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Performance assessment for airport noise charge policies and airline network adjustment response

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Abstract

Noise charges have been introduced at major airports to mitigate external noise. This research investigated airline network design, by considering aircraft noise charges, and analyzing the performance of airport noise charge policies, from multiple perspectives. We formulated an airline network design model for minimizing airline operating costs, to determine optimal air routes and flight frequencies, as well as types of aircraft, in response to airport noise charges. We further assessed the performance of different noise charge policies by evaluating changes in airport operating profits and the social cost to residents surrounding the airport. An empirical example, using the Chiang Kai-Shek International Airport, illustrates how airports should determine optimal noise charge policies, from different perspectives. The results show that airlines may adjust types of aircraft, flight frequencies and flight routes, in response to hub airport noise charge policies, which may lead to changes in social costs, airport revenues, and weekly aircraft schedules. Landing fees setting may, in addition, affect the control an airport has over social costs, due to noise surcharges.

Keywords: Noise charges; Environmental cost; Aircraft type; Flight frequency

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1. Introduction

Since the 1978 airline deregulation in the US the hub-and-spoke structure has become a mainstream airline network system. A hub airport not only attracts more business, and boosts air transportation demand, but also exacerbates the problem of noise nuisance, air pollution, air safety and congestion (Nero and Black, 1998; Janic, 1999). Of these problems, noise nuisance is undoubtedly the most significant. Environmental externalities are factors that cause market failure; that is, related damage costs cannot be eliminated through market mechanisms. Environmental economists advocate incentive-based (IB) environmental regulations, in an attempt to internalize these external costs, through government intervention. An airport noise charge is an example of environmental regulations, considered to be an effective and economic way to offset these externalities; in addition, noise charges may encourage airlines to voluntarily eliminate pollution, thus minimizing operating costs.

A noise surcharge or a discount on aircraft landing fees is applied at most airports, according to aircraft noise levels. The application of discounts for quieter aircraft and noise surcharges for noisier aircraft is an encouragement to airlines to use more ‘‘silent’’ aircraft. Airlines’ costs increase as they add more flights departing from or arriving at airports that charge fees for high noise levels. In response to this increase in operating costs, airlines may reduce the number of flights, or cancel landings at those airports, which are noise sensitive. This can cause re-allocation of the airline’s routes and flight frequencies. There is thus a trade-off between a decrease in profits, due to the elimination of flights, and an increase in costs, because of airport noise charges. To fulfill the demand, there is a choice between using large aircraft, which may generate higher noise costs per landing but can carry more passengers, and small aircraft, which may have lower noise costs, but require more flights. From the airport’s perspective, the busier the airport, the higher the noise fee, charged per landing, to offset the environmental damage and compensate surrounding communities for the noise impact. However, airports may realize a reduction in flights and, consequently, operating revenue, if they increase aircraft noise charges. They must deal with the trade-off between environmental improvement and revenue losses, when determining noise charge policies. Consequently, an airline’s network design and an airport’s noise penalties have a high correlation.

The externality of the environment, and its impact on both airline operating costs and network structure, has not received the attention it deserves. Carlsson (1999) studied the performance of various noise control policies, but did not provide quantitative results. Hayashi and Trapani (1987) discussed the impacts of different environmental regulations on airline flight frequencies and fares, using economic concepts. Nero and Black (1998) focused on environmental externalities using a conceptual spatial model, addressing the environmental impacts related to extensive hubbing.

Alamdari and Brewer (1994) analyzed airlines’ operating policies in response to increased aircraft fuel tax. Kanafani and Ghobrial (1985) investigated the impacts of airline hubbing on airport economics and found that charging airport congestion costs had little impact on airline hubbing, but could make airlines reduce flight frequencies. Janic (2003) modeled network performance by using integer programming techniques, to maximize total network profits for given operational capacity and environmental constraints, under conditions where environmental externalities were internalized. To summarize, few studies have combined network modeling and economic theory to formulate integrated models analyzing airport noise charge policies, which also accommodate the airlines' network adjustment responses.

This study has focused on passenger airlines, with air routes, types of aircraft and flight frequencies being decision variables, determined to meet an airline's cost optimization, subject to satisfying customer demand, while considering environmental regulations. Since noise costs are the most significant environmental costs among all civil aviation external costs (Levinson et al., 1998), our study focused on airport noise pollution charges and their impact on airlines, airports and nearby residents. In noise regulation issues, airports and airlines act out roles as operators and users, respectively, so applying airport noise regulations directly impacts airline companies. Although passenger demand may be affected by changes in an airline's routes or types of aircraft, noise regulations can more significantly and directly impact airlines, than passengers do. Airlines may reduce flight frequencies, reallocate aircraft and change routes in response to noise regulations. Reducing flight frequencies may reduce passenger demand, while using larger aircraft may increase passenger demand. Therefore, under the influence of these two factors, it is impossible to conclude whether passenger demand is influenced by reallocation of types of aircraft, flight frequencies or changes in routes, as an airline responds to airport noise charges. Thus, we have assumed that passenger demand is fixed, addressing only the impact of airport noise charges on changes in airline network design.

The remainder of this paper is organized as follows. In Section 2, regulation policies and noise charges, currently applied in major international airports, are investigated. The overall research architecture in this study comprises two models: an airline network design model, in response to airport noise charges is formulated in Section 3; the second airport noise charge assessment model, based on multiple perspectives, is described in Section 4. A case study, involving the CKS airport, in Taiwan, is presented in Section 5, illustrating the application of the models. Concluding remarks are offered in Section 6.

2. Regulation policies and noise charges

From the environmental economics perspective, environmental regulations in pollution control can be classified into two categories: command and control (CAC) environmental regulations and incentive-based (IB) regulations (Downing, 1984). In theory, IB instruments, such as environmental taxes and charges are better than so-called CAC regulations, such as engine standards and restrictions on flight movements, airport curfews and noise budget restrictions. In recent years, there has been a growing interest in IB environmental regulations. Economists have advocated IB regulations to encourage airlines to voluntarily eliminate pollution, as a way of minimizing their operating costs. International Civil Aviation Organization (ICAO) (1996) recommended that IB regulations should be in the form of charges, rather than taxes, since taxes usually become the fiscal resources of governments, while a noise surcharge imposed on airlines may be an incentive for them to purchase quieter aircraft. Furthermore, there should be no fiscal goals behind the charges, which should be only related to cost. Air transportation must not be discriminated against, when compared with other modes of transportation; the funds from charges should be used to mitigate the negative environmental impact of emissions.

Carlsson (1999) analyzed the possibility of applying IB regulations on domestic civil aviation in Sweden and discussed several related critical issues, both practical and theoretical. In the short-run, the environmental performance of an IB regulation may be poor, since the most likely way of reducing emissions is by way of reducing the number of flights. This could clearly conflict with the regulator's other goals, but the effects of CAC regulations can also be effective, and simple rules, such as the phasing-out of specific types of aircraft have had a positive effect on the environment. However, the dynamic properties of IB regulations suggest that, in the long run, an IB regulation will be superior to a CAC regulation. IB regulations may be the incentive to replace old aircraft with new aircraft, which have lower emissions; incentives for cleaner technological innovation are, in general, greater for IB than for CAC regulations. Carlsson (1999) further discussed the prospects of implementing an optimal IB regulation and compared these with present regulations and pricing schemes, showing that the introduction of an IB regulation could improve the overall efficiency of the pricing system.

Noise related regulations, presently in place in major airports, are many and can be classified into fourteen categories: noise abatement procedures, airport curfews, preferential runways, operating quotas, engine run-up restrictions, auxiliary power unit (APU) operating restrictions, noise budget restrictions, noise charges, noise monitoring systems, noise level limits, noise compatibility programs, Stage 2 restrictions, Stage 2 phase-outs and Stage 3 restrictions. A noise charge is the only IB regulation currently applied at the world's 592 airports; all others, classified as CAC regulations, are the popular regulations currently imposed by most of airports. For those airports enforcing IB regulations, most apply a percentage surcharge or discount, according to MTOW (maximum take-off weight), and based on landing fees and the aircraft registration noise category. The most obvious worldwide aircraft noise classification is the ICAOs Annex 16 (International Civil Aviation Organization, 1993), which subdivides jet aircraft into three different Chapters.

