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Aircraft Noise Indexes for Effect Oriented Noise Assessment

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Summary

This article discusses aircraft noise effect assessment with noise effect indexes, such as have recently been developed for noise monitoring purposes at the airports of Zurich and Frankfurt. Aircraft noise indexes are noise assessment instruments that express the overall effects of aircraft noise as a single figure which reflects the total amount of people that are in some way affected by the noise of a particular airport. 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. The paper reviews basic features of noise effect indexes and reports about the development and the current practical application of such indexes. Moreover, it points to specific not yet fully resolved issues such as accounting for the diurnal variation of noise effects, the definition of calculation perimeters, and the weighting of day and night effects including the question of unification of different effect measures into one index.

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1. Starting position

Most western countries feature some sort of noise protection legislation as part of their national law at least for the major noise sources road, rail, and air. 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 efficient 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.

In this paper, we a) report on the basic features of noise effect indexes, b) review preliminary experiences with such indexes as they are applied in Zurich and Frankfurt, and c) point to current and future issues to tackle in order to enhance the indexes.

2. Basic features of noise effect indexes

2.1. 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

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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 little as possible – potentially even at the cost of a few – the best descriptor of 'total noise impact' would be a computable figure that expresses the total number of people aff ected 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 [1]. 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). However, local governments and airport communities in the last years have become aware that these 'traditional' concepts of assessing total impact have some serious drawbacks. The system 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 quasi 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 particular effect category e (e.g. for %HA, %A etc.) takes the general form

$$I_e = \sum_i N_{\mathrm{pop},i} \cdot f_e(L_i), \tag{1}$$

where $N_{\mathrm{pop},i}$ is the number of residents at receiver point i, $f_e(L_i)$ is the 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 value between 0 and infinity). Noise effects become manifest in several effect dimensions. The next section reviews feasible effect indicators and discusses whether different indicators should be integrated into one single effect descriptor or be reported separately.

2.2. Measures of noise effect

The World Health Organization (WHO) in their "Guidelines for Community Noise" [2] lists the following non auditory noise effects as possibly relevant for health impairment: Interference with speech communication, sleep disturbance, cardiovascular and physiological effects, mental health effects, effects on performance, effects on residential behavior, and annoyance. A query of the ISI Web of Science Database [3] that was performed on 30th of April 2010, gave a rough estimate of the attention these effect dimensions have received in the literature. The number of articles with occurrences of the combination with the word "noise" (using the "AND" operator) for the following title words were, in descending order: "annoy*" = 439 articles; "disturb*" = 275; "physiolog*" = 166; "blood pressure" = 100; "cardio*" = 98; "hypertension" = 68; "sleep disturb*" = 54 ("sleep" alone = 213, "awake*" = 20); "reading" = 40; "speech communication" = 36; "cortisol" = 25; "mental health" = 21; "cancer" = 20; "myocardial infarction" = 19; "cognitive perform*" = 16; "stress hormones" = 3. From the above, one can conclude that there are basically four groups of noise effects being investigated in the literature. *Annoyance* and/or *disturbance* are among the most often researched effects, the second rank is occupied by basically *cardiovascular* effects such as hypertension, followed by *sleep disturbance*. The last effect category can be described as *cognitive impairment effects*. Among these effects, *annoyance*, *hypertension* and *sleep disturbances* (*awakenings*) are currently the most important effects which can more or less directly be related to a particular amount of noise exposure and for which exposure-effect functions exist which are backed with a substantial body of scientific data. In the case of hypertension (or other cardiovascular effects), the evidence is less clear at least at lower levels, therefore for an aircraft noise effects index, the most straightforward and useful effect dimensions appear to be annoyance and sleep disturbance.

2.2.1. Annoyance

Annoyance is a central psychological variable in noise effects research and is considered as the most important psychological noise effect. Overall, noise annoyance appears to be a very sensitive indicator of adverse noise effects and by itself means that noise affects people's quality of life. The rather general expression of annoyance is assumed to provide the best estimate of the overall effect environmental noise exerts on society. This is the reason for the EU to build its actual strategy to combat noise upon the assessment of noise effects derived from so called standard ("EU") noise annoyance curves [4]. It is quite obvious that annoyance, although not the only, but undoubtedly one of the most important effect dimensions of noise pollution, should be part of the 'effect inventory' of an index.

The annoyance response of a particular individual or a group of individuals can be predicted on the basis of the exposure only with large uncertainty. Noise effects researchers therefore recommend that – according to certain cut-off criteria of the distributions of annoyance ratings in individual studies – the percentage of persons annoyed ("%A") or the percentage of persons highly annoyed ("%HA") be used as the descriptor of noise annoyance in a population. Some of the reasons, why the percentage of the population that strongly reacts to the noise within an exposure category is a better measure of community reaction than the average of an (ordinal or continuous) noise annoyance rating scale, are listed in the seminal paper by Schultz [5]. The number/proportion of highly annoyed persons is a self-evident effect indicator. It can easily be derived from exposure-effect functions which deliver P_{HA} (or %HA) for a given exposure value. Alternatively, P_{A} (or %A) – the percentage annoyed – may equally well serve the purpose at stake.

