A Study on Airlines' Choice Behavior of Aircraft Size

항공사의 항공기 용량 선정 행위에 관한 연구

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Abstract

An airline should consider the number of seats or size of aircraft, when it composes fleet or selects a type of aircraft for some routes. There are two major factors considered for this choice problem under the assumption that the objectives of an airline is a profit maximization: the operating cost and revenue from the aircraft operated. This research tries to solve the problem of aircraft size selection by airline. The study applies four steps to get optimal choice of aircraft size: (1) cost analysis for the relationship between airline operation cost and aircraft size: (2) market share and revenue analysis: (3) flight segment-level analysis, based on the derived cost, demand and revenue functions: and (4) network-level analysis to see how airlines make choice of aircraft size systematically at a network level. An airline can accommodate the increasing air travel demand by either increasing operation frequency, or increasing aircraft size that is represented by seat capacity, or both. Airport runway capacity and productivity depend on the size of aircraft used at airport. This paper presents the understanding of how airlines make decisions on the size of aircraft to operate, how they will adjust their choices when airport capacity is constrained, and how public regulation such as policy for landing fees could influence airlines' aircraft choice.

요 약

항공사는 항공기단을 편성하거나 특정노선에 투입할 항공기종을 결정할 때 항공기 좌석수가 어느 정도인 항공기로 선택할 것인지 심각하게 고려하지 않을 수 없다. 또한 공항의 혼잡 완화 정책과 같은 외부요인도 항공기 크기 선정에 작용하기도 한다. 이때 두 가지 요인을 고려하여 항공기의 크기를 결정하게 되는데, 첫째는 항공기의 운영비용이고 둘째는 예상되는 수익과 시장 점유율이다. 항공사를 이윤 극대화를 목표로 하는 기업이라고 가정하면 좌석 수에 의한 항공기종별 비용과 수익을 이용해 최적의 항공기종을 선택할 수 있다. 본 연구는 다음과 같은 4단계의 분석을 통하여 항공사의 항공기 크기 선택 행위를 분석한다: (1) 항공기 좌석 수에 따른 운영비 분석 (2) 시장점유율과 수익분석 (3) 비용, 수익분석에 의한 단위노선의 항공기 크기 선정 (4)네트워크 단위의 항공기 크기 선정. 항공사는 증가하는 수요를 수용하기 위해 운항횟수를 늘리거나, 대형기종으로 교체해야 하는데 이때 항공기 크기 선정 방법을 잘 선택하여 대처해야 할 것이다. 공항이 혼잡한 경우는 운항횟수 증가가 어려워 대형기로의 교체가 불가피한데 이때도 이윤을 증가를 고려한 의사결정이 필요할 것이다.

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I. INTRODUCTION

An airline can meet the increasing air traffic demand by either increasing operation frequency, or increasing aircraft size that is represented by seat capacity. Airport capacity and productivity can depend on the size of aircraft used at airport. If airlines use larger aircraft, with the same number of aircraft landings or departures, an airport can serve more passengers. However, small aircraft operations still account for a large proportion of total operations in some major airports. For example, at LAX (Los Angles International airport), landings or departures by small aircraft (with fewer than 60 seats) are around 35% of the total operations. Though, airlines have always been complaining about airport congestion and demanding for more runway capacity, runway productivity can be improved without any runway expansion or addition if airlines use larger aircraft rather than increase operation frequency.

It is worth understanding how airlines make decisions on the size of aircraft to operate, how they will adjust their choices when airport capacity is constrained, and how public regulation such as policy for landing fees could influence airlines' aircraft choice. This research will study airlines' choice behavior of aircraft size.

The paper consists of six sections. Chapter 2 briefly reviews the background history related to aircraft size and compares current perspectives on the future of aircraft size. Chapter 3 introduces the objective of the research and Chapter 4 is a literature review on related research topics. Chapter 5 presents a case study. Finally, Chapter 6 is the summary of the research and the conclusion.

II. Historical Development and Current Forecasting

Table 1 is an example of a summary of the seat capacity of some representative aircraft in aviation history. It can be noticed that aircraft in the early years were quite small, and the size grew slowly. In 1958, there was a big jump in aircraft size when jets were introduced, and the seat capacity of Boeing 707 and DC-8 aircraft was more than double that of previous aircraft. Then aircraft grew gradually larger until the introduction of Boeing 747 in 1970; Boeing 747~400 is still the largest aircraft. According to the developed technology of aircraft's engine performance, larger aircraft can fly with more improved cost efficiency.

The trend of aircraft size (in terms of seat capacity per departure) used by all airlines in U.S. domestic markets since 1970s is plotted in Fig. 1.

Table 1. Seat capacity of representative aircraft in history (Source:[1]).
표 1. 역대 주요 항공기종의 좌석용량

Approximate Year Aircraft Starting Service	Aircraft type	Approximate Seat Capacity
1927	Ford Trimotor	13
1929	Lockheed Vega	6
1933	Boeing 247	10
1936	DC-3	21
1939	Stratoliner	33
1946	DC-4	44
1947	Constellation/DC-6	52
1952	Comet	36
1958	707/DC-8	135
1961	DC-8-61	200
1970	747	365
1982	757	186
1983	767	210

