure 14 shows

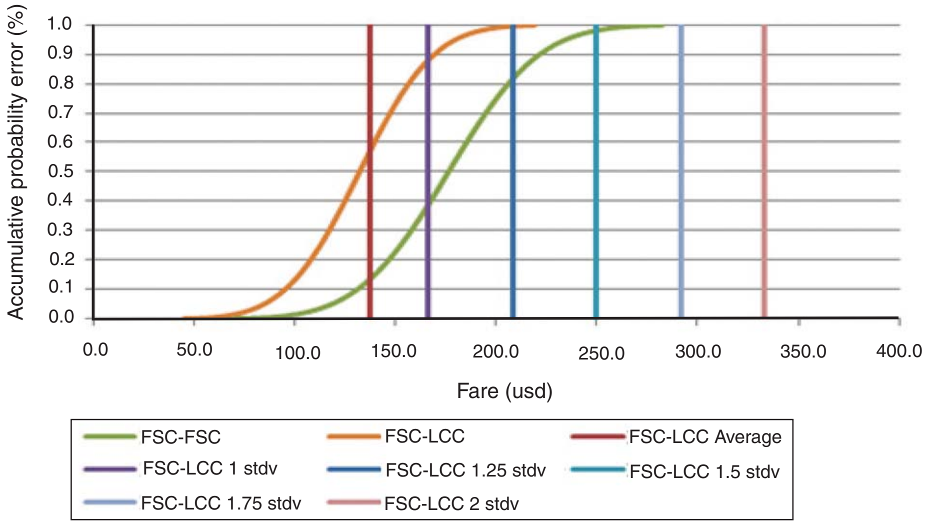

Fig. 14. Accumulative probability error FSC-FSC and FSC-LCC markets 250 mi.

the accumulative probability error for the FSC-FSC and FSC-LCC markets, and the averages fares calculated at different standard deviations.

Table 13 shows the number of FSC-FSC routes fares more expensive than the average fare calculated using the model for the FSC-LCC market at 1, 1.25, 1.5, 1.75, 2, 3, 4 and 5 standard deviations.

The model has found the most expensive routes for the US short-haul market. Table 14 shows the ten most expensive routes from airport to airport, airline, distance, fare, market share and competition. US Airways (US) is operating seven of these routes using Philadelphia (PHL) as origin or destination airport meaning that apart from being the only airline flying these routes, the fact that PHL is a US Airways hub

Table 13
Number of FSC-FSC routes that represent an opportunity for a LCC to enter the market according with the FSC-LCC average fare at different standard deviations

Standard deviation	1	1.25	1.5	1.75	2	3	4	5
Number of routes	7,374	6,498	5,594	4,717	3,921	1,495	476	157

Table 14
Ten most expensive short-haul routes

Airport 1	Airport 2	Airline	Others	Distance (mi)	Fare ($)	% MS	Fare–FSC-LCC 1 Stand. Dev. ($)
ISP	PHL	US	–	130	301.15	91	140.01
CMH	PIT	US	–	144	323.10	97	161.61
HYA	LGA	US	–	197	309.45	97	146.64
BWI	PIT	US	–	210	316.38	95	153.24
CHO	PHL	US	–	210	317.52	95	154.39
ALB	PHL	US	–	212	303.04	94	139.85
DFW	LFT	CO	–	351	306.27	81	139.61
CRW	PHL	US	–	356	311.96	83	145.18
EWR	TOL	CO	AA, DL, NW	506	340.16	30	169.63
EWR	FWA	CO	AA, DL, NW	577	309.08	16	136.77