One important question to address when designing an index that incorporates annoyance, is the choice of an exposure-effect function which is required to model the overall annoyance effect. Basically, one could either rely on a *generalized* curve (such as the "EU" curve) or use a 'local' function, derived from country or airport-specific noise annoyance surveys.

Evidence is increasing that the well-known annoyance curves from former meta-analyses (e.g. [5, 6, 7]) do not correctly reflect the relationship between exposure and the percentage of highly annoyed persons anymore [8, 9, 10, 11] and some authors consider these curves as outdated [12, 13, 14]. The recently published analyses of aircraft noise annoyance in the HYENA study lend support to the possible existence of cultural differences in annoyance which cannot simply be explained by different exposure calculation models [9]. Exposure-effect relationships for annoyance must be regarded as being prone to be the result of the specific cultural environment where annoyance studies take place and possibly also of the noise exposure calculation model that is used for a particular study's exposure assessment. Interestingly, the latter is often completely disregarded by noise effect researchers, although different calculation models (e.g. INM, AzB, FLULA2, NORTIM etc.) might be as strong a source of exposure-response differences between studies, as are different cultural contexts. To date, no perfect agreement could be reached between the different aircraft noise exposure calculation models [15, 16, 17, 18]. Therefore, one has to bear in mind, that the application of an exposure-effect function and the exposure calculation method that was adopted in the underlying annoyance study are mutually dependent. Only if the exposure calculation method for calculating and reporting the index is the same as the method used to derive the exposure-effect relationship, will the result truly reflect the proportion of highly annoyed people in a particular index (and similarly, for other effect dimensions). In this light, the usefulness of a generalized exposure-effect function for forecasting annoyance at a particular airport is questionable and thus it may be advantageous to use locally derived exposure-effect curves. However, this is a preliminary recommendation, as the consequences of using different functions and/or different exposure calculation models have not yet been specifically investigated.

2.2.2. Sleep disturbance

Transportation noise has become a major source of sleep disturbances, amongst others, as a consequence of the increasing tendency of transport companies to evade jammed roads and crowded airspace during the day by rescheduling traffic to the night time, especially cargo and forwarding services. While for the determination of the percentage of highly annoyed (%HA) a de facto standard has emerged over the years – documented in three influential papers by Schultz [5], Miedema and Vos [7] and by the International Commission on Biological Effects of Noise (ICBEN) [19] – no comparable agreement pertaining to a concept of "highly sleep disturbed" exists. In the view of the European Commission Working Group on Health and Socio-Economic Aspects, "high sleep disturbance" is the expression of a subjective feeling of disturbance as it can be collected with questionnaire items [20]. However, there exists no standardization as how to measure "high sleep disturbance" to date.

In the last years, partly extensive studies investigating objective sleep quality parameters [21, 22, 23, 24, 25, 26, 27, 28] have become available which qualify to be used to derive an indicator of sleep disturbance in a reproducible manner. Among these, awakenings from single noise events, defined as the transition from a stage of sleep to the wake stage, e.g. by means of Polysomnography (PSG), have become one of the most often adopted criteria in night time noise protection concepts. The most commonly published exposure-response functions for night time noise and sleep disturbance pertain to the relationship between the maximum sound pressure level ($L_{\max}$) of an (aircraft) noise event and the probability of awakening reactions P_{AWR} [21]. These functions are derived by scoring the relative frequencies of awakening while being exposed to aircraft noise (usually measured at the ear of the sleeper) and subtracting the relative frequency of so called *spontaneous* awakenings [29]. Awakenings are a good night noise effect indicator for several reasons: (1) Awakenings are a very sensitive form of reaction to environmental stimuli during sleep, (2) they constitute a severe disruption of the normal sleep process, and (3) the indicator is sufficiently specific, occurring relatively rare in the absence of acoustic triggers. While we advocate the use of polysomnographically measured awakenings here, it must be pointed out that, basically, any kind of binary reaction types (including behavioral/signaled awakenings such as proposed in the ANSI/ASA norm S12.9-2008 [30]) could be used as the basis for quantifying night noise effects within the scope of an aircraft noise effect index.

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

$$N_{\mathrm{AWR}_i} = \sum_{j=1}^{n} f(L_{\max_{ij}}), \tag{2a}$$

$$I_{\mathrm{AWR}} = \sum_{i} N_{\mathrm{pop}_i} \cdot N_{\mathrm{AWR}_i}, \tag{2b}$$

where i, j are the indexes for receiver points i and noise events j, n is the number of noise events within the observation period, $L_{\max_{ij}}$ is the 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.

3. Overview of the aircraft noise indexes used at Zurich Airport and proposed for 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 local governments. Their development has been fostered by the increasing public concern as regards noise nuisances around the respective airports 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 current 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. 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.

3.1. 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 proposed to use impact descriptors instead of exposure measures for environmental assessment purposes [1] 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 [31]. 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 [32]. 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 [33].

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 researches 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.

3.2. Zurich Aircraft Noise Index (ZFI)

3.2.1. History

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. The densely populated areas to the south and east of the airport are exposed during particularly critical shoulder hours. In the past years, since adoption of the new operating plan, residents around the airport quickly figured out that even if the noise exposure in different communities is the same in terms of average level, the 'net' effect of noise on people depends on a variety of other factors of which the different sensitivities to noise at different times of day and hence their interaction with the flight schedule play a major role. 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 [34], 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.

