Aircraft noise indexes - recent developments and current applications*

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ABSTRACT

In this paper, we briefly report about recent developments and current applications of aircraft noise indexes at the airports of Zurich where, since a few years, the ZFI (Zürcher Fluglärm Index) is in force, and Frankfurt with its FFI/FNI (Frankfurter Fluglärm Index).

INTRODUCTION

Aircraft noise indexes are integral noise monitoring instruments that express the overall effects of aircraft noise, created by a particular airport as one or two rating figures. By accounting for the most important effect measures (such as annoyance or awakening reactions) and by weighting these measures according to the population density at each grid point within a defined geographic perimeter, noise effect indexes provide residents and authorities with an integral picture of the total noise effect.

Usually, noise protection and abatement concepts are based on predicting annoyance from time-integrated levels of acoustic energy (such as the L_{eq}, L_{dn}, or L_{den}) and setting exposure limits below which it is generally assumed that the well-being of the majority of the population is not seriously affected. In contrast to roads or railway lines, airports can more easily be understood as clearly circumscribable noise emitting installations, similar to industry complexes. The air traffic they 'produce' is responsible for the aircraft noise exposure of the population living in the vicinity of the airport. The overall noise effect from one particular airport can thus be expressed in a single figure, e.g. as the number of people living within a particular exposure contour. In this paper, we propose a more elaborate and effect-oriented approach to aircraft noise assessment with – as they will be called – noise effect indexes. Noise effect indexes are an effective measure to evaluate different operation modes of an airport as a whole, or to survey the effectiveness of previously installed noise abatement measures as well as to monitor changes of the distribution of the noise burden around an airport's vicinity. By expressing noise effect as number of people affected, they can also be used as a basis for (financial) compensation schemes between different municipalities.

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The development of noise effect indexes has been fostered by the increasing public interest in aircraft noise assessment and related legal issues as well as increasing scepticism towards established forms of noise legislation. In particular, the airport expansion plans in Frankfurt and the increasing political pressure in Zurich in the last decade has prompted plans by the local governments and the airport authorities to develop noise effect indexes to measure the overall effect of aircraft noise on the population both as regards the current state as well as the situation when new flight regimes will eventually be installed. In this paper, we report on the basic features of noise effect indexes and review preliminary experiences with such indexes as they are applied in Zurich and Frankfurt.

EXPRESSING NOISE IMPACT AS NUMBER OF PEOPLE AFFECTED

The total noise impact an airport generates is depending on the operating plan enforced, type and number of airplanes, flight routing, time of day (or night) and many other factors. It is in the nature of things that such factors are oftentimes subject to public debate. Governments or airport authorities are thus prone to be impelled to evaluate the 'best' (in their view) possible mode of operation of an airport and to substantiate their decisions. Assuming that the 'best' possible mode of operation would be a mode which affects as few people as possible – potentially even at the cost of a few – the best descriptor of 'total noise impact' would be a computable figure expressing the total number of people affected by a particular level of effect. Noise effect indexes exactly accomplish this task. In their basic form they are calculable monitoring values that are capable of expressing total current noise impact or predicting unwanted noise effects of current and future flight scenarios (e.g. after changes of flight routes) of a single airport.

The idea of expressing noise impact instead of using acoustic measures in the form of number of people (affected) is not revolutionary. In the literature, it has been formulated as early as 1993 (Hede 1993). The most often adopted concept to describe total noise impact of such installations as airports is counting the number of residents derived from census population figures within a particular noise contour (often at the levels of exposure limits set out in the law). The idea of counting people within exposure contours on one hand ignores people that are affected below the exposure that defines the contour in question, and on the other – more importantly – does not differentiate enough between different exposure classes and therefore, different magnitudes of effect. Consider the following example: The probability to be "highly annoyed" at a particular exposure level is a continuous function of the exposure level, hence the best estimate of the number of people that are in fact "highly annoyed" at a particular location is the multiplication of the number of residents with the probability in question. To obtain the grand total of the number of people affected by a particular effect, the individual results of all the distinct locations (grid points, receiver points) within the relevant area that is covered by the index must be summed up. Practically, the calculation of a noise effect index therefore requires a grid of receiver points, e.g. using a one-hectare resolution and a set of criteria which define the set of receiver points that are part of the index.

