Airline Strategic Fleet Planning Framework

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Abstract: This paper developed an Analytic Hierarchy Process (AHP)-based framework to quantify influential key aspects, namely operation, economy, and environment that greatly affect airline fleet planning decision-making. The developed framework is embedded with a traveler mode choice modeling process in order to capture supply-demand interaction explicitly under uncertainty. It is beneficial to the airline management to allocate flexibly appropriate weight (priority) on the respective key aspect for fleet planning purposes. By investigating Malaysia Airlines and AirAsia as a realistic case study, the findings reveal that the developed framework is useful to: (1) capture and quantify influential key aspects mathematically in making strategic fleet planning, (2) assure adequate fleet supply of airline to meet stochastic demand, (3) model supply-demand interaction in greater details, (4) maximize the operational profit of the airline at a desired service level, (5) provide a greater flexibility to the airline to acquire/lease aircraft throughout the long-term planning horizon.

Keywords: Fleet Planning, Mode Choice, Key Aspect, Supply-demand Interaction, Uncertainty

1. INTRODUCTION

Airlines need to establish an efficient and sustainable fleet planning framework to ensure travel demand is met satisfactorily at a desired level of service. Under such a competitive multimode transportation system, an effective fleet planning model is essential to ensure a profitable operation and a high level of passengers' satisfaction. In addition, demand uncertainty is influenced greatly by the occurrence of unexpected events such as the volatility in fuel prices, political instability, economic downturns and natural disasters. When these events occur unpredictably, travel demand would decrease tremendously and this would pose additional challenge to the airline in making fleet planning decision. Accordingly, various aspects that affecting airline's profit margin should be considered in making optimal fleet planning decision.

Among the key aspects that receiving great concern from the airlines are operational and economy aspects (AirAsia Berhad, 2010; Malaysia Airlines, 2010). The operational aspect refers to respective perspective which associates directly with the aircraft activities or the operating system of the airlines. This includes the traffic rights and the operating routes that could be flown with a particular aircraft. The economy aspect refers to potential financial gains and economy status of the airlines. This includes the cash balance and debt/lease financing of the airlines.

In addition, the issue of environmental sustainability is receiving increasing attention nowadays and hence the environmental aspect which corresponds to the green concern of the airlines need to be taken into consideration in making fleet planning decision in view that

different aircraft type (for optimal fleet planning) possesses different environmental performance. Specifically, it was found that aircraft emission, noise and fuel consumption are influential environmental factors that generate varying pollution levels (International Civil Aviation Organization, 2010).

For the airlines, the relevant key aspects are vital to be considered in making strategic fleet planning decision so that a desired level of demand could be met realistically (i.e. by having an adequate fleet supply throughout the planning horizon). Otherwise, the resultant decision-making may not be suitable to support the operating networks strategically. For example, if the airlines only consider economy aspect in making fleet planning decision, they would assure their utmost profit probably by acquiring/leasing the most economical aircraft (primarily for cost reduction) which tends to be small aircraft (single-aisle). However, these aircraft may not be appropriate and coherent for practical use due to the fact that the operation of small aircraft is limited to a particular range (maximum distance flown) and hence they are only practically suitable to support short-haul network but not medium or long-haul network. This shows that the operational aspect is a crucial element to assure the operational feasibility of airlines. Correspondingly, the airlines have to handle fleet planning decision-making with care by taking into consideration various key aspects. Otherwise, it would results in a substantial loss to airlines not only in terms of monetary aspect but also the interest or loyalty of passengers.

Besides, it is also important for the airline to understand and predict the future travel trend and demand in making strategic fleet planning decision. Airlines could only achieve their desired level of service with maximum profit by capturing supply and demand management simultaneously in fleet planning. In such a competitive environment, air transport is constantly challenged by other transport modes which are perceived to be cheaper and easily accessible. For example, domestic flights (short-haul) are competing with coach buses, trains and private vehicles. Thus, airlines need to keep up with the latest mode choice decision of the travelers (for continual services improvement). As such, some travel survey studies (e.g. Mason, 2000, 2001; Barett, 2004; Evangelho *et al.,* 2005) have been carried out to examine passenger's mode choice behavior. Although these studies are beneficial, none of them show how the findings (from the survey) could be used to assist airlines in making strategic fleet planning decision.

In view that air travelers, as the main users of the air transportation system, would contribute the market share and main income to the airlines, it is undeniable that travelers' response would impact the planning and managerial decision-making of airlines (including fleet planning) to a great extent. Furthermore, demand fluctuation behaves uncertain (under uncertainty and intense competition) and hence the airlines need to have a well-developed fleet planning model in order to assure that there is an adequate fleet supply, right on time, to support the current operating networks strategically and profitably. To make optimal fleet planning decision, this study proposes a methodology to capture both the supply and demand perspective by using Analytic Hierarchy Process (AHP). AHP is chosen because it possesses the capability to capture fuzziness and vagueness (uncertainty) explicitly by allowing respective judgments to vary over the values of a fundamental scale 1-9 (Saaty and Tran, 2007). This could reflect realistically fleet planning problem of airlines under uncertainty. The relevant key aspect (operation, economy and environment) are captured in the fleet planning model through the definition of probable phenomena (with the associated probabilities). They are considered in the objective function of the fleet planning optimization model. By doing this, the decision-making of fleet planning would assure a proper aircraft supply for each operating period throughout the planning horizon to support the entire

operating system of the airlines. Consequently, stochastic demand under uncertainty could be met profitably at a desired service level.

2. LITERATURE REVIEW

2.1 Fleet Planning

Past studies adopted various approaches to solve fleet planning problem. However, they did not show how optimal fleet planning decision is made with regard to the influential key aspects of decision-making. With the aim to maximize operational profit, Listes and Dekker (2005) adopted scenario aggregation-based approach to determine fleet composition (aircraft choice) to meet short-term stochastic demand. Apparently, airline's economy is included in the objective function (for the profit maximization) while the operational consideration is captured by assigning appropriate aircraft type to meet travel demand. However, long-term fleet planning problem may not be solved strategically in view that their model only captured short-term demand. Furthermore, the extent for which operational and economy aspects influencing fleet planning decision-making is not explored. Specifically, Wei (2006) employed game-theoretical model to investigate the impact of airport landing fees on the selection of aircraft size and service frequency of airlines (for optimal profit). Although operational and economy aspects are captured at some extent, the sole focus on landing fees in affecting airline's decision-making might be too restrictive. Furthermore, demand fluctuation that could affect fleet planning decision is not tackled. To minimize operating cost, Hsu *et al.* (2011a, 2011b) formulated stochastic dynamic programming model to solve fleet planning problem. They determined optimal service frequency (with the corresponding aircraft type) of each operating route to support the existing operating networks. However, their formulations might be too simplistic by considering travel demand as a sole constraint in fleet planning. This may affect the operations of the airlines in providing a desired service level to meet stochastic demand. More recently, Khoo and Teoh (2013) developed a fleet planning optimization model to obtain optimal profit of the airlines under uncertainty. The optimal solution is obtained by defining a particular probability of operational and economy aspects. However, there is no further exploration on how to quantify the probability of the respective aspect (operational and economy). Focusing on environmental aspect, Givoni and Rietveld (2010) discussed the choice of airlines on aircraft size and service frequency (at a desired service level). It was found that a lower service frequency (by operating larger aircraft) would produce lesser amount of emission and noise. This signifies that environmental performance of aircraft could affect fleet planning decision at varying degrees but the extent for which the environmental aspect affecting the relevant decision-making is not discussed explicitly.

