

This article was downloaded by: [National Chiao Tung University 國立交通大學]

On: 25 April 2014, At: 02:08

Publisher: Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Transportmetrica A: Transport Science

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/ttra21>

Fleet dry/wet lease planning of airlines on strategic alliance

Chaug-Ing Hsu^a, Ching-Cheng Chao^b & Peng-Shien Huang^a

^a Department of Transportation Technology and Management, National Chiao Tung University, Hsinchu, 300, Taiwan, ROC

^b Department of Shipping and Transportation Management, National Kaohsiung Marine University, Kaohsiung, 811, Taiwan, ROC

Accepted author version posted online: 25 Nov 2011. Published online: 21 Dec 2011.

To cite this article: Chaug-Ing Hsu, Ching-Cheng Chao & Peng-Shien Huang (2013) Fleet dry/wet lease planning of airlines on strategic alliance, *Transportmetrica A: Transport Science*, 9:7, 603-628, DOI: [10.1080/18128602.2011.643508](https://doi.org/10.1080/18128602.2011.643508)

To link to this article: <http://dx.doi.org/10.1080/18128602.2011.643508>

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at <http://www.tandfonline.com/page/terms-and-conditions>

Fleet dry/wet lease planning of airlines on strategic alliance

Chaug-Ing Hsu^{a*}, Ching-Cheng Chao^b and Peng-Shien Huang^a

^aDepartment of Transportation Technology and Management, National Chiao Tung University, Hsinchu 300, Taiwan, ROC; ^bDepartment of Shipping and Transportation Management, National Kaohsiung Marine University, Kaohsiung 811, Taiwan, ROC

(Received 5 October 2010; final version received 15 November 2011)

Airlines form strategic alliances in hope of cost minimisation. This study develops a model that deals with issues regarding fleet purchase, dry/wet leases and disposal of aircraft, taking into consideration the impact of a strategic alliance between airlines on fleet planning. Using dynamic programming to determine the initial optimal number and type of aircraft for dry/wet leasing, purchase and lease, the multi-objective model formulated can achieve minimisation of total fleet planning costs. Further, this study simulates the step-by-step negotiation process between decision-makers of two allied airlines. Through interactive bargaining, the airlines can adjust the alliance-related parameters to narrow the difference in expected profits and reach a final negotiated compromise solution acceptable to both airlines in the strategic alliance. A satisfactory negotiation result aiming for lower post-alliance costs in the best interests of one individual airline may not be the most optimal for the overall interests of the alliance. The sensitivity analysis of aircraft acquisition costs offer airlines a better understanding of the cost range and cost threshold for aircraft owned/held for different durations and acquired by different approaches.

Keywords: fleet planning; dynamic programming; alliance; dry/wet lease; interactive bargaining

1. Introduction

The impact of the economy on passenger demand for air transportation is significant, and variations in passenger demand directly affect the operations of airlines. To meet passenger demand, airlines need to make adjustments in the sizes of their fleets while trying to minimise extra operation costs incurred due to surplus or insufficient seating capacity. Costs related to fleet purchase/lease account for a great proportion of an airline's operation costs; hence, it is important that airline management determine how to optimise fleet planning during the fluctuations of an economic cycle in order to reduce costs and increase profits.

Using dynamic fleet planning of an individual airline as a foundation (Hsu *et al.* 2011), this study incorporates the concepts of dry/wet leasing and multi-objective interaction between allied airlines when deciding on fleet expansion or reduction. Cost functions are developed taking into consideration greater cost efficiency resulting from shared resources and joint maintenance between airlines in the alliance. Through dry/wet

*Corresponding author. Email: cihsu@mail.nctu.edu.tw

leasing, allied airlines can lease aircraft, equipment and crews from each other, enabling both to achieve optimisation of fleet size through interactive bargaining. A case study of two international airlines in Taiwan serves to illustrate the feasibility and applications of the model developed. Our findings reveal that wet leasing allows airlines in strategic alliances greater flexibility in fleet expansion and reduction. This enables optimal decisions to be made regarding aircraft purchase, as well as the number, type and duration of aircraft leases needed for meeting variations in passenger demand at different time points in an economic cycle.

The contribution of this article is that it explores fleet purchases, dry/wet leasing and disposal of aircraft, taking into consideration the impact of strategic alliances on fleet planning between airlines. Further, this study simulates the step-by-step negotiation process between decision-makers of two allied airlines. Through interactive bargaining, the airlines can adjust the alliance-related parameters to narrow their differences in profits and reach a final negotiated compromise solution acceptable to both airlines in the strategic alliance. The alliance-related parameters include proportion of shared maintenance costs, lease duration and discount. Analysing pre- and post-alliance costs can shed light on the economic benefits brought by the strategic alliance. The optimal solution obtained by the proposed model may sometimes be deemed unacceptable to the allied airlines and related parameters will then be adjusted for further interactive bargaining to reach a negotiated compromise solution satisfactory to the airlines involved. Such processes can serve as useful references for airline management when deciding on replacement scheduling and when negotiating the rental, lease duration and proportion of maintenance costs for leases between allied airlines.

In recent years, airlines have seen significant cost reductions based on strategic alliances. Obvious examples of airlines' strategic alliances include Star Alliance, One World and Sky Team. With respect to the typology of strategic alliances in the airline industry, Rhoades and Lush (1997) and Gudmundsson and Rhoades (2001) came up with nine different types of alliances classified according to commitment of resources and complexity of arrangements. Among them, code sharing, wet lease and computer reservation systems (CRS) are the types with the greatest stability and longest duration. Code sharing is the most basic and common type of alliance, which is the shortest lasting and involves the least resource commitment. In comparison, wet lease of aircraft/equipment/crews involves more resource commitment and a longer term of cooperation. Leasing of aircraft among airlines can generally be divided into two types: dry lease and wet lease. The former refers to leasing the aircraft itself, while a wet lease occurs when one carrier rents the aircraft, crew, maintenance and insurance of another.

There are two typical alliance types used in international airline alliances, i.e. parallel and complementary alliances. Following Park *et al.* (2001), a parallel alliance refers to the collaboration between two air-carriers who, prior to their alliance, are competitors on some routes of their networks. A complementary alliance refers to a situation where two air-carriers link up their existing networks and build a new complementary network to feed traffic to each other. Oum *et al.* (2004) examined the effect of horizontal alliances on firm performance in terms of productivity and profitability. They further showed that the level of cooperation in horizontal alliances influences the strength of the alliance effect on productivity and profitability. Yan and Chen (2007) developed several coordinated scheduling models, which would help the allied airlines determine the most satisfactory fleet routes and timetables under the alliance. Wan *et al.* (2009) investigated the impact of

airline alliances on airfares on non-stop hub-to-hub routes and found that the impact of alliances on transatlantic hub-to-hub airfares varies depending on the alliance, possibly due to the ability of an alliance to coordinate fares.

In actual practice, airlines often engage in code sharing, and dry and wet leases as forms of strategic alliances. Chen and Chen (2003) developed a theoretical model and conducted an empirical analysis of the effects of complementary and parallel code sharing on the load factors of international airline operations. When demand increases as a result of the expansion of a global network, a complementary alliance airline needs to increase the seat supply as well in order to maintain a satisfactory level of service convenience. For a parallel alliance airline, however, the presence of alliance partners on the same route makes a difference, because it can supply fewer seats than its complementary counterpart by conducting risk pooling with alliance partners. Brueckner (2001) analysed the effect of such alliances on traffic levels, fares and passengers' welfare. Wen and Hsu (2006) presented an interactive airline network design procedure to facilitate bargaining interactions necessitated by international code-share alliance agreements.

In sum, previous studies on airline alliances (e.g. Oum and Park 1997, Park 1997, Goh and Uncles 2003, Oum *et al.* 2004) focus mostly on code sharing and analysis of actual practice. In a typical lease contract, the owner of the aircraft (the lessor) grants to another party (the lessee) the exclusive right to use the aircraft for an agreed period of time, in return for periodic payments (Gavazza 2010). A wet lease occurs when one carrier rents the aircraft and staff of another (e.g. Balair/CTA-Swissair to Palma de Mallorca). In a franchising arrangement, the operating airline rents the brand name of another airline but supplies its own staff and aircraft (Beyhoff 1995, Rhoades and Lush 1997). The equilibrium in alliance formation may lead to a scenario without alliances, with a parallel alliance or with a double complementary alliance, depending on the size of the market and the intensity of economies of traffic density (Flores-Fillol 2009).

Airlines can satisfy the fluctuation of demand through fleet dry/wet lease planning of airlines on strategic alliance. Currently, there is no relevant literature based on an in-depth investigation of airline alliances from the perspective of fleet planning using a mathematical model. In fleet planning and replacement scheduling, strategic alliances among airlines would facilitate negotiations for leasing aircraft. In this way, the surplus capacity and idle aircraft of one carrier could help make up for the insufficiency of another. This not only allows greater flexibility in fleet planning and scheduling, but also streamlines operations, thus minimising operation and maintenance costs and achieving higher cost efficiency.

The remainder of this article is organised as follows. Section 2 formulates the dynamic fleet planning model of allied airlines. Steps involved in the optimisation of interactive bargaining between allied airlines are also discussed. A case study is presented in Section 3 to illustrate the application of the model and the bargaining process for reaching the negotiated compromise solution. The effects of changes in key parameters of the strategic alliance on decision-making are also explored. Section 4 contains our concluding remarks and suggestions for future research.

