Quantifying Environmental Green Index For Fleet Management Model

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Abstract: Worldwide environmental issue is worsening nowadays and hence more attention is certainly required. To fulfill the social responsibility to preserve the environment, transport operators should concern the issue of environmental sustainability considerably. Nevertheless, there is no available method on how to quantify 'green index' that could provide a proper guidance to the transport operators. Therefore, a 'green index' model is formulated to capture fleet emission, fuel efficiency and noise. The proposed model is able to quantify the 'green level' of fleet in response to stochastic demand. An illustrative case study is presented to examine the applicability of the framework. The findings show that emission, fuel efficiency and noise could affect the 'green index' of fleet at varying degrees, depending on both internal and external factors. It is anticipated that this study may reveal some beneficial insights for the transport operators to operate environmentally and profitably.

Keywords: Emission, Fuel Efficiency, Noise, Green Index, Environmental Sustainability

1. INTRODUCTION

Nowadays, global environmental issue becomes one of the challenges for the transport operators to sustain in such a complicated transportation system. As reported in International Civil Aviation Organization (ICAO) (2010), aviation sector accounts for about 2% of total global carbon dioxide (CO_2) emission, which is approximately 13% of the CO_2 emission from all transportation sources. In terms of greenhouse gases (GHGs), transportation sector is found to generate 13% of the global GHGs. Undeniably, there are quite a lot of critical consequences due to the existence of substantial pollutants in the air. The reported consequences includes air pollution, climate change impacts, health effects, land-use and ecosystem imbalance (Janic, 1999; Williams *et al.*, 2002; Franssen *et al.*, 2004; Jarup, 2005, Brueckner and Girvin, 2008; Prats *et al.*, 2011). Correspondingly, many alleviation approaches, namely climate change mitigation strategies, advances in alternative fuel, technological improvement and management of hazardous materials have been carried out by the relevant parties in the transportation sector (Transportation Research Board, 2012) in lessening the pollutants generated from the transport activities. Besides, various standard rules and policies had been implemented to monitor emissions. For instance, the implementation of emission trading scheme (ETS) had been enforced in reducing emission (Albers *et al.*, 2009; Rothengatter, 2010; Stanley *et al.*, 2011; Vespermann and Wald, 2011). Apparently, greater concern and increasing efforts of respective transportation sectors to preserve the environment highlight the global awareness and attentions towards environmental sustainability. In such a case, transport operators definitely play a vital role to fulfill their social responsibility in preserving the environment.

From the financial aspect, some transport operators were also suffering substantial financial losses in emitting excessive pollutants to the air. The airlines are charged £1000 for penalties in producing excessive noise (Boeing, 2011) while the vehicle that does not meet the emissions standards, the daily charge is £100 for larger vans and minibuses and £200 for lorries, buses, coaches and other heavy vehicles (Transport for London, 2012). According to ICAO (2008), it is approximated that fuel consumption accounted for 30% of total airline operating expenses. This highlights the crucial impacts of the environmental issues on the operational profit of the transport operators. Therefore, the effects of these elements should be captured accordingly for the transport operators not only to operate environmentally but also economically.

2. LITERATURE REVIEW

Many past studies had been conducted to look into the issues of environmental sustainability. Generally, the existing studies could be categorized in 2 major fields, i.e. aviation sector and non-aviation sector.

2.1 Environmental Issues in Aviation Sector

For the aviation sector, there are 3 major concerns, namely aircraft emission, fuel efficiency and aircraft noise. Recognizing the impacts of aircraft emission, Williams *et al.* (2002) showed that altitude restrictions on aircraft could be an effective means in reducing climate change effect. Miyoshi and Masan (2009) proposed a carbon calculation prototype to monitor aircraft emission while Yamaguchi (2010) discussed the voluntary CO_2 emissions reduction scheme by employing econometric analysis. With the aim to foster the utilization of environmentally friendly engine technology, the effect of airline emission charges and local emission charges were analyzed by Brueckner and Zhang (2010) and Scheelhaase (2010), respectively. Givoni and Rietveld (2010) inspected the environmental consequences upon the choice of aircraft size and service frequency. They revealed that a large aircraft would be required for short-haul operation to reduce the environmental impact.

In addition to the use of alternative fuels, demand shift and carbon pricing, Sgouridis *et al.* (2011) revealed that technological and operational efficiency improvements are significant to decrease the side effects to the environment. Besides, Janic (1999) highlighted that larger aircraft would decrease average level of noise and fuel consumption while Morrell (2009) showed that the utilization of larger aircraft is effective not only in reducing emission but also in improving fuel efficiency. Nikoleris *et al.* (2011) estimated fuel consumption and emissions during taxi operations. Their results show that idling and taxiing states at constant speed or braking were found to be two largest sources of fuel burn and emissions. Besides, Janic (2003) showed that noise and air pollution quotas have significantly affected the airport and airline's performance. Lu (2009) measured the social costs of aircraft noise and engine emission to set up environmental charges. Specifically, Girvin (2009) discussed aircraft noise-abatement and mitigation strategies while Hsu and Lin (2005), Lijesen (2010) and Brechet and Picard (2012) evaluated airport noise charge policies and the corresponding airline network adjustment response.

From the studies as mentioned above, it could be deduced that an efficient airline's strategy (including fleet planning) plays an important role in sustaining the environment. As such, the airlines need to plan properly if they were to concern the environment. Although these studies had covered environmental impacts of the aircraft emission, fuel efficiency and aircraft noise at certain extent, most studies focused on single element (emission, fuel efficiency or noise). It is important to note that in order to assure an environmentally sustainable system, the focus on single element is too restrictive as there is no single strategy that works perfectly to sustain the environment (Yang *et al.*, 2010; Sgouridis *et al.*, 2011; Nealer *et al.*, 2012). More importantly, these studies did not quantify the 'green level' which is influenced greatly by aircraft emission, fuel efficiency and noise. How these elements contribute to the 'green level' of the airlines is not explored explicitly. Therefore, the element of emission, fuel efficiency and noise are considered reasonably in this study in formulating a 'green index' model for the transport operators to operate environmentally.

2.2 Environmental Issues in Non-aviation Sector

To ease the environmental issue in other transportation sector (non-aviation sector), there are some major mitigation efforts, including land-use management, modal shift/intermodal planning, scheduling and route optimization, energy and technological enhancement, alternative fuel adoption, policy implementation and noise-abatement strategies, as reported in the literature. About the same concern as could be seen in the aviation sector, many studies focused on vehicles emission, fuel efficiency and noise.

