# The Fallacy of Using NII in Analyzing Aircraft Operations

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**Three measures of noise annoyance (Noise Impact Index, Level-Weighted Population, and Annoyed Population Number) are compared regarding their utility in assessing noise reduction schemes for aircraft operations. While NII is intended to measure the average annoyance per person in a community, it is found that the method of averaging can lead to erroneous conclusions, particularly if the population does not have uniform spatial distribution. Level-Weighted Population Annoyed Population Number are shown to be better indicators of noise annoyance when rating different strategies for noise reduction in a given community.**

## Introduction

THE problem of reducing a community's annoyance from aircraft noise may be viewed as an optimization task. Regardless of the proposed form of solution (modifications of noise sources, land use, or aircraft operations), various alternatives are best judged via a quantitative measure of the annoyance. The reliability of the solution will depend upon how suitably the measure represents the effects of the noise on the community. Three measures will be examined here: Noise Impact Index (NII), Level-Weighted Population (LWP), and Annoyed Population Number (APN). The comparison has been motivated by difficulties encountered with the use of NII as a criterion in noise reduction efforts. It will be shown that NII has an inherent deficiency in its formulation; that alternative criteria such as LWP or APN are superior for use in judging the reduction in annoyance for a given community. While the deficiency in NII's formulation may be intuitively clear, this paper will demonstrate the consequences of using NII to analyze aircraft operations. For purposes of comparison, each of the three measures will be employed to calculate a set of landing trajectories that results in minimum annoyance to a community.

## Assessment of Noise Impact

Each of the measures to be compared indicates the extent (number of people affected) and intensity of the annoyance. The distribution of people is modeled as a finite element grid, with a uniform density of people within each cell. Computer simulation of aircraft operations over the community provides noise levels for any point on the ground. (See Refs. 1 and 2 for details on the implementation of these models.) The community surrounding Sky Harbor International Airport in Phoenix, Arizona will provide an example population distribution for use in comparing annoyance measures.

### Level-Weighted Population (LWP)

The annoyance indicator LWP, devised by the National Academy of Sciences Committee on Hearing, Bioacoustics, and Biomechanics,[3,4] assumes that the intensity of annoyance due to noise varies with the noise level. The relation between annoyance and noise level is characterized by the intensity weighting function $W(L_{dn})$, where $L_{dn}$ is the average day-night noise level, defined as

$$L_{dn} = 10 \log_{10}\left\{ \sum_{t=1}^{N} w_t 10^{L_{A,t}/10}/N \right\} \tag{1}$$

where
$w_t$ = 1 for noise between 7 a.m. and 10 p.m.
10 for noise between 10 p.m. and 7 a.m.
$N$ = number of noise level samples taken in 24 h
$L_{A,t}$ = $t$th sample of the noise level, A-weighted

A plot of $W(L_{dn})$ is shown in Fig. 1. The analytic expression for $W(L_{dn})$ is

$$W(L_{dn}) = 3.36\times10^{-6}\times10^{0.103L_{dn}}/(0.2\times10^{0.03L_{dn}} + 1.43\times10^{-4}\times10^{0.08L_{dn}}) \tag{2}$$

This function is based upon a collection of social surveys of annoyance caused by various types of noise.[5] Although this synthesis represents possibly the best available data for annoyance prediction, it is unbounded in magnitude. This is acceptable, though since there is usually a predictable upper bound on $L_{dn}$.

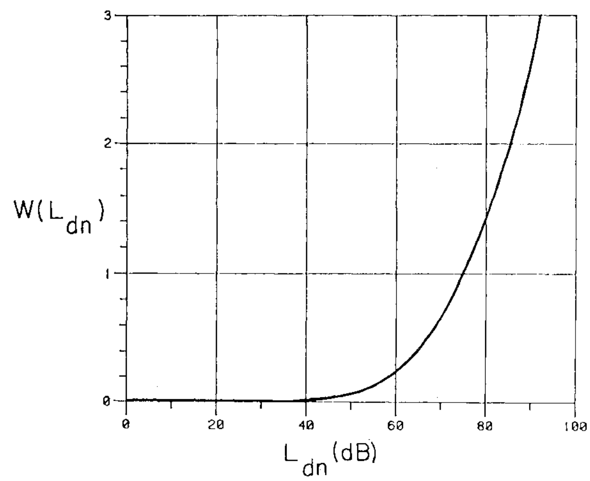


Fig. 1 Intensity weighting function for NII.