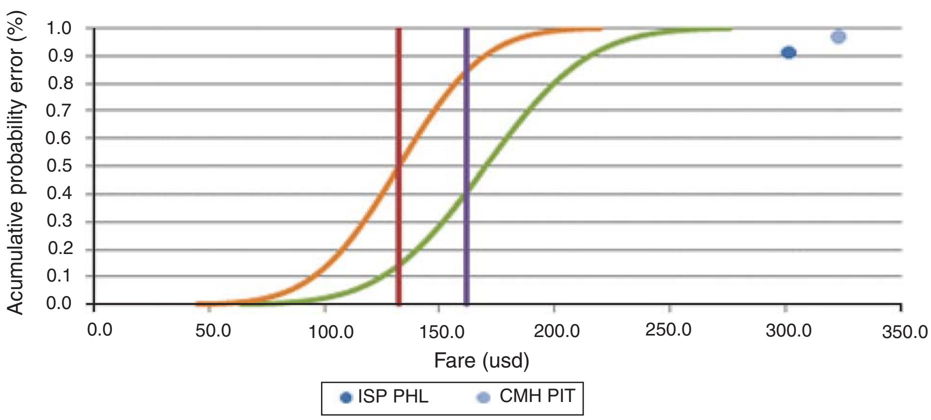

Fig. 15. Most expensive routes range distance (0,150).

increase fares, Figs. 15–17. The most expensive routes are in the North-East area of the United States. The competition between airlines alliances and other airlines can be noticed in two routes, from Newark (EWR) to Toledo (TOL) and from EWR to Fort Wayne Indiana (FWA). In both routes, Continental (CO) and Delta Airlines (DL) are Skyteam members. CO priced the most expensive fare in both routes, whilst DL has very competitive fares in both routes, Fig. 18.

In a non-competing airline scenario between different airline business models, FSC's present the highest fares, and FSC's will just lower their fares as much as they need to win market share, Fig. 18. Figure 19 shows the most expensive routes founded by the proposed model at 5 standard deviations for long-haul markets. It is clear that the most expensive long-haul routes are in the East cost of the United States might be because these routes are serving those cities with the highest incomes per capita in the United States. It is important to remember that these routes are selected by the proposed model just depending on routes fares. These routes are expected to be less as other important factors for routes selection are considered such as routes passenger demand and aircraft operations performance.

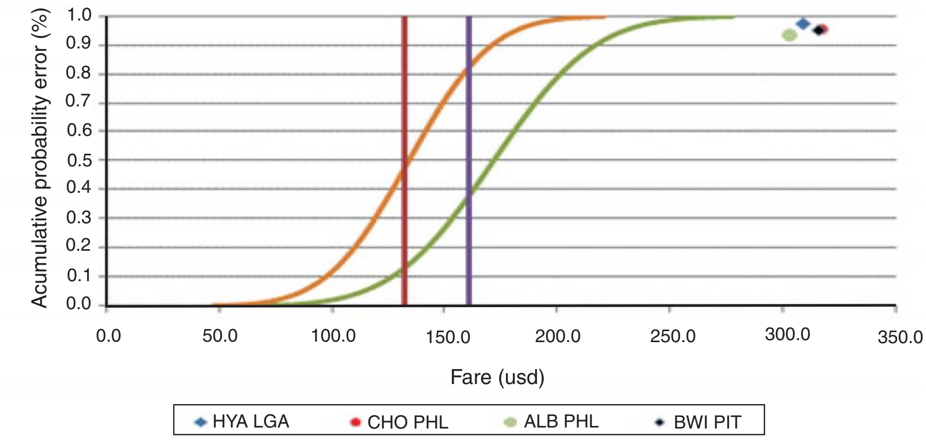

Fig. 16. Most expensive routes range distance (150,250).