Although the aforementioned studies are relatively relevant in solving fleet planning problem strategically, they mainly focused on the technical perspective for which the extent on how the key aspects (operation, economy and environment) of fleet planning play the role to make a strategic decision is not explored explicitly. Furthermore, none of the existing studies capture demand-supply interaction in solving fleet planning problem.

2.2 Mode Choice of Travelers

Globally, the competition among the airlines is intensifying mainly due to the evolution and substantial growth of low-cost carriers (LCCs). The competition between the LCCs and full-

service carriers (FSCs), with the relevant mode choice analysis, could be seen in Mason (2000, 2001), Barrett (2004) and Evangelho *et al.* (2005). These studies showed that the underlying factors which affecting travelers' mode choice are price (airfare), in-flight service, comfort, flight schedule, service frequency, punctuality, reliability, mileage program, VIP lounges, trip purpose as well as the socio-economic factors of travelers (e.g. age and income level). Besides, some past studies revealed that the FSCs had lost a significant proportion of travelers to the LCCs (which constantly offer low airfare). Subsequently, this leads to a substantial financial loss (for the FSCs). This has become one of the challenges of the airlines in assuring a profitable market share. As such, how to sustain and stand out in such a competitive airline industry certainly requires operational and managerial efficiency.

Apart from the intense competition between the LCCs and FSCs, there's a direct competition between the air transport and ground transport. The competition between high-speed train (HST) and air transport were examined by Gonzalez-Savignat (2004), Ortuzar and Simonetti (2008) and Adler *et al.* (2010). It was found that travel time, travel cost, service frequency and the age of travelers are some determinants for the travelers in making their mode choice decision. Although these studies have revealed the competition of air transport with ground transport to a certain extent, other types of ground transport (e.g. bus, car) and specific type of airlines (e.g. budget airlines) were not considered explicitly in these studies. Furthermore, the study area was limited to European countries.

Therefore, it could be seen that the existing studies on the competition of the air transport and ground transport is very limited. Moreover, there is no study that considers mode choice analysis in making optimal fleet planning decision. Most of the existing mode choice analyses (as mentioned above) only focus on the airline's traveling attributes and traveler's preference for which the impacts in affecting fleet planning are not inspected. This element should be considered owing to the fact that the aircraft utilization and the operations of the airlines correlate closely with the trend of travel market (especially under uncertainty). This necessitates the incorporation of mode choice modeling in fleet planning.

Concisely, this paper contributes to the literature in four areas as listed below:

(1) It deals with multiple criteria (with numerous key aspects) fleet planning decision-making in acquiring/leasing aircraft strategically to meet stochastic demand.
(2) It is capable to quantify the probability of key aspect in fleet planning (in terms of the operational, economy and environmental aspect) that realistically reflects the practical concerns of the airlines.
(3) It captures supply-demand interaction in greater details by embedding mode choice modeling (traveler's response) necessarily for the respective operating networks.
(4) It assures an adequate fleet supply (aircraft composition) to meet stochastic demand profitably under competitive multimode transportation system.

3. FLEET PLANNING MODEL WITH OPERATIONAL, ECONOMY AND ENVIRONMENTAL ASPECTS

3.1 Nomenclature

The notations used for n types of aircraft (at the age of y) are listed as follows:

Parameters

t	Operating period
T	Planning horizon

$MAX_{budget(t)}$	Allocated budget for aircraft acquisition and leasing
D_t^S	Stochastic demand (correspond to probable phenomenon *S*)
r_t	Discount rate for which the discount factor is $(1+r_t)^{-t}$
α	Significance level of demand constraint
β	Significance level of lead time constraint
γ	Significance level of selling time constraint
$E(fare_t^S)$	Expected value of flight fare per passenger
$E(\cos t_t^S)$	Expected value of flight cost per passenger
p_s	Probability to have I_t^P and I_t^L (correspond to probable phenomenon *S*)

Functions

$P(I_t^P + I_t^L)$	Discounted profit function (by having I_t^P and I_t^L)
$TR(I_t^P + I_t^L)$	Total revenue of airline
$TC(I_t^P + I_t^L)$	Total cost of airline
$f(D_t^S, A_t^n)$	Function of the number of flights in terms of D_t^S and A_t^n
$gf(D_t^S, A_t^n)$	Function of the traveled mileage in terms of $f(D_t^S, A_t^n)$
$hgf(D_t^S, A_t^n)$	Maintenance cost function in terms of *g*
$C(fuel_{tn})$	Function of fuel expenses

Sets

$X_t^P = (x_{t1}^P, x_{t2}^P, ..., x_{tn}^P)$	Quantity of aircraft to be purchased
$X_t^L = (x_{t1}^L, x_{t2}^L, ..., x_{tn}^L)$	Quantity of aircraft to be leased
$I_t^P = (I_{t1y}^P, I_{t2y}^P, ..., I_{tny}^P)$	Initial quantity of purchased aircraft
$I_t^L = (I_{t1y}^L, I_{t2y}^L, ..., I_{tny}^L)$	Initial quantity of leased aircraft
$U_t = (u_{t1}, u_{t2}, ..., u_{tn})$	Setup cost of aircraft acquisition
$S = (s_1, s_2, ..., s_k)$	Probable phenomenon to have I_t^P and I_t^L
$PURC_t = (purc_{t1}, purc_{t2}, ..., purc_{tn})$	Purchase cost of aircraft
$LEASE_t = (lease_{t1}, lease_{t2}, ..., lease_{tn})$	Lease cost of aircraft
$DP_t = (dp_{t1}, dp_{t2}, ..., dp_{tn})$	Payable deposit for aircraft acquisition
$DL_t = (dl_{t1}, dl_{t2}, ..., dl_{tn})$	Payable deposit for aircraft leasing
$SEAT_n = (seat_1, seat_2, ..., seat_n)$	Number of seats of aircraft
$SOLD_t = (sold_{t1y}, sold_{t2y}, ..., sold_{tny})$	Quantity of aircraft sold
$RESALE_t = (resale_{t1y}, ..., resale_{tny})$	Resale price of aircraft
$DEP_t^P = (dep_{t1y}^P, dep_{t2y}^P, ..., dep_{tny}^P)$	Depreciation value of purchased aircraft
$DEP_t^L = (dep_{t1y}^L, dep_{t2y}^L, ..., dep_{tny}^L)$	Depreciation value of leased aircraft