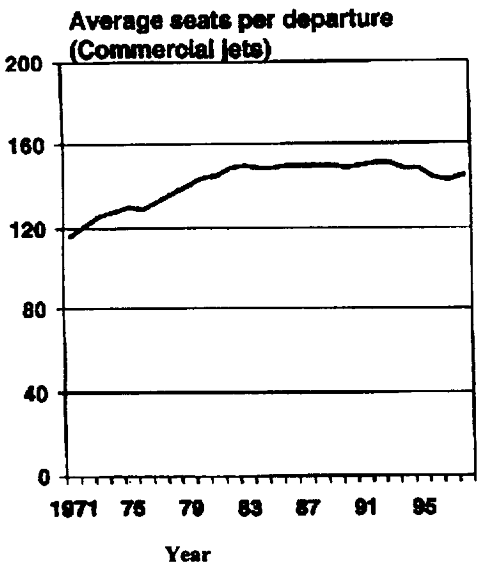
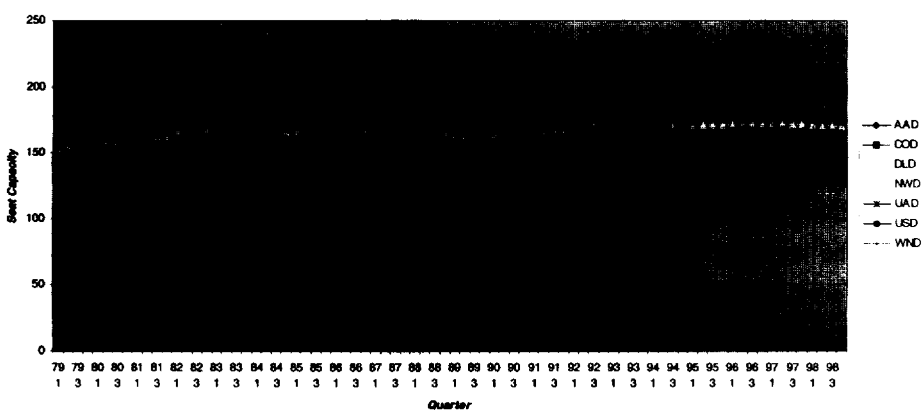


Fig. 1. Average seats per departure by US airlines in domestic markets(Source[3]).

그림 1. 미국 국내선 항공시장의 투입항공기의 평균 좌석 수

[2]. From early 1970s to the middle of 1980s, the average seats per departure increased from 120 to 145, and was almost unchanged for the next 10 years until 1995. Then there was a small dip variation in the years between 1995 to 1998. It is probably because non-stop direct flights are more favored recently and this lead to utilization of smaller aircraft to meet smaller volume of demand for point-to-point service, than connecting services.

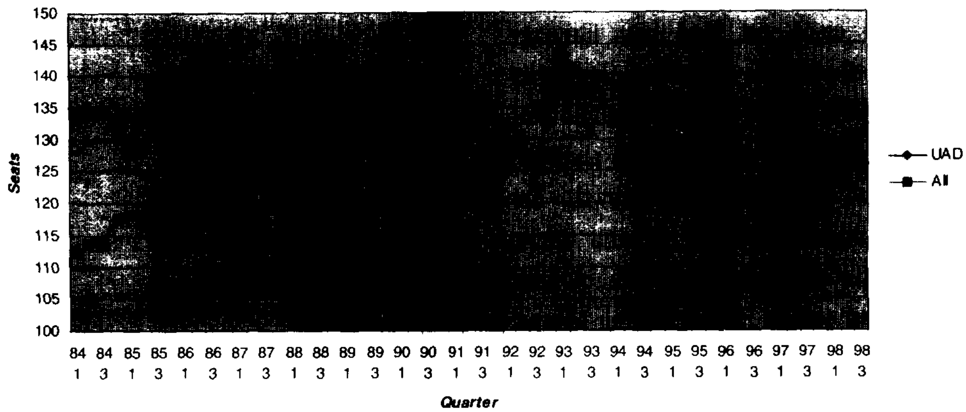
The time-series aircraft seat capacity for the seven largest airlines in the U.S. domestic market is shown in Fig. 2. For all these airlines, aircraft size kept changing from the early 1970s to the middle of 1990s, and then was almost constant in the next three years until now. There is always difference in aircraft size between different airlines. For example, the aircraft currently used by Delta Airlines are about 40 seats larger on average than those used by US Airways. Aircraft size variation can also be seen in a specific segment. Fig. 3. shows a comparison between aircraft size used by United Airlines (UA) and the average size used by all airlines in the segment of San Francisco International (SFO) airport to Los Angels International (LAX) airport. Interestingly, as the figure shows, aircraft size used by UA is usually



(The numbers are calculated by dividing the total Seat-Miles by total aircraft Miles based on data in database Form 41).

Fig. 2. Time series aircraft size for the seven largest US airlines.

그림 2. 미국 7대 항공사 평균좌석수의 시계열분석



(Source: Form 41)

Fig. 3. Aircraft size in the market from SFO to LAX.
그림 3. 샌프란시스코-로스엔젤레스 노선의 항공기 좌석 수

smaller than the average size by all airlines in this market, especially in the last five years, when the market share of UA was getting larger and larger (UA has 80% market share now). In conclusion, we can say that average aircraft sizes of an airline might be influenced by the operational strategy of each airline. Even for same route, each airline serves different size of aircraft.

For a forecast of aircraft size in the future, the annual publication of "FAA Aerospace Forecasts" is frequently referred. But the forecasts given by FAA differ vastly from year to year. For example, in the year 1998 version, FAA forecasts that in 2009, aircraft sizes of US air carriers for domestic operation and total system operation will reach 166.6 and 186.2, respectively (from 142.6 and 159.2, respectively, in 1997). But, in the 1999 version (March 1999), the numbers are changed to 148.5 and 168.7, respectively, which are about 15% smaller than those in previous year's version.

