



Aircraft replacement scheduling: A dynamic programming approach

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ABSTRACT

This study developed a stochastic dynamic programming model to optimize airline decisions regarding purchasing, leasing, or disposing of aircraft over time. Grey topological models with Markov-chain were employed to forecast passenger traffic and capture the randomness of the demand. The results show that severe demand fluctuations would drive the airline to lease rather than to purchase its aircrafts. This would allow greater flexibility in fleet management and allows for matching short-term variations in the demand. The results of this study provide a useful reference for airlines in their replacement decision-making procedure by taking into consideration the fluctuations in the market demand and the status of the aircraft.

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1. Introduction

The ability to match fleet capacity to passenger demand is one of the crucial factors deciding the profitability of an airline. The extent to which economic cycles influence air transportation demand is quite apparent. An economic recession usually accompanies reduced air demand, resulting in insufficient revenue and surplus capacity that further burdens the airlines with fleet idle costs, thereby lowering profits. On the other hand airlines also suffer a great profit loss under a quick economic recovery, when the fleet capacity may not be able to expand in time to satisfy the high demands, due to the time lag between ordering, receiving and operating of extra aircraft. Although aircraft replacement decisions can be made in advance in order to match future demand, the fluctuating and cyclical nature of passenger demand complicates the fleet capacity management problem.

Decisions about fleet capacity management are classified under airline strategic planning, which involves decisions such as when to purchase, lease or dispose of aircraft. Fleet expansions and reductions are achieved through aircraft purchase, lease or by disposing of the surplus airplanes. Leasing an airplane gives the airlines flexibility in capacity management. However, airlines must pay a risk premium to leasing companies for bearing the risks (Oum et al., 2000). Also, the lease cost for an airplane may be very high when there is a high demand for them in the market. The scrapping and replacing of an existing aircraft is generally motivated by the physical deterioration of the aircraft or the availability of newer, more efficient ones. However, the decision to replace can be scheduled in advance to coincide when the airline market is forecasted to going into downward trend, thereby reducing the operating and maintenance costs. How to schedule capacity expansion or reduction decisions in advance is an essential and critically important task for the airlines, since the aircraft fleet must not only serve current but also future demands. Although any particular replacement decision is necessarily influenced by the current fleet composition as well as any possible future demand, it still has a long-term impact on the airline fleet. Under these

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circumstances, accurate demand forecasts are required to enable the airlines to properly schedule their aircraft replacement decisions in response to the fluctuating and cyclical demands.

Past studies have investigated the issues in the context of fleet capacity problems, such as decisions on aircraft type, flight frequency (e.g. Kanafani and Ghobrial, 1982; Teodorovic and Krmar-Nowic, 1989) and optimal combinations of owned and leased capacity (Oum et al., 2000). Researchers have studied fleet management problems at operational and tactical levels in addition to the strategic level (e.g. Powell and Carvalho, 1997; Jin and Kite-Powell, 2000). There is scant literature available on replacement cost in relation to fleet capacity management over different time periods, or for revenue loss associated with dynamic and cyclical demand.

In this study, the cost of operating an aircraft is dependent upon its status, as defined by type of aircraft, age and total mileage traveled. The fleet is composed of different number and status of purchased and leased aircraft. On the demand side, this study employs the Grey topological forecasting method combined with the Markov-chain model to forecast passenger traffic and capture the random and cyclic demand. The decision periods are identified according to the pattern of the passenger demand cycles over the length of the study period. For each decision period, the airline makes decisions not only on whether and which aircraft to be replaced with a purchased or leased one, but also on whether or not to purchase or lease an aircraft as an entirely new addition to the fleet.

This study aims to determine an optimal replacement schedule for an airline by considering the randomness in airline operations and the cyclical demand through the use of stochastic dynamic programming. This study will also determine the optimal candidate aircraft to be recruited or disposed of. The stochastic dynamic programming method is solved with backward dynamic programming in which the impact of replacement decisions made at a specific period under uncertain passenger demand on airline operation can be fully considered. This study first formulates airline cost function of a decision period assuming independent decision-making results between periods. These costs include operating cost, replacement cost and penalty cost. The operating cost is the cost related to the operation of the existing fleet. The replacement costs arise from the replacement decisions made at a specific period. In addition, a penalty cost is introduced to reflect losses in revenue associated with the difference between the forecasted and realized passenger demand. The expected cost function of the period is further formulated by taking into consideration the cost dependent relationship between decisions made in neighboring periods and the probabilities of different variations in the forecasted and realized passenger demand. Then, the stochastic dynamic programming model for the replacement schedule can be formulated to determine the optimal replacement schedule by minimizing the total expected cost of each period over the study period.

The remainder of this paper is organized as follows: Section 2 reviews the literature on fleet capacity and equipment replacement problems. Section 3 formulates the cost functions based on a single period operation. Section 4 provides the stochastic dynamic programming model for determining the optimal schedule of the replacement decisions. A numerical example is provided in Section 5, to illustrate the application of the models and the effects of changes in key parameters on the optimal solutions. In section 6, we make our concluding remarks.

2. Literature review

The fleet capacity of an airline is the total number of different types of aircraft purchased, leased and scrapped over a period of time. Relevant studies have focused mainly on choosing the right type of aircraft, route, and flight frequency using deterministic mathematical programming methods (e.g. Kanafani and Ghobrial, 1982; Teodorovic and Krmar-Nowic, 1989; Yan et al., 2006). Wei and Hansen (2007) considered the factors of competition in the decisions on both aircraft size and service frequency. They examined the impact of these decisions on both the cost and the demand of air transportation.

Equipment replacement problems in industries with high capital assets have been widely discussed in industrial engineering and operations research literature (e.g. Hartman, 2004, 1999; Rajagopalan, 1998; Jones et al., 1991). Hartman (2001) examined the effect of probabilistic asset utilization on the replacement decision making process, using dynamic programming. Powell and Carvalho (1997) dealt with the multi-commodity fleet problem and formulated the problem as a dynamic control problem. Jin and Kite-Powell (2000) explored the replacement problem for a fleet of ships for a profit-maximizing operator, assuming a homogenous fleet and uniform demand. Wu et al. (2005) addressed a rental fleet-sizing problem in the truck-rental industry. They combined both operational and tactical decision levels, subject to uncertain customer travel time and non-stationary customer demand. Oum et al. (2000) developed a model for the airlines to determine the optimal mix of leased and owned capacity, taking into consideration that the demand for air transportation is uncertain and cyclical. The empirical results suggested that the optimal demand for the airlines would range between 40% and 60% of their total fleet. The financial status of the airline and the passenger demand are critical factors when it comes to leased and owned capacity decisions. Although the uncertainty in demand has been included and investigated in the literature, research regarding the schedules of the above decisions and their impacts on airline operation and the total cost over a time horizon is scant. Furthermore, the cost dependent relationships between subsequent periods due to replacement decisions made in previous periods have not been discussed yet.

When it comes to methods to forecast airline passenger demand, the multi-regression model and the time-series model are the most widely employed. Horonjeff and McKelvey (1994) generalized past literature and classified airline passenger traffic forecasting models into four categories: judgment prediction, trend projection and speculation, market analysis and econometric modeling method. However, the number of available traffic observations has usually not been large enough

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