$DLT_t = (DLT_{t1}, DLT_{t2}, ..., DLT_{tn})$ Desired lead time of aircraft acquisition

$DST_t = (DST_{t1}, DST_{t2}, ..., DST_{tn})$ Desired selling time of aging aircraft

3.2 Model Formulation

Practically, the profit margin of the airlines is contributed by the total revenue and total operating cost. The total revenue, $TR(I_t^P + I_t^L)$ of the airline can be expressed as follows:

$$TR\left(I_t^P + I_t^L\right) = E\left(fare_t^S\right) D_t^S + \sum_{i=1}^{n}\sum_{y=1}^{m} sold_{tiy} resale_{tiy} \text{ for } t = 1,...,T; S = s_1,...,s_k \quad (1)$$

The first term on the right-hand side of Eq. (1) indicates the expected income from the sales of flight tickets (at the demand level D_t^S) while the second term denotes the income from the sales of aging aircraft. Note that there are *n* types of aircraft at the age of *y* in supporting the operating networks. The total operating cost, $TC(I_t^P + I_t^L)$ of the airline can be outlined by:

$$\begin{aligned} &TC\left(I_t^P + I_t^L\right) \\ &= E\left(\cos t_t^S\right) D_t^S + \sum_{i=1}^{n} u_{ti} + \left(purc_{ti}\right)\left(x_{ti}^P\right) + \sum_{i=1}^{n} lease_{ti}\left(x_{ti}^L\right) + \sum_{i=1}^{n} hgf\left(D_t^S, A_t^i\right) + \sum_{i=1}^{n}\sum_{y=1}^{m}\left(I_{tiy}^P\right)\left(dep_{tiy}^P\right) + \\ &\sum_{i=1}^{n}\sum_{y=1}^{m}\left(I_{tiy}^L\right)\left(dep_{tiy}^L\right) + \sum_{i=1}^{n} dp_{ti}\left(x_{ti}^P\right) + \sum_{i=1}^{n} dl_{ti}\left(x_{ti}^L\right) + \sum_{i=1}^{n} C\left(fuel_{ti}\right) \text{ for } t = 1,...,T; S = s_1,...,s_k \end{aligned} \quad (2)$$

The terms on the right-hand side of Eq. (2) signify the expected cost of flight, aircraft purchase cost, lease cost, maintenance cost, depreciation expenses, payable deposit of aircraft acquisition/leasing and fuel expenses, respectively.

Fleet planning model is probabilistic as the travel demand is stochastic (not deterministic) due to the occurrence of unexpected event which is unpredictable in the real practice. The characteristic of fleet planning problem is that some elements are random (including the level of travel demand which is uncertain) that giving rise to the element of stochastic demand and this results in a probabilistic issue. To make optimal aircraft acquisition and leasing decision, a probabilistic dynamic programming model is adopted due to its capability to decompose the fleet planning model into a chain of simpler and more tractable sub-problems. Mathematically, the developed fleet planning model which aims to maximize the operational profit, $P\left(I_t^P + I_t^L\right)$ of the airline can be presented as follows:

$$P\left(I_t^P + I_t^L\right) = \max_{X_t} \frac{1}{\left(1+r_t\right)^t} \begin{Bmatrix} p_{s_1}\left(TR\left(I_t^P + I_t^L\right) - TC\left(I_t^P + I_t^L\right)\right) + ... + \\ p_{s_k}\left(TR\left(I_t^P + I_t^L\right) - TC\left(I_t^P + I_t^L\right)\right) + P_{t+1}\left(I_t^P + I_t^L\right) \end{Bmatrix} \text{ for } t = 1,...,T \quad (3)$$

Subject to:

Budget constraint: $\sum_{i=1}^{n} purc_{ti} x_{ti}^P + \sum_{i=1}^{n} lease_{ti} x_{ti}^L \le MAX_{budget(t)}$ for $t = 1,...,T$ (4)

Demand constraint: $\sum_{i=1}^{n}\left(SEAT_i\right)\left(f\left(D_t^S, A_t^i\right)\right) \ge (1-\alpha) D_t^S$ for $t = 1,...,T; S = s_1,...,s_k$ (5)

Sales of aircraft constraint: $sold_{tiy} \le I_{(t-1)i(y-1)}^P$ for $t = 1,...,T; i = 1,...,n; y = 1,...,m$ (6)

Lead time constraint: $DLT_{ti} \ge F^{-1}(1-\beta)\sigma_{LT} + \mu_{LT}$ for $t = 1,...,T; i = 1,...,n$ (7)

Selling time constraint: $DST_{ti} \geq F^{-1}(1-\gamma)\sigma_{ST} + \mu_{ST}$ for $t = 1,...,T; i = 1,...,n$ (8)

As displayed in the developed fleet planning model (3), the key aspects of fleet planning decision-making are captured in the developed model by defining *k*-th probable phenomenon (with the associated probabilities) in the form of $p_{s_1},...,p_{s_k}$. Specifically, the element of p_{s_1}, p_{s_2} and p_{s_3} respectively signifies the probability of the operational, economy and environmental aspects in making strategic fleet planning decision. More details about the probable phenomena indicators, p_{s_k} could be seen in Khoo and Teoh (2013). The term $(1+r_t)^{-t}$ in the model (3) is used for the discounted value across the planning horizon.

The developed model (3) aims to maximize airline's profit for which the decision variables are the quantity of aircraft to be purchased and/or leased throughout the planning horizon. The developed model (3) is optimized subject to five practical constraints. In particular, budget constraint (4) ascertains whether if the solution is financially feasible for the airlines for which the total purchase and leasing cost of aircraft should not exceed the allocated budget for aircraft acquisition/leasing. Demand constraint (5) ensures that stochastic demand is to be met satisfactorily at the targeted service level, $1-\alpha$. For some airlines, aging aircraft which is less cost-effective might be sold at the beginning of a certain operating period particularly when the airlines make decision to purchase/lease new aircraft. Thus, the sales of aircraft constraint (6) limits that the quantity of aircraft sold are not more than the quantity of aircraft owned by the airline. Lead time constraint (7) and selling time constraint (8) respectively indicate when the airline is supposed to order new aircraft and release aging aircraft for sales. Lead time is assumed to be normally distributed with mean μ_{LT} and standard deviation σ_{LT} (for which $F^{-1}(1-\beta)$ is the inverse cumulative probability). Similarly, it is assumed that selling time has a normal distribution with mean μ_{ST} and standard deviation σ_{ST} (with $F^{-1}(1-\gamma)$ as the inverse cumulative probability). Optimally, the developed model (3) would assure the airline to possess an adequate aircraft supply (via acquisition and leasing) to meet stochastic demand at a desired service level.