3.2.2. Features of the ZFI

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 ($L_{\mathrm{Aeq},06-22\mathrm{h}}$) and the number of *highly sleep disturbed* persons within the noise exposure contour of 37 dB ($L_{\mathrm{Aeq},22-06\mathrm{h}}$) 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 and Oudshoorn [35]. 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 dB(A) ('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 [36].

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 HA, 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 [37]. 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 [21]. 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 [37]. Practical experiences and some figures are reported in [38]. 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 2008 and is reported in [39].

3.2.3. Criticism

The introduction of the ZFI met with criticism, both pertaining to its scientific foundation as well as concerning its applicability for noise policy purposes. Some aircraft noise protesters considered it "old wine in new skins" (http://www.vfsn.ch) because it was, for the annoyance component, still based on extracting %HA from the average 16h-L_{Aeq}, the latter being widely regarded as unsuitable for e.g. the noise impact assessment during shoulder hours.

There is room for improvement also from a scientific perspective, for several reasons: The definition of the calculation perimeter (cp. Section 4.1) 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 [13]), they were missing at the time the ZFI was developed. Therefore, the choice was made for a well-established dose-response function [35]. 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, $L_{\mathrm{Aeq},06-22\mathrm{h}}$ 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 [40]. Some of these issues will be discussed in section 4.

3.3. The system of noise indexes proposed for Frankfurt Airport (FFI and FNI)

3.3.1. History

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. Schreckenberg, Basner, and Thomann 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 by Schreckenberg *et al.* have been documented in [41].

3.3.2. Differences and similarities between ZFI and FFI

For the whole 24-hour period of the day, the primary aircraft noise effect index FFI describes the number of persons highly annoyed by aircraft noise (HA) in areas within the 55 dB(A) L_{dn} contour. The 55 dB(A) L_{dn} contour was chosen by the RDF in order to only account for 'relevantly' noise-burdened residents in the index. This decision was made with reference to the "Daytime protection zone 2" as defined in the German Act for the Protection against Aircraft Noise [42]. The Daytime protection zone 2 includes areas within the 55 dB(A) $L_{\mathrm{Aeq,16h}}$ contour. Within this zone, noise insulation must be provided for buildings in order to protect residents from aircraft noise. Currently, there is an ongoing discussion as whether to lower the criterion in the index to 53 dB(A). In contrast to the ZFI, which uses $L_{\mathrm{Aeq,16h}}$ and relies on a generalized exposure-annoyance function, 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 [43]. 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.* [21] is used for this purpose. 0.75 additional awakenings is a normative setting.

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 whole 24-hour 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.

4. Specific issues and further development

In the course of further development of aircraft noise effect indexes, such as the ones discussed, several inherent difficulties must be carefully addressed. One of these issues for example is the question by which criteria a perimeter within which an index is calculated, should be defined and how such a particular choice of criteria can be legitimated. Another problem is the treatment of specifically sensitive shoulder hours or, more generally, the accounting for the diurnal variation of annoyance across the 24-hour-day. Both ZFI and FFI are quite simple indexes and the attainable level of detail in the modeling of effects is certainly not exhausted yet. Some approaches to enhance the sensitivity and prognostic accuracy of noise effect indexes will be discussed in the next sections.

4.1. Definition of a perimeter

As noise from in- and outbound aircraft can principally cover areas of very large extent, the area in which an index should be calculated must be limited in some way. The area in which residents are regarded as (potentially) affected by aircraft noise and hence 'counted' for an index can be referred to as *perimeter*. A perimeter defines a set of receiver points (grid points) that meet particular requirements. All receiver points within the perimeter then account for ('are part of') the index. Basically, there are three different options to define a noise index perimeter:

- the perimeter is based on politico-geographic boundaries that are arbitrarily defined,
- the perimeter boundaries are defined by a particular noise exposure contour,
- the perimeter is defined according to a minimal level of effect (e.g. 0.5 awakening reactions per night) that must prevail at all its receiver points.

The decision for a particular type of demarcation is non-trivial, as is the choice of a cut-off criterion for a receiver point to belong to the perimeter or not.

The (absolute) level of a noise effects index not only depends on acoustic parameters, but to a large degree on the *size* of the perimeter. If noise effect indexes are considered to serve as a tool for either comparing different modes of operation at an airport or to describe the changes of the total noise burden over the years, e.g. to survey regulatory measures such as banning noisy aircraft, an index with a small perimeter around the airport obviously reacts more quickly in terms of proportional alteration than an index that covers a large area with many residents. Changes in the operation of an airport primarily affect the close vicinity of an airport. If the shape and size of the perimeter is itself regarded as an important result of the calculation of the index, the demarcation criterion should be based on effect measures only. In practice, this means that one has to set an effect minimum (e.g. 25% HA) below which a receiver point does not belong to the perimeter.

