# Airports' noise nuisance and emissions: estimation and validation through INM and EDSM simulation at Italian airports

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## Abstract

This paper presents the development of two indexes for the evaluation of airports' environmental externalities such as emissions (LAP) and noise nuisance (ANE) produced by the aircrafts. We verify their reliability through the comparison of the results with the outputs of models calculations at three Italian airports. The Integrated Noise Model (INM) has been used for the calculation of noise levels, while the Emissions and Dispersion Modeling System (EDMS) has been adopted for air pollutants.

As for ANE, for each type of aircraft in the airport's fleet-mix, noise levels are calculated with INM at the ICAO certification measurement points since the index is built upon certification data. Likewise LAP index comparison has been conducted running the emissions inventories with EDMS.

Specifically INM results have been compared with ANE values and then logarithmically averaged to obtain the synthetic index while EDMS inventory results, for each pollutant, have been multiplied for their costs to obtain the LAP values.
The procedure test has been run on three specific yearly scenarios, 1999, 2004, 2008, at three Italian major airports.
Preliminary results show a good correspondence for ANE (± 2 dB) and a correlation between LAP calculated from EDMS and the time in mode.

**KEYWORDS**: Aircraft Noise, Engine emission, Simulation

**CLASSIFICATION**: Environmental Issues in Air Transport Industry

## 1 **Introduction**

Like all human activities, also those related to air transport produce impacts on the environment both in local and in global scale: the most important are noise and emission of pollutants.
Noise pollution can be harmful to the health of the populations living in areas neighbouring the airports. A continuous exposure to high levels of noise results in damage to the human organism in particular to its cardiovascular system and causes other disorders such as stress and impaired concentration. The high sensitivity to this issue of the communities surrounding the airports led Civil Aviation bodies such as ICAO, starting from the seventies, to develop policies for its mitigation.
As for air quality the Aviation transportation emits pollutants in different environmental compartments: through airports introduce pollutants both into the soil and in the surrounding waters, but the atmosphere is the main sensitive receptor. The engine emissions during flight operations contain greenhouse gases ($N_2O$, $CO_2$, and $CH_4$), polluting gases ($NO_x$, CO, NMVOC and $SO_2$), particulate matter and metals such as arsenic, chromium, copper, nickel, selenium and zinc.
This paper deals with the local impacts produced by this sector, providing a general methodology for computing airport local externalities.
In order to assess the impact of aircraft operations on the local environment, we have developed two indexes, the first one describing airport noise ANE, Airport Noise Exposure, while the second one the emissions of the major pollutants LAP, Local Air Pollution. Road traffic in the proximity of airports, supporting activities of ground support equipment (mostly passengers shuttle, catering services and refueling) and other airport sources are deliberately omitted from the study.
Indexes calculation is based on aircraft certification values, measured according to ICAO Annex 16 Vol.1 and Vol.2, with regards to noise and emission of unburned hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen ($NO_x$) and soot. The latter aspect has been ignored, however also emissions of $SO_2$, PM and $CO_2$ are considered in the index definition.

## 2 The noise index

As a first step in its definition, for each aircraft in the study we converted the Effective Perceived Noise Levels (EPNL) in the Sound Exposure Level (SEL), the most acknowledged metric to describe noise events, as it expresses the sound energy produced during an acoustic event. Since there is no precise relation between the two metrics (it is strongly dependent on the noise spectrum and the measurement point), it has been resolved to use INM to determine their difference at the three certification measurement points. In this way certification EPNLs retrieved from ICAO databanks have been converted to SEL values. More precisely, in order to minimize errors arising from a not certain correspondence between simulated and actual flight profile, we considered four categories of aircraft, calculating the average difference values. The results are presented in Table 1.

Table 1, INM Average difference between EPNL and SEL (dB) for each aircraft category.

| | **Approach** | **FlyOver** | **Lateral** |
|---|---|---|---|
| **Propeller** | 5 | 3 | 4 |
| **Regional** | 3.75 | 2 | 1.75 |
| **Narrow Body** | 3.75 | 2.25 | 2.25 |
| **Wide Body** | 4.25 | 3.25 | 2.75 |

Next step consisted in the definition at each certification reference point (k) of the annual evaluation level of airport noise, ANE, a descriptor similar to LVA, the index established by the Italian airport noise regulation[1] that can be expressed as:

$$ANE_{(k)} = 10\,LOG\left[\frac{1}{3600 \cdot 24 \cdot 365}\sum_{ops} 10^{\frac{SEL+W}{10}}\right] = 10\,LOG\left[\sum_{ops} 10^{\frac{SEL+W}{10}}\right] - 74.988$$

where W is a correction factor, equal to 10 dB, applied to SEL if the event takes place during the night-time.