3.3 Quantify Probable Phenomena Indicators with Analytic Hierarchy Process (AHP)

By allowing the relevant judgments to vary over the values of a fundamental scale of 1-9, AHP possess the capability to capture the fuzziness (uncertainty) in making a multi-criteria decision (Saaty and Tran, 2007). Specifically, the judgments made with the AHP, in the form of pair-wise comparison, are fuzzy (uncertain). As such, the fleet planning decision-making of the airline which is, in fact, uncertain could be solved by making use AHP suitably. This could reflect realistically the fleet planning problem of the airline in a better manner. As displayed in Figure 1, a three-stage modeling framework is developed with the AHP to quantify the probability of key aspects (probable phenomena indicators) for fleet planning purpose.

Stage 1 involves the judgment and comparison among the decisional criteria of fleet planning for which the modeling framework commences by evaluating the relative comparison of *n* decisional criteria with a comparison scale of 1-9 (Saaty, 1977, 1980, 1990). Based on some publicly accessible published reports (AirAsia Berhad, 2004; KPMG, 2007; Lessard, 2012; Malaysia Airlines, 2010; Ryanair, 2012), four decisional criteria, namely decision policy of the airline (DP), consultancy of the experts (CE), past performance of the airline (PP) and travelers' response (TR) are identified as the influential decisional

criteria in making optimal fleet planning decision. Specifically, the decision policy of the airline (DP) refers to a particular course of action for the airline to make operational and managerial decision while the consultancy of the experts (CE) applies to the advices or judgments of the consultants/panels towards the operating performance, financial management as well as the decision-making of the airline. To support the operating networks strategically, the past performance of the airline (PP) includes the perspectives of demand and supply for which the perspective of demand takes account of travel trend while the aspect of supply considers the fleet performance in servicing the operating networks. From the perspective of the users of the air transportation system, travelers' response (TR) focuses on the mode choice modeling which reveals the behavior/perception of travelers towards airline's services. It is important to note that some degree of inconsistency is expected due to the fact that the decision-making is made based on the subjective judgment of the decision makers. Therefore, the consistency of the resultant judgment matrix needs to be examined accordingly.

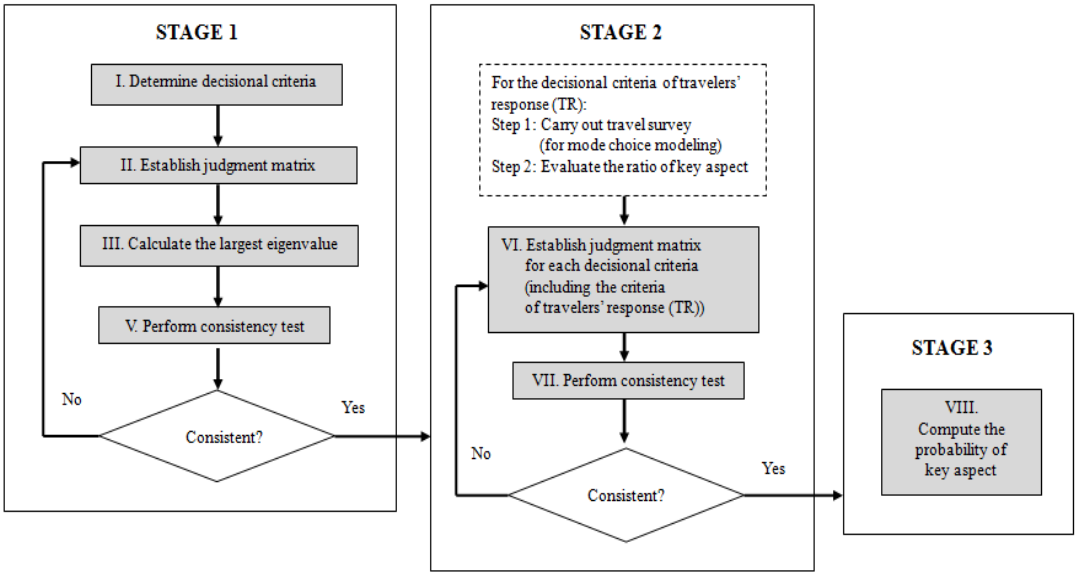

Figure 1. The modeling framework to quantify the probability of key aspect

Stage 2 focuses on the judgment and comparison among the key aspects for each decisional criteria. At this stage, similar procedure of stage 1 is carried out to form the judgment matrix that reflects the relative comparison among the key aspect for specific decisional criteria. In order to form the comparison matrix of the key aspect with regard to travelers' response (TR), following procedure can be carried out:

Step 1: Conduct travel survey for mode choice modeling

Travel survey can be undertaken necessarily by the airline to examine the preference of travelers as well as its impacts in fleet planning. Specifically, travel survey for different trip purposes (e.g. leisure or business) can be carried out for different destinations (e.g. local or trans-border). The response of travelers obtained via travel survey (input) is then utilized to generate mode choice modeling models (output). The estimated parameters of the respective trip which constitute the mode share of the operating network can be obtained from the mode choice modeling.

Step 2: Evaluate the ratio of key aspect

The mode share of the operating network (obtained from step 1) which corresponds to the respective key aspect can be evaluated accordingly to obtain the relative comparison of the key aspect. The framework to evaluate the ratio of key aspect is shown in Figure 2. By considering W contributing components of key aspect and also P operating network, the respective ratio of key aspect can be computed as follows:

$$s_i : s_j = \left| \frac{\sum Net_d F_{S_i}^w}{\sum Net_d F_{S_j}^w} \right| \text{ for } i,\ j = 1,...,k; w = 1,...,W; d = 1,...,P \tag{9}$$

where Net_d applies to the respective operating network (in terms of the choice probability or mode share) and $F_{S_k}^w$ denotes the relevant contributing component of the key aspect. Specifically, the numerator and denominator of Eq. (9) assure that the mode choice of travelers (demand perspective) corresponds directly with the influential key aspects of fleet planning (supply perspective) by relating the mode share (i.e. the choice probability of travelers) of a specific operating network with the contributing components, $F_{S_k}^w$ of a particular key aspect. Remarkably, the value of a contributing component of a particular key aspect is constituted by the mode choice decision of travelers. In fact, the fleet planning of the airline would also influence mode choice decision to a certain extent. Thus, it could be inferred that there is a two-way modeling relation between the demand and supply perspectives. This would be particularly apparent under the occurrence of unexpected events (i.e. stimulates stochastic demand under uncertainty).

Finally, *Stage 3* computes the end result which is the probability of the key aspect (i.e. the probability of operational, economy and environmental aspects) in making strategic fleet planning decision. The probability of the respective key aspect can be evaluated as follows:

$$\text{Probability} = \sum A_i^* B_r^* \tag{10}$$

where A_i^* represents the average of row i of the normalized matrix A (with n decisional criteria in stage 1) while B_r^* denotes the average of row r of the normalized matrix obtained from stage 2.