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Level-Weighted Population is defined by

$$\mathrm{LWP} = \int W(L_{\mathrm{dn}}) p(L_{\mathrm{dn}}) d(L_{\mathrm{dn}}) \tag{3}$$

where $p(L_{\mathrm{dn}})$ is the number of people receiving noise between $L_{\mathrm{dn}}$ and $L_{\mathrm{dn}} + d(L_{\mathrm{dn}})$. The integration is performed over the range of $L_{\mathrm{dn}}$ considered to be annoying. By convention, the lower limit is 55 dB; the upper limit is the highest level present. Evaluation of the integral is facilitated by approximating it as the discrete sum

$$\mathrm{LWP} \simeq \sum_{i}^{n} W(L_{\mathrm{dn}})_i P(L_{\mathrm{dn}})_i \tag{4}$$

where $i$ is the cell index, $P(L_{\mathrm{dn}})_i$ the number of people in the $i$th grid cell, $L_{\mathrm{dn}}$ the noise level received at the geometric centroid of the cell,‡ $n$ the number of cells receiving $L_{\mathrm{dn}} \geqslant 55$ dB at their centroids, and $W(L_{\mathrm{dn}})_i$ the intensity weighting for that $L_{\mathrm{dn}}$.

### Noise Impact Index (NII)

This measure, also developed by the National Academy of Sciences,[3] is defined as

$$\mathrm{NII} = \mathrm{LWP} \Big/ \int p(L_{\mathrm{dn}}) d(L_{\mathrm{dn}}) \tag{5}$$

where the variables and limits of integration are the same as in Eq. (3). Again, a discrete sum is used to approximate the integral

$$\int p(L_{\mathrm{dn}}) d(L_{\mathrm{dn}}) \simeq \sum_{i}^{n} P(L_{\mathrm{dn}})_i \tag{6}$$

= total population exposed to annoying noise levels

The purpose of the denominator is to normalize LWP, making NII an indicator of the average annoyance per person in the community. Such an indicator is quite useful when comparing noise problems in different communities (with widely different populations); however, it will be demonstrated that the presence of this normalization casts doubt on the effectiveness of NII as a criterion for assessing different solutions in any one community.

### Annoyed Population Number (APN)

For practical reasons, perhaps a more tangible indicator of community annoyance would be desirable. An example of such an indicator (defined by the authors) is APN, which attempts to measure the total number of people who are annoyed.

The model of annoyance intensity used by APN differs from that of LWP and NII in two ways: the sound level scale used is maximum dB(A), and the intensity weighting function is

$$\begin{aligned} W_{\mathrm{APN}} &= 6.5885 \times 10^{-12} \times (L_{A,\max})^{5.957603}, & L_{A,\max} &\leq 75.3 \text{ dB(A)} \\ &= 1, & L_{A,\max} &\geq 75.3 \text{ dB(A)} \end{aligned} \tag{7}$$

where

$$\begin{aligned} L_{A,\max} &= \text{max A-level received, 7 a.m. to 10 p.m.} \\ &= \text{max A-level received} + 10 \text{ dB(A), 10 p.m. to 7 a.m.} \end{aligned} \tag{8}$$

‡It is assumed that $L_{\mathrm{dn}}$ does not vary rapidly within the boundaries of the cell.