$ANE_{(k)}$ values for each measurement point have been calculated from OAG statistics. OAG data provide operational data from the majority of Commercial Aviation actors. In this study we analyzed the traffic operating in the main thirty national airports covering a ten years period from 1999 to 2008.

Finally, in order to obtain a synthetic index for the single airport, $ANE_{(k)}$ have been logarithmically averaged to obtain an energetic mean:

$$ANE_{year\ AVG} = 10\,LOG\left[\frac{1}{3}\sum_{points} 10^{\frac{ANE_{(k)}}{10}}\right]$$

The fact that departures are doubly represented in relation to arrivals (Flyover and Lateral Measurement Point) can be considered acceptable, since they cause more annoyance to the people living nearby the airport infrastructure than the latter.

## 3 Local Air Pollution Index

The total emission of pollutant *p* produced by aircraft *i* ($Q_{pi}$) during the LTO cycle, can be calculated as follows:

$$Q_{pi} = n_{ij} \cdot \left(\sum_{f=1}^{4} E_{jpf} \times d_f \times Fc_{fj}\right)$$

where $n_{ij}$ is the number of engines of type *j* mounted on aircraft *i*. $E_{jpf}$ is the specific engine *j* emission factor of the pollutant *p* (kg) for the phase *f*. $d_f$ is the duration of the phase *f* and $Fc_{fj}$ is the indicated specific fuel consumption in kg/sec of the engine *j*.

Hence, multiplying $Q_{pi}$ by the number of aircraft *i* at airport *A*, $n_{iA}$, we get the total amount of pollutant *p* (kg) it produces:

[1] The entire annual scenario is considered instead of that representing its 3 mostly bust weeks as required by the decree.

$Q_{pA} = n_{iA} * Q_{pi}$

To aggregate the contribution of all pollutants into a single index, representing the LAP, we considered each specific cost ($C_p$), as estimated by Dings et al. (2003): 4 Euro/kg for HC, 9 Euro/kg for $NO_x$ and 0 Euro/Kg for CO. Carbon monoxide (CO) emissions from aircraft operations do not appear to result in substantial health effects and therefore its cost estimation is null (Dings et al.. 2003; Givoni and Rietveld. 2010).
For each airport *A* the Local Air Pollution (LAP) index is thus obtained, as the sum of the mass of each pollutant weighted for the relative cost of damage:

$$LAP_A = \sum_{p=1}^{5} C_p \times Q_{pA}$$

## 4 Indexes validation

In order to estimate the capability of the developed indexes to provide a good representation of the investigated scenarios, ANE and LAP results have been compared with those output of models simulation.
From the ten years period analysis of the thirty major Italian airports it has then been resolved to consider three specific yearly scenarios, 1999, 2004, 2008 for the three Lombardy major airports, Milan Malpensa, Milan Linate and Bergamo Orio al Serio.
ANE levels at the certification measurement points have been calculated using INM, considering average daily scenarios while emissions inventories has been run using EDMS.
INM results have been directly compared with the ANE values and then logarithmically averaged to obtain the synthetic index, EDMS inventory results for each pollutant have been multiplied for their costs to obtain the LAP values.

### 4.1 Noise levels

Bearing in mind that the objective of the study is to verify the capability of the tool to give a preliminary but accurate assessment of the acoustic climate, each scenario has been simulated taking into account the real airport and airspace layouts.
While certification tests require, either for approach and takeoff, that their aircraft flies on a straight route, real flights use different runways and different arrival and departure routes.
In order to compare ANE results to simulated data, and thus verify the good correspondence, it has been necessary to reproduce certification measurement points for each route/runway combination in order to be consistent with the certification procedure.
For this purpose, for each airport scenario, traffic data has been divided over the different STARs and SIDs and processed as a specific INM case.
Noise levels, for each certification measurement point, have consequently been logarithmically summed up to obtain the final results to be compared with the ANE values.
To better illustrate the procedure we focus on Milan Malpensa airport which is much more complicated than Linate's and Bergamo's with two runways (and a corresponding number of STARs) and several SIDs. A total of seven cases, five for Flyover and Lateral points (5 SIDs [2]) and two for Approach points, have been simulated.
Observation points were located directly under the specific routes in the case of Flyover (as shown in Figure 1) and Approach measurement points, and to the side of each runway in the case of Lateral measurement point.