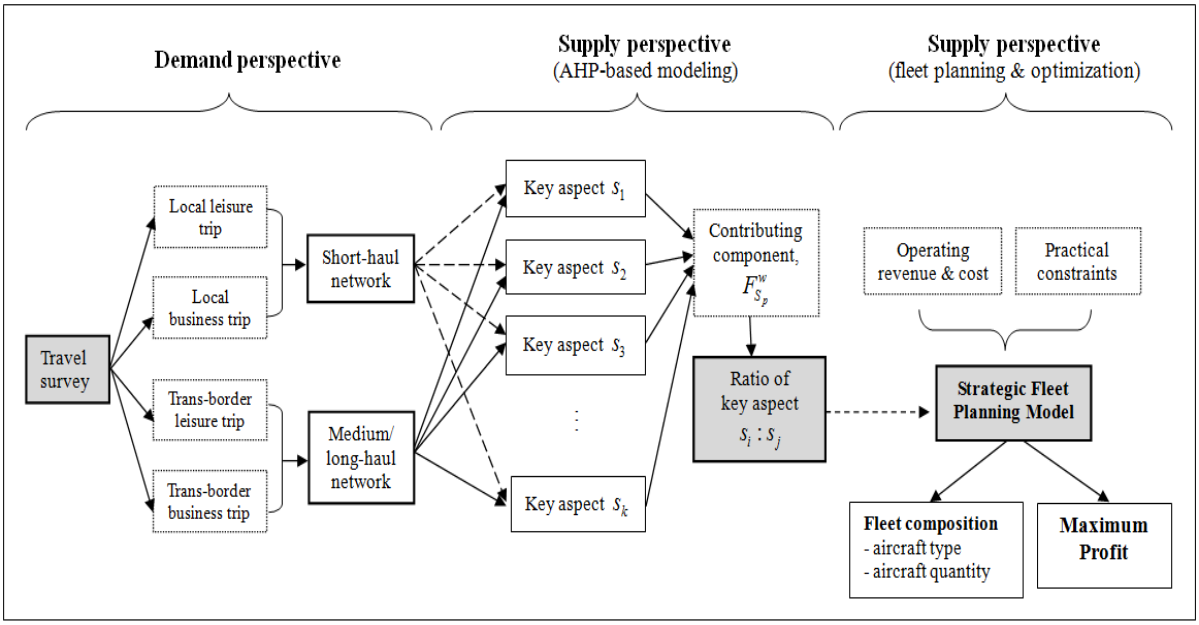

Figure 2. The evaluation of the ratio of key aspect

3.4 The Linkage of Mode Choice, AHP-based Modeling Framework and Fleet Planning

As illustrated in Figure 2, fleet planning is a multi-criteria decision-making problem for which several key aspects (e.g. operation and economy) have to be considered. While providing an adequate fleet supply, it is also important to capture mode choice behavior (traveler's response) in view of the fact that air travelers (passengers) are the main users of the airline's services which constitutes the market share and main income to the airline. Furthermore, traveler's behavior was changing with the extensive growth of multimode transportation network. As such, how the airlines make an optimal fleet planning decision is vital to meet travel demand profitably at a desired service level. Therefore, fleet planning of the airlines which is, in fact, uncertain (primarily due to stochastic demand) and greatly governed by various key aspects (multi-criteria) could be solved strategically with the aid of the AHP. AHP-based modeling framework can be adopted to quantify the key aspects as the associated outcome of the fleet planning decision-making is not deterministic (probabilistic) at the point of planning. The airline would amend their strategy suitably by considering multiple key aspects. In view of the respective key aspect is greatly driven by the risk considerations (uncertainty) which associate closely with the operating aircraft of the airline, the resultant key aspect may vary (with different impacts) across a variety of aircraft type. In other words, it is likely for the key aspect to vary in accordance to the existing aircraft composition of the airline, i.e. the existing fleet supply of the airline would constitute the formation of the key aspect and this would affect the profitable fleet planning decision-making in return.

4. ILLUSTRATIVE EXAMPLE

This section illustrates the applicability of the AHP-based modeling framework to quantify the probability of key aspect in fleet planning, i.e. the illustrative example shows systematically how the proposed framework produces the probability of operational, economy and environmental aspects. Subsequently, the resultant probability would be used necessarily to optimize fleet planning model (in the next section).

4.1 Quantify Probable Phenomena Indicators

Four decisional criteria, i.e. decision policy of the airline (DP), consultancy of the experts (CE), past performance of the airline (PP) and travelers' response (TR) are chosen. Besides, some published reports are compiled with the aid of simulation approach for which the simulated data representing the relative comparison of ten managerial experts (decision makers) towards the decisional criteria. The perceptions of the managerial experts are compiled as geometric mean (Aczel and Saaty, 1983) in order to compute the judgment matrix A as follow:

$$A = \begin{bmatrix} 1 & 0.75 & 0.57 & 1.00 \\ 1.33 & 1 & 0.77 & 1.32 \\ 1.74 & 1.29 & 1 & 1.68 \\ 1.00 & 0.76 & 0.60 & 1 \end{bmatrix}_{4x4}$$

Following the AHP procedure, the largest eigenvalue, λ_{max} and the consistency ratio (CR) of matrix A signify that the matrix A is consistent (reliable).

Four stated preference travel surveys (for local leisure trip, local business trip, trans-border leisure trip and trans-border business trip) had been undertaken in 2011 in order to model the mode choice decision of travelers (Teoh and Khoo, 2012a, 2012b). These surveys aim to identify and analyze the preference of travelers towards ground transport (bus, car and train) and air transport (FSC and LCC). Generally, the operating networks of the airlines can be categorized as short-haul and medium/long-haul networks. In such a case, local leisure trip and local business trip (domestic flights) are classified as short-haul network while trans-border leisure trip and trans-border business trip are included for medium/long-haul network. These networks are then utilized to evaluate the ratio of key aspect. Based on the survey results (as shown in Table 1), the average mode share of the respective operating network which corresponds to the key aspect of operational, economy and environmental of the airline are evaluated accordingly to compare the respective key aspect. To do this, the relevant contributing components of each key aspect are taken into account to assess the relationship of the operating network and corresponding key aspect.

As mentioned earlier, the relevant contributing component of the operational aspect of the airline may refer to several perspectives, including the number of passengers carried and the load factor in servicing operating networks. On the other hand, the economy aspect of the airline may cover numerous components, including the operating revenue and available capacity (seats) while the environmental aspect captures the fuel consumption of the airline in response to the fuel efficiency of the operating networks. The data of these aspects are compiled according to the accessible information from Malaysia Airlines (2010). The evaluation of the ratio of key aspect is shown in Table 2.