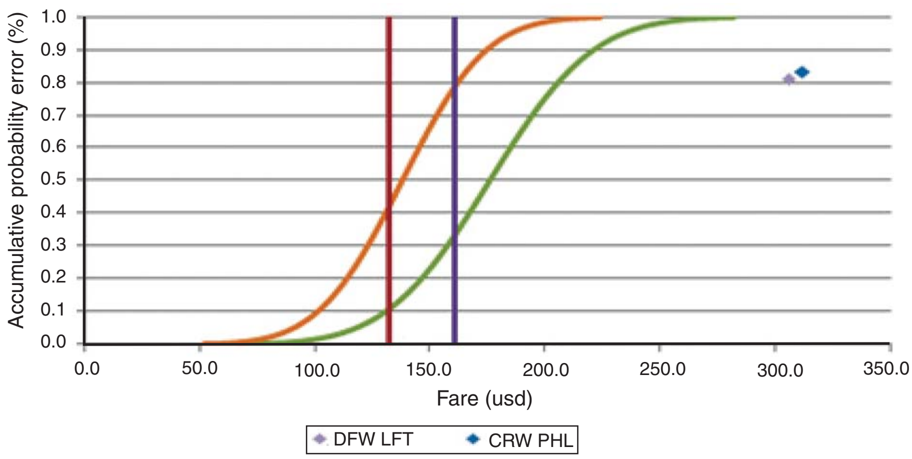

Fig. 17. Most expensive routes range distance (250,350).

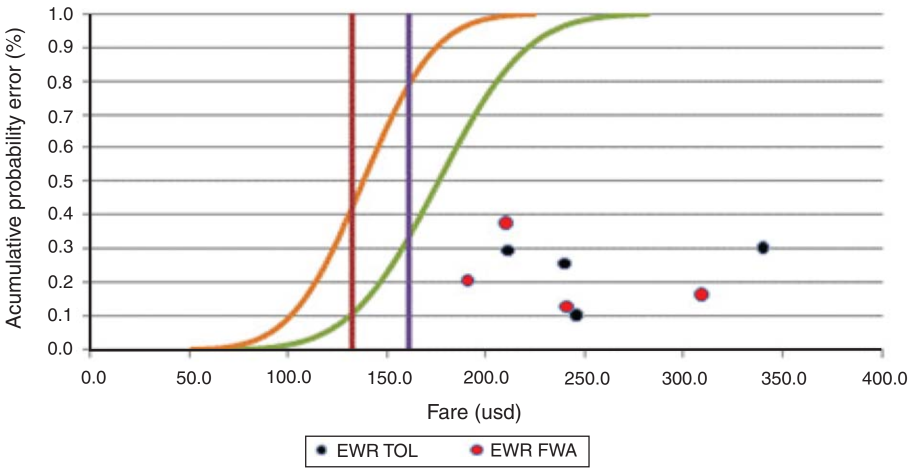

Fig. 18. Most expensive routes range distance (350,750).

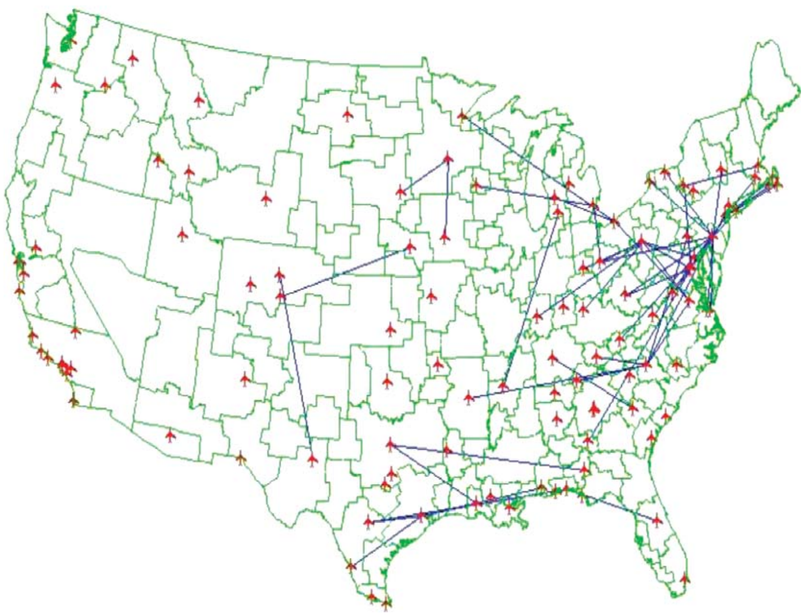

Fig. 19. Most expensive short haul routes, less than 700 mi.