Probably, aircraft manufacturing companies are concerned about the aircraft size favored by airline in the future more than anyone else. Boeing and Airbus, the two main aircraft providers, perceive the size of the aircraft in the future quite differently from each other, and they use different categorization of aircraft size and definition of "world total fleet" in their reports. In Boeing's "1999 Current Market Outlook," the company emphasizes that, to accommodate future air travel growth, airlines will focus on the strategy of more frequencies, not larger aircraft. It forecasts that, for the next twenty years, single aisle and regional jets will maintain its current 73% share of the world fleet; and the proportion of large airplane (Boeing 747 and larger) is expected to decline from 8% to 6%. But Airbus's "Global Market Forecast 1998-2017" (April 1998) states that "the forecast growth in passenger traffic will be accommodated largely by an increase in the number of seats in the airline fleet". It forecasts that the proportion of smaller aircraft (fewer than 210 seats) in the world fleet will be reduced from 73% to 57%, and the proportion of larger aircraft will increase from 29% to 43%. In terms of air traffic capacity, Airbus forecasts that very large aircraft (more than 400 seats) will provide more than 20 percent of the air traffic capacity in 2017, although their capacity share was only 1% in 1998.

Although we could not find any literature regarding the methodologies that FAA, Boeing or Airbus used in their forecasting, we can see that one key factor influencing their forecast results is the regional and global economic growth. For example, the economic recession in Asia during 1997~1998 "disturbed" significantly all of their world fleet forecast results. But, in all their forecast reports, there is no systematic study on airlines' decisions on aircraft size, or how airlines may adapt their choices to meet airport congestion and traffic growth in the future.

Ⅲ. Research Objectives and Methods

The objectives of this research are to understand airlines' choice behavior regarding the size of aircraft. We will find out what the optimal aircraft size for an individual airline is in a specific market or network, and find out how market features influence each airline's choice of aircraft.

Fig. 4. shows a simplified decision-making framework for airline's flight operation. The core of this framework is the set of airlines' decision variables, including operation frequency, aircraft size, flight scheduling, charging fare, and routing structure. Airlines' decisions are driven by three types of forces: forces from the demand side (air travelers), from the supply side (airport, aircraft, labor, fuel and etc), and from competition with other airlines. The choice of aircraft for each market is decided by interaction with other strategic decisions within an airline, and depends on aircraft technology, operation cost, passenger demand, flight distance, the capacity of related airports, competition with other carriers, and the total number of each aircraft type available in their fleet.

The general approach for this research is to

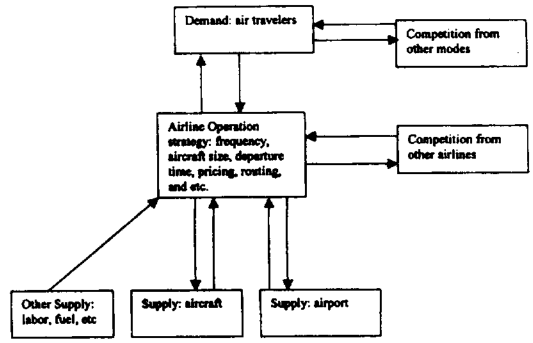


Fig. 4. A Simplified decision-making framework related to airline operation.

그림 4. 항공사의 운항 의사 결정 모형도

model airlines' choice of aircraft from economics point of view. We assume that all airlines are profit maximizers: they make "optimal" decisions on aircraft size based on the costs of the supply including aircraft cost and passenger service cost and the revenues derived from the demand such like passenger fares. The two basis functions of this research are: a) airline cost function, which takes aircraft size as a variable; b) airline market share and revenue functions, by using the variable of aircraft size. Based on these functions, we will analyze airlines' choice of aircraft size at two levels: flight segment level and network level.

Ⅳ. Literature Review

4-1 Literatures Related to Cost Analysis

Literature review in this part focuses on categorizing airline operation costs and building cost functions involving aircraft size.

Meyer and Cliton classify airline costs into six categories. For each aircraft type, the total cost is the sum of six separate cost components: fuel cost, flight crew cost, miscellaneous flying expenses and oil costs, maintenance cost, cost of owning and insuring equipment, and landing fees[4]. The calculation is basically detailed accounting; the cost functions he uses do not build a direct relationship between the cost components and airline output variables such as number of passengers or aircraft miles.

Bailey et al classifies airline costs into three categories: overhead costs, flight costs and passenger costs. Overhead costs consist of costs that are not affected by operational changes in a particular market in short run, such as capital cost. Flight costs include salaries of the flight crew, fuel, maintenance, landing fees, and ground service. Passenger costs consist of costs associated with passenger services such as reservation, food service on board, and ticketing at gate. Bailey et al provide a table to compare direct aircraft operation cost by a variety type of aircraft for different stage length (flight distance), and they find that the least-cost aircraft type depends on stage length. They use a statistical model to calculate the average cost per passenger in a given market, using explanatory variables such as the market's distance, the number of origin and destination passengers, flight into a slot constrained airport or not, service by a newly certificated airline or not, and traveler's time sensitivity[5]. A similar statistical model for the total airline cost is introduced by Caves et al[6]. The variables used in their study for the total cost function include: airline output (revenue passenger miles), network characteristics (number of points served), factor prices, airline control variables (average stage length and average load factor), and time specific and firm specific dummy variables. The cost functions based on these statistical models do not take aircraft size into consideration and do not have clear economic explanations.

