

## Research Article

### Assessing Noise Impact around Airports: A Fuzzy Modeling Approach

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**Abstract:** In this communication the problem of assessing the noise impact of airport operations on surrounding communities is treated. The specific objective of this study is to provide a tool to predict the noise impact resulting from the modification of traffic patterns as a consequence not only of possible traffic increase but also of rearrangements of departure and arrival procedures and tracks. It is a general opinion that to assess accurately the noise impact over people, or annoyance, noise cannot be only represented by an overall noise index and the corresponding level areas as produced by software like Integrated Noise Model (INM). The perception of traffic noise near airports is quite subjective and is dependent of many other parameters in general characteristic of the nearby air transport activity. So in this paper, fuzzy modeling is used to generate from traffic information on one side and from a mapping of local activities on the other side, a quantitative evaluation of noise impacts at different locations around an airport. This will allow to identify the critical locations with respect to noise as well as to perform sensitivity analysis studies when comparing different traffic scenarios.

**Keywords:** aircraft noise impact, noise indexes, fuzzy dual numbers and calculus.

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## INTRODUCTION

The air traffic developments over the last decades as well as the urban advances have been generating significant critical situations regarding the noise annoyance in surrounding areas of many airports. That is why ICAO has requested to develop the necessary tools to assess the environmental benefits, including noise issues, which can be associated with ATM (Air Traffic Management) improvements. Within the balanced approach philosophy [1] to manage the noise issue at airports, it has been considered that the air navigation system should also contribute by considering noise in the implementation and operation of the new developments of the global air navigation system. In such a situation, the aeronautical noise assessment becomes an important issue when assessing new traffic scenarios and new departure or landing procedures. This estimation has been traditionally done using trajectory segmentation models.

Since noise was accepted as a serious component of environmental pollution, many studies have been performed in order to evaluate the degree of the problem and to develop appropriate noise indexes to assess and predict the noise impact on the airport surrounding communities.

Here a clear distinction must be established between subjective and objective noise impacts. The perception of aircraft noise near an airport by an individual is quite subjective and depends not only on the physical characteristics of this noise (levels distribution, spectrum, time occurrence distribution) over a span of time and over the given area where this person moves, but also of many personal parameters such as occupation, age, state of health and local sources of noise contributing to personal background noise. Then at the level of individuals, the subjective impact of aircraft noise is the result of a rather complex process. The generalization of subjective evaluation through some averaging process to populations presenting quite often a large degree of heterogeneity appears hazardous.

In the present study, the objective impact of aircraft noise is only considered. The objective impact of noise at a given location is here considered to result from the local noise parameters and the geographical distribution of population and human activities. Generally the objective noise impact over people cannot be only represented by an overall noise index and the corresponding level areas as produced by software like INM. In this context, this paper presents a fuzzy modeling approach which generate from traffic information on one side and from a mapping of local activities on the other side, a fuzzy evaluation of the objective noise impact at different locations around an airport.

The aim of this paper is to provide a quantitative tool to predict the objective noise impact resulting from the modification of traffic patterns as a consequence not only of possible traffic increase but also of rearrangements of departure and arrival procedures and tracks. This tool adopts the fuzzy dual formalism to be able to cope with its inherent uncertainty in a feasible way. Then, it will be possible to perform analysis and predictions to identify critical locations with respect to noise as well as to perform sensitivity analysis studies when comparing different traffic scenarios.

**EVALUATION OF ELEMENTARY NOISE IMPACTS**

*Deterministic evaluation of noise impact*

The sound exposure at a given location  $l$  during a time period  $[t_1, t_2]$  is given by (Mora-Camino<sup>4</sup>):

$$SE(l, T) = \int_{t_1}^{t_2} p_A^2(l, t) dt \text{ where } T = [t_1, t_2] \text{ ----- (1)}$$

where  $p_A(l, t)$  is the noise pressure through a  $A$ -type filter. The two following assumptions are adopted with respect to the sound exposure index:

- Temporal additivity (where the  $T_p, p=1$  to  $P$ , are disjunctive time intervals) :

$$SE(l, T_1 \cup T_2 \dots \cup T_M) = \sum_{p=1}^P SE(l, T_p) \text{ -----(2)}$$

Additivity with respect to incoherent noise sources:

$$SE_{total}(r, T) = \sum_{s=1}^n SE_s(r, T) \text{ ----- (3)}$$

One of the main noise metric used in the aeronautical domain is the sound exposure Level ( $SEL$ ) given at a location  $l$  by:

$$SEL(l, T) = 10 \log_{10} (SE(l, T) / p_0^2) = 10 \log_{10} \left( \int_{t_1}^{t_1+T} (p_A(l, t)^2 / p_0^2) dt \right) \text{ ----- (4)}$$

where  $p_0$  is a given reference pressure level.