In terms of land-use planning, Potoglou and Kanaroglou (2005) estimated vehicle emission by inspecting transportation interactions with land-use planning. They highlighted that urban integrated model is required to reduce emission. For mode shift planning, Steenhof *et al.* (2006) explored the processes leading to GHGs emission changes and assess the possible consequences in the future. They showed that GHGs emission was primarily influenced by increasing freight operations and modal shift towards heavy trucks. More recently, Nealer *et al.* (2012) inspected mode shift policies by evaluating the energy and GHG emission mitigation effectiveness. For inter-modal planning, Patterson *et al.* (2008) looked into the potential reduction of CO_2 emission by estimating the demand for inter-modal services. In terms of optimization method, Ericsson *et al.* (2006) produced route choice with the lowest fuel consumption instead of the shortest time or distance. They showed that the proposed navigation system is able to generate the best route in terms of fuel economy. To solve bus scheduling problem, Li and Head (2009) evaluated emission reduction with alternative energy sources. They pointed out that the implementation of upper bound on emission is effective in reducing emission.

To inspect energy and technological improvement, Yedla and Shrestha (2003) examined the impact of quantitative (cost, energy saving potential, emission reduction potential) and qualitative (technology availability/adaptability, implementation barriers) criteria in selecting alternative transportation options for environmentally sustainable transport system. They showed that the inclusion of qualitative criteria explains the failure of many alternative transport options. Skippon *et al.* (2012) compared the impacts of technological improvement and behaviorally-based abatement approaches by considering cumulative emission budgets. They showed that technological developments and behavioral change policies need to be applied deeply. For alternative fuel adoption, Mierlo *et al*. (2004) evaluated the assessment of vehicles with alternative types of fuels and different types of drive train. Johnston *et al*. (2012) inspected the impacts of biodiesel blending on freight emission. Their results show that the changes in emission due to biodiesel are smaller than engine and control technologies. Egilmez and Tatari (2012) proposed realistic policy options to decrease emission. They showed that the integrated approach of policy-making (by integrating fuel efficiency, public transportation and electric vehicle usage) has a crucial impact on the success of policy implementation.

With the aim to reduce noise pollution, King *et al*. (2011) quantified the effect of the 'bus gate' on noise levels. Their results show that the impact on noise levels is minimal. Calvo *et al*. (2012) evaluated the noise emission produced by a vehicle in real driving conditions and identified the noisiest driving behaviors. The results show that neither driver experience nor sex has any appreciable impact on noise generated, and engine type has little effect. Freitas *et al*. (2012) assessed traffic noise based on 3 key factors, namely payment type, traffic speed and traffic density. The findings show that higher car speeds and high traffic densities always lead to greater annoyance. Besides, cobblestones were found to be the most annoying pavements while open asphalt rubber pavement imposes less annoyance than dense asphalt.

From the literature, it is observable that the issue of environmental sustainability could be eased from various aspects. Nevertheless, these studies just focused on a specific mitigation strategy in tackling environmental impacts. As mentioned earlier, the only consideration on single factor is too restrictive. How the influential element (eg. emission, fuel and noise) affecting the overall 'green level' is not considered in these studies and thus the transport operators would not know their overall environmental performance. Therefore, a proper 'green index' model is indeed necessary to quantify environmental impacts explicitly, particularly to achieve a win-win situation between the environment and transport operators.

2.3 Evaluate Environmental Impacts

Till to date, there is very limited studies quantified environmental impacts of transportation fields. To assess the environmental impacts for a highway route and paving project, Boclin and Mello (2006) presented a decision support method and their results show that the 'park-highway' is the most promising alternative in giving the best ecological, economic and social performance. Rossi *et al*. (2009, 2012a, 2012b) examined three-dimensional concept of sustainability to interpret the preferences of the decision makers and also to identify the most important characteristics of alternative transportation policies. The limitation of these studies is that they primarily focused on transportation alternatives analysis for which there is no exact quantification approach that could be used to evaluate the green level of the environment. In other fields (not transportation system), Silver (2000) evaluated the effects of finfish mariculture on coastal zone water quality by adopting fuzzy logic approach. Four fuzzy sets (nil, moderate, severe and extreme impacts) were defined for which the corresponding partial memberships have been combined to produce a single comprehensive score as an overall measure of environmental quality. More recently, Valente *et al.* (2011) categorized old mining sites and described their environmental impact (low, medium and high). They showed that the use of fuzzy logic to obtain the environmental impact index allowed the integration of quantitative and qualitative components. Some other relevant studies in employing fuzzy logic to evaluate environmental impacts could also be seen in Phillis and Andriantiatsaholiniaina (2001) and Andriantiatsaholiniaina *et al*. (2004).

Although above-mentioned studies claimed that both quantitative and qualitative elements could be captured, the resultant outputs were only an approximation (not exact solution). The precision of the results is questionable. As such, a proper approach which can produce precise solutions is certainly necessary. Furthermore, these studies just focused on a specific evaluation at present. They did not reveal the comparison between current period and past performance. Without this component, the improvement status of a current operating period could not be identified (unless further analysis is carried out). Therefore, this study proposes a framework that is able to quantify exact environmental performance by conducting a direct evaluative comparison between current operating period and its previous performance. With this element in place, exact performance of each operating period throughout the planning horizon can be evaluated accurately. Additionally, this study is able to capture stochastic element. The fluctuation of demand level should be incorporated as it would affect the activities of the operators and hence the environmental performance measures will vary. However, none of the existing studies address this aspect in quantifying the environmental performance. To fill this gap, this study develops a ‘green index’ model that allows the transport operators to quantify the 'green level' throughout the planning horizon in response to the environmental performance and also demand fluctuation of each operating period. By capturing fleet emission, fuel efficiency and noise, a ‘green indicator’ towards the operating performance of the transport operators can be identified clearly. An illustrative case study is demonstrated to examine the feasibility of the proposed methodology. The findings show that the proposed methodology is viable, contributing to the managerial practices of the transport operators. It is anticipated that this study may reveal some informative highlights to the transport operators in order to provide a better service profitably and environmentally which would benefit the travelers and community in return.

This paper is organized as follows. Section 1 briefly discusses the concerns and impacts of the environmental sustainability. Section 2 addresses related literature review on environmental issues. Section 3 explains the formulation of ‘green index’ model. Section 4 examines the feasibility of the proposed methodology by presenting an illustrative case study with a comprehensive discussion on the computational results. Section 5 highlights the contributions of the proposed methodology as well as the managerial implications. Section 6 concludes the study and suggests the prospect research in the future.