Table 1. The evaluation of the ratio of key aspect (for travelers' response)

		Operational aspect, s_1		Economy aspect, s_2		Environmental aspect s_3
Operating network	Average mode choice	Load factor, $F_{S_1}^1$	Passengers carried, $F_{S_1}^2$	RPK, $F_{S_2}^1$	ASK, $F_{S_2}^2$	Fuel efficiency, $F_{S_3}^1$
Short-haul	37.4350	50%	45%	10%	10%	68%
Medium/long-haul	26.2575	50%	55%	90%	90%	32%
$\sum Net_d F_{S_p}^w$		63.1336		54.7505		33.8582
Ratio of key aspect		$s_1 : s_2 = 1.15,\ s_1 : s_3 = 1.86,\ s_2 : s_3 = 1.62$				
Note: RPK refers to revenue passenger kilometres while ASK refers to available seats kilometers.						

Table 2. The evaluation of key aspect in fleet planning

Key aspect	Decisional criteria				Probability
	DP (0.1977)	*CE* (0.2630)	*PP* (0.3396)	*TR* (0.1997)	
Operational (s_1)	0.4429	0.4429	0.4429	0.4154	0.4374
Economy (s_2)	0.3873	0.3873	0.3873	0.3614	0.3821
Environmental (s_3)	0.1698	0.1698	0.1698	0.2232	0.1805

By having the ratio of key aspect, the judgment matrix of travelers' response, B_{TR} could be formed as follows:

$$B_{TR} = \begin{bmatrix} 1 & 1.15 & 1.86 \\ 0.87 & 1 & 1.62 \\ 0.54 & 0.62 & 1 \end{bmatrix}_{3x3}$$

Besides, there are three more decisional criteria, i.e. decision policy of the airline (DP), consultancy of the experts (CE) and past performance of the airline (PP). The judgment matrices of these decisional criteria are assumed as follows (due to the lack of accessible data):

$$B_{DP} = \begin{bmatrix} 1 & 1 & 3 \\ 1 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{bmatrix}_{3x3}, B_{CE} = \begin{bmatrix} 1 & 1 & 3 \\ 1 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{bmatrix}_{3x3}, B_{PP} = \begin{bmatrix} 1 & 1 & 3 \\ 1 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{bmatrix}_{3x3}$$

By carrying out the consistency test (based on the AHP approach), the consistency of these matrices were confirmed because $CR < 0.1$ for all matrices. Thus, it can be reasonably verified that these matrices are consistent (valid) in making optimal fleet planning decision.

Lastly, the respective probability of the key aspect is summarized in Table 2. Table 2 shows that the probability are $p_{s_1} = 0.4374$, $p_{s_2} = 0.3821$ and $p_{s_3} = 0.1805$ for the operational, economy and environmental aspects, respectively. Practically, $p_{s_1} = 44\%$ signifies the likelihood of aircraft possession (via acquisition or leasing) in accordance to the operational aspect of the airline (s_1) while its complement, i.e. $p_{s_2} = 38\%$ and $p_{s_3} = 18\%$ refer to the probability of aircraft possession by taking into account the aspect of economy (s_2) and environmental (s_3). Note that $\sum_{\forall i} p_{S_i} = 1$ and this completes (100%) the decision-making of the airline in fleet planning.

5. APPLICATION IN OPTIMIZING FLEET PLANNING MODEL

This section makes use the resultant probability of operational, economy and environmental aspects (from the previous section) to optimize fleet planning problem, i.e. to determine the optimal quantity of the respective aircraft type to meet stochastic demand profitably.

5.1 Data Description

Assume that there are three types of aircraft, i.e. A320-200, A330-300 and B737-800 which are operated for a set of origin-destination (OD) pairs for a planning horizon of eight years. Most of the data input are compiled based on the available reports (AirAsia Berhad, 2010; Malaysia Airlines, 2010; Airbus, 2010a, 2010b, 2010c; Boeing, 2012). Remarkably, the developed model is not restricted to the type of aircraft used, i.e. it can be used for any type of aircraft operated by the airlines (including Airbus and Boeing). According to some airlines (Malaysia Airlines, 2010a; AirAsia Berhad, 2010a), the acquisition of new aircraft requires a period of five years (in average) to be completely delivered by the aircraft manufacturer. Under certain circumstances, the actual lead time might be longer than the agreeable lead time (between the airline and aircraft manufacturer) and this will result in the late or delay of aircraft delivery. Besides, the airlines also have to place their acquisition/leasing order in

advance (earlier) in order to receive the respective aircraft, right on time, for operations. As such, it could be deduced that the illustrative example, with the planning horizon of eight years, is reasonably and practically needed to optimize aircraft acquisition/leasing decision. To capture demand uncertainty, the level of stochastic demand of each operating period is obtained by applying the modeling framework of demand uncertainty (Khoo and Teoh, 2013). Based on the AHP approach as illustrated earlier, the probability of key aspects, i.e. $p_{s_1} = 0.4374$, $p_{s_2} = 0.3821$ and $p_{s_3} = 0.1805$ are used respectively for the operational, economy and environmental aspects. For the benchmark scenario, the other data input are listed as follows:

- Three possible phenomenon are considered, i.e. $k = 3$
- At $t = 1$, initial quantity of aircraft are $I_{11}^P = I_{12}^P = I_{13}^P = 35$ and $I_{11}^L = I_{12}^L = I_{13}^L = 0$
- At $t = 1$, initial quantity of aircraft to be three years old is $I_{113}^P = I_{123}^P = I_{133}^P = 3$
- Budget, $MAX_{budget(t)} = \$6,500$ million
- Discount rate, $r_t = 5\%$
- Significance level of demand constraint, $\alpha = 5\%$
- Significance level of lead time constraint, $\beta = 5\%$
- Significance level of selling time constraint, $\gamma = 5\%$
- Deposit of aircraft acquisition, $DP_t = 10\%\left(purc_{tn}\right)$
- Deposit of aircraft leasing, $DL_t = 10\%\left(lease_{tn}\right)$
- Setup cost, $u_{ti} = 0$ for $i = 1,..., n$
- $DLT_{tn} \sim N(2, 0.4)$, $DST_{tn} \sim N(1.5, 0.3)$
- The level of stochastic demand is

$$D_t^{s_1} = D_t,\ D_t^{s_i} = \left(1-\alpha\right) D_t^{s_{i-1}},\ i = 2,..,\ k \tag{11}$$

- The function of number of flights is

$$f = 22.57\left(A_t^n\right)^2 - 9.776\text{x}10^2 A_t^n + 7.83\text{x}10^4\ [\text{R}^2 = 0.97] \tag{12}$$

where A_t^n is the total number of aircraft possessed by the airline.

- The function of traveled mileage is

$$g = 2,066f - 2,875,383\ [\text{R}^2 = 0.83] \tag{13}$$

- The function of maintenance cost is

$$h = 5.177\text{x}10^3 + 7.97\text{x}10^{-3} g\ [\text{R}^2 = 0.94] \tag{14}$$

- The function of fuel expenses is

$$C\left(fuel_{tn}\right) = 7.46f + 8.3\text{x}10^{-5} f^2 - 98,572 \quad [\text{R}^2 = 0.88] \tag{15}$$

- The quantity of aircraft is

$$NA = 10^{-5} NP - 73.6\ [\text{R}^2 = 0.92] \tag{16}$$

where NP is the number of travelers.