Keeler uses time series and airline cross sectional data to estimate long-run airline cost function[7]. The total costs consist of direct costs and indirect costs. Direct airline costs include expense for crew salaries, fuel, aircraft maintenance, and aircraft capital investment: total direct airline costs are measured by costs per block hour for each aircraft type. Indirect operating costs include expense for sales, reservations, aircraft cleaning and fueling, airport rentals, cabin service, and administration. A regression model is built in this article for total indirect cost based on explanatory variables: available ton-miles, revenue ton-miles and available ton-departures. Douglas and Miller use the Form 41[1)] data to build a cost function for scheduled air service[8]. The total cost consists of aircraft costs and passenger service costs. Direct costs for a specific aircraft type are represented as a function of block time or distance. The costs of providing services to travelers are generally assumed to be proportional to direct measures of passenger traffic such as revenue passenger enplaned or revenue passenger miles, which are estimated for each aircraft type.

In summary, airline operation costs are usually categorized as: direct aircraft cost, indirect aircraft cost and passenger service cost. There are different approaches to estimating airline costs, including management accounting, statistical modeling and econometric modeling. The general econometric approach that Keeler, Douglas and Miller used more than 20 years ago can be applied in our research. But it is necessary to use more recent and consistent data to build cost functions to see how airline costs are influenced by the size of the aircraft operated.

[1)] Financial statements of all major, national, and large regional airlines which report to the USDOT pursuant to CFR Part 241. These include Balance Sheets, Income Statements, Operating Costs by Equipment Type, and Summary Operating Statistics by Equipment. Data from 1977 to current is published quarterly.

4-2 Literatures Related to Demand and Market Share Analysis

The literature review in this part focuses on literatures concerning the impact of operation frequency and aircraft size on airlines' market demand or market share.

Many existing demand forecasting methods, such as the four methods summarized by O'Connor (1995) and the gravity-like models introduced by Verleger (1972), do not consider operation frequency and aircraft size in estimating total air travel demand in a market[9],[10]. The results based on these demand models could only be regarded as "potential" passenger demand, since any factors of airline supply is not considered as a factor influencing travelers' demand in these models.

Hansen specifies a passenger's utility function using operation frequency, fare and flight distance, and builds a Logit model for demand analysis[11]. Norman and Strandens directly relate operation frequency to the waiting time and cost for passengers, and build a probabilistic air travel demand model, under the assumption of a uniform distribution for desired departure times over a time interval[12]. But aircraft size is not taken into consideration in these models.

"Schedule delay," which is used for airline demand and market share analysis by many researchers, involves both operation frequency and aircraft size. This concept was first introduced by Douglas and Miller (1974) and subsequently applied by Viton (1986) in a case study[13]. "Schedule delay" has two components. The first component is frequency delay, which represents the elapsed time between an individual traveler's preferred time and the time of next scheduled flight. The second component is stochastic delay, which represents the additional time that a traveler must spend in trip-making because earlier (preferred) flights may be fully booked. Douglas and Miller estimate empirical frequency and stochastic delay functions by using regression and simulation methods. The results show that frequency delay is a nonlinear function of frequency, and stochastic delay is also a nonlinear function of frequency, aircraft size and demand in the market. The concept of "schedule delay" is used in a linear regression model by Abrahams (1983) to estimate the total air travel demand in a single market[14]. Besides "schedule delay," other explanatory variables in his model include: ticket price, air-auto modal split index, population index, income index, and the rate of Gross National Product Growth.

Simultaneous equations for both demand and supply functions are used by Meyer (1985) to study the demand of short-haul air service on low-density routes. In the demand model, the dependent variable is the number of passenger trips, and the independent variables are aircraft size, operation frequency, population, passenger enplanements, fare, flying time and estimated driving time. In the supply model, the dependent variable is operation frequency, and the independent variables include the number of passenger trips and aircraft size. Due to the requirement to solve the two equations simultaneously, the roles of frequency and aircraft size are not revealed directly in the demand model. Furthermore, Meyer's research treats all the airlines as one firm, and does not consider competitions.

In summary, the concept of "schedule delay" has been used extensively to study the impact of operation frequency and aircraft size on airlines' demand. But, no model has been built or applied to study how each airline's demand or revenue is influenced by aircraft size and operation frequency in a competitive environment.

4-3 Literatures Related to Airline's Choice of Aircraft

This part discusses again previous research works concerned with airlines' choice of aircraft from economic point of view.

Using the concept of "schedule delay," Douglas and Miller (1974), and Viton (1986) try to find the optimal (for maximum total social welfare) flight frequency and aircraft type by minimizing the total passenger incurred costs and total carrier costs. The total cost for a passenger is the value of "scheduled delay" plus the value of travel time. Based on airlines' demand and cost functions, Douglas and Miller analyze firms' optimal choices of aircraft size and frequency and market equilibrium. The total demand in terms of number of air passengers is a function of average fare, passengers' perception for "schedule delay" and other service quality. Total cost of airline is dichotomized into aircraft costs (in terms of number of departures), and passenger cost (in terms of number of passengers). Since the model is built for an airline in regulated environment, the price is treated as a given parameter. The market share of passenger traffic for each airline is a function of operation frequency of the airline itself and its competitors. Since "schedule delay" is determined by operation frequency and aircraft size, a firm's "optimal" strategy and industry equilibrium could be derived by assuming that each firm is competing in operation frequency to achieve maximum profit in a single market. This model treats aircraft size as an endogenous variable; it is restricted to price regulation and has not been applied to any practical case.

Other models, such as those proposed by Hansen (1996), Jeng (1987), Ghobrial (1983), and Bruckner and Zhang (1999) treat aircraft size either as constant or endogenous, and find optimal frequency for airlines' operations thereby. These models analyze the relationship between airlines' choice of operation frequency and routing structure[11],[14],[15],[16]. Hansen analyzes the situation of airlines' operation in a competitive environment and assumes that demand is endogenous. Jeng and Ghobrial deal with only one airline and assume that total demand is inelastic to the airline's operation decisions.