3. METHODOLOGY

3.1 Nomenclature

For the operating period $t = 1,2,...,T$, the notations used for n types of fleet at age y are listed as follows:

<u>Parameters</u>

T	Planning horizon
D_t	Demand level
m	Status of fleet (1: new fleet, 2: aging fleet)
A_t^n	Total operated fleet
S_t^n	Aging aircraft to be sold
EX_t	Excessive emission
FEI_t	Fuel efficiency index
EXN_t^n	Excessive noise
ER_{tn}^m	Emission rate
θ	Parameter of environmental sustainability
UB_t	Upper bound of total emission
CN_t^n	Cumulative noise level
LF_t	Load factor
TN_t^n	Threshold of noise
AP_t	Average fuel price

X_t^n Quantity of new fleet to be purchased or leased
I_{ty}^n Initial quantity of fleet

Functions
$NF_n^m(D_t, A_t^n)$ Function of service frequency in terms of D_t and A_t^n
$TM_n^m(D_t, A_t^n)$ Function of traveled mileage in terms of D_t and A_t^n
$FC_n^m(D_t, A_t^n)$ Function of fuel consumption in terms of D_t and A_t^n

Decision variables
G_E Green level of emission
G_F Green level of fuel efficiency
G_N Green level of noise
GFI Green index

3.2 Formulation of Green Index

In order to capture the environmental sustainability, there are numerous factors (i.e. n factors) to be considered. This section formulates a green index (GFI) as a green indicator for the transport operator to operate environmentally in response to the green levels of relevant environmental factors. The proposed model of green index is shown in Figure 1. It could be seen that each environmental factor will basically generate different green level which will then produce the green index as an overall green indicator.

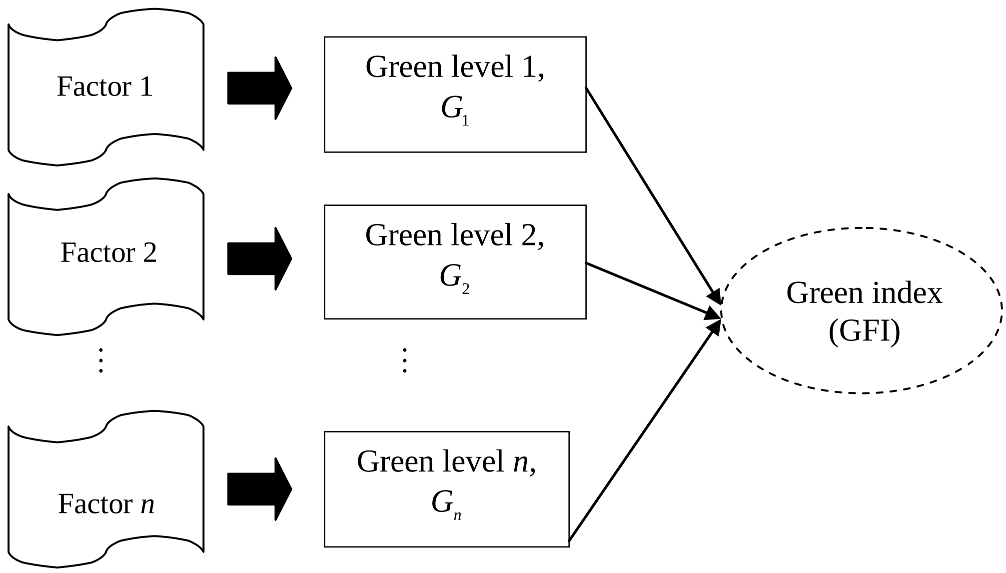

Figure 1. The model of green index (GFI)

It is important to note that the green index of fleet may vary across the level of stochastic demand. This could be justified by the quantity of fleet in operation which would generate green levels differently. In response to demand fluctuation, the proposed framework is able to quantify corresponding green index to meet probable scenarios of demand. Practically, there are 3 scenarios of demand to be considered: when there is no change of demand level (for subsequent operating periods) as well as when there is an increment or a drop of demand. Concisely, the proposed framework is able to quantify the green index of fleet accordingly for all possible changes of demand level. This is certainly crucial for the transport operators to sustain environmentally while meeting demand fluctuations.

For illustration purpose, 3 influential factors namely fleet emission, fuel efficiency and fleet noise are considered. The following section formulates green index as a green indicator for the transport operators to operate environmentally. Subsequently, the green levels of fleet emission, fuel efficiency and noise are quantified accordingly.

3.2.1 Quantify green index (GFI)

As mentioned earlier, there are 3 major factors, namely fleet emission, fuel efficiency and noise to be considered in order to capture the environmental sustainability. By capturing the green levels of these elements, the proposed model in quantifying the green index of fleet is demonstrated in Figure 2 while the corresponding scaling of green index is shown in Figure 3. The index scaling in Figure 3 shows that the index value of 1 (i.e. $GFI = 1$), which acts as the base value, implies that there is no improvement for the current operating period comparing to previous operating period. The value of green index which is greater than 1 (i.e. $GFI > 1$) indicates that current operating period outperforms previous period. Conversely, the value of green level which is less than 1 (i.e. $GFI < 1$) signifies that previous operating period performs better than current operating period. In other words, a higher index signifies the achievement of a higher green level. In such a case, the elements of the green level of fleet emission (G_E), fuel efficiency (G_F) and fleet noise (G_N) with the value less than 1 refers to an unsatisfactory condition for a current operating period while the value more than 1 shows an improvement in current operating period. Generally, the function of green index, GFI is defined as follows.

$$\text{Green index, } GFI(I_t) = \frac{1}{n}\sum_{\forall i} G_i,\ i \in n \tag{1}$$

for which I_t denotes the initial quantity of fleet to be supplied by the transport operators in order to meet travelers' demand. By considering n environmental factors, Equation (1) is able to quantify the resultant green index of fleet while meeting stochastic demand (by having I_t in operation).

By taking into consideration the elements of emission, fuel efficiency and noise, i.e. when $n = 3$, the green index of fleet can be expressed as follows:

$$\text{Green index, } GFI(I_t) = \frac{G_E + G_F + G_N}{3} \tag{2}$$

where the computation of the green levels of G_E, G_F and G_N are discussed in the following section. As addressed earlier, the element of $GFI(I_t) = \frac{G_E + G_F + G_N}{3} = \frac{1+1+1}{3} = 1$ serves as a base value, i.e. there is no improvement in terms of the green levels of fleet emission, fuel efficiency and noise of a current operating period. $GFI(I_t) > 1$ signifies that there is a promising improvement in terms of the green levels of fleet. Operationally, this can be achieved by improving G_E, G_F and G_N for the green level of emission, fuel efficiency and noise, respectively (note that the index scaling as illustrated in Figure 3 also applies to the green levels of emission, fuel efficiency and noise).