[2] Runway 35L SIDs uses 280, 310, 320 MXP VOR radials while runway 35R 040 and 358 radials.

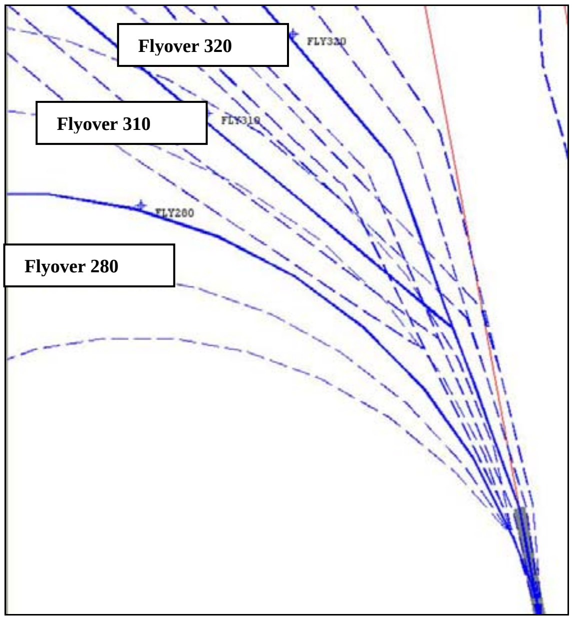


Figure 1, Flyover points for Milan Malpensa runway 35L.

Flyover, Lateral and Approach INM levels for 2008 scenario are showed in Table 2.

Table 2, INM Noise Levels for specific route for Milan Malpensa airport, scenario 2008

| Measurment Points – Routes | Noise levels (dBA) |
|---|---|
| *Flyover-040* | 56,3 |
| *Flyover-280* | 49,7 |
| *Flyover-310* | 55,3 |
| *Flyover-320* | 58,1 |
| *Flyover-358* | 55,2 |
| *Lateral-040* | 60,7 |
| *Lateral-280* | 63,2 |
| *Lateral-310* | 51,4 |
| *Lateral-320* | 57,2 |
| *Lateral-358* | 55,1 |
| *Approach-35 L* | 62,7 |
| *Approach-35 R* | 62,6 |

In Table 3 are shown the logarithmical average values of Flyover, Lateral and Approach for the three scenarios. Results differ by less than 1 dB(A).

Table 3, ANE results comparison to INM noise levels for Milan Malpensa airport.

| MXP scenario | ADNL | INM Levels | Δ |
|---|---|---|---|
| 1999 | 66,6 | 67,9 | -1,3 |
| 2004 | 66,0 | 66,6 | -0,6 |
| 2008 | 66,7 | 65,1 | 1,6 |

The same procedure has been adopted for Milan Linate (LIN) and Bergamo Orio al Serio (BGY) airports. Both have one runway active for Commercial Aviation. Milan Linate SIDs are designed built on three radials while Bergamo on two. Results for the scenarios analyzed are shown in table 4.

Table 4, ANE results comparison to INM noise levels.

| LIN and BGY scenario | ADNL | INM Levels | Δ |
|---|---|---|---|
| LIN 1999 | 61,3 | 63,1 | -1,8 |
| LIN 2004 | 62,5 | 64,5 | -2 |
| LIN 2008 | 62,3 | 63,7 | -1,4 |
| BGY 1999 | 54,4 | 52,7 | 1,7 |
| BGY 2004 | 59,7 | 56,0 | 3,7 |
| BGY 2008 | 60,3 | 57,9 | 2,4 |

## 4.2 Emission of pollutants

Regarding emission inventory, the results for each scenario simulation are shown in Table 5, where the quantity of pollutants emitted by Lombardy major airports is expressed in kg/year.
As abovementioned, EDMS results were converted in LAP indexes (Table 5) using the abovementioned cost factors.