In contrast to integrated *noise exposure metrics* (e.g. L_{Aeq}, L_{dn}), noise effect indexes can be regarded as integrated *effect metrics*. While exposure metrics are insensitive towards the presence of people, integrated effect metrics express the overall noise effect an airport exerts on the population around it. The basic idea behind expressing noise in terms of people is that policy makers can quickly grasp the overall noise effect of a facility in a single number which is self-explanatory and does e.g. not require any knowledge of acoustic measures. The outcome of noise, e.g. the number of people highly annoyed, is more easily comprehensible than abstract decibel values. This is quite practical for policy-makers planning flight routes and residential settlement patterns in noise-impacted areas.

The calculation of an index I for a set of receiver points i for a particular effect category e (e.g. for %HA, %A etc.) takes the general form

$$I_e = \sum_i N_{pop,i} \times f_e(L_i) \qquad (1)$$

with:

$N_{pop,i}$ Number of residents at receiver point i
$f_{e(L_i)}$ Function of the exposure L at receiver point i for the effect category e

If e.g. the effect-category specific exposure-effect function yields the probability of high annoyance (P_{HA}), a value between 0 and 1, then the index I equals the best statistical estimate of the number of highly annoyed people within the area the index is calculated.

It is of course also possible to express other effect measures than number of people such as e.g. total number of aircraft noise induced awakening reactions (in that case, the effect-category specific exposure-effect function can theoretically take a real value between 0 and infinity). The inclusion of single event-related awakening probability within a noise effects index does require the computation of the distribution of the frequency of single event metrics (such as L_{max}) within the night time. The average number of awakenings at a particular receiver point for a single person $N_{AWR,i}$ (2a), and the total number for the whole index I_{AWR} (2b) within a chosen observation period, is then given by

$$N_{AWR_i} = \sum_{j=1}^{n} f(Lmax_{ij}) \qquad (2a)$$

$$I_{AWR} = \sum_i N_{pop_i} \times N_{AWR_i} \qquad (2b)$$

with:

i,j Indexes for receiver points i and noise events j
n Number of noise events within the observation period
$Lmax_{ij}$ Maximum sound pressure level produced by event j at receiver point i

The question of *severity* of a particular number of aircraft noise induced awakenings in terms of possible health impacts is a matter of ongoing discussion in the scientific community. However, to the general public, awakening reactions are an easily explainable and plausible indicator for night noise effects.

OVERVIEW OF THE AIRCRAFT NOISE INDEXES USED AT ZURICH AND FRANKFURT AIRPORT

This section briefly reviews the "Zurich Aircraft Noise Index" (ZFI) and the "Frankfurt Aircraft Noise Index" (FFI). Both ZFI and FFI are officially released by governmental authorities. Although the authors of this article have – to different degrees – been involved in either the development or evaluation of these indexes, they claim no authorship and hence no responsibility for any scientific or practical shortcomings these indexes may be burdened with. In the next sections, the historical background, aim and scope, and the current application of the ZFI and FFI index are described.

Historical perspective

The first (published) ideas of adopting an integral approach towards noise rating by promoting the assessment of total noise impact of a given source according to population density, appeared in the early nineties in Australia. Hede (1993) proposed to use impact descriptors instead of exposure measures for environmental assessment purposes and in 2000, Southgate and colleagues proposed the Person-Events Index (PEI) and the Average Individual Exposure Index (AIE) to assess the total noise load of airports (Department of Transport and Regional Services 2000). In Norway, authorities have introduced a noise index called SPI (Norwegian "støyplage indeks"). This indicator is based on the total noise dose from separate sources, the number of residents that are exposed to these doses, and dose-response relationships that describe the annoying properties of these sources (Gjestland et al 2002). The environmental authorities of Norway have decided to use this index to monitor progress towards a noise reduction target that has been passed in the parliament in 1999. A suggestion for incorporating the health effects from all noise sources in a population-density weighted joint index have also been formulated in France recently (Baulac et al. 2010).