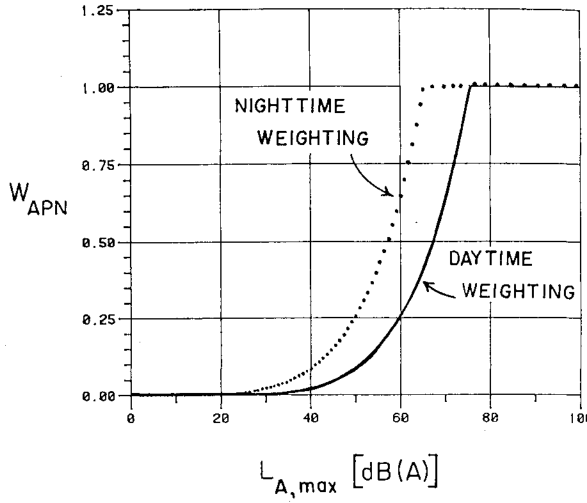


**Fig. 2 Weighting function for APN.**

This weighting function is suggested by data§ obtained from Kryter.[6] A plot of $W_{\mathrm{APN}}$ appears in Fig. 2. $W_{\mathrm{APN}}$ is interpreted as the fraction of people receiving noise who will be annoyed (and rate the noise environment "unacceptable".[6]

Annoyed Population Number is defined as

$$\mathrm{APN} = \left[ \sum_{i}^{n} \left( W_{\mathrm{APN}} (L_{A,\max,\,\mathrm{day}})_i P_i + W_{\mathrm{APN}} (L_{A,\max,\,\mathrm{night}})_i P_i \right) \right] \Big/ P_{\mathrm{total}} \tag{9}$$

where the day-night notation is the same as in Eq. (1), $P_i$ the $i$th population group, $n$ the number of groups, and $P_{\mathrm{total}}$ the total population being considered. Note that daytime and nighttime are treated separately, so that some people are included twice. This poses no serious problem if APN is used for evaluating the *relative* improvements from various noise reduction strategies.

#### *Deficiency in NII*

As an example of the problem with NII, consider a simple population distribution of just two clusters of people, as shown in Fig. 3. The people receive noise from a number of commercial aircraft, all of which fly on only one of the paths shown (each path has constant altitude; only the ground tracks are indicated). A computer simulation, based on the noise models in Ref. 2 was used to calculate the noise levels and values of NII and LWP. Table 1 gives the results for each of the tracks.

Tracks 2-4 all have lower LWP than track 1, but the NII values rank differently. Track 2 has the lowest NII value and track 4, with the lowest LWP value, has the highest NII. This problem occurs because the denominator of Eq. (5) (the number of people receiving $L_{\mathrm{dn}} \geq 55$ dB) varies depending on which track the aircraft fly. Clearly, the use of track 4 exposes fewer people to $L_{\mathrm{dn}}$ values above 55 dB than does track 2, yet the NII value associated with track 4 is higher than that of track 2. Conversely, track 4 yields a lower value of LWP. It is the presence of the other 8000 people (who are receiving an $L_{\mathrm{dn}}$ of only 56 dB) that lowers the average annoyance. The example demonstrates that the two measures of annoyance can lead to quite different solutions to the problem of reducing the annoyance. While this example uses operational modifications to reduce the annoyance, it is conceivable that similar conflicting results could appear in studies that involve noise source or land-use modifications.

§The units were converted to dB(A).

## Comparison of the Measures Using a Real Population Distribution

The community to be used in the comparison is that surrounding Sky Harbor International Airport in Phoenix, Arizona. Figure 4 shows the distribution of people in the community.

For landings on the runway indicated in Fig. 5 there are two entry points (initial approach fixes). This figure shows the nominal ground tracks of the landing paths; the glide slopes are 3 deg. To obtain the data for calculating the noise annoyance, computer simulations of aircraft operations on these paths were performed. An estimate of the aircraft types operating at this airport was obtained from the Official Airline Guide.[7] Improved trajectories (with respect to noise annoyance) were computed using the methods described in Refs. 1 and 2.