CKS airport, an international airport in Taiwan, as well as ten other airports was used for the case study in Section 5. Appendix A describes the noise charge methods used in some of these airports. Based on the noise levy formulas in Appendix A, levies on airport noise levels can be further categorized into (1) those included in the airport surcharge and (2) those included in the landing charges, according to the noise pollution levels of each aircraft type. Those airports applying method (1) include CKS airport, Sydney airport, Tokyo-Haneda airport as well as the Dutch Government Noise Levy. Based on the formulas currently applied in those airports, a generalized noise levy formula may be represented as

$$\mathrm{NU}_j^k = \begin{cases} q \times (\mathrm{EPNdB}^k - l) + e \times \mathrm{MTOW}^k & \mathrm{EPNdB}^k \geqslant l \\ 0 & \mathrm{EPNdB}^k < l \end{cases} \tag{1}$$

Here NU_j^k is the noise levy per landing for aircraft k at airport j; different aircraft will be charged differently. EPNdB^k is the noise level incurred by aircraft k, MTOW^k is the MTOW for aircraft k, with q representing the noise levy principle used by the airport. The estimate for parameter q is determined by dividing the annual noise pollution prevention budget by the estimated annual noise volume. Parameter q stands for the monetary value, per noise unit, and is the financial factor in the noise levy formula. The larger the aircraft, the higher the noise pollution level, so e is a noise levy parameter with respect to the MTOW of an aircraft. When $e = 0$, the formula for the noise levy is related to the noise incurred by a certain type of aircraft, but not to the MTOW. If the noise level incurred by aircraft k is higher than the airport-specified threshold noise level, then once it lands at airport j, it will be charged the noise levy calculated by Eq. (1). On the other hand, if the aircraft noise level is lower than the threshold, indicating that this type of aircraft is quiet, it is excused from paying a noise levy. In addition, the linear relationship between $(\mathrm{EPNdB}^k - l)$ and q, in the formula, is different from airport to airport, and may consist of other mathematical forms, such as $q \times 2^{(\mathrm{EPNdB}^k - l)}$.

Noise levies at Amsterdam-Schiphol airport and Frankfurt airport are paid using a factor as part of the landing surcharge. The general formula, used in these airports is

$$\mathrm{NU}_j^k = (d_j^k - 100)\% \times \mathrm{LD}_j^k \tag{2}$$

Here, LD_j^k is the charge per landing for aircraft k at airport j, and d_j^k is the deduction for the quietness level of aircraft k. If $d_j^k = 100$, any airline flying aircraft k, and landing at airport j, will have no landing surcharge; this means the noise levy is zero. If $d_j^k > 100$, then the airline will have to pay $(d_j^k - 100)\% \times \mathrm{LD}_j^k$ dollars more for the landing. Furthermore, if $d_j^k < 100$, then the airline will pay $(d_j^k - 100)\% \times \mathrm{LD}_j^k$ dollars less for the landing. Consequently, this levy formula may encourage airlines to fly quieter types of aircraft.

According to the various airport levy systems, noise levies for selected types of aircraft were calculated. Fig. 1 further compares noise levies on various types of aircraft at different airports, illustrating that the order of noise surcharges, for various aircraft, varies across different airports. If the airport noise charge is levied simply according to the noise level incurred by each aircraft type, e.g., as levied by the Dutch Government, Sydney and Tokyo-Haneda airports, then the amounts levied for different types of aircraft are in the same order as for the noise levels incurred by different types of aircraft. In this case, the sequence from high to low was B-747-200, B-747-400, MD11, A300-600R, B-777-200, B-767-300R and A320. At CKS airport, the levy was based

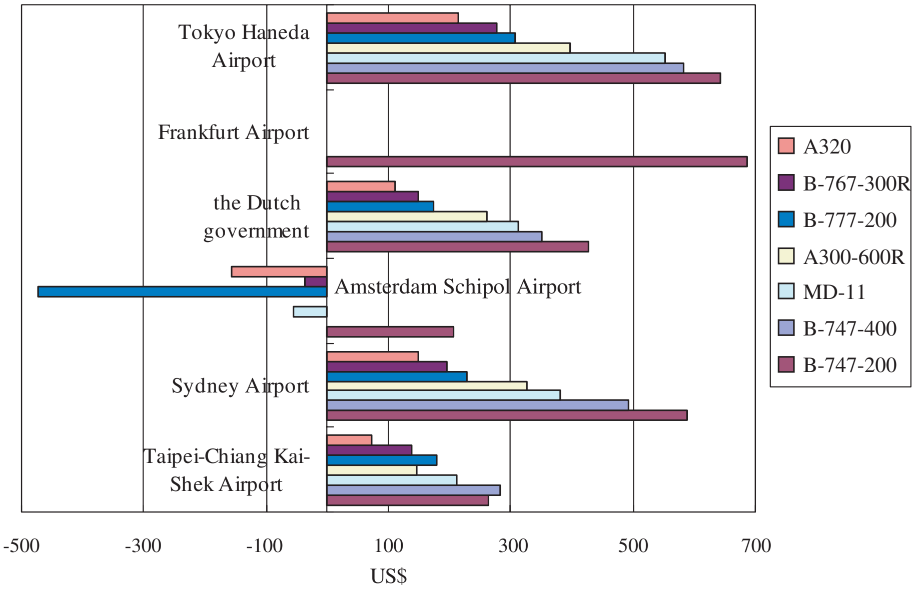

Fig. 1. Comparison of noise levies on various types of aircraft at different airports.

on both the noise level and the MTOW of each aircraft, and dependent on the weight, placed by the airport, on these two factors.

In Amsterdam-Schiphol and Frankfurt airports, both the size and the noise levels of each aircraft type are categorized and taken into consideration for determining the noise levy. At Amsterdam, MD11, B-767-300R, A320, B-777-200 enjoy a 5% cut in landing charges, which results in a negative value for the noise levy. Moreover, B-747-200 have to pay 15% more for landing charges, while B-747-400 and A300 both scored zero, using this formula, and do not have to pay a noise levy.

From the above discussion, it can be seen that major airports currently employ different levy formulas. Our study adjusted various parameters in the formulas, altering the noise levies, in light of the different strategies controlling aircraft noise levels, in the example described in Section 5. The following section formulates an airline network design model to determine optimal flight frequencies, aircraft types and routing in response to different noise levy charges. The network adjustments, made by airlines in response to the various airport noise charges, may result in changes to airport operating profits, and the impact and social cost associated with noise; these factors are formulated in the airport noise charge assessment model, shown in Section 4.

3. The airline network design model

The airline network design problem in this study was defined as determining an airline's flight frequencies, aircraft types and air routes (Teodorovic et al., 1994). Consider an airline network $G(N, A)$, where N and A represent the set of nodes, and the set of links of graph G, respectively. Let $R(R \subseteq N)$ denote the set of origin cities, and S represent the set of destination cities ($S \subseteq N$), where $R \cap S \neq \emptyset$. Next, any given O-D city pair $r-s$ is connected by a set of routes $P_{rs}(r \in R, s \in S)$ throughout the network. The decision variable in the airline network design model is f^k_{rsp}, which represents the weekly frequency of flights served by aircraft $k(k \in K)$ along route P_{rs}. Let f_{ij} represent the weekly flight frequency on link $i-j$, where $i, j \in N$. Furthermore, the link frequency is the sum of the frequencies on all routes going through that link, which can be expressed as a function of the route frequencies as $f_{ij} = \sum_r \sum_s \sum_p \sum_k \delta^{rsp}_{ij} f^k_{rsp}$, where δ^{rsp}_{ij} is the indicator variable; if $\delta^{rsp}_{ij} = 1$, then link $i-j$ is a part connecting O-D pair $r-s$; otherwise, $\delta^{rsp}_{ij} = 0$. Let Q_{ij} represent the weekly number of passengers on link $i-j$, and Q^k_{rsp} represent the weekly number of passengers of the flights served by aircraft $k(k \in K)$ along route P_{rs}. By using the same indicator variable, the relationship between the link flow and the route flow is $Q_{ij} = \sum_r \sum_s \sum_p \sum_k \delta^{rsp}_{ij} Q^k_{rsp}$.