2. Dynamic fleet planning of allied airlines

Hsu *et al.* (2011) formulated the dynamic fleet planning model of an individual airline. The fleet planning model takes into consideration various factors including fleet

commonality, purchasing price, aircraft characteristics (range, fuel efficiency and size), maintenance resources and economy of scale. The direct operating costs are all those expenses associated with operating a fleet of aircraft, among which depreciation, flying and maintenance costs have greater effect on replacement decision-making. Depreciation cost reflects the reduction in the value of the existing fleet and can be calculated using the purchase price of the different aircraft. The flying cost of an aircraft will change according to fleet commonality and aircraft characteristics. The maintenance cost of an aircraft varies with maintenance resources, fleet commonality and economy of scale. In particular, the possibility of dry/wet leasing between allied airlines should also be taken into account when making decisions on fleet expansion or reduction. Let '0' and '1' denote the target airline and an allied airline, respectively. The definitions of symbols in this study is as follows:

- q the type of an aircraft
- a_q the capacity of a q -type aircraft
- t the decision period
- r^0 a serving route of the target airline
- B_{q,r^0}^t the number of purchased q -type aircraft for route r^0 in the fleet of the target airline at period t
- b_{q,r^0}^t the change in the number of purchased q -type aircraft for route r^0 of the target airline at the beginning of period t
- $C_{r^0}^t$ the total cost for fleet planning of the target airline on route r^0 during period t
- S^t the set of all aircraft operated by the airline during period t
- d^t the set of aircraft obtained or disposed of at period t
- $C^t(S^t, d^t)$ the total cost from period t forward, given that the fleet is S^t and replacement decision is d^t
- $C^{*t}(S^t)$ the corresponding minimum value of $C^t(S^t, d^t)$
- D_{q,r^0}^t the number of q -type aircraft on dry leases for route r^0 of the target airline at the beginning of period t
- $E_{r^0}^t$ the total penalty cost for the current fleet of the target airline on route r^0 during period t
- e^t the number of years during period t
- $F_{r^0}^t$ the forecasted passenger demand on route r^0 at period t
- G_q^t the salvage cost for a q -type aircraft during period t
- $h_{r^0}^t$ the average indirect cost per passenger on route r^0
- $I_{r^0}^t$ the average revenue loss associated with unit insufficient seats on route r^0 during period t
- $J_{r^0}^t$ the average revenue loss associated with unit surplus seats on route r^0 during period t
- k_{q,r^0}^t the total flight frequencies of a q -type aircraft on route r^0 during period t
- L_{q,r^0}^t the number of leased q -type aircraft for route r^0 of the target airline at the beginning of period t
- l_{q,r^0}^t the change in the number of leased q -type aircraft for route r^0 of the target airline at the beginning of period t
- $f_{r^0}^t$ the actual passenger demand on route r^0 during period t
- $\ell^t(f_{r^0}^t)$ the penalty cost function due to the inaccurate forecast on route r^0 at period t

$M_{r^0}^t$	the fixed maintenance cost (overhead) on route r^0 of period t
λ	the duration of the lease
$N_q^{t\lambda}$	the average lease cost for a q -type aircraft with a lease period λ at period t
n	agreed discount offered for lease between allied airlines
$O_{r^0}^t$	the total operation cost for the current fleet of the target airline on route r^0 during period t
P_q^t	the average purchase cost for a q -type aircraft at period t
w	three possible fluctuations for the demand
$P_{wr^0}^t$	the probability of demand fluctuations w at period t of the target airline on route r^0
r^1	a serving route of an allied airline
$S_{r^0}^t$	the fleet composition of the target airline on route r^0 at the beginning of period t after entering into alliances with an allied airline
T	the total study period
$U_{r^0}^t$	the total replacement cost for the current fleet of the target airline on route r^0 during period t
V_q^t	the variable maintenance cost of a q -type aircraft during period t
$W_{qr^0}^t$	the number of q -type aircraft on wet leases for route r^0 of the target airline at the beginning of period t
g	the average annual interest rate
X_g^t	the average remaining resale ratio of the original purchase price with an average annual interest rate g in period t
Y_q^t	total depreciation cost of a q -type aircraft during period t
$\Psi_q^t(\lambda)$	the annual rent for wet leases of a q -type aircraft during period t as agreed on by the two airlines
$\Omega_q^t(\lambda)$	the annual rent for dry leases of a q -type aircraft during period t as agreed on by the two airlines
ε	the discount of the annual rent
$\eta_{qr^0}^t$	the change in the number of q -type aircraft on dry leases for route r^0 of the target airline at the beginning of period t
θ	the proportion of expenses of aircraft maintenance and crew salaries undertaken by the lessee airline
μ_q^t	the discount of annual variable maintenance cost for a q -type aircraft during period t
π_q^t	the annual rent for the dry lease of a q -type aircraft during period t
ν_q^t	the discount of purchase cost for a q -type aircraft during period t
$\omega_{qr^0}^t$	the change in the number of q -type aircraft on wet leases for route r^0 of the target airline at the beginning of period t

2.1. Model formulation

In this study, subscripts q , r^0 and t denote the type of an aircraft, a serving route of the target airline and the decision period, respectively. Let $S_{r^0}^t$ stand for the fleet composition of the target airline on route r^0 at the beginning of period t after entering into alliances with other airlines. The fleet comprises all purchased and leased aircraft, as well as those on dry and wet leases from allied airlines, which can be expressed as

Downloaded by [National Chiao Tung University] at 02:08 25 April 2014

$S_{r^0}^t = \{B_{qr^0}^t, L_{qr^0}^t, D_{qr^0}^t, W_{qr^0}^t\}$. In other words, fleet planning for r^0 during period t involves four decisions with respect to aircraft to be purchased, leased, dry leased and wet leased, expressed as $d_{r^0}^t = \{b_{qr^0}^t, l_{qr^0}^t, \eta_{qr^0}^t, \omega_{qr^0}^t\}$. The relationship between $S_{r^0}^t$ and $d_{r^0}^t$ is as follows:

$$S_{r^0}^t = S_{r^0}^{t-1} + d_{r^0}^{t-1} \quad \forall t, r^0, \quad (1)$$

$$\begin{cases} B_{qr^0}^t = B_{qr^0}^{t-1} + b_{qr^0}^{t-1} \\ L_{qr^0}^t = L_{qr^0}^{t-1} + l_{qr^0}^{t-1} \\ D_{qr^0}^t = D_{qr^0}^{t-1} + \eta_{qr^0}^{t-1} \\ W_{qr^0}^t = W_{qr^0}^{t-1} + \omega_{qr^0}^{t-1} \end{cases} \quad \forall t, q, r^0, \quad (2)$$

where $D_{qr^0}^t$ and $W_{qr^0}^t$ denote the number of q -type aircraft on dry and wet leases, respectively, for route r^0 of the target airline at the beginning of period t . Both of them are integers and can be positive, negative or zero. A positive integer implies that the fleet includes aircraft on lease from an airline in the alliance, while a negative integer means that the fleet has aircraft on lease to an allied airline. Let $\eta_{qr^0}^t$ and $\omega_{qr^0}^t$ stand for the change in the number of q -type aircraft on dry and wet leases, respectively, for route r^0 of the target airline at the beginning of period t . Similarly, both of them are integers and can be positive, negative or zero. A positive integer implies more aircraft on lease or recalled from other airlines in the alliance, while a negative integer means more aircraft returned or on lease to allied airlines. The relationship between these two sets of integers is as follows:

$$\begin{cases} \sum_{r^1} (B_{qr^1}^t + L_{qr^1}^t + D_{qr^1}^t + W_{qr^1}^t) \geq \sum_{r^0} (\eta_{qr^0}^t + \omega_{qr^0}^t), & \text{if } \sum_{r^0} (\eta_{qr^0}^t + \omega_{qr^0}^t) \geq 0 \\ \sum_{r^0} (B_{qr^0}^t + L_{qr^0}^t + D_{qr^0}^t + W_{qr^0}^t) \geq \sum_{r^0} |\eta_{qr^0}^t + \omega_{qr^0}^t|, & \text{if } \sum_{r^0} (\eta_{qr^0}^t + \omega_{qr^0}^t) < 0 \end{cases} \quad \forall t, q, \quad (3)$$

$$\begin{cases} \sum_{r^0} \eta_{qr^0}^t = - \sum_{r^1} \eta_{qr^1}^t \\ \sum_{r^0} \omega_{qr^0}^t = - \sum_{r^1} \omega_{qr^1}^t \end{cases} \quad \forall t, q, \quad (4)$$

$$\begin{cases} \sum_{r^0} D_{qr^0}^t = - \sum_{r^1} D_{qr^1}^t \\ \sum_{r^0} W_{qr^0}^t = - \sum_{r^1} W_{qr^1}^t \end{cases} \quad \forall t, q. \quad (5)$$

Equation (3) expresses the total number of aircraft that the target airline decides to lease from an allied airline during period t (i.e. $\sum_{r^0} (\eta_{qr^0}^t + \omega_{qr^0}^t)$), it should not exceed the total number of aircraft owned by the allied airline during period t (i.e. $\sum_{r^1} (B_{qr^1}^t + L_{qr^1}^t + D_{qr^1}^t + W_{qr^1}^t)$). In the same way, the total number of aircraft the target airline decides to lease for use by the allied airline during period t (i.e. $\sum_{r^0} |\eta_{qr^0}^t + \omega_{qr^0}^t|$) should not exceed the total number of aircraft owned by the target airline during period t (i.e. $\sum_{r^0} (B_{qr^0}^t + L_{qr^0}^t + D_{qr^0}^t + W_{qr^0}^t)$). Equations (4) and (5) denote the total numbers of aircraft the target airline decides to lease from and that are leased by an allied airline, respectively, during period t . Equivalently, they represent the total number of aircraft that

the allied airline decides to lease to and that are on lease from the target airline, respectively, during period t .