With NII as the annoyance measure, the optimum pair of trajectories obtained is that shown in Fig. 6. Values of NII, LWP, and APN for this pair are compared with corresponding values for the nominal paths in Table 2. Using either LWP or APN as the annoyance measure, the optimum pair is radically different from the nominal set, as seen in Fig. 7. It is seen that the percentage improvement in the annoyance

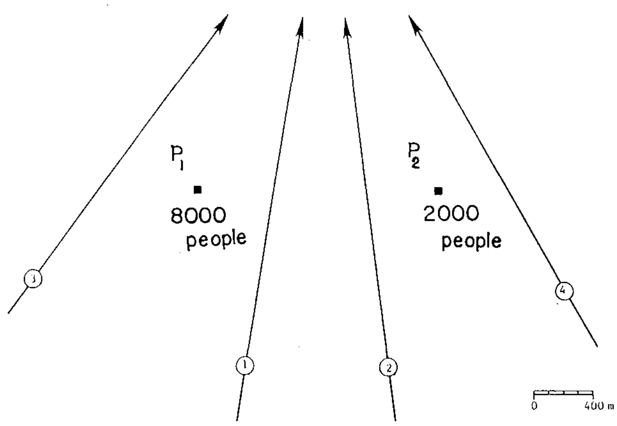


Fig. 3 Simple population distribution—two clusters.

Table 1 Comparison of NII vs LWP (simple population distribution)

| | Track 1 | Track 2 $L_{dn}$ | Track 3 | Track 4 |
|---|---|---|---|---|
| $P_1 = 8000$ | 64 | 56 | 64 | 49.5 |
| $P_2 = 2000$ | 56 | 64 | 49 | 67 |
| LWP | 3,244 | 1,874 | 2,960 | 1,005 |
| NII | 0.3244 | 0.1874 | 0.3701 | 0.5026 |
| $P^a_{total}$ | 10,000 | 10,000 | 8,000 | 2,000 |

[a]Total population receiving annoying levels (>55 dB).

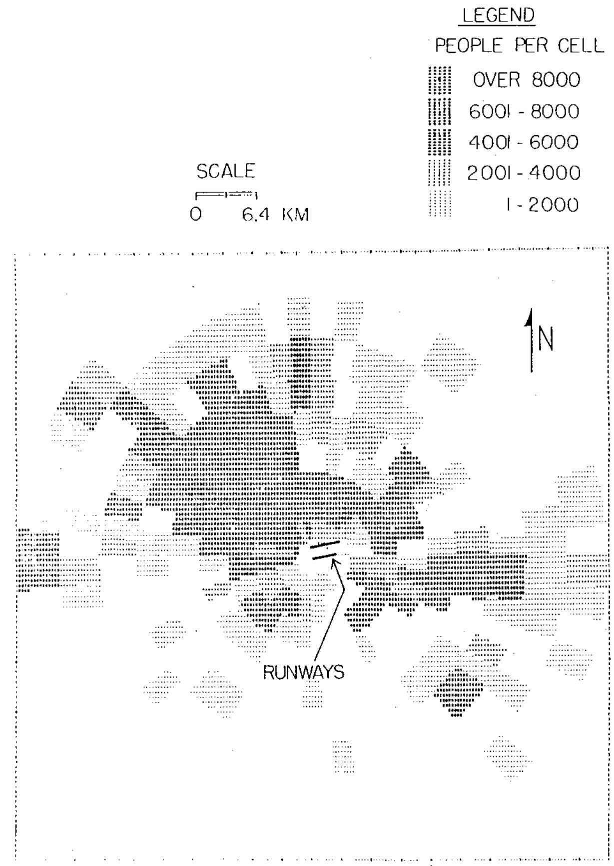


Fig. 4 Population distribution at Phoenix Sky Harbor Airport.

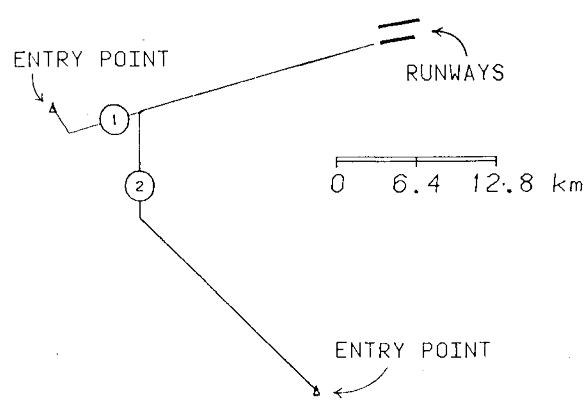


Fig. 5 Nominal trajectories at Phoenix Sky Harbor Airport.