Numerous studies have considered airline network design problems as cost-minimization problems (e.g., Jaillet et al., 1996). The airline network design model in this study determines optimal air routes, flight frequencies and aircraft types by minimizing airline operating costs. Air carrier operating costs are normally divided into direct operating costs (DOC) and indirect operating costs (IOC).

Direct operating costs are all those expenses associated with operating a type of aircraft, including all flying costs, all maintenance costs and all aircraft depreciation expenses. Most airports have their own specific landing fees and noise charges, most of which are determined according to the aircraft's maximum takeoff weight and the airport's financial and environmental policies. Heavier aircraft usually incur higher landing and noise charges.

Let LD_j^k and NU_j^k denote aircraft k landing and noise fees charged by airport j, respectively. Then for airport j, the total landing and noise fees for all flights served by aircraft k in a week is $\sum_i f_{ij}^k(\mathrm{LD}_j^k + \mathrm{NU}_j^k),\ i \neq j$, where $f_{ij}^k = \sum_r \sum_s \sum_p \delta_{ij}^{rsp} f_{rsp}^k$ and is the weekly flight frequency of aircraft k on link $i-j$. Furthermore, let P_r be the average gasoline price and f_k denote the average fuel consumption per mile of aircraft k, then fuel cost of aircraft k for a flight over link $i-j$ with stage length d_{ij} can be represented by $P_r\, d_{ij}\, f_k$. Let b^k represent all other direct operating costs of aircraft k per mile. Then the direct operating cost of the air carrier can be expressed as

$$\mathrm{DOC} = \sum_k \sum_j \sum_i f_{ij}^k(\mathrm{LD}_j^k + \mathrm{NU}_j^k) + \sum_i \sum_j \sum_r \sum_s \sum_p \sum_k f_{rsp}^k \delta_{ij}^{rsp}[d_{ij}(P_r f_k + b^k)] \tag{3}$$

Indirect operating costs are those expenses related to passengers, rather than to the aircraft. Kanafani and Ghobrial (1982) noted that the unit indirect operating cost per passenger could be considered as a constant. Then, the total indirect operating cost, IOC, is

$$\mathrm{IOC} = \sum_i \sum_j w_{ij} Q_{ij} \tag{4}$$

where w_{ij} denotes the unit handling cost per passenger in dollars.

Assume that transportation capacities, offered in terms of the weekly number of seats on each link, must satisfy the weekly number of passengers on each link. Let α_{ij} denote the load factor of aircraft k flying from i to j while n^k is the number of available seats of aircraft k. Then, the average load factor of link $i-j$ can be expressed as $\alpha_{ij} = \frac{Q_{ij}}{\sum_k n^k f_{ij}^k}$. The total utilization of aircraft k must be equal to or less than its maximum possible utilization. For all types of aircraft, we have used the relation referred to by Teodorovic et al. (1994) as $\sum_r \sum_s \sum_p t_{rsp}^k f_{rsp}^k \leqslant u^k A^k$ where A^k represents the total number of aircraft k in the fleet, u^k denotes the maximum possible weekly utilization of aircraft k and t_{rsp}^k denotes the block time of aircraft k on route p_{rs}, including the time spent in the various aircraft trip modes.

Then, the airline network design problem can be formulated as follows:

$$\begin{aligned} \min \quad \mathrm{TC} = {} & \sum_i \sum_j w_{ij} Q_{ij} + \sum_k \sum_j \sum_i f_{ij}^k(\mathrm{LD}_j^k + \mathrm{NU}_j^k) \\ & + \sum_i \sum_j \sum_r \sum_s \sum_p \sum_k f_{rsp}^k \delta_{ij}^{srp}[\beta_{ij} d_{ij}(P_r f_k + b^k)] \end{aligned} \tag{5}$$

$$\text{s.t.} \quad \alpha_{ij} \sum_k n^k f_{ij}^k \geqslant \sum_r \sum_s \sum_p \sum_k \delta_{ij}^{rsp} Q_{rsp}^k, \quad \forall i,j \tag{6}$$

$$Q_{rs} = \sum_p \sum_k Q_{rsp}^k, \quad \forall (r,s), \quad p \in P_{rs} \tag{7}$$

$$\sum_p \sum_k f_{rsp}^k = \sum_p \sum_k f_{srp}^k, \quad p \in P_{rs}, \quad \forall r \tag{8}$$

$$\sum_r \sum_s \sum_p t_{rsp}^k f_{rsp}^k \leqslant u^k A^k, \quad \forall k \tag{9}$$

$$f_{ij} = \sum_r \sum_s \sum_p \sum_k \delta_{ij}^{rsp} f_{rsp}^k, \quad \forall i,j \tag{10}$$

$$\text{all } f_{ij}, f_{rsp}^k, Q_{rsp}^k \geqslant 0 \tag{11}$$

Eq. (5) is the objective function, minimizing total air carrier operating costs, in which β_{ij} is the direct operating cost discount factor between two hub airports. The value of β_{ij} ranges between 0 and 1, and a lower value implies larger flow-economies on the link between two hub airports, thereby discounting more direct operating costs. In Eq. (6), the transportation capacities, offered in terms of the number of seats on each link, must be equal to or greater than the number of passengers on all routes traveling through that link. Eq. (7) defines the sum of the passengers carried by any aircraft k, along any route p_{rs}, as being equal to the total number of passengers traveling between two cities. Eq. (8) determines that an equal number of take-off and landing operations occurs at each airport, within the network, during a week.

4. The airport noise charge assessment model

Different noise charge policies will have different impacts on airport operating profits, the social costs of airport residents nearby and the performance of airport noise control. However, certain conflicts exist among these three objectives pursued by airport authorities. Thus, an airport authority may contemplate the trade-offs among these different objectives, according to such considerations as airport location, airport revenue and environmental and financial policies. For congested airports, located near highly populated areas, airport authorities are likely to strive for controlling noise nuisance and minimizing its impact on nearby residents.

4.1. Average daily noise exposure

This study constructed an average daily noise exposure function, over a week, to assess the noise-control performance of different noise charge policies. This function shows the relationship between the cumulative effects of exposure to noise pollution around airport j, and network design changes, made by air carriers, in response to airport j noise charges.

The DNL index expresses day–night average sound levels of aircraft noise. Most public agencies dealing with noise exposure have adopted DNL in their guidelines and regulations. The average daily noise exposure function in a week, $L_{\mathrm{dn,week}}$, aggregates single event measures at an airport during a week, to calculate the average daily DNL. That is,

$$L_{\mathrm{dn,week}} = 10\log\left(\frac{1}{7}\sum_{k} M_j^k 10^{(L_{\mathrm{AE}}^k + W^k)/10}\right) \tag{12}$$

where $L_{\mathrm{dn,week}}$ is the average DNL during a week at airport j, L_{AE}^k is the sound exposure level produced by a single event of aircraft k during the day, W^k is time-of-day modification for L_{AE}^k and accounts for a presumed increase in human sensitivity to noise during nighttime hours (0 dBA if between 7 a.m. and 10 p.m.; 10 dBA if between 10 p.m. and 7 a.m.). M_j^k is the total number of aircraft k noise events during a week and depends on the decision variable of the airline network design model, f_{rsp}^k. M_j^k can be calculated by aggregating the weekly frequencies of all flights served by aircraft k of all airlines serving airport j. That is,

$$M_j^k = \sum_a \sum_i f_{ij}^{ak} = \sum_a \left(\sum_i \sum_r \sum_s \sum_p \delta_{ij}^{rsp} f_{rsp}^{ak} \right) \tag{13}$$

Superscript a represents any airline serving airport j and $a \in T$, where T denotes the set of airlines serving airport j. Using the same indicator variable, δ_{ij}^{rsp}, in the airline network design model, $\sum_i \sum_r \sum_s \sum_p \delta_{ij}^{rsp} f_{rsp}^{ak}$ represents one airline's weekly frequencies of all flights served by aircraft k on the routes serving airport j. Considering all the airlines serving airport j in the network, the total number of aircraft k noise events at airport j in a week, M_j^k, can be calculated as $\sum_a (\sum_i \sum_r \sum_s \sum_p \delta_{ij}^{rsp} f_{rsp}^{ak})$.