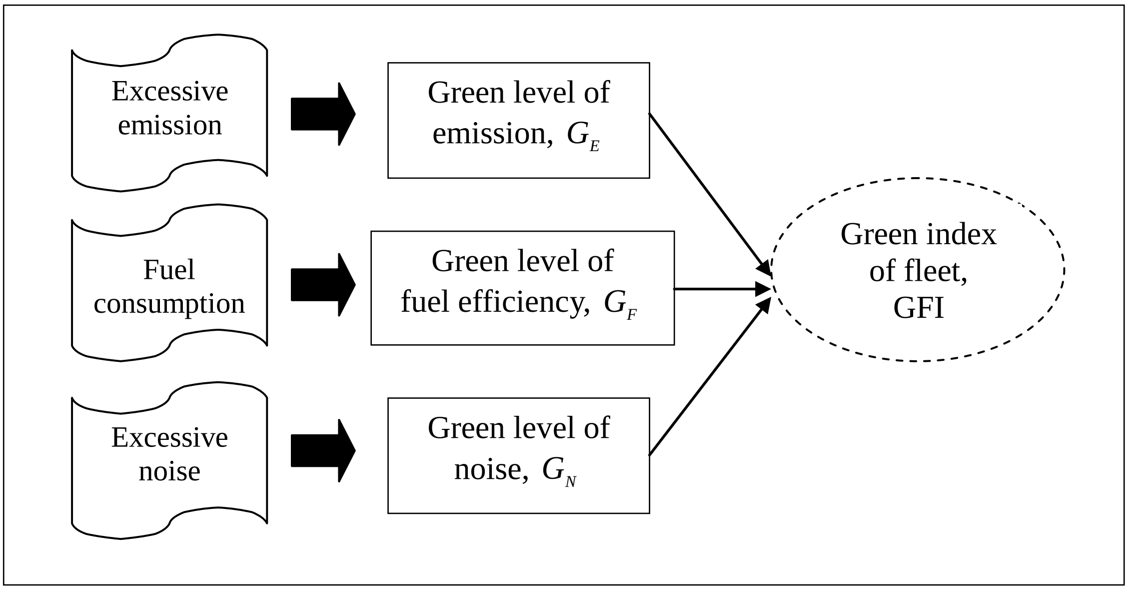

Figure 2. The quantification model of green index

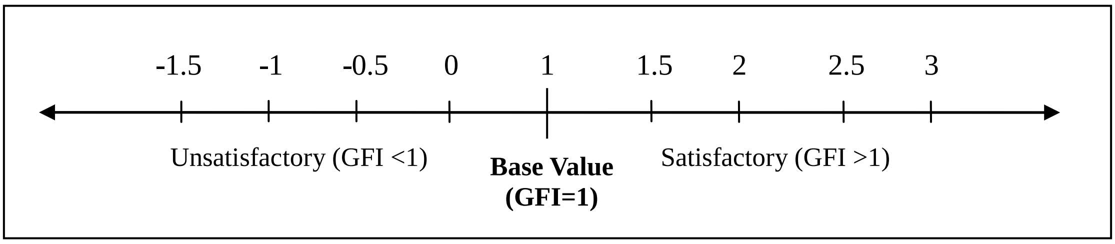

Figure 3. The scaling of green index

3.2.2 Quantify the green level of fleet emission

For the green level of fleet emission, total emission emitted from fleet activities including excessive emission of each operating period is considered accordingly. These elements are important to be captured in order to ensure that the operations of the transport operators adhere to the compliant regulations while playing their roles in sustaining the environment. For instance, the airlines have to ensure that their operations meet the standard limit of aircraft engine emission as determined by ICAO (International Civil Aviation Organization, 2008). In order to determine the green level of fleet emission for a particular operating period, the excessive emission can be computed as follows (by considering the difference of total emission and the compliant upper limit of emission):

$$EX_t = LF_t\left(\sum ER_{tn}^m NF_n^m\left(D_t, A_t^i\right)\right) - UB_t,\ t = 1, 2, ..., T, n = 1, 2, ..., N, m = 1, 2 \quad (3)$$

It is important to note that the element of excessive emission is positive, i.e. $EX_t > 0$ if the total emission is greater than the upper bound of emission. Conversely, $EX_t < 0$ implies that the total emission of a particular operating year is under control (not reaching the upper bound of emission) while $EX_t = 0$ signifies that the total amount of emission is up to the allowable upper bound and hence there is no excessive emission. In such a case, $EX_t \leq 0$ is desirable while $EX_t > 0$ is undesirable for the transport operators because some emission penalties or charges will be imposed on the transport operators for emitting (excessive) substantial emission.

Generally, the green level of emission, G_E can be computed directly by comparing the operating performance of a current operating period with previous operating period, i.e. by getting the difference of excessive emission of the operating period t and $t-1$, which is possible to be zero or non-zero (i.e. positive or negative). This reflects the real situation of the possible excessive emission from the transport activities. Accordingly, the green level of fleet emission can be expressed as follows:

$$G_E = \begin{cases} 1+\dfrac{\Delta EX}{EX_{t-1}}, & EX_{t-1} \neq 0 \\ 1, & EX_t = EX_{t-1} = 0 \\ 0, & EX_{t-1} = 0, EX_t > 0 \\ 2, & EX_{t-1} = 0, EX_t < 0 \end{cases} \tag{4}$$

where $\Delta EX = |EX_t - EX_{t-1}|$. Comparatively, when two successive period produce different excessive emission (i.e. $EX_t, EX_{t-1} > 0$, $EX_t, EX_{t-1} < 0$, $EX_t > 0, EX_{t-1} < 0$ or $EX_t < 0, EX_{t-1} > 0$), the corresponding green level can be computed accordingly by evaluating the ratio of the difference of excessive emission (of both period) and excessive emission of previous period. By doing this, the improvement status of current operating period could be identified. If the current operating period has a better performance than its previous period, the resultant green index is $G_E > 1$ otherwise $G_E < 1$ which means that previous operating period performs better. $EX_t = EX_{t-1} = 0$ signifies that current operating period does not produce excessive emission, i.e. it has the same level with its previous period. Since both period do not show any improvement (in reducing emission), the resultant green level remains as 1. For $EX_{t-1} = 0, EX_t > 0$, the resultant green level is 0 owing to a credit (i.e. index) of -1 which is given to current operating period because it performs worst than its previous period. On the other hand, $EX_{t-1} = 0, EX_t < 0$ implies that current operating period performs better than its previous period. Therefore, the resultant green level is found to double the base value (i.e. 2) due to the fact that a credit (i.e. index) of 1 is given to current operating period for its better performance. This leads to a total index of 2 (i.e. the sum with the base value of 1).