Now, considering a set  $L$  of receptors located around an airport at relevant positions (schools, hospitals, residency areas, etc), and the sets  $R_A$  and  $R_D$  of arrival and departure routes, with  $R = R_A \cup R_D$ , a weighting, which is supposed to be representative of the relative importance and nature of the different receptors and routes (day or night operated), can be introduced:

$$\pi_{lr} \geq 0 \quad l \in L, r \in R \text{ with } \sum_{l \in L} \sum_{r \in R} \pi_{lr} = 1 \text{ -----(5)}$$

Then is introduced the set  $A$  of all aircraft types which can be operated at that airport:

$$A = \cup_{r \in R_A} A_{Rr} \cup \cup_{m \in R_D} D_{Rm} \text{ ----- (6)}$$

where  $A_{Rr}$  is the set of aircraft types allowed on arrival route  $r$  and  $D_{Rm}$  is the set of aircraft types allowed on departure route  $m$ . Using an evaluation tool such as INM, it is possible to compute for each feasible triplet  $(r, a, l)$ ,  $r \in R, a \in A, l \in L$ , an elementary sound exposure level, expressed in  $dB$  and given by:

$$E(r, a, l) = SEL(l, T(a, r, l)) \text{ ----- (7)}$$

where  $T(a, r, l)$  is the duration of the acoustical event at location  $l$  corresponding to an aircraft of type  $a$  flying (arrival or departure) route  $r$ . The computation of these elementary sound exposure levels can be performed using repeatedly INM with unitary traffic as much as  $|A| \cdot |R| \cdot |L|$  times.

*Fuzzy evaluation of elementary noise impact*

Observe also that there is in general a significant degree of uncertainty in the evaluation of the noise elementary impacts. This is mainly the result of track dispersion of the aircraft along the nominal routes and of wind intensity and

direction. Then a fuzzy evaluation of noise impacts can be of interest. Here, to represent the fuzziness of the elementary noise impacts, the fuzzy dual formalism [5] is adopted. Then, the fuzzy noise elementary impact is given by:

$$\tilde{E}(r, a, l) = SEL(l, T(a, r, l)) + \varepsilon \cdot \Delta SEL(l, T(a, r, l)) \quad \text{-----(8)}$$

where  $\varepsilon$  is the pure dual number ( $\varepsilon^2 = 0$ ) and where the dual  $\Delta SEL(l, T(a, r, l))$  is the degree of uncertainty about the elementary noise impact of a noise occurrence of duration  $T$  at position  $l$  for aircraft type  $a$  along route  $r$ . Observe that since the degree of uncertainty has a positive value, relation (8) defines effectively a fuzzy dual number. Here for simplicity only triangular fuzzy dual numbers will be considered, as displayed on figure 1, where  $\mu$  is the classical membership function of fuzzy sets.

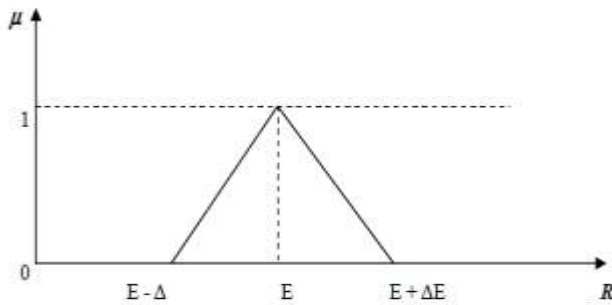


Figure 1 – Example of triangular fuzzy dual number

A first estimate of this dual number is to adopt as real part the mean value of the elementary impact and as dual part, the standard deviation of the elementary noise impact. Depending on the effective distribution of the elementary noise impact for each triplet  $(l, a, r)$ , this choice can be considered acceptable or must be revised.