With the total number of aircraft on dry/wet leases taken into consideration, the total current fleet capacity of the target airline on route r^0 during period t is $\sum_q (B'_{qr^0} + L'_{qr^0} + D'_{qr^0} + W'_{qr^0})k'_{qr^0}a_q$. The total fleet capacity of the target airline on route r^0 during period t should be greater than the fleet capacity to forecasted demand, F'_{r^0} , which can be expressed as

$$\sum_q (B'_{qr^0} + L'_{qr^0} + D'_{qr^0} + W'_{qr^0})k'_{qr^0}a_q \geq F'_{r^0} \quad \forall t, r^0. \tag{6}$$

2.2. Cost functions of allied airlines

For an allied airline with the lease of aircraft involved, the aircraft market faced by an individual airline includes not only the market operated by itself but also those operated by allied airlines. Hence, when considering future fluctuations, changes in passenger demand for both the target airline and the allied airlines should be taken into account. Suppose $\Omega'_q(\lambda)$ and $\Psi'_q(\lambda)$ are the annual rent for dry and wet leases, respectively, of a q -type aircraft during period t as agreed on by the two airlines. Let λ denote the duration of the lease. In the case of a dry lease, the cost includes only the rental of the leased aircraft; while in the case of a wet lease, it also comprises the maintenance cost, rent of the leased equipment and salary of the crew. Generally speaking, for both dry and wet leases, the longer the lease duration, the greater will be the benefits. Figure 1 displays the relationship between annual rent and lease duration for aircraft on dry leases. As can be seen, there exists a declining trend over time, meaning that the longer the lease duration, the lower the annual rent. The same applies for wet leases. That is,

$$\Omega'_q(\lambda) = \begin{cases} \pi'_q & 0 < \lambda < \lambda_1, \\ \pi'_q \varepsilon_1 & \lambda_1 \leq \lambda < \lambda_2, \\ \vdots & \vdots \\ \pi'_q \varepsilon_n & \lambda_n \leq \lambda. \end{cases} \quad \forall t, q, \tag{7}$$

and

$$0 < \lambda_1 < \lambda_2 \cdots < \lambda_n, \quad 0 < \varepsilon_n \cdots \varepsilon_2 < \varepsilon_1 < 1, \quad \lambda, \lambda_1, \lambda_2 \cdots \lambda_n \in I^+ \cup \{0\}. \tag{8}$$

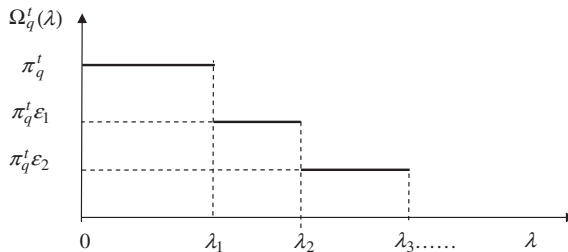


Figure 1. Relationship between annual rent and lease duration for aircraft on dry lease.

Suppose discount n is offered for an aircraft lease as agreed between two allied airlines. Then the annual rent for the dry lease becomes π_q^t for the lease duration λ ranging between 0 and λ_1 . When the lease duration is extended to range between λ_1 and λ_2 , discount ε_1 is agreed upon; hence, the annual rent becomes $\pi_q^t \varepsilon_1$. In the same way, we can express the annual rent for lease durations exceeding λ_n as $\pi_q^t \varepsilon_n$; where λ and $\lambda_1, \lambda_2 \dots \lambda_n$ are non-negative integers while λ, π_q^t and ε are all exogenous variables. Let $P_q^t v_q^t$ represent the average purchase cost for a q -type aircraft at period t and $N_q^{t\lambda}$ denote the average lease cost for a q -type aircraft with a lease period λ at period t . The economy of scale in cost function is reflected in the decrease in purchase cost for an aircraft with an increase in the total number of aircraft purchased in bulk from the same aircraft manufacturer. The discount of purchase cost for a q -type aircraft, v_q^t , will increase due to a greater total number of aircraft purchased in bulk from the same aircraft manufacturer. Hence, the total cost for the target airline to build a fleet on route r^0 during period t will be

$$\sum_q (B_{qr^0}^t P_q^t v_q^t X_g^t + L_{qr^0}^t N_q^{t\lambda} + e^t D_{qr^0}^t \Omega_q^t(\lambda) + e^t W_{qr^0}^t \Psi_q^t(\lambda)) \quad \forall t, r^0, \tag{9}$$

where e^t denotes the number of years during period t .

Maintenance costs can be further divided into fixed and variable maintenance costs. Fixed maintenance costs include maintenance overhead, such as the maintenance of the building and equipment, as well as land rental, which does not vary with the number of aircraft, while variable maintenance costs change with the status of the aircraft. Generally speaking, operating and preventive maintenance costs are higher for older aircraft with more miles travelled, meaning fewer years remaining on their expected service. In addition, the greater the number of aircraft with similar characteristics and fleet commonality, the lower the maintenance cost per aircraft since maintenance resources can be shared. In this study, the maintenance cost function reflects the economy of scale due to fleet commonality.

As mentioned above, maintenance of aircraft on dry leases is not included as part of the lease. In other words, it has to be taken care by the lessee. Hence, if the leased aircraft is of a type different from those currently in the fleet, maintenance costs will soar. On the other hand, if the leased aircraft is of a type currently available in the fleet, then the airline can achieve economies of scale by effective utilisation of equipment and crews. Through wet leases, airlines in strategic alliances can have more cost-effective deployment of aircraft and crews, and keep maintenance cost low by mutual sharing of resources and expenses. Assume that two allied airlines have a wet lease agreement, and θ is the proportion of expenses for aircraft maintenance and crew salaries undertaken by the lessee airline, while the proportion for which the airline owning the aircraft is responsible is $(1 - \theta)$. Let $M_{r^0}^t$ represent the fixed maintenance cost (overhead) of period t and $V_q^t \mu_q^t$ denote the variable maintenance cost of the q -type aircraft. The discount of annual variable maintenance cost for a q -type aircraft, μ_q^t , will increase due to a greater total number of purchased and leased similar q -type aircraft. Then, the total maintenance cost for the target airline on route r^0 during period t will be

$$\sum_q V_q^t \mu_q^t (B_{qr^0}^t + L_{qr^0}^t + D_{qr^0}^t + \varphi_{qr^0}^t \theta W_{qr^0}^t + (1 - \varphi_{qr^0}^t)(1 - \theta) |W_{qr^0}^t|) + M_{r^0}^t, \quad 0 \leq \theta \leq 1. \tag{10}$$

$W_{qr^0}^t > 0$ indicates that the target airline has $W_{qr^0}^t$ number of aircraft on wet lease from an allied airline during period t , while $W_{qr^0}^t < 0$ indicates the target airline has $|W_{qr^0}^t|$ number of aircraft on wet lease to an allied airline during period t . In both cases, indicator $\varphi_{qr^0}^t$ is a binary variable. Its relationship with the number of aircraft in the target airline's fleet on wet lease can be formulated as

$$\varphi_{qr^0}^t = \begin{cases} 1, & \text{if } W_{qr^0}^t > 0 \\ 0, & \text{else} \end{cases} \quad \forall t, q, r^0. \tag{11}$$

In sum, the total operation cost for the current fleet of the target airline on route r^0 during period t , $O_{r^0}^t$, can be formulated as

$$\begin{aligned} O_{r^0}^t = & \sum_q (B_{qr^0}^t P_q^t \nu_q^t X_g^t + L_{qr^0}^t N_q^{t\lambda} + e^t D_{qr^0}^t \Omega_q^t(\lambda) + e^t W_{qr^0}^t \Psi_q^t(\lambda) \\ & + V_q^t \mu_q^t (B_{qr^0}^t + L_{qr^0}^t + D_{qr^0}^t + \varphi_{qr^0}^t W_{qr^0}^t \theta + (1 - \varphi_{qr^0}^t) |W_{qr^0}^t| (1 - \theta))) + M_{r^0}^t \\ & + F_{r^0}^t h_{r^0} \quad \forall t, r^0. \end{aligned} \tag{12}$$

As for the replacement cost after the airlines enter into an alliance, we assume in this study that the initial fleet compositions of the two allied airlines are not comprised of any aircraft leased from each other. The objective function involves achieving medium- and long-term optimisation of dynamic operation and replacement. In addition, the established model can help calculate the optimal lease duration over the study period. Under the above assumptions, there should not be any breach or early termination of lease agreements; hence, a penalty cost need not be taken into account. Therefore, the replacement cost for the current fleet of the target airline on route r^0 during period t , $U_{r^0}^t$, can be formulated as

$$U_{r^0}^t = \sum_q (\alpha_{qr^0}^t |b_{qr^0}^t| (P_q^t \nu_q^t - Y_q^t - G_q^t) + \beta_{qr^0}^t |l_{qr^0}^t| Z_q^{t\lambda}) \quad \forall t, r^0. \tag{13}$$

Indicators $\alpha_{qr^0}^t$ and $\beta_{qr^0}^t$ are both binary variables, and their relationship with the replacement decisions are as follows:

$$\alpha_{qr^0}^t = 1, \quad \text{if } b_{qr^0}^t < 0 \text{ else } \alpha_{qr^0}^t = 0, \tag{13a}$$

$$\beta_{qr^0}^t = 1, \quad \text{if } l_{qr^0}^t < 0 \text{ else } \beta_{qr^0}^t = 0. \tag{13b}$$

In this study, the decisions on whether and which aircraft should be disposed of depend mainly on the sum of the operating, replacement and penalty costs. However, the airline with safety as its highest priority at all time should dispose of or stop leasing an aircraft immediately once its age and mileage travelled has reached the safety threshold. The utilisation of an aircraft is only influential if the remaining years and mileage travelled factors are within the safety parameters.