Based on the reported data of Malaysia Airlines (2010a) and AirAsia Berhad (20101b), Eqs. (12)-(16) are obtained by conducting polynomial regression analysis while eq. (11) implies the proportion of stochastic demand which corresponds to the respective probable phenomenon. Eq. (12) indicates that the number of flights is affected by total operated aircraft of the airline. Eq. (13) denotes that a flight flies 2,066 kilometres in average. Eq. (14) signifies that a unit cost of 0.00797 is charged as maintenance cost for each additional unit of mileage traveled. For this equation, \$5,177 indicates the estimated maintenance cost without

considering additional traveled mileage. Eq. (15) shows that the total fuel expenses depend on the number of flights. This implies that the fuel expenses associate closely with the total number of aircraft in operations. Eq. (16) displays that every 100,000 travelers requires one additional aircraft, i.e. one traveler requires 0.00001 aircraft.

5.2 Scenarios

In addition to a benchmark scenario, two more scenarios (as shown in Table 3) are examined for further analysis to inspect the relevant influential input in generating strategic fleet planning. Specifically, scenario P focuses on the changes of the decision policy (DP) of the airline, i.e. from the aspect of supply. By allocating different weight (priority) on the operational, economy and environmental aspect in such a way that environmental aspect gains the highest concern (priority) in terms of the decision policy of the airline (followed by operational and economy aspects), scenario P inspects not only the possible variation on the probability of the respective aspect (operation, economy and environment) but also the possible changes of the decision-making in fleet planning. It is anticipated that the resultant outputs are driven by the weight allocation of the airline based on the relevant decision policy (i.e. an influential decisional criteria in fleet planning).

Scenario Q inspects the perspective of demand in terms of the changes of travelers' response (TR). By capturing the possible changes of the mode choice decision of travelers towards the services of the airline (i.e. travel cost reduction), scenario Q inspects the impacts of demand level (in terms of the choice probability) in fleet planning, i.e. by quantifying the possible probability of operational, economy and environmental aspects which could affect fleet planning greatly. Specifically, traveler's response could be compiled by undertaking various travel survey on the respective operating networks (short-haul and medium/long-haul). It is anticipated that scenario P and Q would capture demand-supply interaction in a greater and better manner.

Table 3. Further analysis in solving fleet planning problem

Scenario	Decisional criteria	Description	Judgment matrix
P	Decision policy (DP)	The adjustment on the relative comparison of key aspect is done in the form as follows: environmental ≥ operational ≥ economy	$B_{DP} = \begin{bmatrix} 1 & 2 & 1 \\ 1/2 & 1 & 1/3 \\ 1 & 3 & 1 \end{bmatrix}_{3x3}$
Q	Travelers' response (TR)	The change of travelers' response is investigated towards travel cost reduction strategy. The mode share was found to increase 18.39% (Teoh and Khoo, 2012a, 2012b).	$B_{TR} = \begin{bmatrix} 1 & 1.02 & 1.98 \\ 0.98 & 1 & 1.94 \\ 0.51 & 0.52 & 1 \end{bmatrix}_{3x3}$
Note: With regard to the relative comparison of key aspect, the benchmark scenario is outlined as follows: operational ≥ economy ≥ environmental			

5.3 Results of Benchmark Problem versus Scenario P

The results of the benchmark scenario, scenarios P and Q are shown in Table 4 (with the graphical results as displayed in Figure 4). The results imply that the decisional criteria could affect the probability of key aspect (operational, economy and environmental), optimal profit of the airline as well as fleet planning decision-making. From the results of the benchmark scenario, it could be seen that the comparison relative of key aspect for the respective decisional criteria tends to produce the probability of key aspect in about the same way. This

could be seen in Table 4 for which the judgment matrix of the benchmark scenario which has the relative comparison of key aspect (probable phenomena) in the form of operational ≥ economy ≥ environmental would produce the probability of key aspect in similar way, i.e. probability of operational aspect ≥ probability of economy aspect ≥ probability of environmental aspect. Some changes to the probability of key aspect could be seen in scenario P for which the adjustment of the relative comparison of key aspect has been done on the decision policy of the airline (while other decisional criteria remain unchanged). Scenario P was outlined by putting more weight (relative comparison) on the environmental aspect instead of operational and economy aspects. Subsequently, the results in Table 4 show that the probability of environmental aspect increases about 30% while the probability of operational and economy aspects decreases (compared to the benchmark scenario). However, the probabilities of operational and economy aspects are still higher compared to environmental aspect. This is possible because the resultant probability is affected not only by the decision policy of the airline but also other decisional criteria. This signifies that the decisional criteria of fleet planning have a direct and influential impact on the resultant probability which would subsequently constitute the optimal solution of the airline. Generally, the results confirm that there's a linkage between the decisional criteria and the probability of key aspect as well as the optimal decision of fleet planning. Therefore, the probability of key aspect in fleet planning has to be quantified wisely.

In terms of the profit margin of the airline, Table 4 shows that the benchmark scenario produces a higher profit than scenario P. It could be seen that the average profit of the airline decreases 2.3% (about $7 millions) when the operational and economy aspects have a lower probability than environmental aspect (for scenario P). Thus, it could be deduced that a higher concern (relative comparison) on operational and economy aspects tends to produce a higher profit. This could be explained by the fact that the operational aspect of the airline is mainly playing the role to generate optimal profit (by meeting stochastic demand). Therefore, this aspect is more revenue-sensitive and hence it would impact the average profit margin at a larger scale. Generally, the findings show that instead of the environmental aspect, the operational and economy aspects should be the two major considerations (with higher probability) in fleet planning. This is in line with the practice of the airlines (AirAsia Berhad, 2010; Malaysia Airlines, 2010). In overall, the findings suggest the airline to allocate more weight (probability) on the operational aspect to assure optimal profit. At the same time, the aspects of economy and environmental should be weighted appropriately for a better financial performance. Desirably, the relative comparison of the key aspect should assign the highest concern on the operational aspect, followed by economy and environmental aspect.

Table 4. The results of fleet planning model

		Benchmark scenario	Scenario P	Scenario Q
Probability of key aspect	Operational	0.4374	0.4264 (-3%)	0.4348 (-0.6%)
	Economy	0.3821	0.3391 (-11%)	0.3887 (+2%)
	Environmental	0.1805	0.2345 (+30%)	0.1765 (-2%)
A320-200	Purchase	37	37	38
	Lease	6	6	8
A330-300	Purchase	34	34	34
	Lease	7	6	8
B747-800	Purchase	33	32	35
	Lease	5	7	7
Total fleet size (by year 8)		122	122	130
Number of aircraft (purchased: leased)		104:18	103:19	107:23
Average profit ($ millions)		309	302 (-2.3%)	395 (+27.8%)
Note: The value in bracket denotes the improvement level compared to the benchmark scenario.				