It should be noted that, compared to those without noise charges, if the value of $L_{\text{dn,week}}$ is lower after the airport has deployed the noise charge policy, this implies that the policy has had a positive impact on airport noise control. Thus, variations in the value of the $L_{\text{dn,week}}$ can be used to evaluate the effects of different airport noise charge policies on airport noise control.

4.2. The social cost of airport noise nuisance

The damage caused to the community, by aircraft noise, is difficult to quantify, but is often viewed as resulting in lower property values. The hedonic price method has been developed in a large number of research papers (e.g., Nelson, 1980, 2004); using this method, variations in the weekly social cost of aircraft noise nuisance, caused by changes in the noise charge policy, at airport j, ΔI_j, can be derived as

$$\Delta I_j = \sum_z \mathrm{NDSI}_j \times \mathrm{HP}_j \times (N_{a,j}^z - N_0) \times (H_j^{z'} - H_j^z) \tag{14}$$

where NDSI_j is the noise depreciation index, representing the percentage reduction of average housing prices, per weighted decibel (db(A)) above background noise. In Eq. (14), the area surrounding the airport is divided into z noise contour zones. Each contour zone z has a different number of housing units, H_j^z, depending on the population density and the area of the contour zone. The total damage for each noise contour z is computed by multiplying the number of housing units (H_j^z), the average value of each home unit (HP_j), the noise depreciation index, NDSI_j, and the net increase in the noise level above the background in the noise contour zone ($N_{a,j}^z - N_0$).

However, airlines' network adjustments, in response to noise charges, may reduce airport noise, and consequently, the area covered by contour z will decrease, with the number of housing units in the contour also decreasing. Let $H_j^{z'}$ be the number of housing units in contour z after an airport has deployed a noise charge. The variations in the social cost of contour z, resulting from the new noise charge, can be determined by comparing the number of housing units in contour z, before and after application of the noise charges, and summing all those within the noise contours, as in Eq. (14).

4.3. Airport operating costs and operating revenues

Airlines may adjust their air routes, flight frequencies and choice of aircraft, in response to airport noise charges, which can impact the airport's operating costs and operating revenues. In this study, we merely estimated variations in airport operating costs and operating revenues, resulting from the deployment of an airport noise charge policy.

Airport operating and maintenance costs are some of the major expenses associated with numbers of flights into and out of an airport. Administrative costs, overhead and utility costs, on the other hand, are related to passenger volume. Let o_j^{ak} be the operating and maintenance cost per flight served by aircraft k of airline a serving airport j, and m_j denote the operating cost related to one passenger. We obtained variations in airport operating costs, due to noise charges, $\Delta \mathrm{TC}_j$, as follows:

$$\Delta \mathrm{TC}_j = o_j^{ak} \sum_k \sum_a \sum_i (f_{ij}^{ak'} - f_{ij}^{ak}) + m_j \sum_a \sum_i (Q_{ij}^{a'} - Q_{ij}^{a}) \tag{15}$$

where f_{ij}^{ak} and $f_{ij}^{ak'}$ represent, respectively, the weekly frequency of flights served by aircraft k of airline a on link $i-j$, before and after noise charges; Q_{ij}^{a} and $Q_{ij}^{a'}$ represent, respectively, the weekly number of passengers on link $i-j$ before and after noise charges.

Airport operating revenue primarily includes landing fees, noise charges, ground service charges, rent and concessions lease and airport service charges. Landing fees, noise charges and ground service charges are major revenues associated with numbers of flights, while concessions and airport service charges are related to passenger volume. Let g_j^{ak} be the ground service charges when an airline uses aircraft k to serve airport j, while c_j and h_j represent the concessions and airport service revenue related to passenger volume. Furthermore, let $\Delta \mathrm{TR}_j$ be the variations in airport operating revenues, due to the change in noise charges. Then,

$$\begin{aligned} \Delta \mathrm{TR}_j = {} & \sum_a \sum_k \sum_i \left[\left(\mathrm{NU}_j^{ak'} \times f_{ij}^{ak'} \right) - \left(\mathrm{NU}_j^{ak} \times f_{ij}^{ak} \right) \right] \\ & + \sum_a \sum_k \sum_i \left[\left(\mathrm{LD}_j^{ak} + g_j^{ak} \right) \times \left(f_{ij}^{ak'} - f_{ij}^{ak} \right) \right] + (c_j + h_j) \sum_a \sum_i (Q_{ij}^{a'} - Q_{ij}^{a}) \end{aligned} \tag{16}$$

Herein, variations in the airport total profits, due to the noise charges, $\Delta \mathrm{TP}_j$, is equal to $\Delta \mathrm{TR}_j - \Delta \mathrm{TC}_j$, such that

$$\begin{aligned} \Delta \mathrm{TP}_j & = \Delta \mathrm{TR}_j - \Delta \mathrm{TC}_j \\ & = \left[\sum_a \sum_k \sum_i \left(\mathrm{NU}_j^{ak'} \times f_{ij}^{ak'} \right) - \left(\mathrm{NU}_j^{ak} \times f_{ij}^{ak} \right) \right] \\ & \quad + \left[\sum_a \sum_k \sum_i \left(\mathrm{LD}_j^{ak} + g_j^{ak} - o_j^{ak} \right) \times \left(f_{ij}^{ak'} - f_{ij}^{ak} \right) \right] \\ & \quad + (c_j + h_j - m_j) \times \sum_a \sum_i \left(Q_{ij}^{a'} - Q_{ij}^{a} \right) \end{aligned} \tag{17}$$

where NU_j^k represents aircraft k noise charges from airport j. If $\mathrm{NU}_j^{ak'} - \mathrm{NU}_j^{ak} > 0$, this implies an increase in total airport noise charges.

5. Case study

For a better understanding of how the models work, their application is illustrated, using CKS airport as an example.

The existing noise levy policy, adopted by the CKS airport, is part of the airport surcharge, as discussed in Section 2. The noise levy formula for aircraft k is: $\mathrm{NU}_j^k = q \times (\mathrm{EPNdB}^k - l) + e \times \mathrm{MTOW}^k$, here q = NT\$95, l = 73 decibel, e = NT\$17. In the formula, q is the monetary value per noise unit, l is the aviation noise threshold value set by the airport and e is the noise levy coefficient, with respect to takeoff weight. The noise charges and landing fees, for various types of aircraft in CKS airport, are listed in Table 1. Currently, there are 7 airlines running regularly scheduled international passenger flights to CKS. To simplify the analysis, airlines included in this analysis ran more than 20 scheduled flights per week. They included two large international airlines, A and B, which use the CKS airport as the hub of their international flights, another smaller international airline, C, and four others, D, E, F and G. Altogether, the total scheduled international passenger flights, operated by these seven airlines in one week, at the CKS airport, accounted for 73% of the total scheduled international passenger flights currently using the CKS airport.

The flight routes operated by each airline are listed in Table 2. The bold items represent those with a common takeoff and landing point. To minimize total operating costs, airlines may change the itinerary, to meet passenger demand on these routes. In the case study, airlines A, B, C and E had all of their flights both originating and ending at the CKS airport. Therefore, even if the CKS airport increased the noise levy for aircraft, these four airlines could not cancel their flights, because they had to meet passenger demand on these routes. However, airlines D, F and G used the CKS airport as a transfer station or connecting airport for some of their flights. In this situation, if the CKS airport increased the noise levy, these three airlines could possibly cancel their landings at CKS and discontinue its use as a transfer station or connecting airport. The types of aircraft employed by each airline were as follows: Airline A employed 4 types of aircraft, i.e., B-747-400, B-747-200, A300-600R and MD-11; Airline B employed B-747-400, A300-600R, MD-11 and B-767-3/ER; and the other airlines employed B-747-400, B-747-200, A300-600R, MD-11, B-767-3/ER, A320 and B-777-200.