With the advent of more sophisticated investigation methods, noise effect thresholds were demonstrated to be considerably lower than believed a few decades ago. E.g., in the 70ies, awakening probability due to single aircraft noise events was thought to be negligible below maximum sound pressure levels of about 60 dB(A) [44]. Today, noise events exhibiting $L_{AS,max}$ (at the ear) as low as 33 dB(A) have statistically been related to awakening [21]. Furthermore, as it seems nowadays, there exist considerable fractions of people which are highly annoyed even at low exposure levels, particularly in the case of aircraft noise [13]. For all these reasons, one can principally still compute noise effects in areas which are relatively far away from the airport. If one is out to capture as much 'effect' as possible, an as large as possible perimeter would be most suitable. A large perimeter has some advantages. The greater the perimeter is, the smaller are the chances that residents outside the perimeter contour complain about not being accounted for in the index, thus preventing the development of a public opinion that sees the definition of the perimeter as some form of underhand 'scientific trick' to hide much of the exposure. However, there are two important points to consider: On one hand, the reliability of noise exposure calculations generally decreases with increasing distance from the airport, as the exposure gets lower, affecting the reliability of the index itself [45], and, on the other hand, with increasing distance, chances upon hitting densely populated areas usually increase also. Densely populated areas in combination with low exposure inflate the proportional effect of population size on the index and make the index rather inert. As a consequence of a large perimeter, the noise index would be less suited to be used as a monitoring tool that reflects changes in the modes of operation and/or the introduction of active noise abatement measures, because it rather represents population size than noise effect. In the case of the ZFI, sensitivity analyses have been carried out that document the individual influence on the index of population size and population growth (from one year to the next), the number of movements, the composition of the fleet and its operation during the 24 h day, the allocation of the movements to different air routes, as well as different flight geometries [38, 46].

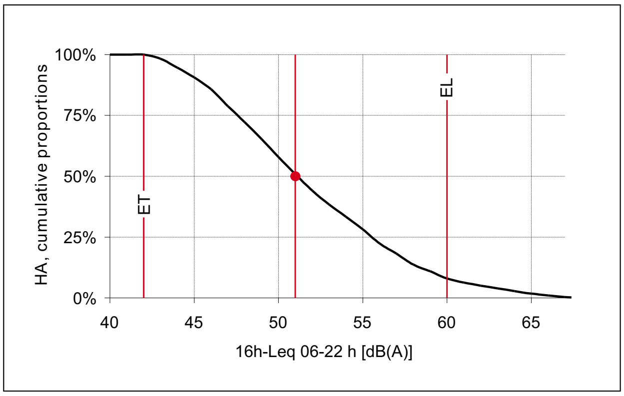

Figure 1. Cumulative proportions of highly annoyed persons within a perimeter defined on the basis of the 16h-L_{eq} (day).

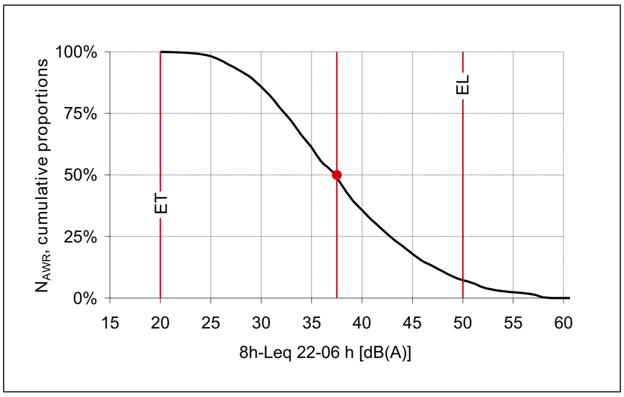

Figure 2. Cumulative proportions of number of awakening reactions within a perimeter defined on the basis of the 8h-L_{eq} (night).

Concerning annoyance, the reviewers of the Frankfurt indexes [47, 48] suggest a demarcation criterion between the *response threshold* (0% HA) and the *critical threshold* of 25% HA. The exact criterion to choose is not directly suggested by scientific evidence. However, the cumulative proportion of highly annoyed persons can be used to pinpoint the demarcation criterion to use. The graphs in Figures 1 and 2 display on the y axis the cumulative proportion of highly annoyed persons during day (Figure 1) and the proportion of the number of awakening reactions at night (Figure 2) within a perimeter defined according to an exposure contour at the level given on the x-axis. The displayed curves are based on the aircraft noise exposure and population around Zurich Airport in the year 2004 and serve as an example. Different airports will, depending on population density distribution, flight paths, traffic volume, and topography, yield different curves.

In both figures, the exposure indicated by "ET" (*effect threshold*) defines the threshold level below the effect in question is, according to the employed exposure effect-function, non-existent (e.g. the effect threshold for %HA according to [49] would be at L_{dn} = 42 dB(A)), hence a perimeter that would be defined as the envelope formed by the exposure contour at ET would cover *all* people that are affected by aircraft noise from the airport.

"EL" demarcates a common *exposure limit* (here at 60 and 50 dB(A) respectively). At 50% cumulative proportion, half the number of highly annoyed persons or half of all awakening reactions attributable to aircraft noise would be considered in the perimeter. We recommend to set the demarcation criterion for receiver points to be included in the perimeter at a value where 50% of the total burden of the effect in question is reached. The corresponding exposure in Figure 1 is at 51 dB(A) and 38 dB(A) in Figure 2 respectively. It must be mentioned that looking at cumulative proportions is just one of several methods of guidance for the initial setting of the demarcation criterion. The demarcation criterion should be defined only once (e.g. in a particular reference year) in order to be able to monitor changes in the index over time.