Actual demand may be underestimated, overestimated and precisely estimated regardless of demand fluctuation, labelled as w , since w represents cyclical demand fluctuation. The fleet capacity planning by air carriers is made in accordance with the forecasted future market demand. There would be unsold or insufficient seats when the actual demand is smaller or greater, respectively, than forecasted demand. As such,

penalty costs arise because of the difference between the actual demand and fleet capacity. If actual demand during period t is smaller than forecasted (i.e. $w = 1$), the airline bears a revenue loss due to the unsold seats. The proportion of unsold seats can be expressed as $F_{r^0}^t - f_{r^0}^t$, where $f_{r^0}^t$ denotes actual passenger demand on route r^0 during period t . On the contrary, when $w = 3$, actual passenger demand is greater than the forecasted demand, meaning the originally planned fleet capacity cannot meet actual passenger demand. As a result, some passengers are denied air transportation service. Not only would that lead to a drop in revenue for the airline, but the inconvenience caused to passengers would also result in poor service quality. In this study, we add a penalty cost for underestimated forecasted demand. The gap in fleet capacity for satisfying actual demand is denoted as $f_{r^0}^t - F_{r^0}^t$. The penalty cost function for route r incurred by demand fluctuating from $F_{r^0}^t$ to $f_{r^0}^t$, $\ell^t(f_{r^0}^t)$, can then be formulated as

$$\ell^t(f_{r^0}^t) = \begin{cases} (F_{r^0}^t - f_{r^0}^t)J_{r^0}^t & \text{for } w = 1, \\ 0 & \text{for } w = 2, \\ (f_{r^0}^t - F_{r^0}^t)I_{r^0}^t & \text{for } w = 3, \end{cases} \quad (14)$$

The value of actual demand further combines the Grey topological forecasting results with the Markov-chain model, to investigate demand fluctuations and determine the probability of the three demand realisations (Deng 1985, 1986, Hsu and Wen 1998, Hsu *et al.* 2011). The total penalty cost on route r^0 during period t is $E_{r^0}^t = \sum_{v_{r^0}} \ell^t(f_{r^0}^t)$. Summing the different cost items discussed above yields the total cost for fleet planning of the target airline on route r^0 during period t , $C_{r^0}^t = O_{r^0}^t + U_{r^0}^t + E_{r^0}^t \forall t, r^0$.

2.3. Model solving and interactive negotiation

Air carriers plan fleet capacity in accordance with the forecasted future market demand. The stochastic dynamic programming model for the replacement schedule can be formulated to determine the optimal replacement schedule by minimising the total minimised expected cost for each period over the study period (Hsu *et al.* 2011). For a given period t , the airline makes replacement decisions in accordance with the forecasted result for period $(t + 1)$, including the three possible demand trends, the demand of period $(t + 1)$ forecasted to be upward, equal or downward compared with the demand of period t . However, actual demand might fall short of the forecasted result. In other words, the total cost of period $(t + 1)$, given by the sum of operating, replacement and penalty costs, is directly affected by the decision made at period t and the forecasted demand for period $(t + 1)$.

As for dynamic programming, the stage and state in this study refer to decision period t and operated fleet S^t , respectively. Let $C^t(S^t, d^t)$ represent the total cost from period t forward, given that the fleet is S^t and replacement decision is d^t . Given S^t and t , let d^{*t} denote any value of d^t that minimises $C^t(S^t, d^t)$ and let $C^{*t}(S^t)$ be the corresponding minimum value of $C^t(S^t, d^t)$. Thus,

$$C^{*t}(S^t) = \min_{d^t} C^t(S^t, d^t) = C^t(S^t, d^{*t}). \quad (15)$$

To further consider the stochastic feature of future demand, the minimum expected sum from period t forward, given that the fleet and replacement decision in period t are S^t and d^t , $C^t(S^t, d^t)$, can be formulated as

$$C^t(S^t, d^t) = \sum_{w=1}^{w=3} p_w^t [C^t + C^{*t+1}(S^{t+1})], \tag{16}$$

where $C^{*t+1}(S^{t+1}) = \min_{d^{t+1}} C^{t+1}(S^{t+1}, d^{t+1})$ is the recursive relationship that identifies the optimal decision for period $(t + 1)$, given the optimal decision for period $(t + 2)$ is available.

Following dynamic fleet planning for an individual airline gives the relationship between the total expected cost $C^t(S^t, d^t)$ and minimised expected cost $C^{*t}(S^t)$ of the two allied airlines during period t , respectively, as follows:

$$C_0^{*t}(S_0^t) = \min C_0^t(S_0^t, d_0^t), \tag{17a}$$

$$C_1^{*t}(S_1^t) = \min C_1^t(S_1^t, d_1^t). \tag{17b}$$

The model for fleet planning allows mutual agreement on lease of aircraft between allied airlines. Hence, besides decision-making regarding purchase, sale, new lease or lease termination of optimal numbers and types of aircraft, fleet planning also involves decisions about dry/wet leases to and from, as well as return and recall of aircraft between the two airlines in the strategic alliance (i.e. $d_r^t = \{b_{qr}^t, l_{qr}^t, \eta_{qr}^t, \omega_{qr}^t\}$), which aims to satisfy future passenger demand on both sides. Through interactive bargaining, airlines can obtain rent for dry/wet leases of aircraft, proportion of shared maintenance costs, lease duration and discount (i.e. θ , λ and ε). With the objective function of achieving minimum total cost by fleet planning of allied airlines, which should be lower than that of an individual airline before entering into an alliance, the model for fleet planning of allied airlines can be formulated as follows:

$$\text{Min } Z_1 = \sum_t C_0^{*t}(S_0^t), \tag{18a}$$

$$\text{Min } Z_2 = \sum_t C_1^{*t}(S_1^t), \tag{18b}$$

s.t.

$$C_0^t(S_0^t, d_0^t) = \sum_{r^0} \sum_{w=1}^3 p_{wr^0}^t [C_{r^0}^t + C_{r^0}^{*t+1}(S_{r^0}^{t+1})], \quad \forall t, \tag{18c}$$

$$C_1^t(S_1^t, d_1^t) = \sum_{r^1} \sum_{w=1}^3 p_{wr^1}^t [C_{r^1}^t + C_{r^1}^{*t+1}(S_{r^1}^{t+1})], \quad \forall t, \tag{18d}$$

$$\sum_t C_0^{*t}(S_0^t) \leq \sum_t C_{0,pre}^{*t}(S_{0,pre}^t), \tag{18e}$$

$$\sum_t C_1^{*t}(S_1^t) \leq \sum_t C_{1,pre}^{*t}(S_{1,pre}^t). \quad (18f)$$

Equations (18a) and (18b) represent the objective functions that minimise the total cost of individual airlines in the strategic alliance. Equations (18c) and (18d) are relationship functions of total cost of the two allied airlines with the current fleets during period t . Equations (18e) and (18f) are the constraint functions stating that the total cost for the two allied airlines should not exceed that before they enter into an alliance (let ‘pre’ denote pre-alliance in Equations (18e) and (18f)). In addition, there are other constraint functions expressed as Equations (1)–(6). They refer, respectively, to the relationship of dynamic fleet planning between the allied airlines in all periods, the constraint that the number of aircraft replaced should not exceed the initial number of aircraft in the fleet in all periods, the relationship between the replacement variable and status variable for dry/wet leases between allied airlines, the constraint that the target airline must lease aircraft from the allied airline and the constraint that the total capacity of the two allied airlines should meet the forecasted passenger demand on all routes during that period.

Dynamic fleet planning for an airline is divided into two parts. The first part concerns fleet planning of an individual airline with no strategic alliance, which involves decision-making on purchase, sale, new lease or lease termination of aircraft to meet forecasted fluctuations in passenger demand. Air carriers plan fleet capacity in accordance with the forecasted future market demand. The stochastic dynamic programming model for the replacement schedule can be formulated to determine the optimal replacement schedule by minimising the total minimised expected cost for each period over the study period (Hsu *et al.* 2011). The second part allows mutual agreement on the lease of aircraft between allied airlines. Hence, besides the above-mentioned four types of decision-making, fleet planning also involves decisions on dry/wet leases to and from, as well as return and recall of aircraft between, the two airlines in the strategic alliance, which aim to satisfy future passenger demand on both sides.

Determining fleet planning also involves decisions about dry/wet leases to and from, as well as return and recall of aircraft between the two airlines in the strategic alliance, expressed by Equations (18a)–(18f) and (1)–(6), is a two-objective non-linear programming problem of the general form:

$$\text{Min}\{Z_1(x), Z_2(x)\}, \quad x \in X, \quad (19)$$

where x is the set of decision variables, i.e. $x = \{b_{qr}^t, l_{qr}^t, n_{qr}^t, \omega_{qr}^t, \forall t, q, r\}$; $X \in \Phi^n$ is the set of feasible points defined by given constraints, i.e. Equations (18c)–(18f) and (1)–(6); $Z_1(x)$ and $Z_2(x)$ in Equations (18a) and (18b) are the two objective functions, respectively, to be minimised. Directly applying the notion of optimality for single-objective non-linear programming to this two-objective non-linear programming allows us to arrive at a complete optimal solution that simultaneously minimises these two objective functions. However, in general, such a complete optimal solution does not always exist when the objective functions conflict with each other (Sakawa 1993). In our problem, these two objectives conflict with each other. The constraint method for characterising Pareto optimal solutions attempts to solve the following constraint problem formulated by taking one objective function, $Z_1(x)$, and allowing the other objective function, $Z_2(x)$, to be an

inequality constraint for some selected values of e_2 (Haimes and Hall 1974, Steuer 1986, Sakawa 1993):

$$\begin{aligned} & \text{Min } Z_1(x) \\ & \text{s.t. } Z_2(x) \leq e_2, \\ & x \in X. \end{aligned} \tag{20}$$

Then, both Pareto optimal solutions and trade-off rates can be obtained by altering the values of e_2 and solving the corresponding constraint problems. In this manner, various scenarios of fleet planning between the two airlines in the strategic alliance can be generated from Pareto optimal solutions for decision makers. The compromise solution is a Pareto optimal solution that has the shortest geometrical distance from the ideal point. In the case study, compromise programming is applied to determine and derive a compromise solution from the Pareto optimal solutions. The steps of solution are shown in Appendix A.

In this study, the objective of obtaining a compromise solution in dynamic fleet planning is total cost minimisation for each airline in the strategic alliance. In the model there is a constraint in that the post-alliance total cost should be less than the pre-alliance cost. However, a situation may arise where the difference in cost reduction between the two airlines is too great and one airline may refuse to accept the fleet planning result. Further negotiation would then commence for adjustment in related parameters. With reference to the optimal solution obtained in the initial phase, both airlines can add new constraints to the previously set parameters, including rental for dry/wet leasing of aircraft, proportion of shared maintenance costs and lease duration and discount, for interactive bargaining until a negotiated compromise solution satisfactory to both airlines is reached. This study uses four steps (Appendix B) to simulate the interactive bargaining involved in reaching a negotiated compromise solution in dynamic fleet planning for allied airlines.