Input values for the parameters of airport operating costs and operating revenues were estimated from published data and are listed in Table 3. To estimate the number of households located within the three areas near the CKS airport, which were exposed to different noise contours, the number of households per square kilometer in the noise-controlled area was estimated, by employing the FAA Integrated Noise Model (Federal Aviation Administration, 1999). Fig. 2 shows the noise contours, surrounding the CKS airport, which used weekly airline flight and noise level data by overlaying noise contour charts with a geographical map of the area. The estimation

Table 1
Noise fees and landing fees for various types of aircraft at CKS airport

Aircraft	Noise fee (US\$)	Landing fee (US\$)
B-747-400	282	2975
B-747-200	264	2678
A300-600R	146	1282
MD-11	213	2134
B-767-3/ER	137	1406
A320	74	638
B-777-200	178	1859

Source: International Air Transport Association (2000).

Table 2
Major airline flight routes of CKS airport

Airlines	Routes
A	SFO-TPE
	LAX-TPE
	NYC-TPE
	NYC-ANC-TPE
	SYD-TPE
	AMS-BKK-TPE
	FRA-BKK-TPE
	TYO-TPE
	HNL-TPE
	HNL-TYO-TPE
	HKG-TPE
	SIN-TPE
	SIN-HKG-TPE
	JKT-TPE
	BKK-TPE
	BKK-HKG-TPE
	FUK-TPE
	HKT-TPE
	OKA-TPE
	KUL-TPE
	SGN-TPE
	DPS-TPE
	KUL-HKG-TPE
	NGO-TPE
B	YVR-TPE
	LAX-TPE
	VIE-BKK-TPE
	NYC-ANC-TPE
	SYD-TPE
	AMS-BKK-TPE
	MFM-TPE
	TYO-TPE
	PEN-SIN-TPE
	LHR-BKK-TPE
	HKG-TPE
	SIN-TPE
	PTY-LAX-TPE
	JKT-TPE
	BKK-TPE
	AKL-TPE
	FUK-TPE
	BEN-TPE
	SUB-DPS–TPE
	KUL-TPE
	SGN-TPE
	DPS-TPE
	KIX-TPE

Table 2 (*continued*)

Airlines	Routes
C	BKI-TPE MFM-TPE HKT-TPE
D	TYO-TPE **TYO-TPE-HKG** **TYO-HKG** OKA-TPE
E	MFM-TPE BKK-HKG-TPE HKT-HKG-TPE BKK-TPE
F	SIN-TPE **SIN-TPE-TYO** **SIN-TYO** SIN-HKG-TPE **SIN-TPE-LAX** **SIN-TYO-LAX**
G	**HKG-TPE-TYO** **HKG-TYO** HKG-TPE **HKG-TPE-SEL** **HKG-SEL**

Table 3
Parameter values related to airport operating costs and revenues (unit: US$)

Aircraft	o_j^{ak}	c_j	g_j^{ak}	h_j
B-747-400	149	3.72	569	9.1
B-747-200	149	3.72	551	9.1
A300-600R	149	3.72	373	9.1
MD-11	149	3.72	519	9.1
B-767-3/ER	149	3.72	380	9.1
A320	149	3.72	234	9.1
B-777-200	149	3.72	462	9.1

Note: o_j^{ak} is the operating and maintenance cost per flight served by aircraft k of airline a serving airport j.
c_j is the concessions related to passenger volume.
g_j^{ak} is the ground service charges when an airline uses aircraft k to serve airport j.
h_j is the airport service revenue related to passenger volume.

data indicated that there were 583 households in the level 1 noise-control area and 304 households in the level 2 noise-control area; the level 3 noise-control area was classified as unsuitable for residency. The study further estimated the total number of noise affected households, using the noise levy formula. The social costs associated with aviation noise were calculated, using the parameter values listed in Table 4 and Eq. (14).

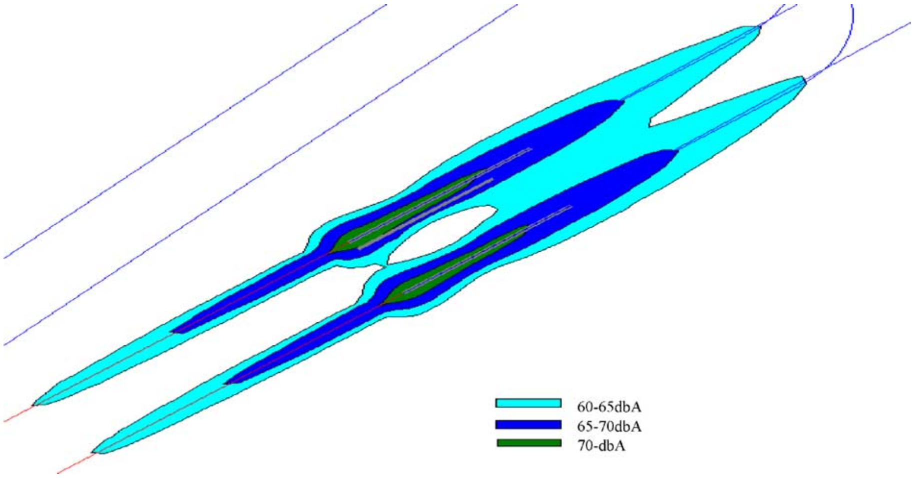

Fig. 2. Noise exposure map for CKS airport.

Table 4
Parameter values related to noise nuisance social costs

NDSI_j	HP_j	N_0
0.0068[a]	132,900[b](US$)	55 (db)

[a] *Source:* Liao (1999).
[b] *Source:* Sinyi Realty (1999).

Table 5 shows the results of applying the airline network design model, described in Section 3, using the current noise levy. In addition, the weekly average noise level, airport operating profits and the social costs of aviation noise at CKS were calculated, using the airport noise charge assessment model, from Section 4; the results are shown in Table 6. As mentioned in Section 2, the Sydney and Tokyo airports and the Dutch Government adopted similar noise levy formulas to those in use at the CKS airport. Yet we can see from Table 7, that despite the similarity of collecting levies, through airport surcharges, the parameter definitions and measurements in the noise levy formulas are different from airport to airport. We further assumed, therefore, that the CKS airport had adopted the noise levy formulas of Sydney, Tokyo and the Dutch Government; we compared the results with those of the current formula, to determine a more appropriate formula for the CKS airport. Table 8 shows the results.

As shown in Table 8, when other noise levy formulas were adopted, airlines tended to fly more B-747-400 aircraft, which are larger, but also noisier. In such cases, although the total number of flights per week was reduced, the combined effects of type of aircraft and flight frequencies resulted in an increase in the weekly noise level at the CKS airport. In all three alternatives, none of the airlines chose to give up any landing rights, despite the change in the noise levy formula. Therefore, it seems that the CKS will not lose its regular routes and passenger demand, even with a different noise levy. As a result, there was no change in the passenger related concession revenues and the airport service charges for the three levy formula alternatives. However, both the operating profits and the social costs of aviation noise at the CKS airport increased for all three alternatives.