Within the past years, the local governments of the Canton of Zurich in Switzerland and later the State of Hessen in Germany have independently commissioned noise effects researchers and acousticians to make propositions for an integral noise impact assessment method for aircraft noise at their airports which were later called "Zürcher Fluglärm-Index" (ZFI) and "Frankfurter Fluglärm Index" (FFI), respectively.

Zurich Aircraft Noise Index (ZFI)

As a consequence of the restrictions pertaining to the usage of southern German airspace, which were put into effect by the German government as of October 19th 2001, the airport authorities in Zurich were forced to adopt a quite complex flight regime for inbound flights which burdens different communities at different times of day. In the wake of the emerging public pressure to tackle the noise problems at Zurich Airport, the government of the canton of Zurich decided to establish an advanced aircraft noise effects monitoring method in order to keep a close watch on how the noise situation around the airport develops. The monitoring method should be able to calculate the total aircraft noise impact on the population around Zurich airport, and express it in a meaningful way. Furthermore, it should also allow effect-oriented assessments of the noise single communities are burdened with in order to compare and evaluate different operating plans in terms of the overall noise effect they produce. The method's predictions should also be accurate enough so that active noise mitigation measures that were implemented, such as changes of flight routes, or changes of the fleet, were reflected in the result. Based on a preliminary suggestion – made within the scope of a feasibility study (Hofmann 2006) – an assessment procedure called "Zürcher Fluglärm Index" (ZFI) emerged in 2006 and was quickly adopted by policy as aircraft noise impact estimation method for Zurich Airport.

The most important feature of the ZFI index is that it combines measures of effect and population density measures within a single figure. This figure expresses the net noise effect as the sum of the number of *highly annoyed* persons within the noise exposure contour of 47 dB(A) for the day ($L_{Aeq,06\text{-}22h}$) and the number of *highly sleep disturbed* persons within the noise exposure contour of 37 dB ($L_{Aeq,22\text{-}06h}$) at night. These choices do not imply any scientifically founded effect threshold, but are basically normative settings. For the 'day' period, 5 dB penalties are charged during the hours 06-07 h and 21-22 h. To derive the number of highly annoyed persons (HA), for each hectare grid point within the relevant contour, the percentage highly annoyed (%HA) is derived based on the exposure-effect function for aircraft noise annoyance by Miedema & Oudshoorn (2001). The resulting percentage is multiplied with the number of residents within the hectare and the result is summed up within the exposure contour (which also defines the relevant perimeter). Presently, the area covered by the 47 dBA ('day') contour amounts to about 450 square kilometers, with about 400,000 residents, of which roughly 30,000 are considered highly annoyed by aircraft noise (Volkswirtschaftsdirektion des Kantons Zürich 2008).

To assess aircraft noise effects during night time, in analogy to the concept of *highly annoyed*, the measure "highly sleep disturbed" (HSD) was conceived. In contrast to the HA component, HSD cannot be calculated from average exposure, but is based on the distribution of maximum sound pressure levels per hectare grid point and their potential to evoke awakening reactions. The maximum sound pressure levels on the ground for each single flight are calculated using the radar flight track records from the year the index is calculated for (Empa 2006). The awakening probability as depending on the maximum sound pressure level of single aircraft noise events is calculated with a function derived from a large field study carried out by Basner and collaborators (2006). Based on the number of individual events and their awakening probability, the total number of awakening reactions of an average person per night living within the respective hectare is assessed. From this number, an arbitrary link function estimates a probability to be "highly sleep disturbed". Again, this probability is multiplied with the number of residents within the hectare, yielding the indicator HSD.