3. Case study

Our case study for illustrating the application of the proposed model involved two international airlines, Airline A and Airline B, of Taiwan. The optimal solution of dynamic fleet planning is first calculated for each individual airline, followed by a compromise solution for airlines in the strategic alliance. Sensitivity analysis is then performed on important parameters of the model to explore their impact on fleet planning and cost minimisation for allied airlines. The analysis results serve only to validate the feasibility of the proposed model and do not reflect the current status and development of the two airlines. To simplify the analysis, four routes for each airline are chosen for pre- and post-alliance dynamic fleet planning according to the following criteria. First, a wide variety of aircraft types are assigned to these routes. Second, they have relatively higher passenger demand. Third, there is no code sharing. Generally speaking, there exists great disparity in passenger demand among the different routes. Code sharing is thus a common practice, where routes with relatively lower passenger demand share the same aircraft to enhance fleet utilisation and reduce cost. To avoid having the same aircraft serving different routes, which complicates aircraft assignment and replacement consideration, we exclude routes with code sharing.

According to the above-mentioned criteria, four routes are chosen for each airline, all starting from Taipei (TPE) and with respective destinations at Seoul (SEL), Rome (ROM), Los Angeles (LAX) and Brisbane (BNE) for Airline A, and at Paris (PAR), Tokyo (TYO), San Francisco (SFO) and Sydney (SYD) for Airline B. The forecast results from the Grey topological forecasting model represent the demand on the routes for all airlines on the market. This study further estimates demand carried by an individual airline based on its market share (Teodorovic and Krcmar-Nozic 1989, Hsu *et al.* 2011). Table 1 lists the type of aircraft, number weekly flights, fare, market share and forecasted demand in different periods for each route. The purchase price of aircraft for Airline A is back-calculated from their current value with a 2.5% inflation assumed by the airline. The current value of aircraft for Airline B is not available. The purchase price and all other related parameters are estimated with reference to the study of Hsu *et al.* (2011) and information from the annual report published by Airline B. Applying all these parameter values into the model established in this study yielded the optimal fleet planning and the total cost for both airlines before and after alliance.

3.1. Fleet planning solution for individual airline

It is assumed that the two airlines have the same division of time periods studied and made decisions on fleet planning at the same point in time. Due consideration was given to the changing environment faced by decision-makers of air carriers and duration of the dry/wet lease. Too long a study period could undermine the accuracy of the forecasted demand. We divided the 8-year study duration (2004–2011) into two periods, each with 4 years. That is to say, there are two occasions of fleet planning or replacement scheduling, one in 2004 and the other in 2008. Tables 2 and 3 show the dynamic fleet planning results and the total expected cost, respectively, obtained using the approach described in Hsu *et al.* (2011). The results in both tables provide the values for the constraint equations used in subsequent dynamic fleet planning for the two airlines after entering into strategic alliance, with the objective of achieving a post-alliance total expected cost lower than the pre-alliance total. The optimal solution of fleet planning shown in Table 2 also highlights a tendency of airlines in replacement scheduling. They are more inclined to purchase/lease the same type of aircraft currently in the fleet, rather than considering a different type, in order to avoid the higher maintenance costs involved for a fleet of varied types of aircraft.

3.2. Fleet planning solution for allied airlines

With no access to the practical details of how the two airlines entered into alliances, we assume there are no preset conditions and the values of alliance-related parameters are listed in Table 4. Using the model described in Section 2.3, we can obtain the replacement schedule after negotiation and the related costs. Table 5 lists the final fleet composition after replacement scheduling and the decisions taken pre-/post-alliance, and after the first round of negotiations for the two study periods. It can be seen that in the first period, Airline A's pre-alliance decision to sell a B747-400 on the TPE-LAX route changed post-alliance to wet leasing it to Airline B for the TPE-SFO route. Similarly, Airline B's pre-alliance decision to lease a B747-400 from another airline for the TPE-SFO route changed post-alliance to wet leasing it from Airline A. In the second period, Airline A's pre-alliance

Table 1. Parameter values for different routes of two airlines.

Route, r	Initial fleet composition, number of aircraft, aircraft type, $(q, y)^*$	Weekly flight frequencies (one-way)	Fare (NT\$ per trip)	Market share, MS_r (%)	Forecasted demand ^c	
					$t=0$	$t=1$
Airline A^a						
TPE-SEL	1, B747-400, (1,5) 1, B737-800, (3,6)	14	9,765	89.81	1,445,634	1,322,644
TPE-ROM	2, A340-300, (4,6)	8	34,230	50.00	655,629	579,557
TPE-LAX	2, B747-400, (1,5) 1, B747-400, (1,3)	21	31,500	37.10	1,884,041	2,201,467
TPE-BNE	1, A340-300, (4,3)	2	32,550	20.13	41,078	41,724
Airline B^b						
TPE-PAR	1, B747-400, (1,6)	3	34,320	100	316,826	312,412
TPE-TYO	2, B777-300ER, (5,1) 1, B777-300ER, (5,4)	21	13,520	11.69	1,019,298	1,004,921
TPE-SFO	2, B747-400 Combi, (2,8)	10	34,840	38.07	1,206,806	1,277,946
TPE-SYD	1, B777-300ER, (5,4)	2	31,720	41.99	123,628	146,588

Source: ^a<http://www.china-airlines.com/en/about/about.htm>.^b<http://www.evaair.com/html/b2c/english/>.^cForecasted in this study.Notes: * It is difficult to obtain data about the accumulated mileage of an aircraft. This study does not consider an aircraft's accumulated mileage in the case study. The subscripts q and y describe the status of an aircraft as to its type and age, respectively. Let $q=1, 2, 3, 4, 5$ denote B747-400, B747-400 Combi, B737-800, A340-300 and B777-300ER, respectively.

Table 2. Fleet planning on different routes of two airlines.

Route, r	Decision-making, d^t			Fleet composition after replacement, S^2
	Initial fleet composition, S^0	First period, $t=0$	Second period, $t=1$	
Airline A	$S^0 = \{B_{1,5}^0 = 3, B_{4,6}^0 = 2, L_{1,3}^0 = 1, L_{3,6}^0 = 1, L_{4,3}^0 = 1\}$	$d^0 = \{b_{1,5}^0 = -1, l_{3,4}^0 = 1, l_{4,4}^0 = 1\}$	$d^1 = \{b_{4,10}^1 = -1, l_{4,5}^1 = 1, \}$	$S^2 = \{B_{1,13}^2 = 2, B_{4,14}^2 = 1, L_{1,11}^2 = 1, L_{3,14}^2 = 1, L_{3,12}^2 = 1, L_{4,12}^2 = 1, L_{4,9}^2 = 1, L_{4,11}^2 = 1\}$
TPE-SEL	1, B744 (purchased) 1, B738 (leased from)	1, B738 (leased from)	No change	1, B744 (purchased) 2, B738 (leased from)
TPE-ROM	2, A343 (purchased)	1, A343 (leased from)	1, A343 (sold)	1, A343 (purchased)
TPE-LAX	2, B744 (purchased) 1, B744 (leased from)	1, B744 (sold)	1, A343 (leased from)	1, A343 (leased from) 1, B744 (purchased) 1, B744 (leased from)
TPE-BNE	1, A343 (leased from)	No change	No change	1, A343 (leased from)
Airline B	$S^0 = \{B_{2,8}^0 = 2, B_{3,1}^0 = 2, L_{1,6}^0 = 1, L_{5,4}^0 = 2\}$	$d^0 = \{l_{1,5}^0 = 1\}$	$d^1 = \{l_{5,4}^1 = 1\}$	$S^2 = \{B_{2,16}^2 = 2, B_{3,9}^2 = 2, L_{1,14}^2 = 1, L_{1,13}^2 = 1, L_{5,12}^2 = 2, L_{5,8}^2 = 1\}$
TPE-PAR	1, B744 (leased from)	No change	No change	1, B744 (leased from)
TPE-TYO	2, B773ER (purchased) 1, B773ER (leased from)	No change	No change	2, B773ER (purchased) 1, B773ER (leased from)
TPE-SFO	2, B744C (purchased)	1, B744 (leased from)	No change	2, B744C (purchased) 1, B744 (leased from)
TPE-SYD	1, B773ER (leased from)	No change	1, B773ER (leased from)	2, B773ER (leased from)

Table 3. Total expected cost of different routes of two airlines in different periods.

Route, r	First period $t=0$	Second period $t=1$	Total expected cost of each route	Total expected cost of all routes
Airline A				
TPE-SEL	23,049.91	18,738.08	41,787.99	175,661.30
TPE-ROM	19,723.28	12,607.76	32,331.04	
TPE-LAX	43,475.00	40,175.64	83,650.64	
TPE-BNE	9,568.72	8,322.91	17,891.63	
Airline B				
TPE-PAR	13,108.98	12,560.06	25,669.04	149,948.59
TPE-TYO	21,567.27	19,108.77	40,676.04	
TPE-SFO	34,448.48	30,879.98	65,328.46	
TPE-SYD	8,801.95	9,473.10	18,275.05	

Note: unit: NT\$1,000,000, NT\$1 \cong US\$0.0299.

Table 4. Total expected cost and optimal replacement decisions made in the first period.

Symbols	Meaning	Value
n	Agreed discount offered for lease between allied airlines	1
λ_1	Duration for Period-1 discounted lease between allied airlines	4 years
ε_1	Period-1 discount for lease between allied airlines	0.8
θ	Proportion of expenses of aircraft maintenance and crew salaries undertaken by the lessee airline in a wet lease	0.5

decision to lease an A340-300 for the TPE-LAX route changed post-alliance to recalling a B747-400 on wet lease to Airline B for the TPE-SFO route. With the return of the B747-400 on the TPE-SFO route on wet lease in the first period to Airline A, Airline B decides to lease the same type of aircraft for the TPE-SFO route from another airline.