3.2.3 Quantify the green level of fuel efficiency

It is anticipated that fleet is more fuel-efficient if it utilizes less fuel in servicing the operating networks. Less fuel consumption for a particular fleet (e.g. new fleet) is beneficial to the transport operators to travel further. Therefore, total traveled mileage and total fuel consumption are considered in quantifying the green level of fuel efficiency. This highlights that from the management and operational perspectives, the transport operators should consider their fleet planning wisely, especially in getting new fleet (via acquisition or leasing) in order to assure fuel efficiency while meeting stochastic demand operationally. Mathematically, the fuel efficiency index, FEI_t can be expressed as follows:

$$FEI_t = \frac{\sum TM_n^m}{\sum FC_n^m}, t = 1, 2, ..., T, n = 1, 2, ..., N, m = 1, 2 \tag{5}$$

Generally, the green level of fuel efficiency can be computed by comparing the operating performance of a current operating period with previous operating period, i.e. based on the fuel efficiency index of operating periods t and $t-1$. By doing this, the green level of fuel efficiency, G_F can be defined as follows:

$$G_F = 1 + (FEI_t - FEI_{t\text{-}1}), t = 1, 2, ..., T \quad (6)$$

As mentioned earlier, green level of 1 signifies that there is no improvement of current operating period comparing to its previous period. It is anticipated that $G_F < 1$ if previous operating period outperforms current operating period (when $FEI_t = 0, FEI_{t\text{-}1} > 0$). Conversely, the situation of $FEI_t > 0, FEI_{t\text{-}1} = 0$ would result in the value of G_F which is greater than 1 (i.e. $G_F > 1$) due to the fact that the fuel efficiency index of current operating period is higher than its previous period. For $FEI_t = FEI_{t\text{-}1}$, it could be seen that $G_F = 1$ for the same performance of two successive period.

3.2.4 Quantify the green level of fleet noise

In order to quantify the green level of fleet noise, total noise emitted (including excessive noise is there is any) during the fleet operations of each operating period is considered in order to ensure that the operations of the transport operators adhere to the compliant regulations. By taking into account the difference of cumulative noise level of fleet and permitted noise threshold, excessive noise level can be evaluated as follows:

$$EXN_t^i = CN_t^i NF_i - TN_t^i NF_i, t = 1, 2, ..., T, i = 1, 2, ..., n \quad (7)$$

Operationally, cumulative noise level of fleet can be computed based on the total service frequency of fleet of a particular operating period. This highlights that the service frequency of fleet and the corresponding cumulative level needs to be planned and controlled wisely due to the great impacts to the community as well as the transport operators. In such a case, how to ensure that the total cumulative noise level does not exceed the threshold of fleet needs to be captured. For instance, some airports set a particular threshold of aircraft noise for which the airlines exceed the threshold have to pay noise charges as a penalty. For Equation (7), the element of excessive noise level which is positive (i.e. $EXN_t^i > 0$) shows that the cumulative noise level is more than the permitted threshold. This is an undesirable situation for the transport operators as they need to pay more for excessive noise level. On the other hand, $EXN_t^i < 0$ implies that the cumulative noise level of a particular operating period is lesser than the allowable limit (under control) while $EXN_t^i = 0$ signifies that the cumulative noise is equivalent to the allowable limit (i.e. no excessive noise).

Similar to the concept in quantifying the green level of fleet emission (as described in section 3.2.2), the green level of noise can be computed by comparing the operating performance of a current operating period with its previous period, i.e. based on the excessive noise of operating periods t and $t-1$. Similarly, the green level of noise, G_N for two consecutive operating period could be defined as follows:

$$G_N = \begin{cases} 1 + \dfrac{\Delta EXN}{EXN_{t-1}^i}, & EXN_{t-1}^i \neq 0 \\ 1, & EXN_t^i = EXN_{t-1}^i = 0 \\ 0, & EXN_{t-1}^i = 0, EXN_t^i > 0 \\ 2, & EXN_{t-1}^i = 0, EXN_t^i < 0 \end{cases} \quad (8)$$

where $\Delta EXN = \left| EXN_t^i - EXN_{t-1}^i \right|$. Basically, when two consecutive periods produce excessive noise differently, the corresponding green level can be computed by evaluating the ratio of the difference of excessive noise (of both period) and excessive noise of previous period. If the current operating period performs better than its previous period, the resultant green index is $G_N > 1$. Otherwise, $G_N < 1$ implies that previous operating period has a better performance. $EXN_t^i = EXN_{t-1}^i = 0$ signifies that current and previous operating periods do not produce excessive noise, i.e. they have no improvement in reducing noise level and hence the resultant green level remains as 1. For the cases of $EXN_{t-1}^i = 0, XN_t^i > 0$ and $EXN_{t-1}^i = 0, EXN_t^i < 0$, the resultant green levels are 0 and 2, respectively owing to a credit (i.e. index) of -1 and 1 are given respectively to current operating period.

4. AN ILLUSTRATIVE CASE STUDY

In order to examine the applicability of the proposed model, this section carries out a case study focusing on the airline industry with the aim to quantify the green levels of aircraft emission, fuel efficiency and aircraft noise. The case study demonstrates how these 3 factors (i.e. aircraft emission, fuel efficiency and aircraft noise) constitute to the green index as a green indicator for the airlines to operate environmentally.

4.1 Data Description

In this case study, 2 types of aircraft i.e. A320-200 and A330-300 are considered for a set of OD pairs. Only 2 types of aircraft are considered as many of the low-cost carriers operate their business with few varieties of aircraft types (O'Connell and William, 2005). In addition, a planning horizon of 5 years is also justified as according to Malaysia Airlines (2010) and AirAsia Berhad (2010), the acquisition of new aircraft, in average, requires a period of 5 years to be delivered completely. Table 1 shows the emission rate of aircraft, by considering 3 major pollutants i.e. nitrogen oxides (NO_x), hydrocarbons (*HC*) and carbon monoxide (*CO*) which are emitted during the landing and take-off (LTO) stage (International Civil Aviation Organization, 2011a).

Table 1. Aircraft emission during LTO stage

Aircraft	Amount of $NO_x + HC + CO$ (kg/aircraft)
A320-200	12
A330-300	29

A benchmark problem is created to test the applicability of the proposed methodology in quantifying the green levels of emission, fuel efficiency and noise as well as the corresponding green index for each operating period. Most of the values for the input data are obtained from the published reports (AirAsia Berhad, 2010; Malaysia Airlines, 2010; Airbus, 2010; ICAO, 2011b). These values are shown as follows:

By assumption:

- At $t = 1$, initial quantity of aircraft to be 3 years old is $I_{13}^1 = I_{13}^2 = 4$
- Parameter of environmental sustainability, $\theta = 96.5\%$

By assumption (based on real data):

- At $t = 1$, initial quantity of aircraft is $I_1^1 = I_1^2 = 50$
- Load factor of aircraft, $LF_t^n = 77\%$