Finally HA and HSD are added together, resulting in the single value ZFI. The detailed calculation rule of the ZFI is documented in Empa (2006). Practical experiences and some figures are reported in (Schäffer et al. 2010). The index is currently calculated and reported to the public by the government on a yearly basis in order to allow everyone to gauge the development of the noise situation around the airport. The last available annual calculation was made for the year 2009 and is reported in Empa (2010).

There is room for improvement of the ZFI for several reasons: The definition of the calculation perimeter for the HSD component is not primarily effect-oriented, but arbitrarily set along a 'traditional' average exposure contour although the HSD component is derived from awakening probability which is assessed from maximum sound pressure levels. Although localized exposure-response relationships for the Zurich Airport area are at hand now (e.g. in Brink et al. 2008), they were missing at the time the ZFI was developed. Therefore, the choice was made for a well-established dose-response function (Miedema & Oudshoorn 2001). Although the chosen Miedema/Oudshoorn function pertains to the L_{dn} measure, it is applied to a weighted 16h-L_{eq} in the ZFI. This is explained with the fact, that in the Zurich Airport region, $L_{Aeq,06-22h}$ is roughly the same as is the L_{dn}. The penalization of shoulder hours is rather based on a normative setting than on empirical data. Furthermore, it has been argued that the index is prone to be influenced too much by the sheer population size at the edges of the perimeter, thus accepting an underrepresentation of the considerable noise impact close to the airport – in the center of the perimeter (Oliva 2006).

The system of noise indexes used at Frankfurt Airport (FFI and FNI)

As part of the development of the so called "Anti-Noise-Pact" (ANP) at Frankfurt Airport, the chairman of the "Regionales Dialogforum Flughafen Frankfurt" (RDF, regional forum for the dialogue at Frankfurt Airport) proposed – in contrast to the one-value-approach adopted for the ZFI at Zurich Airport – *two* noise indexes for monitoring the aircraft noise situation at Frankfurt Airport. The indexes are called the "Frankfurt Aircraft Noise Index" (FFI) and the "Frankfurt Night Index" (FNI). Whereas the primary index FFI calculates the number of people highly annoyed by aircraft operations around Frankfurt Airport, the FNI is meant to supplement FFI – it assesses nocturnal air traffic effects by expressing the number of awakenings due to aircraft noise at night-time. Both FFI and FNI combine exposure measures and population density measures within a single number.

On December 12th in 2007, in a joint declaration, the air transport industry and the State of Hessen supported the concept of noise assessment based on noise effect indexes with reservation, i.e. only if the proposed indexes are subjected to a scientific evaluation. A group of researchers (Schreckenberg et al. 2009) were commissioned to evaluate, from a scientific viewpoint, whether a regional index is principally suitable to assess aircraft noise development due to changes in number, spatial distribution and type of flights and whether the proposed indexes fulfil the following requirements: (1) The indexes should be a transparent description of the regional aircraft noise development. (2) They should reflect the effects of active noise control measures and they should provide a comparative tool to assess advantages and disadvantages of active noise control measures. (3) At least one of the proposed indexes should be suitable for the definition of a regional noise limit, where countermeasures should be triggered if the limit is exceeded. The results of the evaluation have been documented by Schreckenberg et al. (2009).

Differences and similarities between ZFI and FFI

The primary aircraft noise effect index FFI describes the number of persons highly annoyed by aircraft noise (HA) in areas within the 53 dB(A) $L_{eq,06-22h}$ contour. The 53 dB(A) $L_{eq,06-22h}$ contour was chosen by the RDF in order to only account for 'relevantly' noise-burdened residents in the index. In contrast to the ZFI, which relies on the generalized exposure-annoyance function by Miedema & Oudshoorn (2001), a regional exposure-response curve is incorporated in the FFI, based on data of a field study on aircraft noise annoyance carried out in communities in the vicinity of Frankfurt Airport in 2005 (Schreckenberg & Meis 2006). The FNI serves to assess the effect of nocturnal air traffic by reflecting the number of additional awakenings induced by aircraft noise between 22 h and 6 h, including regions where at least 0.75 additional aircraft noise induced awakenings per night are expected. As is the case with the ZFI, the awakening probability function from Basner et al. (2006) is used for this purpose. 0.75 additional awakenings is a normative setting.