In summary, there has been few research that deals with airlines' choice of aircraft size and operation frequency in a competitive environment from airlines' economic point of view, either for a single market or a specific network, and there has been few model applied in practice yet.

V. Procedure of Analysis

The first part is to analyze the relationship between airline operation cost and the size of aircraft operated. The second part is to build airlines' market share and revenue functions in order to determine the role of aircraft size and operation frequency in the situation of market competition. The third and forth parts analyze airlines' choice of aircraft size at flight segment level and network level, respectively.

The research will utilize airlines' financial and traffic database product Form 41, Onboard and O&D Plus, which are constructed on the basis of the data that all certificated airlines are mandated to report to US Department of Transportation.

5-1 Cost Analysis

The procedure of analysis consists of four parts. The first step is to build a cost function to see how aircraft size influences airline operation cost and find out the economic implications of such influence.

Form 41, the data source for building cost function, classifies airline cost into several functional groups: aircraft operating expense, passenger service expense, traffic serving expense, reservation and sales expense. For the objectives of this research, we are interested in the costs that can be directly assigned to a specific flight, and exclude such costs as reservation and sales expense, advertising and publicity expense, general and administrative cost, which are related to the whole airline operation system. Airline operation costs in our analysis include three components: aircraft capital cost, aircraft operation cost and passenger service cost. Aircraft capital cost will be calculated based on purchase price, assumed service-life time and an assumed interest rate. Aircraft operation cost consists of direct operation cost and indirect service cost. Direct aircraft cost items include aircraft oils, fuels, pilots' and other flight personnel's salary, and flight equipment maintenance. Indirect cost items include control, line service expense, landing fees, ground property maintenance and its depreciation. Passenger service costs include flight attendant expense, food expense and other in-flight expense.

The general cost function is specified as:

$$C_{iOD} = C(S_i, L, Q, H, A_O, A_D) \quad (1)$$

where: C_{iOD} represents total airline cost in a flight segment (flying from airport O to airport D) if aircraft type i is used; S_i is the size (seat capacity) of aircraft i; L is the flight distance(from airport O to airport D); Q is the total number of enplaned passengers; H is the total number of flights; A_O, A_D are dummy variables for the origin and destination airports, respectively.

If airline cost per seat in a specific segment is decreasing with aircraft size, then we say that there is an economy of scale of aircraft size in the airline's operation cost; and if the cost is increasing with aircraft size, then there is a diseconomy of scale. From the function above, we can see that total airline cost per seat (C_{iOD}/S_i) is also a function of flight distance L, number of flights H, number of passengers Q, and airport dummy variables. Therefore, whether there is an economy of scale or a diseconomy of scale of aircraft size in a specific segment depends on flight distance, passenger demand and airport conditions.

Airline Operation cost is only one determinant of airlines' choice of aircraft; the other is the impact of aircraft size on airlines' market share and revenue, which is the second part of this research and will be discussed next.

5-2 Market Share and Revenue Analysis

At first, it is necessary to explain some terminology used in this research through a simple example below:

There are three airports in this system: A, B, and C. One airline company has four flight segments between these airports: AB, BC, CB, and BA. The flights in these segments may use the same or different aircraft. There are six markets (or passenger Origin-Destination (OD) markets): AB, BA, BC, CB, AC and CA. The passengers in these OD markets can be provided with non-stop service (through only one flight segment) such as the service provided in market AB, BA, BC and CB, or multiple-segments service such as the service provided in market AC (through segments

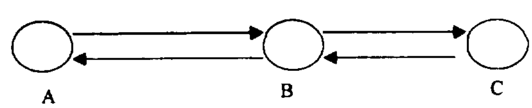


Fig. 5. A simple example of aircraft routing.
그림 5. 항공기 노선의 간단한 예

AB and BC) and CA (through segments CB and BA). In each flight segment, passengers can be either local passengers (who are provided with non-stop service through this segment) or connecting passengers (who are provided with multiple-segments service). In our example, passengers in segment AB can be either in AB market (local passengers) or in AC market (connecting passengers).

For a general case of passenger market, the service quality provided by airline j in market k, denoted as g^j_k, depends on (1) whether the service is non-stop service or multiple-segments service; (2) aircraft size and operation frequency in the specific segment if non-stop service is provided; or aircraft size and operation frequency in all related segments if multiple-segments service is provided. Assuming that ticket price charged by each airline is endogenous to its service quality, the number of passengers and revenue that one airline expects to get depends on its own service quality and the service quality of its competitors:

$$q^j_k = q_k(g^j_k,\ g^t_k,\ \cdots) \qquad (2)$$

$$r^j_k = r_k(g^j_k,\ g^t_k\ \cdots) \qquad (3)$$

where: q^j_k represents the passenger traffic that airline j will get from market k; r^j_k represents the revenue that airline j will get from market k; g^j_k represents the service quality provided by airline j in market k; g^t_k represents the service quality provided by airline t, which is one of airline j's competitors in market k.

Our analysis will start with a simple case of market: "non-stop non-connecting" market, which is served by only non-stop flights, and the number of connecting passengers in these flights is small. In our previous example, market AB is called "non-stop non-connecting" market if (1) the passengers in this market are only served by flight AB (i.e. there is no other multiple-segments service) and (2) the flight in segment AB has very few connecting passengers (such as those in market AC).

In the "non-stop non-connecting" market, airline service quality is determined solely by the frequency and aircraft size in one flight segment for this market. Therefore passenger traffic for airline j is a function of operation frequency and aircraft size provided by airline j and all its competitors in that segment, i.e.:

$$q^j_k = q_k(S^j_k,\ f^j_k,\ S^t_k,\ f^t_k,\ \cdots) \qquad (4)$$

where: S^j_k, f^j_k represent, respectively, the size of aircraft and operation frequency provided by airline j in market k; S^t_k, f^t_k represent, respectively, the size of aircraft and operation frequency provided by airline t, which is one of airline j's competitors in market k.