**ESTIMATION OF CRITICAL NOISE IMPACTS**

*Critical analysis of operations with respect to noise*

From the computation of the elementary impacts, useful information to analyze noise impact can be retrieved. To determine critical situations the upper expected bound of a local impact is defined as:

$$E^+(r, a, l) = E(r, a, l) + \Delta E(a, r, l) \quad r \in R, a \in A, l \in L \quad \text{-----(9)}$$

Then, it is possible to compute indexes such as:

- the critical noise event for the whole airport surroundings characterised by the triplet  $\{r^*, a^*, l^*\}$  such as:

$$\{r^*, a^*, l^*\} = \arg \max_{r \in R, a \in A, l \in L} (\pi_{lr} \cdot E^+(r, a, l)) \quad \text{-----10}$$

- the maximum noise impact which can be expected from a flight characterized by a route  $r$  and an aircraft type  $a$ :

$$10 \log \left( \sum_{l \in L} \pi_{lr} 10^{E^+(r, a, l)/10} \right) \quad a \in A_{Rr}, r \in R_A \quad \text{or} \quad a \in A_{Dr}, r \in R_D \quad \text{-----(11)}$$

When it is assumed that taking into account the importance weightings defined above, there is additivity between noise impacts at different locations.

- the noise critical aircraft for route  $n$ :

$$a_n^c = \arg \max_{a \in A_{Rr} \text{ or } a \in A_{Dr}} \left( 10 \log \left( \sum_{l \in L} \pi_{lr} 10^{E^+(r, a, l)/10} \right) \right) \quad \text{----- (12.a)}$$

- the noise optimal aircraft of route  $n$ :

$$a_n^o = \arg \min_{a \in A_{Rr} \text{ or } a \in A_{Dr}} \left( 10 \log \left( \sum_{l \in L} \pi_{lr} 10^{E^+(r, a, l)/10} \right) \right) \quad \text{----- (12.b)}$$

- the noise critical approach route and departure route for aircraft of type  $a$ :

$$n_{Aa}^c = \arg \max_{r \in R_A, a \in A_{Rr}} \left( 10 \log \left( \sum_{l \in L} \pi_{lr} 10^{E^+(r, a, l)/10} \right) \right) \quad \text{----- (12.c)}$$

$$n_{Da}^c = \arg \max_{r \in R_D, a \in A_{Dr}} \left( 10 \log \left( \sum_{l \in L} \pi_{lr} 10^{E^+(r, a, l)/10} \right) \right) \quad \text{----- (12.d)}$$

*Comparison of noise impacts*

To be able to perform easily comparisons between fuzzy noise impacts two types of operations must be considered:

- The dual differential extension  $\tilde{g}$  of a function  $g$  of a dual variable  $x + \varepsilon y$  may be adopted where:

$$\tilde{g}(x + \varepsilon y) = g(x) + \varepsilon y g'(x) \text{ -----(13)}$$

This extension while rather simple present an acceptable accuracy once  $y$  is small with respect to  $x$ . In our field of application, this should be the case.

- Ranking rules providing partial orderings between triangular fuzzy dual numbers:

First a strong partial order written  $\tilde{\succ}$  can be defined over  $\tilde{\Delta}$ , which is the set of triangular fuzzy dual numbers ( $a + \varepsilon b$ ),  $a \in R, b \in R^+$ , by:

$$\forall a_1 + \varepsilon b_1, a_2 + \varepsilon b_2 \in \tilde{\Delta}: a_1 + \varepsilon b_1 \tilde{\succ} a_2 + \varepsilon b_2 \Leftrightarrow a_1 - b_1/2 \geq a_2 + b_2/2 \text{ ----- (14)}$$

Then a weak partial order written  $\tilde{\succeq}$  can be also defined over  $\tilde{\Delta}$  by:

$$\forall a_1 + \varepsilon b_1, a_2 + \varepsilon b_2 \in \tilde{\Delta}: \|a_1 + \varepsilon b_1\| \tilde{\succeq} \|a_2 + \varepsilon b_2\| \Leftrightarrow a_1 + \rho b_1 \geq a_2 - \rho b_2 \text{ ----- (15)}$$