Table 6 details the corresponding changes in cost pre- and post-alliance, and after several rounds of negotiation. As can be seen, for the TPE-LAX route, Airline A achieves cost reduction of NT\$ 1105.31 million in the first period and NT\$ 1208.8 million in the second period, thus saving a total of NT\$ 2314.11 million in operation costs. On the other hand, for the TPE-SFO route, Airline B manages to cut operation costs by NT\$ 413.32 million in the first period. However, with no change in fleet composition before and after alliance in the second period, no cost reduction is achieved. From the perspective of strategic alliance, two individual airlines in a strategic alliance become a single functioning unit; and any actions between them can be regarded as internal operations, which may not cause actual changes in total costs for the two allied airlines. What contributes to cost reduction post-alliance is decreased interaction between the individual airlines in strategic alliance and other non-allied airlines as a result of the mutual lease of aircraft between the allied airlines. As for replacement scheduling, Airline A sells a B747-400 and Airline B leases one in the first period pre-alliance, while Airline A also leases an A340-300 in the second period pre-alliance. In other words, before they became allies, they had two aircraft

Table 5. Fleet planning pre-/post-alliance and after three negotiations.

		Decision-making, d_t^r , $(\lambda, \varepsilon, \theta)^*$		Fleet composition after replacement, S_r^2	
		First period $t=0$	Second period $t=1$		
Airline A (TPE-LAX), $r^0 = 0$					
Pre-alliance	Initial fleet composition, S_0^0	$d_0^0 = \{\omega_{10}^0 = -1\}$ 1, B744 (sold)	$d_0^1 = \{\omega_{30}^1 = 1\}$ 1, A343 (leased from)	$S_0^2 = \{B_{10}^2 = 1, L_{10}^2 = 1, L_{30}^2 = 1\}$ 1, B744 (purchased) 1, B744 (leased from) 1, A343 (leased from)	
Post-alliance	$S_0^0 = \{B_{10}^0 = 2, L_{10}^0 = 1\}$ 2, B744 (purchased) 1, B744 (leased from)	$d_0^0 = \{\omega_{10}^0 = -1\}$ 1, B744 (wet leased out)	$d_0^1 = \{\omega_{10}^1 = 1\}$ 1, B744 (wet leased out recalled)	$S_0^2 = \{B_{10}^2 = 2, L_{10}^2 = 1\}$ 2, B744 (purchased) 1, B744 (leased from)	
First negotiation	$S_0^0 = \{B_{10}^0 = 2, L_{10}^0 = 1\}$ 2, B744 (purchased) 1, B744 (leased from)	$d_0^0 = \{\omega_{10}^0 = -1\}$ 1, B744 (wet leased out)	$d_0^1 = \{\omega_{30}^1 = 1\}$ 1, A343 (leased from)	$S_0^2 = \{B_{10}^2 = 2, L_{10}^2 = 1, W_{10}^2 = -1, L_{30}^2 = 1\}$ 2, B744 (purchased) 1, B744 (leased from) 1, B744 (wet leased out) 1, A343 (leased from)	
Airline B (TPE-SFO), $r^1 = 1$					
Pre-alliance	Initial fleet composition, S_0^0	$d_0^0 = \{\omega_{11}^0 = 1\}$ 1, B744 (leased from)	No change	$S_0^2 = \{B_{21}^2 = 2, L_{11}^2 = 1\}$ 2, B744C (purchased) 1, B744 (leased from)	
Post-alliance	$S_0^0 = \{B_{21}^0 = 2\}$ 2, B744C (purchased)	$d_0^0 = \{\omega_{11}^0 = 1\}$ 1, B744 (wet leased from)	$d_0^1 = \{\omega_{11}^1 = -1, \omega_{11}^1 = 1\}$ 1, B744 (wet leased from returned) 1, B744 (leased from)	$S_0^2 = \{B_{21}^2 = 2, L_{11}^2 = 1\}$ 2, B744C (purchased) 1, B744 (leased from)	
First negotiation	$S_0^0 = \{B_{21}^0 = 2\}$ 2, B744C (purchased)	$d_0^0 = \{\omega_{11}^0 = 1\}$ 1, B744 (wet leased from)	$d_0^1 = \{\omega_{11}^1 = 1\}$ No change	$S_0^2 = \{B_{21}^2 = 2, W_{11}^2 = 1\}$ 2, B744C (purchased) 1, B744 (wet leased from)	

Notes: *Post alliance: $\lambda = 4, \varepsilon = 0.8, \theta = 0.5$; (optimal decisions).
 First negotiation: $\lambda = 8, \varepsilon = 0.8, \theta = 0.5$; (Airline B requested).
 Second negotiation: $\lambda = 8, \varepsilon = 0.6, \theta = 0.5$; (Airline B requested).
 Third negotiation: $\lambda = 8, \varepsilon = 0.6, \theta = 0.575$; (Airline A requested).

Table 6. Cost comparison pre- and post-alliance and after three negotiations.

	First period $t=0$		Second period $t=1$		Total cost	
	Airline A TPE-LAX	Airline B TPE-SFO	Airline A TPE-LAX	Airline B TPE-SFO	Airline A TPE-LAX	Airline B TPE-SFO
Pre-alliance	43,475.00	34,448.48	40,175.64	30,879.98	83,650.64	65,328.46
Post-alliance	42,369.69	34,035.16	38,966.84	30,879.98	81,336.53 (-2.77% ^c)	64,915.14 (-0.63% ^c)
Change in cost ^a	-1,105.31	-413.32	-1,208.80	0	-2,314.11	-413.32
First negotiation	42,369.69	34,035.16	39,626.73	30,466.66	81,996.42 (-1.98% ^c)	64,501.82 (-1.27% ^c)
Change in cost ^b	0	0	+659.89	-413.32	+659.89	-413.32
Second negotiation	42,675.93	33,728.92	39,932.97	30,160.42	82,608.90 (-1.25% ^c)	63,889.34 (-2.20% ^c)
Change in cost ^b	+306.24	-306.24	+966.13	-719.56	+1,272.37	-1,025.80
Third negotiation	42,414.23	33,990.62	39,671.27	30,422.12	82,085.51 (-1.67% ^c)	64,412.74 (-1.67% ^c)
Change in cost ^b	+44.54	-44.54	+704.43	-457.86	+748.97	-502.40

Notes: unit: NT\$1,000,000 NT\$1 \cong US\$0.0299.

^aDenotes change in cost between pre-alliance and post-alliance.

^bDenotes change in cost post-alliance and after negotiation.

^c% of the money saved by entering into strategic alliance.

leased from other airlines. After entering into an alliance, they no longer leased aircraft from non-allied airlines in the first period and only Airline B newly leases a B747-400 from a non-allied airline in the second period. Hence, strategic alliance facilitates mutual lease of aircraft among allied airlines, thus reducing their dependence on and expenses paid to non-allied airlines, which helps achieve the objective of cost minimisation.

3.3. Fleet planning through negotiations between allied airlines

As seen in Table 6, the cost reduction on the TPE-LAX route for Airline A after entering into strategic alliance is 2.77% while that on the TPE-SFO route for Airline B is only 0.63%, a difference of 5.6 fold. Hence, it is likely that Airline B would deem the compromise solution for fleet planning unacceptable. According to the interactive bargaining procedures described in Appendix B, this study simulates the adjustment in parameter values as put forward by the two airlines during repeated bargaining to reach a negotiated compromise solution satisfactory to both airlines. The results displayed in Table 6 are obtained through three rounds of negotiations with details as follows.

Assume that Airline B is dissatisfied with the large difference in cost reduction compared with Airline A. It then requests Airline A to extend the duration of the wet lease of the B747-400 from 4 to 8 years to make up for insufficient fleet capacity on the TPE-SFO route in the second period. Hence, λ is changed to 8 years. The extended wet lease duration creates the need for Airline A to lease an A340-300 to meet its forecasted passenger demand. After the first negotiation, both airlines have new changes in fleet

composition, as shown in Table 5, and corresponding changes in costs, as shown in Table 6. As can be seen, without replacement scheduling in the first period, the total expected cost remains unchanged; hence, neither airline experiences any change in cost. On the contrary, the replacement scheduling in the second period brings about an increase in costs of NT\$ 659.89 million for Airline A due to the additional lease of an A340-300 but a decrease in costs of NT\$ 413.32 million for Airline B with the wet lease of the B747-400 extended. The negotiated compromise solution between allied airlines still led to an increase in total costs of NT\$ 246.57 million, indicating that interactive bargaining is not always the most cost-effective solution for the airlines in an alliance. In comparison with their pre-alliance cost status, the first negotiation between the two allied airlines resulted in a total cost reduction of 1.98% for Airline A and 1.27% for Airline B. Obviously, the cost-saving difference between the two was narrowed (2.77% for Airline A and 0.63% for Airline B before the first negotiation).

Nevertheless, Airline B is still not satisfied with the already narrowed gap in cost reduction and bargains again with Airline A, requesting a change in the discount in the lease between the allied airlines from 0.8 to 0.6. Such an adjustment does not lead to any change in fleet composition, only costs. As seen in Table 6, the second negotiation with a newly agreed upon discount rate increases the cost for Airline A in both periods by NT\$ 1272.37 million, while Airline B enjoys a total reduction of NT\$ 1025.8 million. Similar to the first, this second negotiated compromise solution led to an increase in total cost of NT\$ 246.57 million. Again, in comparison with their pre-alliance cost status, the percentage reduction in cost after the second negotiation became 1.25% for Airline A and 2.20% for Airline B. This reverses the previous status, with Airline B now having a greater cost reduction than Airline A by 72%.

