Assessing air traffic noise around airports: a fuzzy 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 air 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 access accurately the noise impact over people, noise cannot be only represented by an overall noise index and the corresponding level areas. 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: airport noise; noise impact; fuzzy modelling.

Résumé

Dans cette communication, le problème de l'évaluation de l'impact du bruit des activités aéroportuaires sur les communautés environnantes est traité. L'objectif de cette étude est de fournir un outil pour prédire l'impact du bruit résultant de la modification des schémas de trafic aérien en raison non seulement de l'augmentation possible du trafic, mais aussi des modifications des procédures et des pistes de décollage et d'atterrissage. C'est une opinion générale que pour apprécier avec précision l'impact du bruit aéroportuaire sur les populations, le bruit ne peut être représenté seulement par un indice de bruit global et les zones de niveau de bruit correspondantes. La perception du bruit du trafic aérien à proximité des aéroports est très subjective et dépend de nombreux autres paramètres souvent caractérisant les activités au voisinage de l' aéroport. Donc, dans cet article , la modélisation floue est utilisée pour générer d'une part des informations de trafic et d'autre part une cartographie des activités locales , une évaluation quantitative de l'impact du bruit à différents endroits autour d'un aéroport . Cela permettra d'identifier les points critiques en ce qui concerne le bruit, ainsi que d'effectuer des études d'analyse de sensibilité lorsque l'on compare différents scénarios de trafic .
Mots-clé: bruit aéroportuaire ; impact sonore ; modélisation floue.

1. Introduction

The air traffic development over the last decades as well as the urban growth 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 , Murphy et al. (2011), 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.

2. Evaluation of elementary noise impacts

The sound exposure at a given location l during a time period $[t_1,t_2]$ is given by (Mora-Camino[7]):

$$\mathrm{SE}(l,\mathrm{T}) = \int_{t_1}^{t_2} \mathrm{p}_\mathrm{A}^2(l,t)dt \quad (Pa^2 \cdot s) \quad \text{where } T=[t_1,t_2] \tag{1}$$

where $\mathrm{p}_\mathrm{A}(l,t)$ 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 P disjunctive time intervals) :

$$SE\left(l,T_1 \cup T_2 \cdots \cup T_P\right) = \sum_{p=1}^{P} SE(l,T_p) \tag{2}$$

.- Additivity with respect to n incoherent noise sources:

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

One of the main noise metric used in the aeronautical domain is the sound exposure Level (*SEL*) given at a location *l* for an acoustical event starting at t_1 and of duration *T*, by:

$$SEL(l,T) = 10\log_{10}\left(SE(l,T)/\,p_0{}^2\right) = 10\log_{10}\left(\frac{1}{T_0}\int_{t_1}^{t_1+T}(p_A(l,t)^2/\,p_0{}^2)\,dt\right) \quad (dBA) \tag{4}$$

where p_0 is a given reference pressure level ($20\,\mu P_a$) and $T_0 = 1s$.

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 dimensionless 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:

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

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

$$A = \bigcup_{r \in R_A} A_{Rr} \bigcup_{m \in R_D} D_{Rm} \tag{6}$$

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 $(r,a,l), \quad r \in R, a \in A, l \in L$, an elementary sound exposure level, expressed in *dBA* and given by:

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

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.

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 aircraft along the nominal routes and of wind intensity and direction statistics. Then a fuzzy evaluation of noise impacts can be of interest. Here, to represent the uncertainty relative to the elementary noise impacts, the fuzzy dual formalism, Cosenza et al. (2011), is adopted. Then, the fuzzy noise elementary impact is given by:

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

where ε is the pure dual number ($\varepsilon^2 = 0$) and where the dual $\Delta SEL(l,T(a,r,l))$ is the degree of uncertainty , given in *dB*A, 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 is 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. There μ is the classical membership function of fuzzy sets, Kandel (1986).

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.

