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A bi-objective dynamic programming approach for airline green fleet planning

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ABSTRACT

Ensuring a fleet of green aircraft is a basic step in mitigating aviation pollution issues that are expected to be worsen in the coming years due to rapid air traffic growth. This study proposed a novel methodology in green fleet planning in which both profit and green performance of airline are considered simultaneously and explicitly. To do this, a Green Fleet Index (GFI) is derived as an indicator to quantify the green performance of airline's fleet. It measures the degree of airline compliance with a standard requirement in terms of emission, noise, and fuel consumption. A bi-objective dynamic programming model is then formulated to find optimal aircraft acquisition (lease or purchase) decision by minimizing GFI and maximizing profit. Several interesting results are obtained: (1) considering environmental issue as secondary objective yields a greener fleet; (2) airline's profit is affected, but could be recovered from environmental cost savings; (3) increasing load factor is an effective operational improvement strategy to enhance airline's green performance and raise profit level. It is anticipated that the framework developed in this study could assist airlines to make a smart decision when considering the need to be green.

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Introduction

Globally, aviation industry is claimed to be the most unsustainable transportation mode (Chapman, 2007) in which it accounts for 2.5–3% of carbon dioxide emission (Anger, 2010) and 24% of nitrogen oxides emission (Lee et al., 2009). In general, it is approximated that 1 kg of aircraft fuel produces about 3.16 kg of carbon dioxide, 0.011 kg of nitrogen oxides and 1.25 kg of water vapor (Ralph and Newton, 1996). Apart from air pollution, noise (Janic, 1999; Kroesen et al., 2010) and fuel consumption are other environmental issues caused by extensive aviation activities. As the air traffic is forecasted to grow at 5% annually (IATA, 2009), the pollution is expected to escalate at an alarming level if it is left untreated. Therefore, stricter enforcement on the airlines to follow environmental regulations is implemented in which stiff fines and penalty charges are imposed on airlines that fail to comply with the regulated standards. As a result, airlines might suffer heavy losses due to such environmental charges. Thus, airlines should not neglect the importance of environmental issue not only for the social benefits but also to minimize operational cost for a greater profit level.

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Nomenclature: For a particular operating period t, the notations used for n types of aircraft (at age y) are listed as follows:

Parameters

T	planning horizon
$MAX_{budget(t)}$	allocated budget for aircraft acquisition and leasing
D_t^S	stochastic demand (correspond to phenomenon S)
$ORDER_t$	quantity of aircraft that could be purchased in the market
$PARK_t$	area of parking space as geometry limitation
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
$E\left(fare_t^S\right)$	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 phenomenon S)
A_t^n	total operated aircraft
m	aircraft status (1:new aircraft, 2:aging aircraft)
OLD	proportion of aging aircraft
NEW	proportion of new aircraft
OD	origin–destination (route)
$SEAT_{n,OD}^t$	number of seat (capacity) of aircraft
$f_{n,OD}^m$	service frequency of aircraft
$D_{S,OD}^t$	demand level of route OD
ER_t^n	emission rate of aircraft
$UCE_{n,OD}^t$	unit cost of emission
TEC_t	total emission cost
TNC_t	total noise charges
UNC_t	unit noise charges
NH_t	noise threshold
CMN_t	cumulative noise
$FM_{n,OD}^m$	fuel consumption
UFS_t	unit fuel cost
LF_t	load factor
θ	parameter of environmental sustainability
$g_{n,OD}^m$	traveled mileage
RG_n	aircraft range (maximum distance flown)
DIS_{OD}	distance of a particular operating route, OD
$NP_{n,OD}^m$	number of passengers
GI_E	green emission index
GI_N	green noise index
GI_F	green fuel efficiency index

Functions

$P\left(I_t^P + I_t^L\right)$	function of discounted profit by having I_t^P and I_t^L
$hg\left(D_t^S, A_t^n\right)$	maintenance cost function in terms of traveled mileage, g
$GFI(GI_E,GI_N,GI_{FE})$	green fleet index (in terms of green index)

Sets

$X_t^P = (x_{t1}^P, x_{t2}^P, \ldots, x_{tn}^P)$	quantity of aircraft to be purchased
$X_t^L = (x_{t1}^L, x_{t2}^L, \ldots, x_{tn}^L)$	quantity of aircraft to be leased
$I_t = (I_{t1y}, I_{t2y}, \ldots, I_{tny})$	initial quantity of aircraft
$I_t^P = \left(I_{t1y}^P, I_{t2y}^P, \ldots, I_{tny}^P\right)$	initial quantity of purchased aircraft
$I_t^L = \left(I_{t1y}^L, I_{t2y}^L, \ldots, I_{tny}^L\right)$	initial quantity of leased aircraft

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