- Upper bound of emission, $UB_t = 20,000$ tonnes $= 2\text{x}10^7\, kg$
- Cumulative aircraft noise, $CN_t^1 = 270.2$ EPNdB and $CN_t^2 = 287.5$ EPNdB
- Threshold of noise, $TN_t^n = 265$ EPNdB
- Average fuel price, $AP_t = \$89$ per barrel
- For *n* types of aircraft, the function of the number of flights is

$$NF = 22.57\left(A_t^n\right)^2 - 9.776\text{x}10^2 A_t^n + 7.83\text{x}10^4 \quad [\text{R}^2 = 0.97] \tag{9}$$

- The function of the traveled mileage is

$$TM = 2,066NF - 2,875,383 \quad [\text{R}^2 = 0.83] \tag{10}$$

- For *n* types of aircraft, the function of fuel expenses is

$$FE = 7.46NF + 8.3\text{x}10^{-5} NF^2 - 98,572 \quad [\text{R}^2 = 0.88] \tag{11}$$

From the operational aspect, load factor is a measure of the amount of utilization of the total available capacity of aircraft. In average, load factor of 77% as stated above signifies that the occupancy of the operating aircraft is up to 77% throughout the planning horizon. To alleviate fleet emission, upper bound of emission refers to compliant limit of emission that can be emitted by the aircraft in operation. As mentioned earlier, the airlines have to ensure that their emissions are under the regulated limits as determined by ICAO (International Civil Aviation Organization, 2008). If the total emission exceeds the allowable limit, the airlines will be fined with emission penalty. Similar rules apply in controlling noise pollution for which the threshold of noise refers to maximum level of noise that can be generated from the aircraft activities. Comparatively, the cumulative noise level refers to the accumulated noise level from the aircraft operations, through three major stages, i.e. lateral, flyover and approach.

Based on the data as reported by Malaysia Airlines (2010) and AirAsia Berhad (20101), Equations (9)-(11) are obtained by conducting polynomial regression analysis. The regression analysis shows that Equations (9)-(11) are fitted well as non-linear functions in terms of total operated aircraft, A_t^n. Equation (9) indicates that the number of flights is affected by total operated aircraft (which could be gained from the aircraft acquisition and leasing). Equation (10) denotes that a flight flies 2,066 kilometres in average. Equation (11) shows that total fuel expenses depend on the number of flights, which are operated during the planning horizon. This implies that the fuel expenses associate with the total operated aircraft, A_t^n which is very much depending on the fleet management decision. By considering the ratio of fuel expenses and average fuel price, total fuel consumption could be obtained. In order to compute the emission rate of new aircraft, parameter of environmental sustainability, i.e. θ is needed. It is anticipated that new aircraft emits less emission comparing to aging aircraft and hence it is assumable that $\theta = 96.5\%$. The multiplication of θ and the emission rate of aging aircraft would give the emission rate of new aircraft. In terms of the variation of demand for the benchmark problem, 3 specific scenarios are considered in order to capture demand fluctuation throughout the planning horizon. These scenarios are outlined as follows:
Scenario 1 (S1): there is no change of demand level, i.e. $\Delta D_t = 0$
Scenario 2 (S2): there is an increment of demand level, i.e. $\Delta D_t > 0$
Scenario 3 (S3): there is a fall of demand level, i.e. $\Delta D_t < 0$
for which $\Delta D_t = D_t - D_{t-1}$.

4.2 Sensitivity Analysis

In order to investigate the impact of changes of the inputs to the computational results, 4 additional cases with variations to some of the modeling parameters used in the benchmark problem are outlined as follows:

- Cases A and B have the load factor of 65% and 85%, respectively
- Cases C and D have the noise threshold of 250EPNdB and 285EPNdB, respectively.

4.3 Results and Discussion

4.3.1 Results for benchmark problem

Generally, the results of benchmark problem show that the green index varies greatly in accordance to demand fluctuation and the quantity of aircraft. The results of operating period 3 are illustrated in Table 2 (for the brevity, the results for other operating period are not shown in this paper). As shown in Table 2, there are 27 possible demand combinations, i.e. $(3\,\text{scenarios of demand})^t = 3^3 = 27$ for the operating period 3. For instance, scenario S1S2S3 implies that operating period 1 has no change in terms of demand level, operating period 2 have an increase of demand while operating period 3 has a drop in demand.

In terms of different demand level, the findings show that the green levels of scenario S3 (with a fall of demand) tend to be higher than scenario S2 (with an increment of demand), leading to a higher green index for scenario S3 comparing to scenario S2 throughout the planning horizon. This happens mainly due to the increment of demand level of scenario S2 which involves more aircraft operations, which show a higher tendency to emit more pollutants. As such, it could be seen that the green index associates closely with the level of demand for which the green index is found to be inversely proportional to the demand level. In other words, a higher level of demand results in a lower green index.

In terms of the quantity of aircraft throughout the planning horizon, it could be seen that more aircraft at the beginning of a particular operating period tends to produce a lower green levels of emission, fuel efficiency and noise, i.e. the green level tends to be higher with a lower total aircraft in operation. This could be explained by the aircraft activities which would produce more emission and noise with a higher service frequency. Scenario S2 (with increment of travel demand) has a higher service frequency than scenario S3 (with a fall of travel demand) and hence scenario S2 produces a lower green index compared to scenario S3. Thus, it could be deduced that the green index is also inversely proportional to the quantity of aircraft in operation (primarily due to the service frequency).

From Table 2, it is interesting to see that the findings of scenario S1 is reasonably similar with the results of scenario S3 as the total aircraft in operation for scenario S1 (with no change in terms of demand level) is the same as the total aircraft for scenario S3. Although scenario S3 has a lower level of demand comparing to the scenario S1, the airline would not make immediate decision to sell some aircraft due to the fact the sales of aging aircraft in fact requires selling time duration to look for prospective buyer in advance. As such, the quantity of aircraft as outlined for scenarios S1 and S3 (as shown in Table 2) remains the same. This finding highlights that the green index associates closely with the fleet planning of the airlines, especially to meet demand fluctuation. For the airlines, this is crucial if they were concern to the environment.

As displayed in Table 2, some of the green levels of the emission, fuel efficiency and noise are greater than 1 while some are smaller than 1. As mentioned earlier, the value of green level that is greater than 1 indicates an improvement while the value less than 1 implies unsatisfactory performance for which the aircraft operations of a particular operating period is found to emit more pollutants (produce more emission or noise) and operate less fuel-efficient aircraft. For instance, the green index of the scenario S1S1S1 is negative (i.e. -0.50) mainly due to the green level of fuel efficiency which is nonpositive (-3.49). This signifies that in terms of the green level of fuel efficiency, operating period 2 outperforms operating period 3. In other words, operating period 2 is more fuel-efficient, which is approximately 4 times more efficient than operating period 3. In overall, the green index of operating period 3 is undesirable (as -0.50 is a negative number) although the green levels of emission and noise are nonnegative. This reveals that the resultant green index (could be a negative index) for a particular operating period is relatively depending on the integrative elements of emission, fuel efficiency and noise. For the airlines to sustain environmentally, this highlight is important as there is no single element that could perfectly guarantee a desired green level.