The revenue that an airline company expects to obtain is also a function of aircraft size and operation frequency offered by itself and those offered by all other competitors in this market (one flight segment).

The results from cost, market share and revenue analysis will be applied to the study of airlines' aircraft choice behavior at the flight segment level.

5-3 Analysis for Choice of Aircraft Size for Segment-Level

This part shows the analysis of airlines' choice of aircraft for a single segment which can be regarded as a "non-stop non-connecting" market. We assume that airlines base their decisions on the use of aircraft for one segment solely on the number of local passengers and that the decision for one segment is independent of decisions for other segments.

Utilizing cost, demand and revenue functions, we can both numerically and analytically determine the optimal size of aircraft that an airline should use for a specific market, if we do not consider responses from its competitors.

Comparing these optimal choices with observed ones, and comparing the choices (both optimal and observed) of different airlines in the market, we will exam the "equilibrium" in the market and analyze how different airlines choose their aircraft differently.

Based on market characteristics such as the distance between the origin and destination airports, the degree of competition, the total demand in the market, and airport congestion conditions, all the "non-stop non-connecting" markets can be categorized into groups. By comparing airlines' choices of aircraft size among markets in the same group and between market groups, we will analyze how market features influence airlines' choice of aircraft size.

Also we can find out how airlines will adapt their choices to traffic growth, airport congestion and changes in aviation regulations (such as policy for landing fees), based on the derived cost, demand and revenue functions.

5-4 Analysis for Choice of Aircraft Size for Network-level

Our network-level analysis focuses on airlines' systematic decisions on the size of aircraft to operate at the network level. "Systematic" means that airlines' decision is based on the unit of a network rather than on a single flight segment in the network.

We take a hub-and-spoke network (such as Dallas Fort-Worth Airport (DFW) based hub-and-spoke system used by American Airlines) as a base routing structure for our analysis. In a hub-and-spoke network, passengers in the spoke-to-spoke markets are served by 2-segments flights through connection at hub. For passengers' convenience and their own operation efficiency, airlines will schedule all flight arrivals from spoke airports (or departures to spoke airports) at hub in a short period (almost simultaneously). We call the bundled arrivals of these flights at hub as a "complex" or a "bank." For example, at DFW, American Airlines now has around 50 flights in one bank, and has about ten banks every day. The number of flights in one bank depends on the total number of spokes in the system: the number of banks at a hub depends on operation frequency between hub and spoke. Within a service region, airlines can provide either one-stop service through hub or point-to-point direct service for passengers in a specific market.

Similar to the case of a single market, the total passenger traffic and revenue for an airline whose routing is hub-and-spoke based in a specific service region, depend on (1) average operation frequency between hub and spoke, (2) average aircraft size, (3) number of spokes, and (4) number of markets (from spoke to spoke) served by direct flights. To calculate passenger traffic and revenue at a network level, we can either build network-level demand and revenue models using aforementioned four influential factors as independent variables, or use the aggregation for all markets based on the demand and revenue models for each market introduced in "market share and revenue analysis".

To understand airlines' choices of aircraft size at a network level and find out how airlines will adapt their choices to airport congestion and traffic growth, we will compare airlines' profit in different scenarios, where different operation strategies are used. There are some basic scenarios: (1) Airlines keep the current hub-and-spoke system and the size of aircraft operated in the market, and adaptation can only be made by either increasing or decreasing operation frequency over the whole network. (2) Airlines keep the current hub-and-spoke network, but average size of aircraft, and hence frequency, can systematically increase or decrease. (3) Airlines keep the same aircraft in each market, but they can change their service in certain markets (with a predetermined demand level) from hub-and-spoke to point-to-point, or vice versa. (4) Without changing other decisions, airlines can increase the number of spoke airports in the service region to accommodate the increasing demand. Besides these four basic scenarios, other scenarios can be formed as a mixture of these operation strategies: changing aircraft size, changing operation frequency, changing number of spokes in the system, and switching from hub service to direct service or vice versa.

In different scenarios, airline operation cost will change with number of operations, the size of aircraft and service stage length. Particularly hub-airport related cost will change with variations in hubbing operation features: number of flights in a bank, number of banks, and their impact on runway capacity at hub.

Our future research will find out the optimal scenario of operation strategy that airlines will adopt under different network conditions in terms of airport congestion, traffic growth and change of policies.

Ⅵ. A Case Study Of The Choice of Aircraft Size

Based on the proposed research methodology, we conducted a case study for the SFO to LAX market, which is one of the densest markets in the U.S (in terms of passenger traffic). This section shows the results of this case study.

6-1 Market Description

The distance between SFO airport and LAX airport is 545 miles. The mean and median flight time at present is 73.5 minutes and 76 minutes respectively. The total passenger demand profile from the 1st quarter of 1984 to the 3rd quarter of 1998 is shown in Fig. 6. For last 5 years, United Airlines has been the dominating airline in this