The size and location of the perimeter could in theory (and practice) have an influence on the rank order of the calculated index that would result from different operational alternatives, depending on the flight tracks and the geographic distribution of the population density within the respective perimeter. Therefore, if the intention of using the index is to compare different variants of operation of an airport, the calculations must possibly be made for different sizes of the index perimeter.

4.2. Accounting for time-of-day and day-of-week sensitivities

4.2.1. Diurnal variation of annoyance

Important aspects of noise metrics are their description of the tradeoff between individual exposure levels and number of events as well as the weighting of noise at different times of the day [50]. Whereas accounting for the tradeoff between levels and numbers of events was not very much successful in terms of the adoption of a particular noise metric by legislation, the fact that different times of day somehow call for different (legal) treatment is undisputed. Aircraft noise annoyance studies that have been carried out in the current decade corroborate the assumption that diurnally changing sensitivity to aircraft noise is a factor which independently contributes to the tendency of a person to be highly annoyed at a particular time of day [13, 43, 51]. Ideally, a noise metric that reflects attitudes to aircraft noise should reflect these time of day sensitivities better than metrics based on daily average measures. Most noise policy and noise assessment concepts that are in use nowadays are, however, based on predicting the number of highly annoyed persons from *average* noise exposure levels over relatively long periods of time – such as a 16-hour day or 8-hour night. An issue that has traditionally given rise to discussions in the public as well as among noise researchers is the fact that one "does not hear an equivalent/average level", but single events that often appear in clusters at different times of day which in turn are characterized by a different sensitivity to noise.

Although $L_{\text{Aeq,24h}}$, L_{dn} and L_{den} are in most cases acceptable approximations of community annoyance, they might fail to predict annoyance correctly in the case of (rare) departures from the (typical) timely distribution of noise at an airport throughout days and weeks or in the case of particularly heavy exposure during shoulder hours. Because even when the noise exposure in different communities would be the same in terms of average level, the effect of noise on people is always the result of an interaction between different times of day and the particular timely structure of overflights at the corresponding location. Only as long as the main flight paths out of and into an airport do not change throughout the day, does average exposure-based noise assessment satisfactorily describe the noise burden of a community. At airports where due to meteorological, topographical and/or political reasons, landing and takeoff routes often change during a day (not to be confused with volitional runway alternation), a noise assessment relying on average levels (such as a 24h-L_{eq} or 16h-L_{eq}) is prone to systematically under- or overrate the true impact of air traffic on residents at a particular location. E.g. it can happen, that even if the average exposure at Location A is higher than at Location B, the total 'negative impact' at Location A is smaller, e.g. because the lions share of air traffic affects Location A only during rather non-sensitive hours. For the reasons discussed above, a sophisticated noise effects index must account for the interaction of diurnally varying annoyance with diurnally varying flight operations and in principle also account for the weekly (circaseptan) variation in which the organization of the everyday life resolves. The variation of 'annoyability' across the day can be expressed in decibel equivalents and can be calculated from the coefficients in a binary logistic regression model of the hour-by-hour annoyance as outlined in [52]. Figure 3 shows the profile of diurnal variation of (daytime) annoyance among residents living in the vicinity of the Airports of Zurich and Frankfurt. It is yet open to debate how the diurnal variation of annoyance can be integrated into a noise effects index in a methodologically acceptable manner.

4.2.2. Variations of awakening probability during the sleep period

In most cases, to simplify matters, awakening reactions to noise events in the night are typically regarded as being independent from each other and independent from the time of the night (the noise event occurs). However, this is not the case. As with annoyance, awakening probability is not just dependent on acoustical parameters, but to a considerable degree on the current sleep stage and the time elapsed since sleep onset. During the first half of the night, the proportion of slow wave sleep (SWS) is considerably higher than during the second half of the night and awakening probability is generally reduced during SWS. Basically, the longer one has slept, the easier one can be awakened, but the relationship with time is not linear. This fact becomes important when forecasting the number of awakening reactions (as part of an index). In the literature, in particular early morning noise events are considered to relatively easily disturb sleep [22, 53]. Furthermore, chances that awakening reactions can be remembered are higher at the end of the night than at the beginning, thus prob-

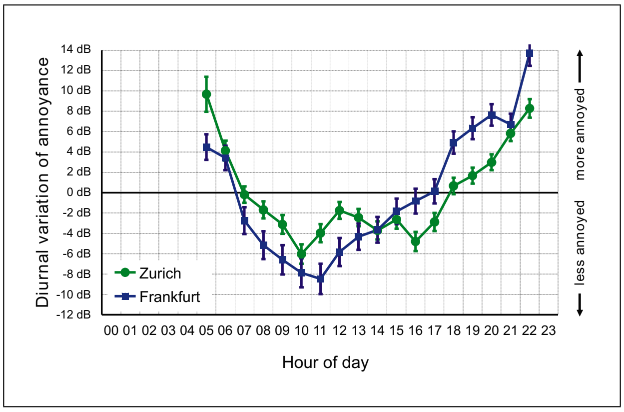

Figure 3. Profiles of diurnal variation of high annoyance, expressed in Decibel values. Hour by hour annoyance and 1-h-L_{eq} exposure data were collected in [13] with residents around Zurich Airport and in [43] with residents around Frankfurt Airport. The method of calculation is described in [52].