Table 5
Optimal weekly flight frequency for each route (one direction)

Airlines	Routes	Aircraft	Frequencies
A	SFO-TPE	B-747-400	7
	LAX-TPE	B-747-400	12
	NYC-TPE	B-747-400	4
	NYC-ANC-TPE	0	0
	SYD-TPE	MD-11	3
	AMS-BKK-TPE	B-747-400	7
	FRA-BKK-TPE	B-747-400	3.59
	TYO-TPE	A300-600R	20.82
	HNL-TPE	B-747-400	6.26
		MD-11	1.82
	HNL-TYO-TPE	0	0
	HKG-TPE	A300-600R	43.91
	SIN-TPE	MD-11	11.33
	SIN-HKG-TPE	0	0
	JKT-TPE	MD-11	6.10
	BKK-TPE	B-747-400	17.08
		A300-600R	3.42
	BKK-HKG-TPE	0	0
	FUK-TPE	A300-600R	7
	HKT-TPE	MD-11	2.62
	OKA-TPE	B-747-400	9.34
	KUL-TPE	MD-11	6.10
	SGN-TPE	A300-600R	7
	DPS-TPE	MD-11	6.10
	KUL-HKG-TPE	MD-11	6.10
	NGO-TPE	A300-600R	7
B	YVR-TPE	B-747-400	5.89
	LAX-TPE	B-747-400	14
	VIE-BKK-TPE	B-747-400	2.30
	NYC-ANC-TPE	B-747-400	7.56
	SYD-TPE	MD-11	1.01
		B-767-3/ER	1.49
	AMS-BKK-TPE	B-747-400	4
	MFM-TPE	B-747-400	14.23
	TYO-TPE	MD-11	2
	PEN-SIN-TPE	A300-600R	5.08
	LHR-BKK-TPE	B-747-400	3
	HKG-TPE	A300-600R	36.62
		MD-11	1
	SIN-TPE	B-767-3/ER	10.33
	PTY-LAX-TPE	B-747-400	2
	JKT-TPE	B-747-400	7
	BKK-TPE	A300-600R	17.82
	AKL-TPE	B-767-3/ER	4
	FUK-TPE	A300-600R	5.09
	BEN-TPE	B-767-3/ER	6.78
	SUB-DPS–TPE	B-767-3/ER	3

(*continued on next page*)

Table 5 (*continued*)

Airlines	Routes	Aircraft	Frequencies
	KUL-TPE	A300-600R	7
	SGN-TPE	B-747-400	5.36
	DPS-TPE	B-747-400	1.36
	KIX-TPE	B-767-3/ER	7
C	BKI-TPE	B-747-200	4.55
	MFM-TPE	A300-600R	13.45
	HKT-TPE	A300-600R	2.44
D	TYO-TPE	B-747-200	28.99
	TYO-TPE-HKG	B-747-200	7.80
	TYO-HKG	0	
	OKA-TPE	B-747-200	7.81
E	TPE-MFM	A300-600R	31.18
	TPE-HKG-BKK	A300-600R	19.39
	TPE-HKG-HKT	A300-600R	4.16
	BKK-TPE	A300-600R	19.39
F	SIN-TPE	A320	37.33
	SIN-TPE-TYO	0	
	SIN-TYO	A320	49.96
	SIN-TPE-LAX	0	
	SIN-TYO-LAX	B-747-400	14
	SIN-HKG-TPE	B-747-200	3.34
G	HKG-TPE	B-777-200	56.78
	HKG-TPE-TYO	B-747-200	49.55
	HKG-TYO	0	
	HKG-TPE-ICN	B-777-200	30
	HKG-ICN	0	

Furthermore, the study compared these alternatives, using three evaluation criteria, i.e., total landings per week, average noise level per week and aviation noise social costs. The Sydney noise levy formula was found to be better than the other two. However, regarding airport operating profits, the Sydney noise formula yielded a lower return than those of the Tokyo Haneda airport and the Dutch Government. There was also an increase in social costs of up to $4516, and an increase in operating profits of $122,876; thus, the cost performance ratio for the Sydney model was 1:27. Consequently, the Sydney model was chosen for further comparison. Compared with the current CKS noise levy formula, the operating profits from the Sydney formula were better, while the noise level control and social costs were less favorable, as seen in Table 8. The CKS authority should carefully consider the trade-offs among increasing airport profits, reducing noise levels and social costs. Since the social costs associated with airport noise are closely related to average weekly noise levels, we further simplified the airport noise levy evaluation by using only two major objectives; those of increasing airport profits and reducing social costs.

This two-objective evaluation problem can again be simplified, into a single-objective evaluation problem, by weighting the two objectives and calculating their sum. Fig. 3 shows the differ-

Table 6
Current noise charge policy analysis for CKS airport

Aircraft	Weekly flight frequencies (flights/week) (one direction)
B-747-400	132.97
B-747-200	102.05
A300-600R	239.75
MD-11	54.18
B-767-3/ER	32.60
A320	37.33
B-777-200	86.78
Total	685.67
Average DNL during a week (dBA)	72.78
Airport operating revenues	
Concession and airport service charge (US$)	1,996,452
Noise revenue (US$)	133,572
Landing fee and ground service charge (US$)	1,595,941
Airport operating costs (US$)	102,170
Airport operating profits (US$)	3,623,795
Social cost of aircraft noise nuisance (US$)	3,655,953

Table 7
CKS, TYO, SYD and the Dutch government noise formulas

Airport	Noise formula	q (US$)	EPNdB	Airport threshold noise level (dBA)
CKS	$q \times (\mathrm{EPNdB} - 73) + 17 \times \mathrm{MTOW}$	2.88	Noise level for take-off	73
TYO	$q \times \lceil \mathrm{EPNdB} - 83 \rceil$	30.67	Average of noise levels for fly-over and approach	83
SYD	$q \times 2^{(\mathrm{EPNdB}-265)/15}$	90	Sum of noise levels measured at three points	265
The Dutch Government	$\lfloor q \times 10^{(\mathrm{EPNdB}-270)/45} \times$ a factor depending on the number of engines$\rfloor$	89	Sum of noise levels measured at three points	270

Note: q is monetary value per noise unit.
Source: International Air Transport Association (2000).

ence in the sum of CKS profits and social costs, between the Sydney and current CKS noise levy formulas, under various weightings of the two objectives. For the weighting pairs with positive values, CKS airport obtained higher total profits and social costs, if it adopted the Sydney noise levy formula. Fig. 3 also shows that if the CKS authority is more concerned about social costs, due to noise levels, giving it more weight, the Sydney levy formula would yield a better result and, thus, is the best formula to adopt.

Table 8
Assessment for applying current CKS, TYO, SYD and the Dutch Government noise charge policies at CKS

Aircraft	Weekly flight frequencies (flights/week) (one direction)			
	CKS	TYO	SYD	The Dutch Government
B-747-400	132.97	142.50	134.27	142.4
B-747-200	102.05	102.05	102.05	102.05
A300-600R	239.75	239.75	239.75	239.75
MD-11	54.18	42.41	53.17	42.55
B-767-3/ER	32.60	31.83	31.83	31.83
A320	37.33	37.33	37.33	37.33
B-777-200	86.78	86.78	86.78	86.78
Total	685.67	682.66	685.18	682.70
Average DNL during a week (dBA)	72.78	72.79	72.78	72.79
Airport operating revenues				
Concession and airport service charge (US$)	1,996,452	1,996,452	1,996,452	1,996,452
Noise revenue (US$)	133,572	311,235	256,376	193,746
Landing fee and ground service charge (US$)	1,595,941	1,596,596	1,595,942	1,596,588
Airport operating costs (US$)	102,170	101,723	102,099	101,728
Airport operating profits (US$)	3,623,795	3,802,560	3,746,671	3,685,058
Social cost of noise nuisance (US$)	3,655,953	3,696,145	3,660,469	3,695,694

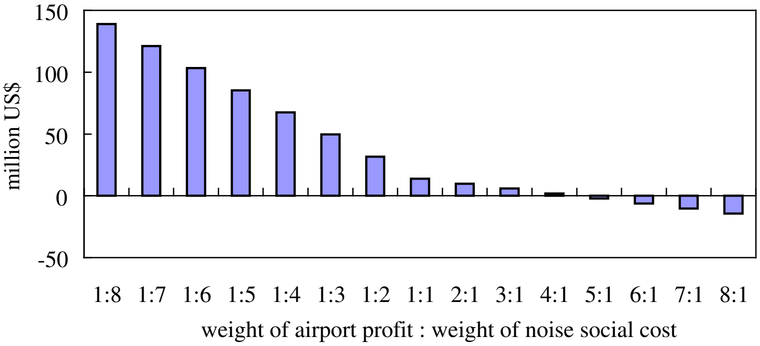

Fig. 3. The difference in total CKS profits and social costs, between adopting the Sydney and the current CKS noise levy formulas, under various weighting objectives.