More, a fuzzy equality written  $\tilde{\cong}$  can be defined between two fuzzy dual numbers by:

$$\begin{aligned} \forall a_1 + \varepsilon b_1, a_2 + \varepsilon b_2 \in \tilde{\Delta}: \|a_1 + \varepsilon b_1\| \tilde{\cong} \|a_2 + \varepsilon b_2\| \text{ ----- (16)} \\ \Leftrightarrow a_2 \in [a_1 - b_1/2, a_1 + b_1/2] \text{ et } a_1 \in [a_2 - b_2/2, a_2 + b_2/2] \end{aligned}$$

Then, the min and the max operators for triangular fuzzy dual numbers can be introduced:

$$c + \varepsilon \cdot \gamma = \max \{a + \varepsilon \cdot \alpha, b + \varepsilon \cdot \beta\} \text{ ----- (17)}$$

with  $a, b \in R, \alpha, \beta \in R^+$  where  $c = \max \{a, b\}$  and  $\gamma = \max \{a + \alpha/2, b + \beta/2\} - \max \{a, b\}$

$$d + \varepsilon \cdot \delta = \min \{a + \varepsilon \cdot \alpha, b + \varepsilon \cdot \beta\} \text{ ----- (18)}$$

with  $a, b \in R, \alpha, \beta \in R^+$  where  $d = \min \{a, b\}$  and  $\delta = \min \{a + \alpha/2, b + \beta/2\} - \min \{a, b\}$

Then it will be possible to compare the different fuzzy noise impacts considered in the previous subsection.

**GLOBAL EVALUATIONS OF NOISE IMPACT**

*Deterministic evaluation of global noise impact*

According to the definition of deterministic elementary noise impact, given a traffic flow pattern  $(\phi_{ra})_{r \in R, a \in A}$  for the airport, the corresponding local noise impact at receptor  $l$  is given by:

$$N_l = 10 \log \left( \sum_{r \in R} \sum_{a \in A} \pi_{lr} \phi_{ra} 10^{E(r,a,l)/10} \right) \quad l \in L \text{ ----- (19)}$$

while the global noise impact of this traffic flow pattern is given by:

$$G = 10 \log \left( \sum_{r \in R} \sum_{a \in A} \sum_{l \in L} \pi_{lr} \phi_{ra} 10^{E(r,a,l)/10} \right) \text{ -----(20)}$$

Observe that this global noise index is more objective than those based on the size of the surface over a given noise level since it can take into account the effective land use around the airport.

*Fuzzy evaluation of global noise impact*

Then, given a traffic flow pattern  $(\phi_{ra})_{r \in R, a \in A}$  for the airport, its local fuzzy noise impact at receptor  $l$  is such as:

$$\tilde{N}_l = 10 \log \tilde{g} \left( \sum_{r \in R} \sum_{a \in A} \pi_{lr} \phi_{ra} 10^{E(r,a,l)/10} \left( 1 + \varepsilon \frac{\text{Log}(10)}{10} \Delta E(r,a,l) \right) \right) \quad l \in L \text{ ---- (21)}$$

while its global noise impact is given by:

$$\tilde{G} = 10 \log \tilde{g} \left( \sum_{r \in R} \sum_{a \in A} \sum_{l \in L} \pi_{lr} \phi_{ra} 10^{E(r,a,l)/10} \left( 1 + \varepsilon \frac{\text{Log}(10)}{10} \Delta E(r,a,l) \right) \right) \text{ ----- (22)}$$

Then:

$$\tilde{N}_l = N_l + \varepsilon \Delta N_l \quad l \in L \text{ ----- (23)}$$

with:

$$\Delta N_l = \text{Log}(10) \cdot \left( \sum_{r \in R} \sum_{a \in A} \pi_{lr} \phi_{ra} 10^{E(r,a,l)/10} \Delta E(r,a,l) \right) / \left( \sum_{r \in R} \sum_{a \in A} \pi_{lr} \phi_{ra} 10^{E(r,a,l)/10} \right) \quad l \in L \text{ ----- (24)}$$