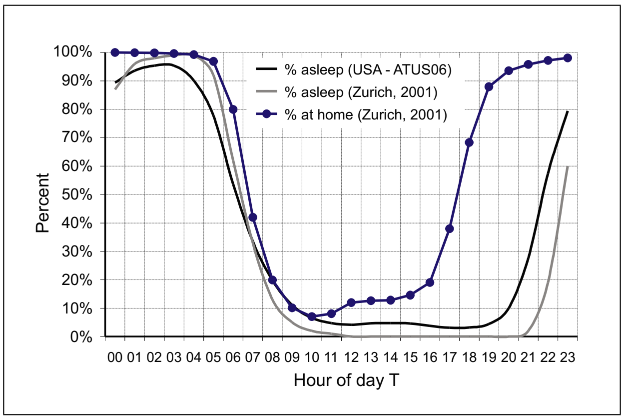

Figure 4. Fractions of the population asleep during an average day (including weekend days) from two different data sources (smoothed curves); Estimate of the fraction of people that are 'at home' for each hour of day during an average weekday.

ably contributing to greater annoyance from nightly aircraft noise events when they happen during early morning. It is currently an open question whether awakenings in the beginning of the night or awakenings towards the end of the sleeping period are more detrimental to restorative processes. However, it seems rational to account for the time-dependent vulnerabilities to be awoken by noise events during sleep the one or the other way. But it is yet open how to accurately integrate the variation of the vulnerability to awake into a noise effects index.

4.3. Differentiation of "day" and "night" effects

4.3.1. Night vs. day / sleep vs. wake

Provided different classes of effects of aircraft noise must be related to either the day or night period – which obviously makes sense – the different effect calculations must relay on a proper definition of "day" and "night" periods. Most noise legislation defines the start of the day period to be at 6 or 7 h, the latter being the European Union's default value in the Environmental Noise Directive (END) [4] and the beginning of the night at 22 or 23 h. However, there is obviously no scientific legitimation for an abrupt beginning and ending of day and night periods at hand and people also do not abide their life rhythm by the rules defined in noise legislation. Therefore, for an effect-oriented assessment system, it appears imperative, that – irrelevant of *de jure* legislation – the *de facto* sleeping habits of the population of interest should be the relevant criterion to define night and day.

Data about sleeping habits of humans can be obtained from international time use databases, such as provided by the center for time use research (http://www.timeuse.org), from local or national statistics bureaus, or must be gathered from the population of interest. In time use surveys, respondents will typically be asked which kind of activity they carry out at what time of day and for how long. They will usually also be asked at what time they go to bed (to sleep) and get up in the morning. Thus, for each of the 1440 minutes of a day, it can principally be reconstructed whether a responding person was 'in bed' (trying to sleep or sleeping) or not. The proportion of people 'asleep' and 'awake' in a given sample for each of the 24 hours of a day can then be roughly calculated as

$$\mathrm{Pasleep}_T = \frac{1}{60N}\sum_{m_T=0}^{59} n_{m_T},$$
$$\mathrm{Pawake}_T = 1 - \mathrm{Pasleep}_T, \qquad (3)$$

where $\mathrm{Pasleep}_T$ is the proportion of people asleep at hour T (where $T = 0$ is the time period between 00 h and 01 h), Pawake_T the proportion of people awake at hour T (where $T = 0$ is the time period between 00 h and 01 h). m_T is the Minute 0…59 within hour T, n_{m_T} the number of people in the sample that reported being asleep in minute m of hour T and N is the sample size.

Once the 24 values for $\mathrm{Pasleep}_T$ or Pawake_T have been obtained, the effect categories that are part of a noise effect index can be weighted according to the proportion of people being in the sleep or wake period. Figure 4 shows how to basically weight noise effect dimensions that are specific to the state of wakefulness or sleep. The graphs show the fractions of the population asleep for each hour T as calculated from two different data sources: (1) The first source were the freely available datafiles from the American Time Use Survey (ATUS) from the year 2006 [54]. ATUS is carried out on a yearly basis by the U.S. Bureau of Labor statistics and systematically collects information on how people living in the United States spend their time. The ATUS curve in Figure 4 is based on 28'771 sequences of sleep from 12'943 individuals. (2) The second data source were two aircraft noise annoyance surveys of inhabitants of communities around Zurich Airport that Brink and collaborators carried out in the years 2001 and 2003 [13].

The proportions of people asleep during each hour in the ATUS survey add up to 8.78 hours of sleeping per average day and, accordingly, 15.22 hours of being awake. The effective sleeping time in terms of the physiological definition of 'sleep' according to [55] or [56] is most certainly less, because on one hand, intermittent wake periods in the night are still counted as sleep and on the other hand, people seem to slightly overestimate their total sleep time in general [57]. It becomes obvious that, depending on the cultural context, one should consider the sleep/wake profiles, if available, that best match the behavior in the population of interest.