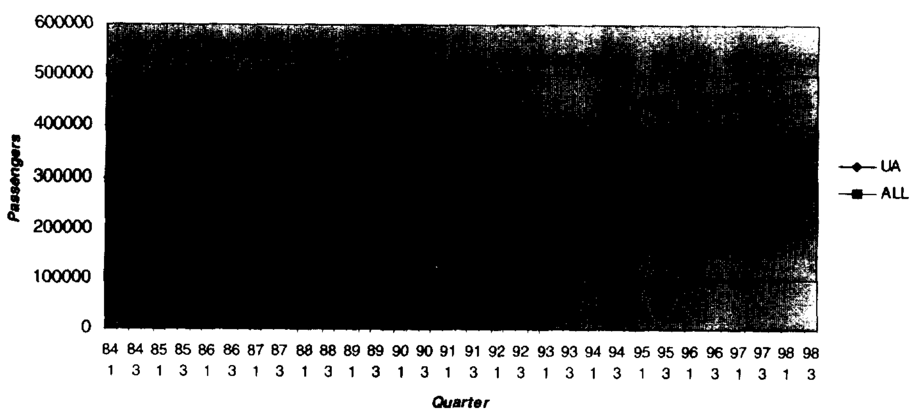


Fig. 6. Passenger demand profile for UA and all airlines.
그림 6. UA와 기타 항공사의 항공여객 수요

market and has 80% market share of enplaned passengers. From the Airline Service Quality Performance (ASQP) database, which is reported by the ten largest U.S airlines, United Airlines (UA) has 38 of the 45 total fights on a typical day; Continental, Delta and Alaska have three, three and one flight, respectively. At present, UA uses two types of aircraft in this market: Boeing 737-300 and Boeing 737-500.

6-2 Assumptions

Several assumptions are made for the cost analysis and market share analysis in this case study:

1) Airline operation and competition in this market are not influenced by other markets.
2) Passenger service cost is assumed to be the same for all aircraft types in cost analysis.
3) Difference in airline costs related to each airport (such as difference of landing fees between airports) is not taken into consideration in cost analysis.
4) Aircraft capital cost is not included in airline operation cost. Instead, we include aircraft rental cost in direct aircraft operation cost using Form 41 data in cost analysis.
5) The total demand and revenue in this market are assumed to be exogenous in market share and revenue analysis.
6) Passengers have no preference of airlines in this market.

6-3 Cost Analysis

The airline cost in this case study consists of three components: direct aircraft operation cost, indirect aircraft operation cost and passenger service cost. Database Form 41 lists average direct aircraft operation cost for each aircraft type and for each carrier in unit of cost per block-hour per flight. In this case study, we calculate the total direct aircraft cost per flight by multiplying this unit cost by block hours for one flight. Since larger aircraft usually have longer stage length than smaller aircraft, and there are some costs that are related to only departure or landing of aircraft at airport, the method based on the unit cost per block hour would underestimate direct aircraft cost for larger aircraft. Presumably, indirect aircraft cost (including control, line service and landing fees) for the same type of aircraft operated by different airlines should be the same, but this hypothesis can be rejected statistically in our preliminary analysis. Therefore we use the data from Form 41 to build an indirect cost function specifically for United Airlines.

A linear statistical model for aircraft indirect cost is specified as:

$$Cia = \alpha_0 + \alpha_1 * S + \alpha_2 * L + \varepsilon \quad (5)$$

where: Cia is aircraft indirect cost per flight; S stands for aircraft seat capacity; L is flight distance; ε is the random error term.

Since the data in Form 41 are aggregated by quarter for all flights by all types of aircraft, we use the quarterly average data for both dependent variable and independent variables to do regression. Time series quarter data, from the 3rd quarter of 1987 to the 2nd quarter of 1998, are used to estimate the parameters in our analysis (with the help of the statistical software SAS). No serious autocorrelation between the time series quarter data is found afterwards. Inflation is taken into consideration by multiplying the cost by an inflation factor for each year. The estimation results are shown in Table 2.

Therefore the indirect aircraft cost function (with the same notations as above) is:

Table 2. Estimation results for UA indirect aircraft cost function.

표 2. UA의 간접비 함수 추정 결과

Variables	Coefficients	T for H0: Parameter=0
Constant (1)	-1540	-2.2
Seat (S)	11.75	3.2
Mile (L)	0.86	3.7

$$Cia = -1540 + 11.75S + 0.86L \tag{6}$$

It should be emphasized that there is a range of aircraft size and flight distance in which the function is valid.

Indirect aircraft cost per seat is:

$$Cias = -1540/S + 11.75 + 0.86L/S \tag{7}$$

Combining indirect aircraft operation cost with direct operation cost, we can compare total aircraft cost per flight and the total cost per seat in the SFO to LAX market between several types of aircraft (for the 3rd quarter of 1998). The result is shown in Table 3 below.

Passenger service cost per enplaned passenger is estimated to be 15 dollars per passenger in this market (SFO to LAX) for all aircraft types, based on the data in Form 41.

6-4 Market Share and Revenue Analysis

The flight segment from SFO to LAX can be regarded as a "non-stop non-connecting" market, since there is only direct service in this market, and the number of connecting passengers through this segment is not significant. Thus we assume that airlines' decisions on operation frequency and aircraft size for the flight of SFO to LAX are determined by the local passengers.

In this case study, we assume that the index of service quality for airline j in this market is specified as:

$$g^j = (S^j)^{\eta 1} (f^j)^{\eta 2} \tag{8}$$

Where: S^j stands for the seat capacity of aircraft used by airline j; f^j is operation frequency provided by airline j; η_1 and η_2 are parameters.

Since United Airlines has 80% market share annually in the past five years, we treat all other airlines in this market as an aggregate "other" airline. Thus, the demand function regarding the number of passengers that UA expects to attract can be specified as:

Table 3. Comparison of aircraft operation cost in SFO to LAX market.