Table 15 shows the ten most expensive routes from airport to airport, airline, distance, fare, market share and competition for the long-haul market. Even when there is competition between different FSC's in some of these routes, the lowest fare still very expensive. The most expensive routes are in long-haul markets, so the possibility for low-cost operations in long-haul routes exists but with a high risk because FSC's operating those routes easily can lower fares as much as the LCC's in long-haul routes.

It is also important to notice that some of these routes have other airports nearby, such as John F. Kennedy (JFK) near La Guardia (LGA) and Newark (EWR), San Francisco (SFO) near San Jose (SJC) and Oakland (OAK), and Los Angeles (LAX) near Glendale/Burbank (BUR), Long Beach (LGB), Santa

Table 15
Ten most expensive long-haul routes

Airport 1	Airport 2	Airline	Others	Distance (mi)	Fare ($)	% MS	Fare–FSC-LCC 1 Stand. Dev. ($)
CSG	SEA	DL	–	2,206	438.84	98	225.85
DUT	SEA	AS	–	1,959	671.33	98	464.50
FAI	SLC	AS	DL	2,184	502.51	13	290.06
FAY	SEA	DL	US	2,384	436.53	37	219.09
HNL	PPG	HA	–	2,600	444.56	100	217.35
HNL	SPN	CO	–	3,710	835.80	85	485.54
IAH	STX	AA	–	2,101	458.84	80	248.47
JFK	LAX	UA	AA, DL	2,475	430.53	15	210.82
JFK	SFO	UA	AA, DL	2,586	439.27	27	213.61
MSY	STX	AA	–	1,813	438.89	88	235.72

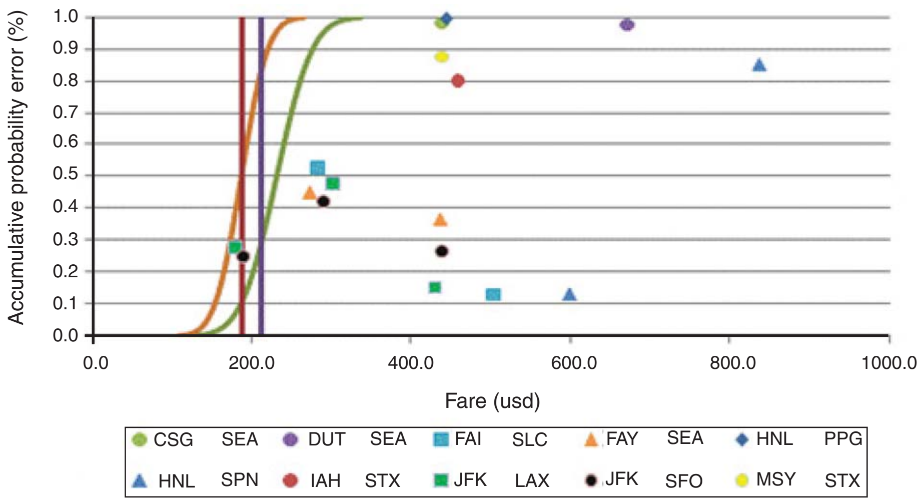

Fig. 20. Ten most expensive long-haul routes.

Monica (SMO), etc., and these routes must be competing with similar routes connecting nearby airports and can be operated by LCC's. Figure 20 shows the ten most expensive long-haul routes. The competition between airlines can be noticed on two routes, from New York JFK to Los Angeles LAX and from New York JFK to San Francisco SFO. In both routes, Delta Airlines (DL) has low fares against American Airlines (AA) and United Airlines (UA). Finally, Fig. 21 shows the most expensive routes in long haul markets founded by the proposed model at 5 standard deviations. As it can be seen, the majority of the most expensive routes founded by the proposed mathematical model belong to the long haul market. Many routes have been founded to go to tourism places such as Hawaii and Puerto Rico, but the airports with more expensive connections are in Philadelphia and Washington DC. Again it is important to remember that these routes are selected by the proposed model just depending on routes fares. These routes are expected to be less as other important factors for routes selection are considered such as routes passenger demand and aircraft operations performance.