4.3.2. 'At home' or not

Most published exposure-effect relationships for aircraft noise annoyance account for the exposure at the homes of residents (i.e. the receiver point) although many are not present at their homes all the time. Therefore, an important issue to address in integral noise effects assessment is whether for the time period for which a particular effect is calculated, the calculation should account for the proportion of people that is present at the receiver point. Usually, a quite large part of the population goes to work or to school during weekdays, thus the local population density at some receiver points will temporarily be reduced between about 8 h and 18 h, and will increase at others. The use of residential-based population estimates to assess the noise effect does not reflect the fluctuations that occur as people go about their daily lives – a shortcoming that could be avoided in noise effect indexes. However, knowing where people are throughout the day is clearly "a much greater challenge than knowing where aircraft are" [58]. This proposition points to the idea that the 'noise receivers' themselves are usually highly mobile – triggering the question whether impact assessment should actually rather account for the mobile person than for a fixed geographical point of residence. There are many reasons to regard (principally mobile) individuals instead of geographical locations as the relevant immission points where noise effects take place. One of the very rare empirical analyses of the variation of exposure of the dynamic population throughout a day has been carried out by Greaves and Collins using data from a travel survey among residents around Sydney Airport [58]. They found that when accounting for the mobility of the population across a day instead of just using the static population figures, total aircraft noise impact (per capita) was actually larger. However, for the remainder of this paper and to simplify matters, it shall be assumed that the noise effect should be calculated for the static location 'at home'. Here, one can at least avoid to overestimate the noise effect at times, when the 'average' adult person is not at home: A corresponding density function curve was derived in the above mentioned Zurich surveys by asking the respondents, when they leave their homes in the morning and return back in the evening. The resulting curve is also shown in Figure 4. During an average workday, the time period from about 18 h to 22 h goes along with a relatively high percentage of people spending their time both at home and awake. Therefore, acute annoyance reactions as regarding the 'home situation' can be expected to particularly prevail during this period. The Lden noise indicator as promoted in the Environmental Noise Directive [4] partly accounts for this by penalizing the evening hours between 19 h and 23 h. It can be assumed, but must be verified, that during weekend days, more people spend their time at home, which may call for a separate treatment of aircraft noise during weekends. Currently, this level of detail is not realized in any existing index yet.

4.4. Integration of time-of-day sensitivities and day-night differentiation

When incorporating time-of-day sensitivities and/or a detailed day-night differentiation, it is advisable to basically divide the 24h-day period into several time sections of identical duration. This assures the most straightforward calculation. The most obvious categorization is by the 24 hours of the day. The different time-of-day dependent sensitivities can be accounted for by applying to each hour T a penalty K_T (in Decibels) and the weighting of the two effect categories (%HA and P_{AWR}) can be attained with the multiplication of the effect in each hour T with Pawake_T or $\mathrm{Pasleep}_T$ respectively. Equation (4) defines the indexes I_{HA} (Number of people highly annoyed) and I_{AWR} (Number of aircraft noise induced awakenings) accounting for the proportion of people asleep and awake during particular hours including the hour-specific penalties K_T.

$$\begin{aligned} I_{\mathrm{HA}} &= \sum_i N_{\mathrm{pop},i} \frac{\sum_{T=0}^{23} \mathrm{Pawake}_T f_{\mathrm{HA}}(L_{\mathrm{eq}_{iT}} + K_{\mathrm{HA},T})}{\sum_{T=0}^{23} \mathrm{Pawake}_T}, \\ I_{\mathrm{AWR}} &= \sum_i N_{\mathrm{pop},i} \sum_{T=0}^{23} \mathrm{Pasleep}_T \\ &\quad \cdot \sum_{j=1}^{m_T} f_{\mathrm{AWR}}(L_{\mathrm{max}_{ijT}} + K_{\mathrm{AWR},T}), \end{aligned} \tag{4}$$

where f_{HA} is the exposure effect-function for the probability to be highly annoyed, m_T the number of noise events within hour T, f_{AWR} the exposure effect-function for awakening probability due to aircraft noise events, $K_{\mathrm{HA},T}$ is the penalty for high annoyance to be applied to hour T, $K_{\mathrm{AWR},T}$ the penalty for awakening probability due to aircraft noise events to be applied to hour T and $L_{\mathrm{eq}_{iT}}$ is the average sound exposure level at receiver point i during hour T.

Equation (4) is not more than a draft proposition about how time-of-day sensitivities and the day-night differentiation could be incorporated in an aircraft noise index. The proof of usability of such a kind of calculation is still pending and there are several open questions on how to empirically derive the penalty values $K_{\mathrm{HA},T}$ and $K_{\mathrm{AWR},T}$. Due to the considerable complexity of these issues, they cannot be treated sufficiently within the scope of this article.

4.4.1. Combining different effect categories in a single effect metric

In the context of the reporting of the numbers of highly annoyed people and the number of awakening reactions due to noise, the question may arise if it would be possible to combine different noise effects into one single figure, one that e.g. expresses the number of people 'highly affected' or 'highly impaired' by aircraft noise. The DALY (Disability adjusted life years) concept by the WHO [59] could provide a framework to combining and weighting the different effect categories. But since to date, there is no compelling model or theory available which would describe a relationship between a certain number of noise-induced awakenings and severity of sleep disturbance, we have not yet come to a good conclusion as how to combine the two measurements (Number of awakenings and percentage of highly annoyed) into one single effect metric. Attributing weights to environmental noxae is not a purely scientific exercise, as it involves social and individual values and preferences. Furthermore, as the less severe responses to environmental conditions tend to affect the highest number of people, variation in severity weights has a large impact on the estimates of the burden of impairment. De Hollander *et al.* therefore concluded, that severity weights for noise effects such as noise annoyance or noise-induced sleep disturbance, must be established with great care [60]. This is the reason why at the moment, we do not recommend to combine the two effect dimensions. However, if we accept that the question of correctly weighing different effects is unresolved and hazard the consequences of (systematically) over- or underestimating one effect against the other, it is possible to combine %HA and P.