The CKS airport authority could alter the monetary value per unit of noise to increase the noise levy for various types of aircraft landing there. Fig. 4(a)–(c) shows, respectively, variations in the social costs, airport profits and total weekly scheduled flights, due to the increased noise levy. When the monetary value per unit of noise was NT$2495, Airline G cancelled its flights on the Hong Kong–Taipei–Tokyo route and used non-stop flight service between Hong Kong and Tokyo, to meet the demand. As shown in Fig. 4(a)–(c), when the monetary value per noise unit was around NT$2495, the curve of social costs, airport profits and weekly scheduled flights was noticeably reduced, the social costs being cut by about $300,000 and the airport profits going down by about $350,000.

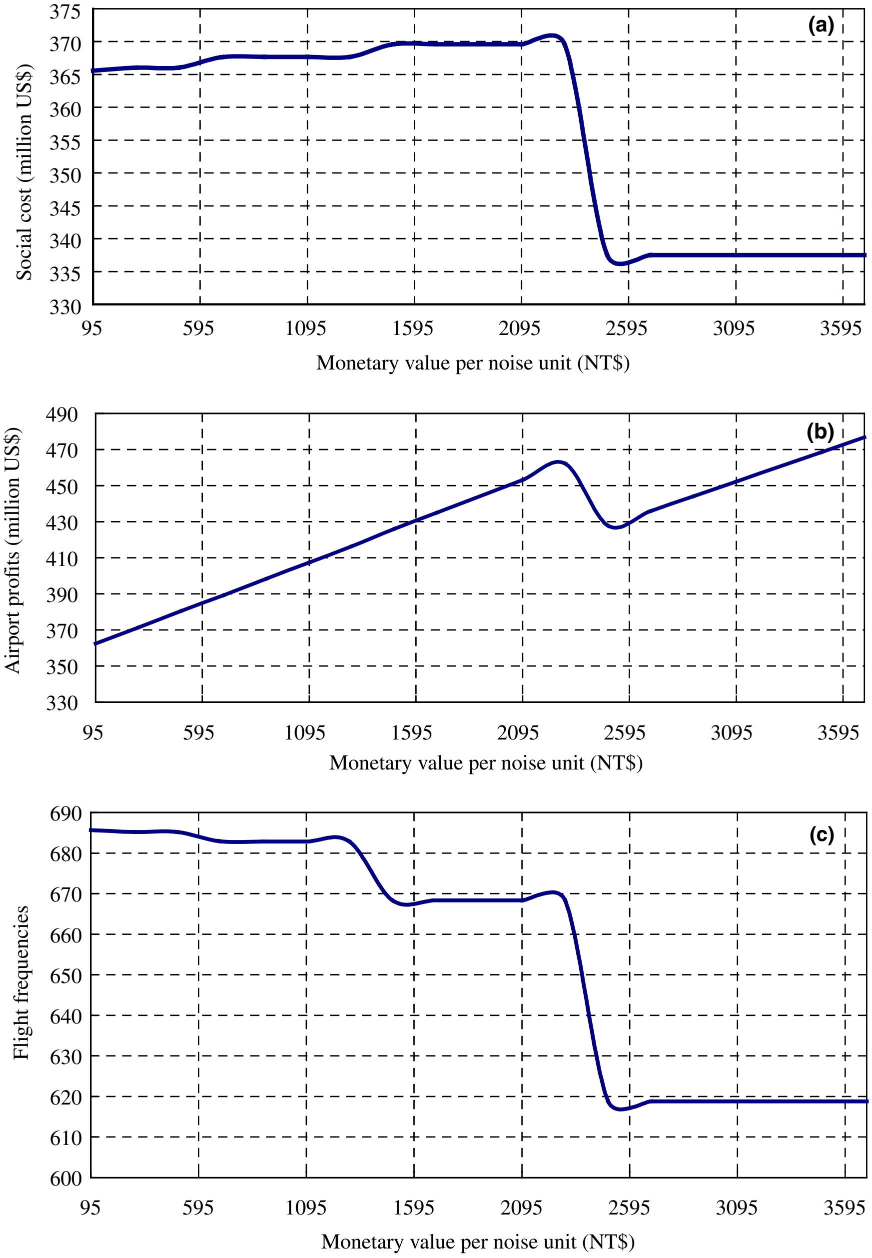

Fig. 4. Results for CKS Airport, when adopting current noise charge formula: (a) social cost, (b) airport profit, (c) weekly flight frequencies.

As the monetary value per noise unit increased to NT$2495, which is the turning point where the airline may begin to give up CKS operations, airlines tended to adjust aircraft types and flight frequencies, to cope with the rising noise levy. As shown in Fig. 4(c), when the noise levy value fell below NT$2495, the trend was to reduce total landings per week. That is to say, airlines flew larger aircraft with lower flight frequencies. However, as shown in Fig. 4(a), the social costs went up slightly before the monetary value per noise unit reached NT$2495. Levesque (1994) investigated the characteristics of aviation noise and its impact on social costs and categorized them into three factors: the noise level of a single flight and schedule and aviation noise variations, using the Box–Cox exchange coefficient function. He showed that a single flight noise level factor had the most significant impact on social costs, followed by aviation noise variations and the number of scheduled flights. This shows that if the CKS airport continues to apply its current noise levy formula and uses a monetary value per noise unit of less than NT$2495, it is likely that the airlines will adopt the strategy of reducing flight frequencies and flying larger aircraft, to lower their operating costs. Single flight noise levels impact more on social costs than on reducing flight frequencies; so, reducing social costs by reducing flight frequencies cannot compensate for the higher noise levels incurred by noisier single flights. These discussions suggest that the CKS airport authority may employ CAC regulation to control noisier single flight aircraft, such as implementing operating quotas for noisier aircraft or accelerating Stage 3 restrictions. This could effectively control the average weekly noise levels as well as the social costs.

A further reduction in the CKS airport landing charges may illustrate how such a reduction may affect the existing noise levy. Fig. 5 shows the effect of an increased noise levy on social cost control, when the landing charges were reduced by 25%. If the CKS airport does not reduce the landing charges, it will not be able to control social costs, using the current noise levy formula. As shown in Fig. 4(a), when the monetary value per unit of noise was less than NT$2495, the social costs were not significantly reduced, despite an increase in the noise levy. Nevertheless, if the CKS authority decreases landing charges by 25%, then the social costs can be effectively controlled through an increase of the noise levy, if the monetary value per unit of noise is NT$895.

As shown in Fig. 5, when the monetary value per unit of noise is NT$895, the social cost curves for the two cases, (i.e., reducing the landing charges by 25% and with no decrease in landing charges) intersect. This indicates that the combination of decreasing landing fees by 25% and increasing the noise levy to NT$895, would have the same result in controlling social costs as that

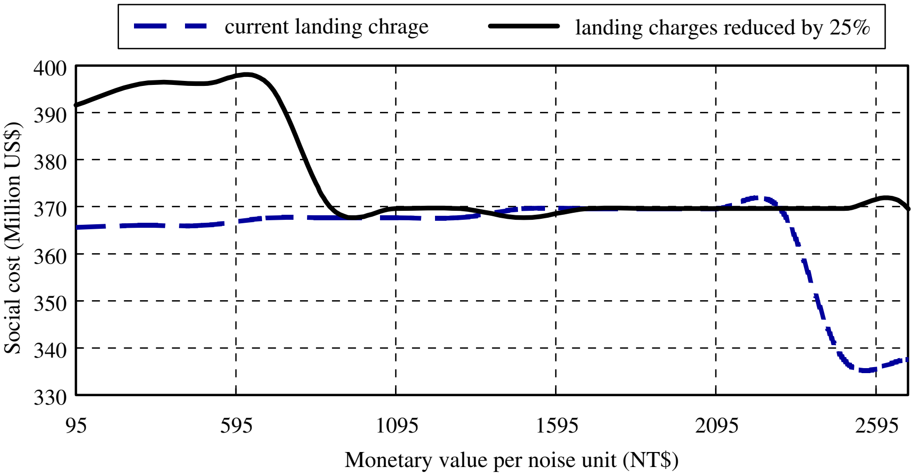

Fig. 5. Social costs of CKS airport, under different landing fee charges.

of maintaining the high current landing charges with a lower monetary value per unit of noise of NT$95. The landing costs for a specific aircraft type includes landing charges and noise levies, which can affect the airline's choice of aircraft and flight frequency. The ratio of landing charges to total landing and noise charges, may change the effectiveness of noise levies on the decisions made by an airline regarding aircraft types and flight frequency. Because the landing charges at the CKS airport are presently too high, the effect of the noise levy on social costs has already been diminished. As a result, the existing combination of landing charges and noise levies cannot effectively control the social costs of noise.