Naturally, Airline A feels dissatisfied with such a reversal and proposes further bargaining. According to their pre-alliance total costs, Airline A bears the higher cost, NT\$ 83,650.64 million, which is 1.28 times that of Airline B's NT\$ 65,328.46 million. Hence, the eventual cost reduction for both airlines should be proportional to the difference in total cost. The only remaining parameter available for further adjustment is the proportion of expenses on aircraft maintenance and crew salaries undertaken by the lessee airline in a wet lease. As seen in Table 6, the third round of interactive bargaining yields a negotiated compromise solution with Airline A having a cost increase of NT\$ 748.97 million and Airline B having a cost reduction of NT\$ 502.4 million. Like the two previous negotiations, the third negotiated compromise solution led to an increase in total costs of NT\$ 246.57 million. Again, in comparison with their pre-alliance cost status, both airlines enjoyed the same percentage reduction in cost of 1.67% after the third negotiation, but the total costs saved by Airline A is 1.28 times that by Airline B, the same proportion as their initial total cost. Under this situation, instead of 0.5, $\theta = 0.575$, meaning the lessee airline in the wet lease, Airline B in this case, shoulders a larger proportion of expenses on aircraft maintenance and crews than Airline A, which leases the B747-400 for 8 years to Airline B. The eventual negotiated compromise solution was satisfactory to both airlines and was thus considered optimal. Figure 2 summarises the changes in costs for the two airlines at different stages.

As seen in the above discussion, taking into consideration forecasted passenger demand and current fleet capacity, individual airlines can achieve greater cost reductions and more efficient fleet utilisation by replacement scheduling and through interactive bargaining with allied airlines to reach a negotiated compromise solution. Using the

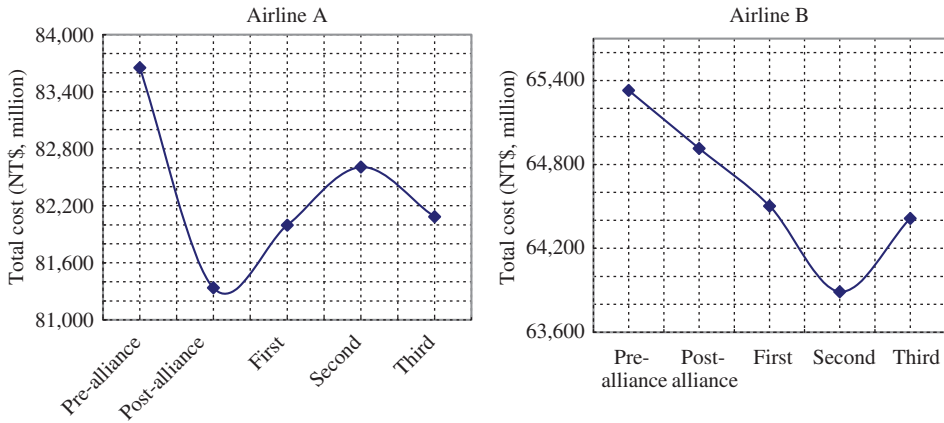


Figure 2. Changes in costs for Airlines A and B at different stages.

proposed dynamic fleet planning model, we gain a better understanding of the changes in total costs for individual airlines, and obtain their optimal replacement schedules for different periods. The simulated bargaining process reveals that the costs achieved through interactive bargaining between allied airlines is often larger than the optimal solution obtained by the modelling, meaning the negotiated compromise solution is not the most cost-effective for the alliance. Nevertheless, the allied airlines are satisfied with the cost reduction achieved through interactive bargaining, instead of the compromise solution with the objective of cost minimisation. In sum, a satisfactory negotiation result aiming for lower post-alliance costs in the best interests of individual airlines may not be the most optimal for the overall interests of the alliance.

3.4. Sensitivity analyses of aircraft acquisition cost

In replacement scheduling, airlines acquire aircraft through purchase and lease from non-allied airlines, as well as dry and wet leases from allied airlines. The cost involved in these acquisition approaches vary with the duration the aircraft is owned/held. With a B747-400 as an example, and using the parameters of lease duration and discount rate between allied airlines, we examine which acquisition approach to adopt in replacement scheduling and the optimal lease duration for cost minimisation. Lease duration for the first and second periods λ_1 and λ_2 are set to 4 and 8 years, respectively, and discount rates for the two periods ε_1 and ε_2 are set to 0.8 and 0.6, respectively. Figure 3 displays the sensitivity analysis of cost thresholds for the different aircraft acquisition approaches. Each figure shows the replacement threshold cost for a particular acquisition approach in the shaded area. The shaded area is formed by the overlapping of cost thresholds for the three other acquisition approaches. For example, Figure 3(a) shows the replacement cost threshold for purchase of aircraft and the shaded area is the cost threshold for lease, dry and wet lease of aircraft. As can be seen, the longer the aircraft is owned, the smaller the annual cost of the purchase decision, implying that cost efficiency increases with time, while the cost threshold for deciding on aircraft purchase is also lower over time. Figure 3(b) shows no

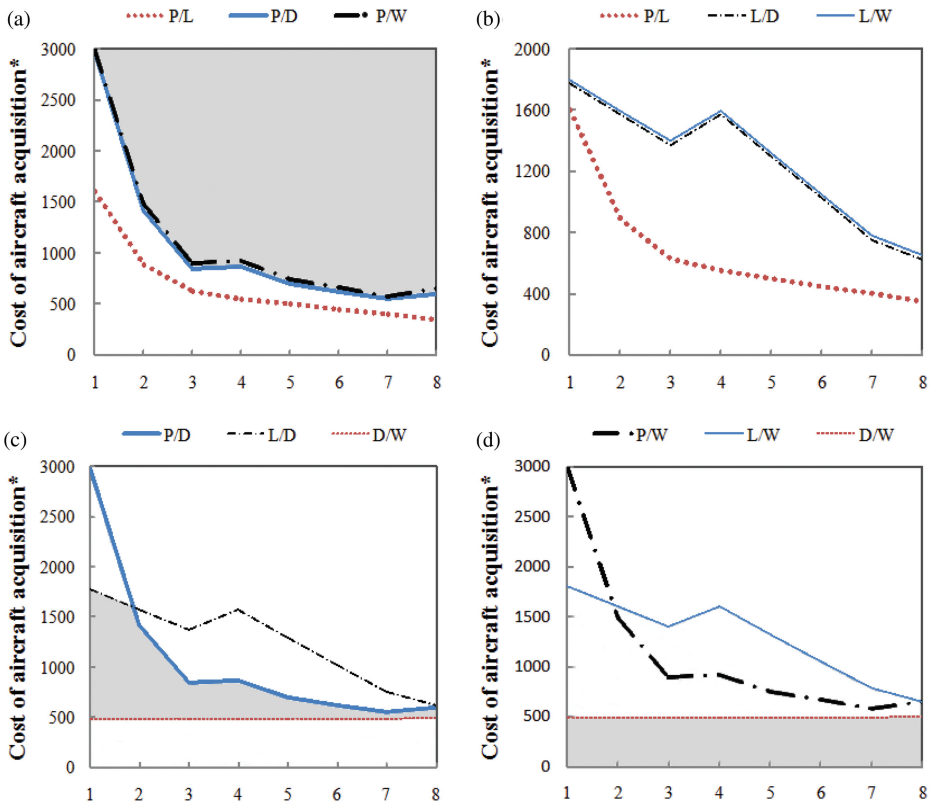


Figure 3. Replacement cost for purchase, lease, dry lease and wet lease of aircraft. (a) Replacement cost for purchase of aircraft. (b) Replacement cost for lease of aircraft. (c) Replacement cost for dry lease of aircraft. (d) Replacement cost for wet lease of aircraft. Note: P: Purchase, L: Lease, D: Dry lease, W: Wet lease. *:unit: NT\$1,000,000 per year, NT\$1 \cong US\$0.0299.

shaded area, indicating that replacement cost through lease of aircraft from non-allied airlines is higher than that of other acquisition approaches. For replacement scheduling, the airline can achieve more cost savings through purchase or dry/wet leasing, rather than leasing from non-allied airlines. As seen in Figure 3(c) and (d), acquiring aircraft through dry and wet leases, respectively, involve lower costs than purchase or lease. In the long term, the cost efficiency of aircraft purchase increases over time, causing the threshold for dry leasing of aircraft to be lower. Comparatively, wet leasing has the advantage of decreasing maintenance costs shared between allied airlines. Hence, the longer the lease duration, the more the total cost decreases, thus achieving greater cost efficiency.

The results of the above sensitivity analysis offer airlines a better understanding of the cost range and cost threshold for aircraft owned/held for different durations and acquired by different approaches. This serves as a useful reference both for replacement scheduling of individual airlines and for negotiation on lease cost and duration with allied and non-allied airlines.

4. Conclusion

The contribution of this article to the literature is that it explores fleet purchase, dry/wet leases and disposal of aircraft, taking into consideration the impact of a strategic alliance between airlines on fleet planning. Further, this study simulates the step-by-step negotiation process between decision-makers of two allied airlines. Through interactive bargaining, the airlines can adjust the alliance-related parameters to narrow the difference in profits and reach a final negotiated compromise solution acceptable to both airlines in the strategic alliance. The alliance-related parameters include proportion of shared maintenance costs, lease duration and discount. From the perspective of replacement scheduling, this study establishes operation cost functions for an airline in different periods to analyse the cost benefits for mutual lease and maintenance of aircraft between airlines in the strategic alliance. With the objective of total cost minimisation for individual airlines and a lower post-alliance total cost, compared with that pre-alliance, the dynamic fleet planning model is implemented to obtain the optimal solution of replacement scheduling between allied airlines assuming their total fleet capacity exceeds forecasted passenger demand.

Dry/wet leasing between allied airlines is an effective and efficient means for achieving better fleet utilisation where the surplus capacity of one airline can be leased to compensate for insufficiencies of another. While the owner airline can profit from its surplus capacity, which would otherwise incur idle costs or high replacement scheduling costs, the lessee airline can enjoy a lower cost for wet leasing of aircraft compared with purchase or leasing from a non-allied airline. As our results show, the two airlines in the strategic alliance indeed enjoy lower replacement scheduling than that pre-alliance. What contributes to cost reduction post-alliance is decreased interaction between the individual airlines in the alliance and other non-allied airlines due to the mutual leasing of aircraft between the allied airlines. Nevertheless, the optimal solution obtained by the proposed dynamic fleet planning model may sometimes be deemed unacceptable by the airlines. The interactive bargaining process developed facilitates the two airlines adding to or revising the terms of the allied lease and, through repeated interactive bargaining, come up with a negotiated compromise solution with which both airlines are satisfied.