Since the beginning of this year, the indexes FFI/FNI serve as the primary planning tool of the RDF, the Regional Forum for the Dialogue at Frankfurt Airport and are used by the Forum to suggest and negotiate active noise abatement measures with the airport authorities.

ZFI and FFI/FNI share many conceptual similarities, but differ in some aspects. First, it must be mentioned that the FFI was conceived only after some initial experience with the ZFI was at hand. While the ZFI index uses two different effect measures to be integrated into one single figure, the FFI covers the 16-hour day period but regards only annoyance as effect measure. The FNI gives supplemental information on night noise impact, thus avoiding the delicate issue of combining different effects in a single number. Last but not least is the ZFI index part of the cantonal public law and thus has legal force, which is not the case for the FFI.

CONCLUDING REMARKS

The strengths of noise effect indexes are that they (1) express the effects of a certain exposure scenario of a whole airport in one single figure (per effect dimension), and (2) all residents that, according to objective criteria, belong to the basic calculation perimeter, are accounted for in the index and weighted according to the effective noise burden they carry. Noise effect indexes thus overcome the primary weakness of traditional noise assessment, whose focus is rather on *exposure* than on *impact*. Using indexes, the overall noise effect is reflected more accurately in the resulting figure than simply the counting of residents within a particular noise contour. Noise effect indexes can be used to compare the full range of the noise damage assignable to operating regimes at airports, e.g. in order to be able to choose the least burdensome one. If combined with a limit value that should not be exceeded by an airport as a whole, they can generate political pressure to enforce stronger and more effective means of active noise abatement.

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Differential exposure of the urban population to road traffic noise in Hong Kong

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INTRODUCTION

Recent studies have shown that biased environmental policy and enforcement, combined with differential market forces, may lead to disproportionate exposure of certain population groups in the society to environmental pollution (Brainard et al. 2002, 2004). The term "environmental inequality" refers to the unequal distribution of environmental risk or burden in the society (Pellow 2000; Brainard et al. 2002, 2004). Its synonymous term "environmental justice" concerns the broader dimension of fair treatment of all people regardless of ethnicity, age, socio-economic status with respect to the environment (USEPA 2011). In recent years, increasing attention has been given to the unequal exposure of environmental nuisances to air pollution (Baum et al. 1999; Brainard et al. 2002) and noise (Brainard et al. 2004; Hoffman et al. 2003; Pearce et al. 2006).

Noise pollution is an important aspect of environmental quality because of its prominence in many cities, ease to be quantified and potential health impacts (Stansfeld et al. 2000). Hong Kong offers a good opportunity to study environmental inequality. Having an urban acoustic environment dominated by road traffic noise (Brown & Lam 1987), an estimated 18 % of the population is exposed to excessive road traffic noise (HKEPD 2006). Furthermore, Hong Kong's dualistic private and public housing provision mechanism offers a unique experience for the study of environmental inequality. From the social perspective, Hong Kong has a high Gini coefficient which is indicative of significant income inequality (Legislative Council Secretariat 2004).

Little research has been carried out so far in Hong Kong to ascertain if, and to what extent, noise exposure is class-biased, and whether the lower socio-economic stratum is more susceptible than others to environmental noise. The primary objective of the study is therefore to investigate the extent to which differences in road traffic noise exposure are related to the socio-economic status of the urban inhabitants in Hong Kong.

METHODOLGY

To obtain the necessary data for analysis, both noise exposure and socio-economic data are needed. The former was done by noise mapping and the latter obtained from the Census Department. Based on census data, the size of the study unit was determined by the census enumeration unit. Theoretically, the smaller the census unit, the less heterogeneous and the more representative is the data.