표 3. 샌프란시스코- 로스엔젤레스 노선의 기종별 운영비

Aircraft	Seats	Direct cost per hour($)	Direct cost per flight ($)	Indirect cost per flight ($)	Total cost per flight($)	Cost per seat ($)
B-737-300	128	2339	2924	580	3504	27
B-737-500	111	2197	2746	312	3058	27
B-757-200	188	2734	3418	1525	4942	26
B-767-200/ER	168	3194	3993	1210	5202	31
B-767-300/ER	216	3467	4333	1965	6299	29
B-777	292	3677	4596	3162	7758	27
B-747	387	5661	7076	4658	11734	30

$$a^u = Q\frac{g^u}{g^u + g^o} \quad (9)$$

where: Q is the total passenger demand in this market; g^u and g^o stand for the service quality provided by United Airlines and "other" airlines respectively.

Parameters in the functions above, η_1 and η_2, are estimated based on a logarithmically transformed linear model for the market ratio between airlines. The statistical model for the market ratio between UA and the "other" airline is specified as:

$$LN(q^u/q^o) = \eta_1 * LN(S^u/S^o) + \eta_2 * LN(f^u/f^o) + \varepsilon \quad (10)$$

where: q^u and q^o stand for the quantity of passengers obtained by UA and the "other" airline respectively; S^u and S^o stand for the average aircraft size used by UA and the "other" airline respectively; f^u and f^o are available operation frequency provided by UA and the "other" airline respectively; ε is the random error term.

A similar revenue ratio model is built separately for revenue function.

Time series quarter data (1st quarter, 1989 to 2nd quarter, 1998) from the database products of On-Board and OD-Plus are used to do regression in our analysis. There is no serious autocorrelation found afterwards.

The estimation results show that the parameter for aircraft size is not statistically significant in either passenger market ratio or revenue ratio models, which indicates that the difference between aircraft size is not significant in airlines' competition in the last ten years in this market. Therefore the variables for aircraft size are not used in the final models.

Table 4. Estimation results for demand and revenue functions.

표 4. 수요 및 수익 함수 추정결과

Model	Coefficients for operation frequency	T statistics
Passenger market ratio	1.05	16.5
Revenue market ratio	1.04	12.1

The parameters for the operation frequency in these two models respectively are estimated and listed in Table 4.

Then market ratio and revenue ratio functions are specified as:

$$(q^u/q^o) = (f^u/f^0)^{1.05} \quad (11)$$

$$(r^u/r^o) = (f^u/f^0)^{1.04} \quad (12)$$

The market share of passenger traffic and revenue can be derived instantly based on these two functions respectively.

6-5 Analysis Results

To accommodate the passenger demand in the "current" (the 3rd quarter of 1998) SFO to LAX market, UA can have different choice of aircraft type (with different size). Based on the assumption that the "other" airline keep their current strategy (operation frequency and aircraft size), the optimal operation frequency of UA is derived for each aircraft type to maximize profit, and is constrained by a given maximum load factor (0.72 in this case). The results derived numerically based on the cost, demand and revenue functions above are listed in Table 5.

The results in the table show that the optimal aircraft is B-757, with a profit slightly higher than those from two smaller aircraft B-737-300 and

Table 5. Comparison of profit by different aircraft type.
표 5. 기종별 이윤 비교

Aircraft	Seats	Frequency	Revenue($)	Cost ($)	Profit($)
B-737-300	128	3250	21836660	15729809	6106850
B-737-500	111	3800	22214203	16038352	6175850
B-757-200	188	2080	20552826	14372325	6180502
b-767-200/ER	168	2380	20971854	16555852	4416002
B-767-300/ER	216	1750	19979137	15004056	4975081
B-777	292	1220	18673686	13189269	5484416
b-747	387	850	17284160	13424682	3859478

B-737-500, which are currently used by United Airlines in this market. The profit from the largest aircraft B-747 is significantly less than those from others.

Utilizing the models described above, we can also see how UA will change their choice under such circumstances as change of landing fee policy, increase of operation cost due to delay, and restriction of number of operations due to airport congestion. We can also exam the equilibrium in the market, considering response from the "other" airline. SFO to LAX market can be categorized in a market group as "short haul, low price, low competition," and we can compare the results from SFO-LAX market with those from other markets in the same or different market groups for UA and other airlines to analyze their similarities and differences.

It should be emphasized that airlines' actual use of aircraft in each market is constrained by their aircraft fleet and their routing network; on the other hand, airlines make decisions on what type of aircraft to purchase and how to update their fleet, based on the requirement of aircraft in each market and their current fleet. These two issues, which are related to the "fleet assignment problem" and the "fleet updating problem," are not addressed here.

This case study shows that the proposed research methodology is operational. But the cost, demand and revenue functions developed in this section can be improved and refined later on.

6-6 Conclusion

The objective of this research is to understand airlines' choice regarding the size of aircraft operated in the market and how airlines will adapt their choices to airport congestion, traffic growth and policy changes.

The research framework is proposed from an economic point of view with the assumption that each airline is a profit maximizer, and consists of four parts: (1) cost analysis for the relationship between airline operation cost and aircraft size; (2) market share and revenue analysis in order to determine the role of operation frequency and aircraft size in airlines' demand and revenue; (3) flight segment-level analysis, based on the derived cost, demand and revenue functions, to understand an airline's choice and adaptation in a specific segment; and (4) network-level analysis to see how airlines make choice of aircraft size systematically at a network level, and how airlines make adaptations of aircraft size with other systematic operation strategies.

A case study of United Airlines in SFO to LAX market demonstrates that the proposed methodology is operational. However, the variables utilized are not comprehensive enough in the case study because the source data has a limitation, in addition, the study analyzed only one case because of the limitation of time and costs of the study, which is another limitation of the study.

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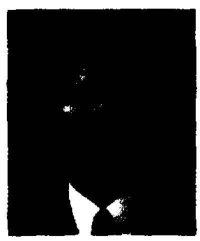

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