Table 2. The results of operating period 3 for the benchmark problem

Ref no.	Scenario (Y1Y2Y3)	I_3^1	I_3^1	X_3^1	X_3^2	S_3^1	S_3^1	EX_3 (10^6)	EXN_3^n (10^3)	FEI_3	G_E	G_N	G_F	GFI
1	S1S1S1	50	50	0	0	4	4	-198	209	43.19	1.00	1.00	-3.49	-0.50
2	S1S1S2	60	60	5	5	4	4	-194	881	30.20	0.98	-2.22	-16.49	-5.91
3	S1S1S3	50	50	0	0	4	4	-198	209	43.19	1.00	1.00	-3.49	-0.50
4	S1S2S1	50	50	0	0	4	4	-198	209	43.19	1.07	1.67	6.88	3.20
5	S1S2S2	60	60	5	5	4	4	-194	881	30.20	1.05	0.59	-6.12	-1.49
6	S1S2S3	50	50	0	0	4	4	-198	209	43.19	1.07	1.67	6.88	3.20
7	S1S3S1	50	50	0	0	4	4	-198	209	43.19	1.00	1.00	-3.49	-0.50
8	S1S3S2	60	60	5	5	4	4	-194	881	30.20	0.98	-2.22	-16.49	-5.91
9	S1S3S3	50	50	0	0	4	4	-198	209	43.19	1.00	1.00	-3.49	-0.50
10	S2S1S1	50	50	0	0	4	4	-198	209	43.19	1.00	1.00	-3.49	-0.50
11	S2S1S2	60	60	5	5	4	4	-194	881	30.20	0.98	-2.22	-16.49	-5.91
12	S2S1S3	50	50	0	0	4	4	-198	209	43.19	1.00	1.00	-3.49	-0.50
13	S2S2S1	50	50	0	0	4	4	-198	209	43.19	1.00	1.67	6.88	3.18
14	S2S2S2	60	60	5	5	4	4	-194	881	30.20	0.99	0.59	-6.12	-1.51
15	S2S2S3	50	50	0	0	4	4	-198	209	43.19	1.00	1.67	6.88	3.18
16	S2S3S1	50	50	0	0	4	4	-198	209	43.19	1.00	1.00	-3.49	-0.50
17	S2S3S2	60	60	5	5	4	4	-194	881	30.20	0.98	-2.22	-16.49	-5.91
18	S2S3S3	50	50	0	0	4	4	-198	209	43.19	1.00	1.00	-3.49	-0.50
19	S3S1S1	50	50	0	0	4	4	-198	209	43.19	1.00	1.00	-3.49	-0.50
20	S3S1S2	60	60	5	5	4	4	-194	881	30.20	0.98	-2.22	-16.49	-5.91
21	S3S1S3	50	50	0	0	4	4	-198	209	43.19	1.00	1.00	-3.49	-0.50
22	S3S2S1	50	50	0	0	4	4	-198	209	43.19	1.00	1.67	6.88	3.18
23	S3S2S2	60	60	5	5	4	4	-194	881	30.20	0.99	0.59	-6.12	-1.51
24	S3S2S3	50	50	0	0	4	4	-198	209	43.19	1.00	1.67	6.88	3.18
25	S3S3S1	50	50	0	0	4	4	-198	209	43.19	1.00	1.00	-3.49	-0.50
26	S3S3S2	60	60	5	5	4	4	-194	881	30.20	0.98	-2.22	-16.49	-5.91
27	S3S3S3	50	50	0	0	4	4	-198	209	43.19	1.00	1.00	-3.49	-0.50
										Average	1.00	0.39	-4.37	-0.99

4.3.2 Results for sensitivity analysis

For the results of sensitivity analysis (as shown in Tables 3-4), case A with load factor 65% is found to emit less emission comparing to the benchmark problem and case B with load factor 77% and 85%, respectively. This could be justified by the total weight of aircraft (inclusive travelers and baggage) which would affect the amount of emission directly. In other words, when the load factor increases (i.e. total weight of aircraft increases), there is more emission and hence the green level of emission decreases accordingly. The results of cases A and B (in Table 3) display that the green level tends to be higher for a lower load factor, i.e. case A produces the highest green level, followed by the benchmark problem and case B. However, for the operating periods 2-4, the green level of emission of case A is the lowest although it produces less emission. This happens primarily owing to the comparison of the emission amount of current operating period with previous operating period, which reflects a better improvement for case B and benchmark problem.

Table 3. The results of the sensitivity analysis for different load factors

		EX_t (10^5)	$EXN_t^n (10^3)$	FEI_t	G_E	G_N	G_F	GFI
Operating period 1	Benchmark problem	-194.42	273	45.84	2.0000	0.0000	1.0000	1.0000
	Case A	-195.29	273	45.84	2.0000	0.0000	1.0000	1.0000
	Case B	-193.84	273	45.84	2.0000	0.0000	1.0000	1.0000
Operating period 2	Benchmark problem	-196.00	348	44.23	1.0160	0.7611	-0.6089	0.3894
	Case A	-196.62	348	44.23	1.0134	0.7611	-0.6089	0.3885
	Case B	-195.58	348	44.23	1.0178	0.7611	-0.6089	0.3900
Operating period 3	Benchmark problem	-196.47	433	38.86	1.0029	0.3879	-4.3673	-0.9922
	Case A	-197.02	433	38.86	1.0024	0.3879	-4.3673	-0.9923
	Case B	-196.11	433	38.86	1.0033	0.3879	-4.3673	-0.9920
Operating period 4	Benchmark problem	-197.29	364	45.89	1.0042	0.7029	8.0348	3.2473
	Case A	-197.71	364	45.89	1.0035	0.7029	8.0348	3.2471
	Case B	-197.01	364	45.89	1.0047	0.7029	8.0348	3.2475
Operating period 5	Benchmark problem	-196.30	461	44.43	0.9951	-2.3368	-0.4657	-0.6025
	Case A	-196.87	461	44.43	0.9959	-2.3368	-0.4657	-0.6022
	Case B	-195.91	461	44.43	0.9946	-2.3368	-0.4657	-0.6026

From the results of cases C and D (as shown in Table 4), it is observable that the variation of the threshold of noise could affect the green level of noise at varying degrees. When the threshold of noise increases, it is less likely for the airlines to exceed the allowable noise level as the airlines have a greater control to monitor their cumulative noise level. The results in Table 4 show that case D (with 285 EPNdB) does not have excessive noise while the excessive noise of case C (with 250 EPNdB) is greater than the benchmark problem (with 265 EPNdB). This could be explained as case C has the lowest allowable limit (followed by the benchmark problem and case D) and hence it is most likely for case C to exceed the permitted threshold. Besides, it is also interesting to see that the benchmark problem, cases C and D generates same green index although respective scenarios produces different amount of excessive noise. This is possible due to the comparison of the excessive noise of a particular operating period with previous operating period for which the respective scenario generate similar improvement. Therefore, the green indexes for all scenarios (as shown in Table 4) demonstrate same values. This highlights that stringent compliance rules (or thresholds) are effective in reducing excessive noise of the aircraft although the resultant green index may display same numerical value across compliant thresholds.