Table 2 Comparison of annoyance measures (for Phoenix Sky Harbor Airport)

| Trajectory set | NII | Δ,%[a] | LWP | Δ,%[a] | APN | Δ,%[a] | Figure showing optimum trajectory |
|---|---|---|---|---|---|---|---|
| Nominal | 0.281 | — | 30566 | — | 0.491 | — | 5 |
| NII optimum | 0.264 | −6 | 31993 | 4.7 | 0.524 | 6.7 | 6 |
| LWP optimum | 0.290 | 3 | 25192 | −17 | 0.445 | −9.3 | 7 |
| APN optimum | 0.290 | 3 | 25192 | −17 | 0.445 | −9.3 | 7 |

[a]Percentage difference from nominal value.

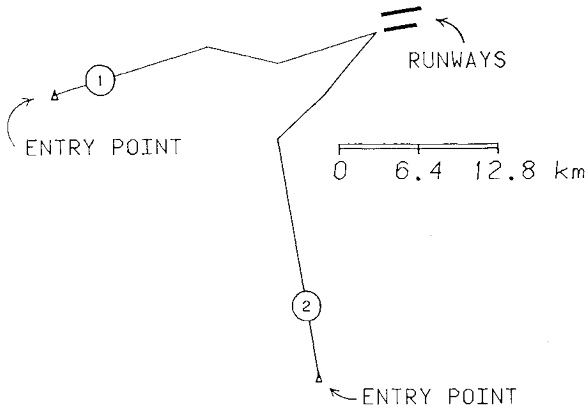


**Fig. 6 Optimum (NII) trajectories at Phoenix Sky Harbor Airport.**

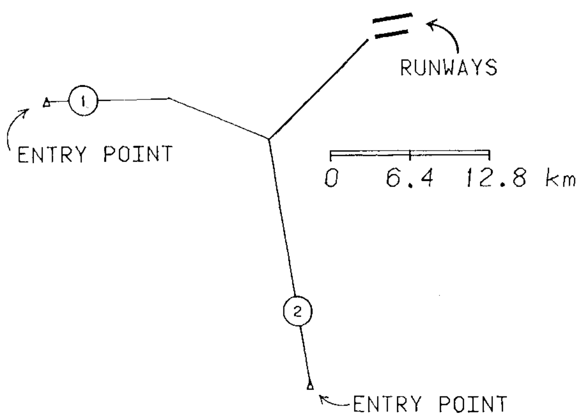


**Fig. 7 Optimum (LWP or APN) trajectories at Phoenix Sky Harbor Airport.**

based upon LWP or APN is greater than that of NII. Examination of the population distribution in Fig. 4 reveals that this phenomenon is similar to what occurs with the simple (two-cluster) population distribution in Fig. 3. The NII is reduced by changing the noise field on the ground in the following way: A large group of people (which formerly received $L_{dn} < 55$ dB) now receives $L_{dn}$ only slightly greater than 55 dB; the resulting LWP increases by a large increment; while the average annoyance per person has decreased (as indicated by NII), the total annoyance (shown by LWP or APN) has increased.

## Conclusions

A study comparing the noise annoyance measures NII, LWP, and APN as criteria for modifying aircraft operations has shown that, in addition to resulting in different amounts of improvement, the solutions derived using each of these criteria can be significantly different themselves. In evaluating alternate noise reduction schemes in a given community, employing NII can lead to erroneous conclusions about the extent of dissatisfaction with the noise environment.

Because of its mathematical definition, NII has been shown to be an unreliable indicator of the amount of change in annoyance for a given community. Use cf a constant population (without regard to the lower limit of 55 dB on $L_{dn}$) would correct this problem. Employing the modified NII would result in the same noise reduction solution as with LWP, since the two measures differ by the constant population factor. Alternatively, if the solution is to be chosen based upon the number of people affected to a particular degree, then a measure such as APN could be employed. All three (including the modified NII) are superior to NII (as it is currently defined) when assessing the effects of noise on populations with clustered distributions.

## Acknowledgment

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