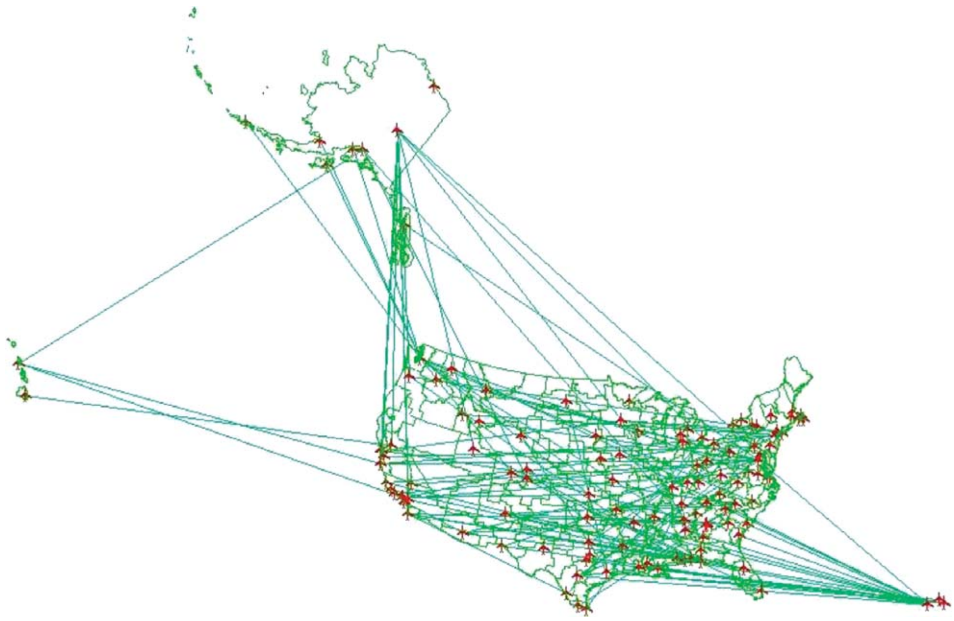

Fig. 21. Most expensive long haul routes, more than 700 mi.

6. Conclusions

Full-service carriers transport twice as much pax than low-cost carriers in the US domestic market. The average unit fare per mi shows that FSC's are in general more expensive than LCC's on all routes according to the distance. However, the gap between FSC's and LCC's decrease as distance increase. The number of pax per mi transported by LCC's is 4 times bigger than the number of pax per mi transported by FSC's. Thus, almost 30% of the total US domestic market is transported by LCC's on 2,062 routes from the approximately 18,000.

FSC-FSC routes are the most expensive and the most common. LCC's are competing just on one third of the US domestic market and they transport the highest number of pax per mi, more than 8 times the FSC's. The results also have shown that LCC's are mostly interested in short-haul markets since the number of long-haul routes operated by LCC's is few and more opportunities have been found in this market by the proposed model.

In this paper a different type of airports have been proposed depending on total number of passenger transported per year. Big airports have lower fares than small airports per route distance. Apparently, airports charge lower fees to LCC's, no matter the airport type. This might be because LCC's bring more pax per mi than FSC's meaning that an LCC flight is expected to bring more people to the airport and revenues can increase and operation costs decrease. The airports with more LCC pax traffic are located near high populated (secondary airport) and tourism cities.

From the results of this paper, it turns out that the mathematical model can be used to study different markets and specific airlines just depending on the route travel distance with a linear regression, including 68% of all the routes by calculating a standard deviation. It can also be used as a tool to help airline managers to determine, as a first step, what routes depending on the competitive fares, represent a possibility of opening new services with the most competitive fare.

The results show that the absence of LCC's operations on routes does not mean that those routes will be expensive; the US market shows routes operated just by FSC's with low fares as much as the LCC's. Even though, the presence of LCC operations cause FSC's to lower fares. Even though, the model is capable to find those routes that are extremely expensive and determine what is the fare that a LCC airline could charge.

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