It is important to note that the resultant green index is relatively depending on 2 major factors, i.e. internal and external factors. Internal factor refers to the component that is directly related to the operations, for instance the quantity of aircraft for a particular operating period and its load factor. On the other hand, the external factor refers to the aspect including compliant facet that is not under the control of the airlines, for instance the threshold noise level at the airport and also the demand fluctuation under uncertainty. Therefore, a proper framework by incorporating both internal and external factors is necessary for the airlines in order to assure an effective improvement in response to the environmental sustainability.

Table 4. The results of the sensitivity analysis for different thresholds of noise

		EX_t (10^5)	$EXN_t^n (10^3)$	FEI_t	G_E	G_N	G_F	GFI
Operating period 1	Benchmark problem	-194.42	273	45.84	2.0000	0.0000	1.0000	1.0000
	Case C	-194.42	569	45.84	2.0000	0.0000	1.0000	1.0000
	Case D	-194.42	-23	45.84	2.0000	0.0000	1.0000	1.0000
Operating period 2	Benchmark problem	-196.00	348	44.23	1.0160	0.7611	-0.6089	0.3894
	Case C	-196.00	725	44.23	1.0160	0.7611	-0.6089	0.3894
	Case D	-196.00	-289	44.23	1.0160	0.7611	-0.6089	0.3894
Operating period 3	Benchmark problem	-196.47	433	38.86	1.0029	0.3879	-4.3673	-0.9922
	Case C	-196.47	902	38.86	1.0029	0.3879	-4.3673	-0.9922
	Case D	-196.47	-360	38.86	1.0029	0.3879	-4.3673	-0.9922
Operating period 4	Benchmark problem	-197.29	364	45.89	1.0042	0.7029	8.0348	3.2473
	Case C	-197.29	757	45.89	1.0042	0.7029	8.0348	3.2473
	Case D	-197.29	-302	45.89	1.0042	0.7029	8.0348	3.2473
Operating period 5	Benchmark problem	-196.30	461	44.43	0.9951	-2.3368	-0.4657	-0.6025
	Case C	-196.30	961	44.43	0.9951	-2.3368	-0.4657	-0.6025
	Case D	-196.30	-383	44.43	0.9951	-2.3368	-0.4657	-0.6025

5. IMPLICATIONS FOR MANAGERIAL AND OPERATIONAL PRACTICES

A proper framework in quantifying green index is necessary for the transport operators to operate profitably and environmentally under uncertainty. In fact, the proposed framework can be applied in any other industry which has a concern on the environment. Practically, the proposed framework (which can be subsequently incorporated into any relevant managerial/operational strategy, e.g. a well-developed fleet management model for fleet planning) is playing a vital role from 3 major perspectives namely social, supply and demand as well as sustainability as addressed below:

From the aspect of social:
- to reduce the pollutants in preserving the environment
- to generate ‘greener’ fleet, leading to a healthier community

From the aspect of supply and demand:
- to manage fleet planning strategically in an environmental friendly manner
- to meet stochastic demand economically and environmentally
- to improve operations system (for performance enhancement)

From the aspect of sustainability:
- to assure profitable operations (in reducing emission costs and fuel consumption)
- to assure the benefits of stakeholders profitably and environmentally
- to promote the good name by increasing the status of the transport operators

For the transport operators, the aspects as addressed above can be achieved satisfactorily by practicing a well-balanced operating system (i.e. by incorporating environmental concerns in managerial and operational system). Theoretically or practically, it could be deduced that green index as an environmental indicator is extremely significant for the transport operators to assure that the operating network is operated in an environmental friendly fashion, which is beneficial to the transport operators (from three aspects as mentioned above). This shows that there is a strong linkage between the proposed framework and the managerial/operational practices. However, there is a theoretical/practical gap that needs to be tackled wisely. Although it could not be denied that the environmental concerns may not be the utmost priority for the transport operators due to the main concern on the operational profit, it is important to note that in fact the environmental costs (as parts of the operating expenses) would affect the optimal profit at varying degrees, especially for long-term fleet planning. As such, a balance between the environment and the profit of the airlines should be maintained. Only by capturing both priorities (i.e. environmental sustainability and operational profit) concurrently, a win-win situation can be achieved. Besides, as revealed by the literature (Yang *et al.*, 2010; Sgouridis *et al.*, 2011; Nealer *et al.*, 2012), there is no perfect single strategy due to the fact that the operational and managerial decision is decisively depending on many inter-correlated factors, e.g. the management policy of the transport operators, standard compliant rules as well as the fleet and resources availability. Therefore, the proposed framework may be altered necessarily to work out a desired operating system, particularly to move one more step further from current footprint (performance).

6. CONCLUSIONS

This study proposed a novel framework to quantify 'green index' by specifically focusing on the elements of fleet emission, fuel efficiency and fleet noise. The proposed study reflects the actual situation of the transportation industry in response to the challenges of the environmental sustainability and demand fluctuation. The proposed framework is able to evaluate possible green index for varying demand. The results of the illustrative case study demonstrated that the proposed framework is sensitive to the modeling parameters as well as stochastic demand. Specifically, green index was found to be disproportionally with the stochastic demand, quantity of fleet in operation as well as its load factor. Besides, the resultant green index was significantly affected by some external factors, including the compliant limits of noise and emission. Certainly, these aspects are important for the transport operators in making managerial decision environmentally, especially in fleet planning. Nevertheless, there are some shortcomings to be improved. This study mainly focused on three environmental factors, which are practical yet the modeling may seems to be simplistic at certain extent. A more comprehensive model may be developed in capturing more influential factors. In order to sustain economically, the operational profit of the transport operators should be considered. For future research, an optimization model will be developed to capture both objectives (profit and green index) in order to work out an optimal green fleet management model. Besides, the demand of travelers is fluctuating and uncertain due to various uncertainties, such as global economic conditions and natural disaster. Therefore, the level of stochastic demand caused by these uncertainties should be captured and incorporated in the fleet management model. This will be left for future research.

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