To obtain an indicator similar to %HA, e.g. a sigmoid function relating N_{AWR_i} to a percentage "highly sleep disturbed" persons (%HSD) may be arbitrarily defined. This approach was taken by the ZFI (cp. section 3.2). The fact that currently, a unified effect measure is not at hand does of course not mean, that there should not be put effort into trying to formulate one in the future.

5. Concluding remarks

In this article, we have summarized the basic concepts of effect-oriented aircraft noise assessment with indexes and have reviewed specific issues that have to be tackled in the scope of future development. The noise effect indexes ZFI and FFI (FNI) in Zürich and Frankfurt respectively were introduced as working examples of aircraft noise assessment with indexes as it is practically carried out today. The present article is rather a methodological review than a strict report of an empirical research project. It tried, supported by data, but not exclusively empirical in the narrowest sense, to explore possible features of future noise indexes and how these might be implemented. 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. The unit of measurement "number of people" (affected) or "number of awakenings from noise" is easily understandable by everyone which facilitates the communication of authorities with the public. 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.

An important requirement for the acceptability of any method of noise assessment by the public or the affected residents respectively, is that the method should be as free as possible from arbitrarily defined sets (e.g. ad-hoc assumptions about the sleep-wake rhythm of the population), but rely as much as possible on scientifically proven relationships between exposure, exposure-time patterns, and effects. Adhering to these principles makes a noise effect index a credible instrument for noise policy, especially at airports where due to operational characteristics a simple assessment method based on average levels does not reflect the variation in annoyance and/or sleep disturbance in a sufficiently accurate manner. As international experience shows, the perceived fairness is a key issue for the political success of noise indicators [61]. While the small differences that emerge from the interaction of a particular flight routing with time-of-day sensitivities may seem negligible on the global level, the psychology behind a fair and equal treatment of all people affected by noise is certainly not. When it comes to noise impact assessment at a small scale, e.g. when comparing communities or negotiating (financial) compensation schemes, people expect to be treated fair and equitable. Thus, the method of how government agencies measure the noise effect around an airport at many maybe very different receiver points must make sure, that this demand is met by the instrument they use. Therefore, the comparatively high level of detail and the relatively large effort to calculate and report noise effects with indexes, such as e.g. suggested in equation (4), appears justified. However, it must be noted that while noise effect indexes may be a practical tool for the authorities, the experience with the introduction of the ZFI in Zurich showed that too complex a measure (that needs many formulae to be calculated) is likely to be treated with suspicion by the public. The question here is if it is justified to pass on such kinds of indexes only because people do not understand them. Currently, we simply have not enough long-time experience with the use and regular reporting of noise effect indexes to answer that question. It is of course very likely that people primarily want to know how they will be affected by the operation of an airport as individuals, thus the figures reported by indexes are likely to be too abstract to be translated into a particular individual noise experience.

Exposure limits, such as set forth in many national noise abatement legislations, are designed to provide an *individ-*

ual minimal protection level for residents on one hand and legal certainty for airport operators on the other – they do not per se serve the objectivation of a more general noise reduction goal that policy may formulates. At this point, noise effect indexes complement exposure limits and can be called in if policy desires to document the adoption of a basically utilitarian principle of dealing with the aircraft noise problem. In the sense here, a 'utilitarian' principle stands for the tendency of authorities to disburden as many as possible from high exposure at the expense of a few. There are, however, other ethical and moral principles that could as well be applied and which would probably lead to different kinds of indexes. It must be pointed out, that the adoption of one particular moral principle inherent in one kind of index, such as the utilitarian principle in the ZFI and FFI, against the adoption of other principles, is not a matter of scientific evaluation, but the object of political discussion on the background of the values that are shared by society.

The construction and application of noise effect indexes bears many difficulties. A few of them were discussed in this article and shall be summarized briefly:

1. Implementing different effect categories in one single effect measure is a delicate task. Currently, we can not recommend combining different effects in a single index;
2. The choice of criteria to define the perimeter, within which an index is calculated, must be thoroughly considered. In any case, it is advisable to define the calculation perimeter based on an envelope reflecting an effect criterion, rather than an acoustic criterion;
3. Authorities must also decide whether to have trust in generalized exposure-effect functions to calculate the effects in question or rely on 'regional' curves that are derived from studies carried out with residents near the airport whose noise emissions and their effects are to be assessed;
4. The approaches discussed so far more or less implicitly assume a static population, when in reality people are of course highly mobile. Thus, noise effect assessment for a static geographic location may not truly reflect the noise impact on the level of individuals;
5. Many effects of the time-patterns of noise both on the small and large scale have not been considered (or implemented in existing indexes) yet, e.g. the beneficial effects of runway alternation, or effects that result from step changes at airports, e.g. 'overshoot' reactions etc. The existence of these classes of effects provide the rationale to further develop the approaches introduced in this article and improve the calculation rules of noise effect indexes in the future.

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