Table 5, EDMS inventory (kg/year) results and monetary conversion.

| | HC | NOx | SOx | PM10 | LAP edms | LAP/MOV edms |
|---|---|---|---|---|---|---|
| **MXP 1999** | 502262,14 | 5767841,3 | 690527,3 | 1224695,25 | 8185326 | 80,48422 |
| **MXP 2004** | 350879,36 | 5426592 | 622719,1 | 979378,8 | 7379569 | 74,09504 |
| **MXP 2008** | 353418,24 | 5602295,9 | 622617,1 | 858571,5 | 7436903 | 75,16768 |
| **BGY 1999** | 35360,256 | 261902,54 | 54364,19 | 74623,05 | 426250 | 43,16238 |
| **BGY 2004** | 49715,912 | 737221,73 | 102325,9 | 63051,45 | 952315 | 64,53966 |
| **BGY 2008** | 99420,992 | 1493491,9 | 201119,9 | 129354,6 | 1923387 | 77,5841 |
| **LIN 1999** | 32175,488 | 1774956 | 233748,8 | 428001,6 | 2468882 | 72,17159 |
| **LIN 2004** | 155774,16 | 2339812,1 | 314593,7 | 533538,6 | 3343719 | 71,74284 |
| **LIN 2008** | 118641,25 | 1925921 | 235432,6 | 370162,2 | 2650157 | 74,27154 |

The comparison between simulated and calculated values is described in Figure 2 for each airport scenario.

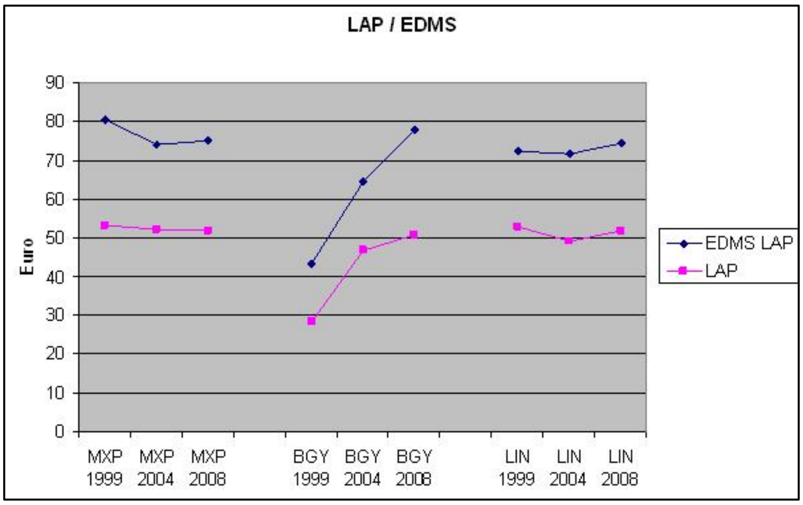


Figure 2, LAP comparison to EDMS scenario results.

To better understand results have been divided by the number of aircraft operations, obtaining the cost of a single operation for the specific airport.

As in the case of noise, EDMS provides higher indexes values. Nevertheless as showed in the graph, the trends during the analysis periods are very similar, meaning that both procedures equally respond to the different changes in fleetmix and volume. The average difference in terms of cost between EDMS scenarios and LAP index is 21,8 euros for single operations.
This overestimation is largely due to the EDMS LTO default single phase times, the so called *time in mode*. As a matter of fact, especially taxiing times result to be much shorter than those assumed in simulation.
To improve EDMS simulation LTO times should be consequently corrected using the actual ones, not available at the moment.

## 5 Conclusions

Indexes definition showed interesting results and significant possible future developments. They allow to identify the most polluting operations and assess the sustainability of a proposed increase in traffic. It is also a useful tool to investigate the consequences coming from changes in the airport fleet mix.
Simulations performed with INM and EDMS models, considered as worldwide standard for these analysis, has allowed to validate our method with good results for the two fields. In particular LAP index results underestimated compared to the EDMS emission inventory while a significant result has been obtained for the noise index. For example the difference between INM and ANE for the Milan Malpensa case is only 1,6 dB(A) for scenario 2008, -1,3 dB(A) for 1999 and -0.6 dB(A) for 2004.
Indexes performance could be improved if traffic data would be directly provided by airport operators. For example LAP index calculation could be more accurate using real data as regards aircrafts and their operational times.
Although the study shows a good correspondence between simulated values and calculated indexes, to confirm the capability of the developed tool to estimate airport noise impact, maps are still necessary to evaluate the spatial propagation of noise, especially relatively to the residential areas.
In fact, ANE cannot describe the specific impact on single receptors and evaluate the influence of flight procedures on noise spatial distribution. Consequently ANE can not substitute INM in airport noise assessment.
Conversely LAP index can be thoroughly effective for the emission inventory calculation, provided that the correct set of input data are used. As regards the evaluation of the impacts on the residential areas, as in the case of the noise study, the dispersion model continues to be necessary to integrate LAP index in providing the concentrations levels of pollutants at receptors.

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