and

$$\tilde{G} = G + \varepsilon \Delta G \text{ ----- (25)}$$

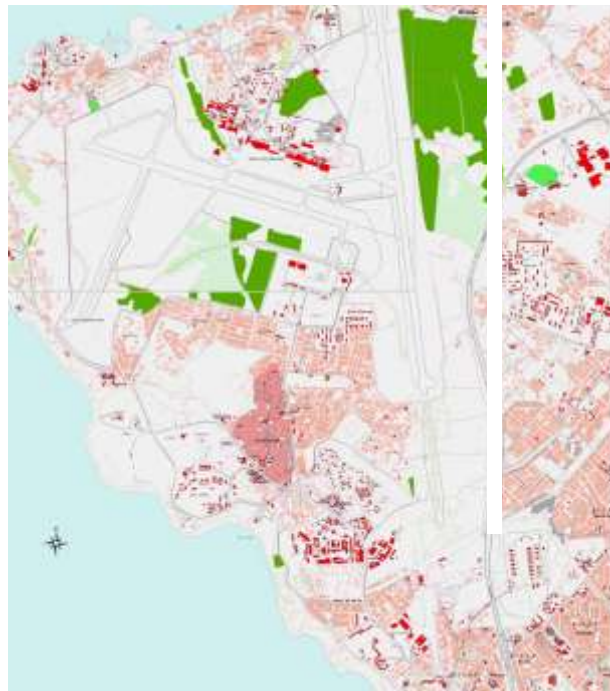
with

$$\Delta G = \text{Log}(10) \cdot \left( \sum_{r \in R} \sum_{a \in A} \sum_{l \in L} \pi_{lr} \phi_{ra} 10^{E(r,a,l)/10} \Delta E(r,a,l) \right) / \left( \sum_{r \in R} \sum_{a \in A} \sum_{l \in L} \pi_{lr} \phi_{ra} 10^{E(r,a,l)/10} \right) \text{----- (26)}$$

In both expressions, the dual term represents the uncertainty about the global noise impact resulting from the uncertainty with respect to the elementary noise impacts

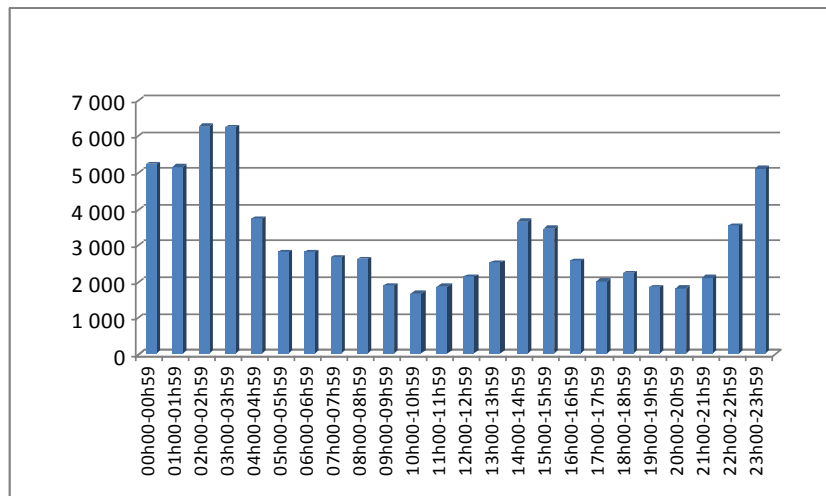
**CASE STUDY**

The considered case study considers Dakar’s International Airport, Leopold S. Senghor Airport, which is today tightly surrounded by different suburbs of Dakar has shown in Map1. Wide body and long range aircraft compose a large part of traffic, while, due to climate conditions, night operations take a large share of it, see table 1.



**Map 1 – Surroundings of Dakar Airport**

**Table 1: Hourly distribution of traffic at Dakar Airport ( year 2010)**



It appears clearly that the noise impact of airport activities over the surrounding population is rather important and that the proposed approach should be quite helpful to assess new scenarios about arrivals and departure traffic at this airport.

### CONCLUSIONS

The aim of this paper has been to provide a quantitative tool to predict the objective noise impact resulting from the modification of traffic patterns as a consequence not only of possible traffic increase but also of rearrangements of departure and arrival procedures and tracks. This tool adopts the fuzzy dual formalism to be able to cope with uncertainty in a feasible way. Then, it will be possible to perform analysis and predictions to identify critical locations with respect to noise as well as to perform sensitivity analysis studies when comparing different traffic scenarios.

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