6. Conclusions

The goal has been to explore airport noise issues, by considering airline network decisions; we developed analytical models, to discover how government agencies or airport authorities, through the application of noise levies, might influence airlines' decisions regarding types of aircraft, flight frequencies and flight routes. Furthermore, changes in airport pollution levels and profits, due to the implementation of different noise charge policies, were further evaluated. These different noise charge policies were evaluated using multi-objectives, i.e., changes in social costs for residents surrounding the airport, and variations in airport operating costs and operating revenues, due to airlines' adjustments to aircraft types, flight frequencies and routing.

We demonstrated the application of the models by using the CKS airport as an example. The results showed that airlines can reduce the impact of an increase in airport noise levies on their operating costs, by changing aircraft types and flight frequencies. When a hub airport decides to collect noise levies, it may force airlines to switch from stopping there, en route, to direct non-stop flights. If aviation authorities raise airport noise levies, airline may choose to use non-stop flights to serve airports originally served by en route flights. In this case, social costs, airport profits, and total weekly landings at the airport may be markedly reduced, since airlines are more likely to fly larger aircraft, with fewer flights, to cope with the rise in airport noise levies. However, because the noise level created by a single flight has a higher impact on social costs than flight frequency, when frequency is reduced, the corresponding reduction in social costs does not compensate for the increase caused by the use of larger and noisier aircraft. These results are in accordance with empirical studies, using actual data, which found that flying larger aircraft with fewer flights actually increased social costs (Carlsson, 1999; Hayashi and Trapani, 1987; Nero and Black, 1998; Alamdari and Brewer, 1994; Kanafani and Ghobrial, 1985). Our study results also showed that current landing charge levels can reduce the effectiveness of the social cost control resulting from noise levies. The values of parameters, such as financial factors in noise levy formulas, may affect airlines' decisions regarding types of aircraft to be operated and flight frequencies on certain routes; as a result, the effect of noise levies on the volume of aircraft noise may also be affected. The results of this study may provide a reference for airlines in the decision making procedures of network planning, as they cope with environmentally related costs; airport authorities and environmental protection agencies may also find it useful in the proposal and evaluation of appropriate noise charge policies.

The effect of noise levies on cargo was not discussed in this study. Future studies may incorporate issues related to cargo flight airport operations, to thoroughly investigate the impact of airport levies on noise level controls. Currently, in addition to noise levy strategies, some airport authorities also employ other control strategies, such as airport curfews, operation quota restrictions, noise volume restrictions, noise volume per aircraft restrictions, Stage 2 aircraft restrictions and Stage 3 aircraft restrictions. The effects of different control strategies on flight frequencies, types of aircraft and flight routes may be further considered in future studies.

Acknowledgments

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Appendix A. Noise charges in selected airports

A.1. Taipei–Chiang Kai–Shek airport

The noise charge formula for CKS airport depends on MTOW and noise level. CKS airport noise surcharge formula is TWD $17 \times \text{MTOW}$ + TWD $95 \times (\text{EPNdB-73})$, where EPNdB represents take-off.

A.2. Tokyo-Haneda airport

The ICAO ANNEX 16 document, Volume 1, specifies that noise certification values of registered aircraft be measured at three different points, i.e., EPNdB Fly-over (Take-off), EPNdB Lateral (Side-line) and EPNdB Approach (Landing) (International Civil Aviation Organization, 1993). The noise surcharge for aircraft operating in Haneda airport is estimated as the sum of EPNdB values for fly-over and approach, divided by 2, minus 83, then rounded up to the next integer; this value is then multiplied by a fiscal factor of 3400 yen. If the average value of fly-over and approach noise levels for any aircraft is less than 83, only landing and take-off charges will be levied, with no noise surcharge, so as to encourage the use of silent aircraft.

A.3. Amsterdam-Schiphol airport

At Amsterdam-Schiphol airport, noise surcharges are levied by both the airport authority and the Dutch government. Amsterdam-Schiphol airport authority classifies aircraft into three categories and levies noise surcharge differentially, using a discount or extra percentage for basic landing and take-off charges. To encourage the use of quiet aircraft, the airport authority defines the quietest aircraft, at $\Delta\text{EPNdb} \leqslant -18$ EPNdb, as noise category 1; these aircraft receive a discount of 10% on the basic landing charge. ΔEPNdb is calculated by subtracting the sum of the three Chapter 3 limit values (in accordance with ICAO document ANNEX 16, Volume 1) by the sum of the three EPNdB noise certification value. Noise category 3, at $\Delta\text{EPNdb} > -9$ EPNdb, includes the noisiest Chapter 3 aircraft and all of Chapter 2 aircraft, which have to pay a noise charge equal to 20% of their basic landing charges. Aircraft with noise levels of -9

EPNdb $\geqslant$ ΔEPNdb $\geqslant$ -18 EPNdb, are defined as noise category 2 and receive no noise charges or discounts.

In addition, the Dutch government has also introduced noise charges at most Dutch airports. The noise charges levied have been earmarked to soundproof existing houses, and will be terminated once the projects around the airport have been completed. All aircraft with an MTOW below 390 kg are free of noise charges; for aircraft with an MTOW at, or above, 390 kg, the scheme for noise charges is $H = \lfloor F \times L \rfloor$, where H is the noise charge in Euros, F is the tariff (€9666) and L is the noise factor. For planes with an MTOW equal to, or between 390 kg and 2000 kg, L is based on the MTOW only; for planes with an MTOW above 2000 kg, L is calculated by $L = n \times 10^{(M-270)/45}$, where M is the sum of the three noise certification values of the aircraft registration, and n is a factor depending on the number of engines and the applicable noise standard.

A.4. Frankfurt airport

Frankfurt airport authority classifies aircraft into seven noise categories, based on noise emissions measured at Frankfurt airport from 1999 to 2001. Noise surcharges, which are paid along with landing and take-off fees, vary with different noise categories. The charges for aircraft in categories 1 and 2 are €0 and €20 per movement, respectively, and account for 80% of the traffic at Frankfurt airport. Chapter 2 aircraft, as well as aircraft without certification, are charged a 24 h curfew, to discourage the use of noisy aircraft. That is, aircraft with this classification may only land and take-off with special permission from the authority, and are charged more for flight movements during the night, between 10:00 p.m. and 05:59 a.m.

A.5. New York—John F. Kennedy airport

Airport noise levels are controlled by noise monitors. Aircraft exceeding 112 EPNdB on takeoff are levied a surcharge of $250.

A.6. Sydney airport

The formula for calculating the amount of noise charge payable per landing is $k \times 2^{(M-265)/15}$; here $k = 191.57$ AUD. The airport usually conducts an annual estimate, where the financial foundation, used for supporting annual noise reduction, is divided by the estimated total annual noise volume generated, to arrive at a monetary value per noise unit, which becomes the financial factor, K. M is the sum of the noise certification levels for aircraft, measured at three different points, as described before. There is no noise charge fee if M is less than 265 EPNdB.

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