Although the negotiated compromise solution may not be the most cost-effective, as long as it can achieve an added cost reduction for the allied airlines, it will be satisfactory and acceptable to both. In addition, the sensitivity analysis results offer the airlines a clear picture of changes in costs over the total number of years an aircraft acquired by different approaches is owned or leased. The longer the aircraft is owned by the airline, the smaller the annual cost of the purchase decision, implying that cost efficiency increases with time, while the cost threshold for deciding on an aircraft purchase is also lower over time. This can serve as a useful reference for airlines when making replacement-scheduling decisions and when negotiating for rental, lease duration and proportion of shared maintenance costs for leases between allied airlines.

Our study has not taken into account discounts offered for aircraft purchases when making replacement-scheduling decisions. Further studies may include this factor for more accurate analysis. In addition, aircraft purchase in this research refers only to purchase of new aircraft and has not considered purchase of old ones. In fact, there exists a second-hand aircraft market. Purchase of used aircraft certainly incurs a lower cost and offers the advantage of a shorter time gap between order placement and final delivery in the face of an unexpected surge in passenger demand. Hence, the possibility of purchase of

second-hand aircraft should also be taken into account in replacement scheduling. For the sake of simplicity, the study period is set to 8 years, which involves only replacement scheduling in the short term. Future research can extend the study period to examine medium- and long-term replacement scheduling. Another limitation of this study is that it considers only passenger demand while neglecting demand for air cargo, which constitutes an important part of demand for air transportation. To get an overall picture of the actual air transportation operation, it is worth exploring replacement scheduling with both passenger and air cargo demands considered.

Acknowledgement

The authors would like to thank the National Science Council of the Republic of China for financially supporting this research under Contract No. NSC 92-2211-E-009-041.

References

- Beyhoff, S., 1995. Code-sharing: a summary of the German study. *Journal of Air Transport Management*, 2 (2), 127–129.
- Brueckner, J.K., 2001. The economics of international codesharing: an analysis of airline alliances. *International Journal of Industrial Organization*, 19 (10), 1475–1498.
- Chen, F.C. and Chen, C., 2003. The effects of strategic alliances and risk pooling on the load factors of international airline operations. *Transportation Research Part E*, 39 (1), 19–34.
- Deng, J., 1985. *Grey system fundamental method*. Wuhan, China: Huazhong University of Science and Technology (in Chinese).
- Deng, J., 1986. *Grey prediction and decision*. Wuhan, China: Huazhong University of Science and Technology (in Chinese).
- Flores-Fillol, R., 2009. Airline alliances: parallel or complementary? *Applied Economics Letters*, 16 (6), 585–590.
- Gavazza, A., 2010. Asset liquidity and financial contracts: evidence from aircraft leases. *Journal of Financial Economics*, 95 (1), 62–84.
- Goh, K. and Uncles, M., 2003. The benefits of airline global alliances: an empirical assessment of the perceptions of business travelers. *Transportation Research Part A*, 37 (6), 479–497.
- Gudmundsson, S.V. and Rhoades, L.D., 2001. Airline alliance survival analysis: typology, strategy and duration. *Transport Policy*, 8 (3), 209–218.
- Haimes, Y.Y. and Hall, W.A., 1974. Multiobjectives in water resources systems analysis: the surrogate worth trade-off method. *Water Resource Research*, 10, 614–624.
- Hsu, C.I., et al., 2011. Aircraft replacement scheduling: a dynamic programming approach. *Transportation Research Part E*, 47 (1), 41–60.
- Hsu, C.I. and Wen, Y.H., 1998. Improved grey prediction models for trans-Pacific air passenger market. *Transportation Planning and Technology*, 22 (2), 87–107.
- Oum, T.H., et al., 2004. The effect of horizontal alliances on firm productivity and profitability: evidence from the global airline industry. *Journal of Business Research*, 57 (8), 844–853.
- Oum, T.H. and Park, J.H., 1997. Airline alliances: current status, policy issues, and future directions. *Journal of Air Transport Management*, 3 (3), 133–144.
- Park, J.H., 1997. The effects of airline alliances on markets and economic welfare. *Transportation Research Part E*, 33 (3), 181–195.
- Park, J.H., Zhang, A., and Zhang, Y., 2001. Analytical models of international alliances in the airline industry. *Transportation Research Part B*, 35 (9), 865–886.

Rhoades, D.L. and Lush, H., 1997. A typology of strategic alliances in the airline industry: propositions for stability and duration. *Journal of Air Transport Management*, 3 (3), 109–114.

Sakawa, M., 1993. *Fuzzy sets and interactive multiobjective optimization*. New York: Plenum Press.

Steuer, P.E., 1986. *Multiple criteria optimization: theory computation and application*. New York: Wiley.

Teodorovic, D. and Krcmar-Nozic, E., 1989. Multicriteria model to determine flight frequencies on an airline network under competitive conditions. *Transportation Science*, 23 (1), 14–25.

Wan, X., Zou, L., and Dresner, M., 2009. Assessing the price effects of airline alliances on parallel routes. *Transportation Research Part E*, 45 (4), 627–641.

Wen, Y.H. and Hsu, C.I., 2006. Interactive multiobjective programming in airline network design for international airline code-share alliance. *European Journal of Operational Research*, 174 (1), 404–426.

Yan, S. and Chen, C.H., 2007. Coordinated scheduling models for allied airlines. *Transportation Research Part C*, 15 (4), 246–264.

Appendix A: The procedures of the compromise programming in dynamic fleet planning for allied airlines

- (1) Related data are collected from two airlines with no alliance. Then, future passenger demand for all routes for each airline is forecasted and the occurrence probabilities of demand fluctuation are calculated. By using dynamic fleet planning (Hsu *et al.* 2011), the optimal replacement schedule and expected cost for each airline prior to its strategic alliance is obtained. The inputs include initial fleet composition, i.e. $S^0 \equiv \{B_{qym}^0, L_{qym}^0, \forall q, y, m\}$ while the subscripts q, y and m describe the status of an aircraft as its type, age and miles travelled, respectively, basic data of aircrafts in the fleet, i.e. $(P_{qym}^t, X_g^t, N_{qym}^{t\lambda}, M^t, V_{qym}^t, Y_{qym}^t, G_{qym}^t, Z_{qym}^{t\lambda})$, parameter values related to routes, i.e. $(k_{qym}^{tr}, H_{qym}^{tr}, h_r, I_r^t, J_r^t)$, and demand fluctuation, i.e. (p_w^t, F_r^t) . The outputs include the set of aircraft obtained or disposed of at period t , i.e. $d^t \equiv \{b_{qym}^t, l_{qym}^t, \forall q, y, m\}$, and the minimum total cost of pre-alliance during period t , i.e. $C_{r,pre}^{*t}(S_{r,pre}^t)$.
- (2) The initial value of related parameters required for dynamic fleet planning of allied airlines, such as reduction in maintenance costs and rental and discounts for aircraft on dry/wet leases, are obtained from each airline in a strategic alliance as reference values in our model. In case the airlines have not reached any agreement on any of the parameters, a reasonable assumed value will be given. All parameters with values either obtained or assumed will then be subjected to sensitivity analysis. The inputs include the initial values of alliance-related parameters, i.e. $(\lambda, \varepsilon, \theta)$.
- (3) The expected cost calculated in (1) and the parameter values obtained in (2) serve as inputs in the dynamic fleet planning model established in this study to yield the Pareto optimal solution on purchase/sale, lease/lease termination, allied lease to/from or lease termination and lease duration of different types of aircraft of the two airlines according to different demand fluctuations in different periods. The outputs include fleet planning for route r during period t and involves four decisions with respect to aircraft to be purchased, leased, dry leased and wet leased, i.e. $d_r^t = \{b_{qr}^t, l_{qr}^t, \eta_{qr}^t, \omega_{qr}^t\}$, and the minimum total cost of post-alliance during period t , i.e. $C_r^{*t}(S_r^t)$.

Appendix B: The procedures of the interactive bargaining in dynamic fleet planning for allied airlines

- (1) First, multi-objectives in dynamic fleet planning for allied airlines are simplified into single-objective modelling. The Pareto optimal solution obtained in the initial phase will be taken

as the basis for further negotiation between the allied airlines. The inputs include fleet planning for route r during period t and involves four decisions with respect to aircraft to be purchased, leased, dry leased and wet leased, i.e. $d_r^t = \{b_{qr}^t, l_{qr}^t, \eta_{qr}^t, \omega_{qr}^t\}$, and the minimum total cost of post-alliance during period t , i.e. $C_r^{*t}(S_r^t)$. The outputs include the new fleet planning and the total cost after negotiation, i.e. $d_{r,n}^t = \{b_{qr}^t, l_{qr}^t, \eta_{qr}^t, \omega_{qr}^t\}^n$ and $C_{r,n}^t(S_{r,n}^t)$.

- (2) In regard to the parameter values for obtaining the Pareto optimal solution of the initial phase, the two airlines in strategic alliance can put forward their expected ideal parameter values, adjust preset ones or add new constraints. Using the same modelling approach in the initial phase, a negotiated compromise solution is obtained. The inputs include the negotiation values of alliance-related parameters, i.e. $(\lambda^n, \varepsilon^n, \theta^n)$. The outputs include the new fleet planning and the total cost after negotiation, i.e. $d_{r,n}^t = \{b_{qr}^t, l_{qr}^t, \eta_{qr}^t, \omega_{qr}^t\}^n$ and $C_{r,n}^t(S_{r,n}^t)$.
- (3) In case the new compromise solution is still unacceptable to either airline, new constraints are added by the respective airlines, and the modelling process is repeated to yield another negotiated compromise solution on fleet planning.
- (4) Interactive bargaining will continue and the process will be repeated until both airlines are satisfied with the negotiated compromise solution obtained.