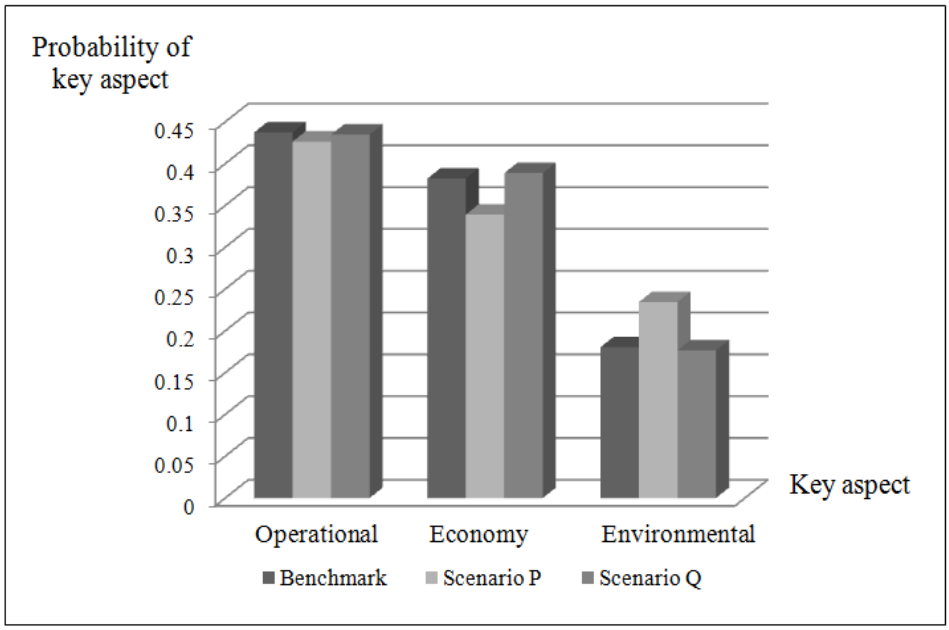

Figure 4. The graphical results of the probability of key aspects

In terms of the fleet size (as displayed in Table 4), it could be seen that the resultant probability of key aspect would affect aircraft acquisition and leasing decision-making. Table 4 shows that the benchmark scenario tends to acquire new aircraft to meet travel demand while scenario P shows a tendency to lease aircraft than purchasing new aircraft. This could be explained by the average profit of scenario P which tends to be lower. In such a case, airline would opt to lease aircraft rather than purchasing new aircraft (with a much higher acquisition cost). This shows that the decisional criteria which associate closely with the probability of key aspect could make a difference in fleet planning.

5.4 Results of Benchmark Problem versus Scenario Q

For scenario Q, the results in Table 4 show that travelers' response towards the strategy of travel cost reduction could affect the probability of key aspect in making fleet planning decision. With this strategy, the mode share of the airline (as stated in Table 3) was found to increase 18% while the probability of economy aspect increases about 2% (as displayed in Table 4). The results in Table 4 also show that the probability of operational and environmental aspects decreases 1% and 2%, respectively. This signifies that travel cost reduction strategy that constitutes a higher mode share is more sensitive to the economy aspect of the airline. This happens primarily due to the monetary concern in terms of the financial management of the airline. In such a case, the probability of economy aspect increases. Correspondingly, the operational and environmental aspect in accordance to the travel cost reduction strategy (i.e. mode share increment) would also be impacted. The change of probability on the operational aspect was found to be minimal while the probability of environmental aspect decreases 2%. This could be justified by the fact that mode share increment of the airline (due to the travel cost reduction strategy) would necessitates more operational and economical adjustments instead of environmental aspect and hence the operational aspect retains about the same probability (with such a minimal change) compared to the environmental aspect. Comparatively, the operational aspect gains the highest

probability and hence its significance in scenario Q could be empirically confirmed. This finding is coherent with the practice of the airlines for which Malaysia Airlines (2012) revealed that to increase mode share (i.e. to meet more sales target) effectively, there is a need to manage operational costs better by improving airline's productivity in both people and processes (which could be directly or indirectly related to aircraft operations). Some of the operative efforts that have been implemented by the airline to increase mode share are effective delay reduction, boarding management, baggage handling and upgrading of internet booking system (Malaysia Airlines, 2012; AirAsia Berhad, 2012).

In terms of the profit of scenario Q, the results in Table 4 show that the strategy of travel cost reduction would increase the average profit by 28% (compared to the benchmark scenario). Approximately, this would contribute about $86 millions for each operating year. This shows that travelers' response towards the travel cost reduction which contributing to a higher mode share would subsequently produce a higher profit level for the airline. Besides, the results in Table 4 reveal that a higher profit of the airline generates a greater flexibility for them in acquiring/leasing new aircraft. This explains the fleet size of scenario Q which comprises about 7% more aircraft comparing to the benchmark scenario. All in all, it could be deduced that travelers' response, as one of the decisional criteria, possesses influential impacts in making fleet planning decision. Therefore, the probability of key aspect which is greatly affected by the decisional criteria of fleet planning has to be quantified appropriately.

6. CONCLUSIONS

Airline fleet planning basically deals with multiple criteria decision-making (with various key aspects) in acquiring/leasing aircraft strategically to meet travel demand. Nevertheless, travel demand is uncertain and highly sensitive under uncertainty. Consequently, it is relatively challenging for the airlines to ensure an adequate fleet supply to meet stochastic demand. Thus, this paper developed Analytic Hierarchy Process (AHP)-based framework to quantify the key aspects of fleet planning, in terms of operational, economy and environmental aspects. The developed framework is embedded with mode choice modeling to capture demand fluctuation (traveler's response) under intense competition of various travel modes. With such element embedded, supply-demand interaction could be modeled in greater details. Airline management can make use the proposed framework to allocate appropriate weight (priority) on the respective key aspect for which the allocation could be adjusted necessarily in making a profitable fleet planning decision (while capturing environmental concern which is receiving greater concerns nowadays). By having the flexibility in adjusting the weight of the key aspects, the proposed framework is able to offer a greater control to the airline in acquiring/leasing aircraft at optimal profit. In overall, the results of an illustrative case study demonstrated that the proposed methodology (embedded with mode choice analysis) is viable in providing optimal solutions in fleet planning. Besides, the findings reveal that airline's optimal profit and fleet planning decision are influenced greatly by influential decisional criteria, which associates closely with the probability of key aspects (probable phenomena). However, the lack of accessible data to obtain the relative comparison of the key aspect for some decisional criteria might affect the empirical analysis. More data could be compiled by approaching the relevant authority of the airline. Alternatively, more publicly accessible data could be compiled if it is available.

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