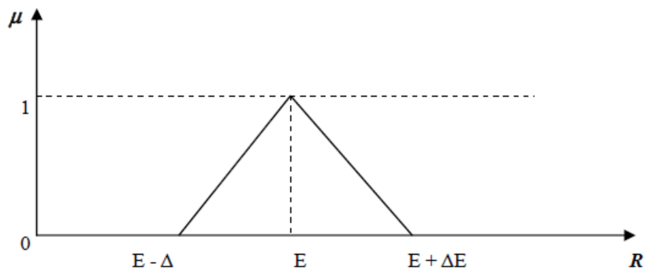

Fig.1 Example of triangular fuzzy dual number

3. Estimation of critical noise impacts

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 in *dBA* is defined as:

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

Then, it is possible to compute indices such as:

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

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

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

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

and 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*:

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

- the noise optimal aircraft of route *n*:

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

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

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

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

The above indices are computed considering the upper expected bounds of local impacts and correspond to a worst case analysis. However to maintain explicit the uncertainty level of impacts, direct computations and comparisons between fuzzy noise impacts can be performed by considering fuzzy dual operations and fuzzy dual ranking rules.

The fuzzy dual addition of fuzzy dual numbers, written $\tilde{+}$, is identical to that of dual numbers and is given by:

$$(x_1+\varepsilon\, y_1)\,\tilde{+}\,(x_2+\varepsilon\, y_2)=(x_1+x_2)+\varepsilon\,(y_1+y_2) \tag{13}$$

Its neutral element is $(0+0\varepsilon)$, written $\tilde{0}$. The fuzzy dual product of two fuzzy dual numbers, written $\tilde{\bullet}$, is given by:

$$(x_1+\varepsilon\, y_1)\,\tilde{\bullet}\,(x_2+\varepsilon\, y_2)=(x_1.x_2+\varepsilon(|x_1|\cdot y_2+|x_2|\cdot y_1)) \tag{14}$$

Ranking rules providing partial orderings between triangular fuzzy dual numbers must be also considered. First a strong partial order written $\breve{\geq}$ 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:

$$\forall\, a_1+\varepsilon b_1\,,a_2+\varepsilon b_2\in\tilde{\Delta}: a_1+\varepsilon b_1\,\breve{\geq}\, a_2+\varepsilon b_2 \Leftrightarrow a_1-b_1/2\geq a_2+b_2/2 \tag{15}$$

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

$$\forall\, a_1+\varepsilon b_1\,,a_2+\varepsilon b_2\in\tilde{\Delta}: \|a_1+\varepsilon b_1\|\,\hat{\geq}\,\|(a_2+\varepsilon b_2)\| \Leftrightarrow a_1+b_1/2\geq a_2-b_2/2 \tag{16}$$

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

$$\begin{gathered}\forall\, a_1+\varepsilon\, b_1\,,a_2+\varepsilon\, b_2\in\tilde{\Delta}: \|a_1+\varepsilon\, b_1\|\cong\|(a_2+\varepsilon\, b_2)\| \\ \Leftrightarrow \\ a_2\in[a_1-b_1/2, a_1+b_1/2]\; et\; a_1\in[a_2-b_2/2, a_2+b_2/2]\end{gathered} \tag{17}$$

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

$$c+\varepsilon\cdot\gamma=\max\{a+\varepsilon\cdot\alpha, b+\varepsilon\cdot\beta\} \tag{18}$$

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

(19)

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 and rank partially the different dual fuzzy noise impacts considered in the previous subsection.

4. Global evaluation of 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:

$$N_l = 10\log\Big(\sum_{r\in R}\sum_{a\in A}\pi_{lr}\phi_{ra}\,10^{E(r,a,l)/10}\Big)\qquad l\in L \tag{20}$$

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

$$G = 10\log\Big(\sum_{r\in R}\sum_{a\in A}\sum_{l\in L}\pi_{lr}\phi_{ra}\,10^{E(r,a,l)/10}\Big) \tag{21}$$

Observe that these global noise indexes are more objective than those based on the size of the surface over a given noise level since they can take into account the effective land use around the airport.

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:

$$\tilde{N}_l = 10\,\tilde{\log}\Big(\sum_{r\in R}\sum_{a\in A} \pi_{lr}\phi_{ra}\, 10^{E(r,a,l)/10}\big(1+\varepsilon\,\frac{Log(10)}{10}\Delta E(r,a,l)\big) \Big) \qquad l\in L \tag{22}$$

while its global noise impact is given by:

$$\tilde{G} = 10\,\tilde{\log}\Big(\sum_{r\in R}\sum_{a\in A}\sum_{l\in L} \pi_{lr}\phi_{ra}\, 10^{E(r,a,l)/10}\big(1+\varepsilon\,\frac{Log(10)}{10}\Delta E(r,a,l)\big) \Big) \tag{23}$$

Then:

$$\tilde{N}_l = N_l + \varepsilon\,\Delta N_l \qquad l\in L \tag{24}$$

with:

$$\Delta N_l = Log(10)\cdot\Big(\sum_{r\in R}\sum_{a\in A} \pi_{lr}\phi_{ra}\, 10^{E(r,a,l)/10}\Delta E(r,a,l) \Big) \Big/ \Big(\sum_{r\in R}\sum_{a\in A} \pi_{lr}\phi_{ra}\, 10^{E(r,a,l)/10} \Big) \qquad l\in L \tag{25}$$

and

$$\tilde{G} = G + \varepsilon\,\Delta G \tag{26}$$

with

$$\Delta G = Log(10)\cdot\Big(\sum_{r\in R}\sum_{a\in A}\sum_{l\in L} \pi_{lr}\phi_{ra}\, 10^{E(r,a,l)/10}\Delta E(r,a,l) \Big) \Big/ \Big(\sum_{r\in R}\sum_{a\in A}\sum_{l\in L} \pi_{lr}\phi_{ra}\, 10^{E(r,a,l)/10} \Big) \tag{27}$$

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.

5. 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 as shown in figure 1. 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.

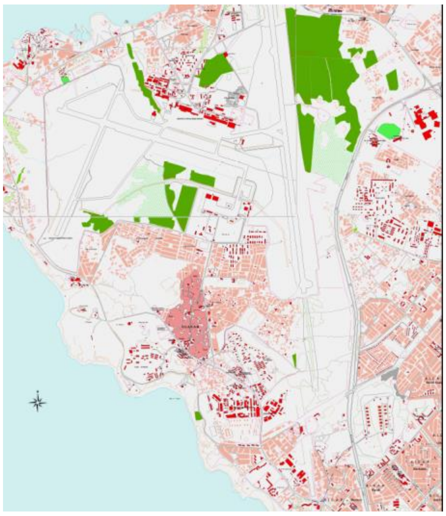

Fig. 1 Surroundings of Dakar Airport

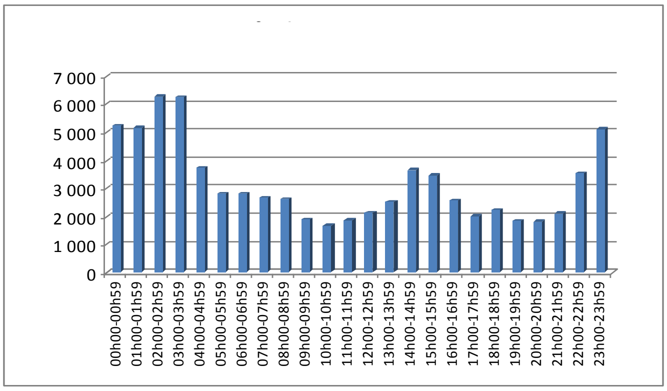

Table 1 – Hourly distribution of traffic at Dakar Airport (year 2010)

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.

6. Conclusion

The aim of this paper has been to provide a quantitative method 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.

References

Murphy M. , A. Leipold, G. Bischoff, N. Raberg, H. Ehmer, (2011). *Study on the Balanced Approach to Noise Management and its Influence on the Economic Impact of Air Transportation*, Institute of Air Transport and Airport Research, March.

Federal Aviation Administration, (2007). *Integrated Noise Model (INM) Version 7.0 User's Guide*, April.

European Civil Aviation Conference, (2005). ECAC , Doc 29: *Report on Standard Method of Computing Noise Contours around Civil Airports*, Volume 2: Technical Guide," ECAC.CEAC, 3rd Edition, July.

Mora-Camino, (2009). *Lecture notes on ICAO Annex 16*, EASA, Köln, March.

Cosenza C.A.N. and F. Mora-Camino, (2011). *Fuzzy Dual Numbers and Sets*, Technical Report, Fuzzy Modelling Laboratory, COPPE, Federal University of Rio de Janeiro, August.

Revoredo T.C., W. El Moudani, F. Mora-Camino, (2012).*Towards the Concept of Airport Noise Capacity*, Euronoise, Prague.

Kandel A. (1986). *Fuzzy Mathematical Techniques with Applications*, Addison-Wesley Publishers Company, ISBN:0-201-11752-5.