UNIVERSITA’ DEGLI STUDI DI MILANO-BICOCCA

Facoltà di Scienze Matematiche, Fisiche e Naturali

PhD in Environmental Sciences

“FRAMEWORK DEFINITION TO ASSESS AIRPORT NOISE AND AIRCRAFT EMISSIONS OF POLLUTANT BASED ON MATHEMATICAL MODELS”

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List of Principal Abbreviations and Acronyms

AIP Aeronautical Information Pubblication

ARP Aerodrome Reference Point

ARPA Agenzia Regionale di Protezione dell'Ambiente

ATM Air Traffic Management

CAA British Civil Aviation Authority

CAEP Committee on Aviation Environmental Protection

dB Decibel

dB(A) A-Weighted Decibel

DNL Day/Night Average Sound Level

ECAC European Civil Aviation Conference

ENAC Ente Nazionale Aviazione Civile

ENAV Ente Nazionale Assistenza al Volo

EPA Environmental Protection Agency

EPNL Effective Perceived Noise Level

ETS Emission Trading Scheme

FAA Federal Aviation Administration

GA General Aviation

GIS Geographic Information System

kt Knot

ICAO International Civil Aviation Organization

ILS Instrument Landing system

INM Integrated Noise Model

IPCC Intergovernmental Panel on Climate Change

LCC Low cost carrier

Leq Equivalent Sound Level

LIMC Malpensa Airport (Milan) (ICAO code)

LIME Orio al Serio Airport (Bergamo) (ICAO code)

LIML Linate Airport (Milan) (ICAO code)

LTO Landing takeoff cycle

LVA Livello di valutazione rumore aeroportuale (Italian airport noise descriptor)
MTOW Maximum TakeOff Weight
NAP Noise Abatement Procedure
NOAA National Oceanic and Atmospheric Administration
NPD Noise Power Distance data
OAG Official Airline Guide
PNL Perceived Noise Level
SAE Society of Automotive Engineer
SEA Società Esercizi Aeroportuale, S.p.a.
SEL Sound Exposure Level
SID Standard Instrument departure
STAR Standard Terminal Arrival route
TIM Time In Mode
VOR Very high frequency Omnidirectional Range

Introduction

During the last ten years, in Civil Aviation sector there have been several initiatives for the development of policies to mitigate the environmental impacts. From ICAO to the single national authorities, like ENAC in Italy, it has been noted a strong increase in studies related to the specific environmental aspects concerning Aviation activities. The last three years have seen a stable 3% sector annual growth trend[1]. Financial crisis, started in 2007, has not changed the estimation of traffic doubling volume for 2020.

It is clear that this air traffic increase will request the upgrading of the airport infrastructures. It is very important that sustainable objectives of economic growth will be set in order to protect environment both on local scale, for communities living near airports, and on global scale, for the limitation of Greenhouse gases. In Italy the main aspect has always been noise pollution because the majority of airports are within densely populated areas.

In Europe after the introduction of specific Directives, emission of pollutants in the atmosphere has seen an increase in perception not only for the development of mitigation projects like CleanSky, but also for the adoption of ETS for the Commercial Aviation sector. However, it does not exist yet a common set of rules around the world. This potentially can create some conflicting situations due to the interdependence between noise and emissions of pollutant[2].

It is necessary to focus on all the environmental aspects to integrate the mitigation policies and operational procedures. The best choice will be made also taking into account capacity and safety issues in order to increase the effectiveness of the interventions.

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[1] ICAO.

[2] Procedure designed to meet stringent noise standards at one airport may compromise emissions of pollutants more generally (Daley. 2010).

This thesis presents a method for the determination of two environmental indexes, the first regarding noise and the second atmospheric emissions produced by flight operations. The study case is the Italian airport system in the period 1999-2008. The indexes have been validated with mathematical models at the three major Lombardy airports. In this way, an “environmental tool” for airport impact analysis, both for actual conditions and future developments, has been created in order to simplify the assessment without using models or measures.

As a descriptor of the airport noise, we opted for an index similar to the Day Night Level, DNL, which is based on the single event noise, weighed accordingly on whether it takes place in day-time or night-time. The name of the index is LVAyear.

As for the impact on air quality, it was decided to assign a monetary cost to emissions to estimate the air traffic externalities in relation to the pollutants considered in this study (HC, NO_x, CO, PM and SO_2). The designed descriptor is called LAP (*Local Air Pollution*) index.

Scenario simulations were done with mathematical models INM to calculate noise levels and EDMS to quantify emissions of contaminants.

As for the structure of the work, chapter 1 and 2 introduce the general aspects concerning noise and gas emissions as well as mathematical models. The procedure for indexes definition is contained in chapter 3 while scenario analysis is described in chapter 4. Results are discussed in chapter 5.

Chapter 1 Environmental aspects of Civil Aviation

Like all human activities, also those related to air transport produce impacts on the environment both in local and in global scale. For impact is intended any alteration of a single component or an environmental system due to factors external to it. The most important are noise, emission of substances in different compartment (air, soil and water) and light pollution.

Noise pollution is harmful to the health of populations living areas neighboring airports. It is shown[3] that continuous exposure to high levels of noise results in damage to the human organism in particular to its cardiovascular apparatus and causes other disorders such as stress and impaired concentration. The high sensitivity to this issue of the communities surrounding the airports drove Civil Aviation bodies such as ICAO, since the seventies, to develop policies aimed at its mitigation.

The Civil Aviation system emits pollutants in different environmental compartments.

An airport introduces pollutants both into the soil and in the surrounding waters, but the atmosphere is the main sensitive receptor.

The emissions from engines during flight operations contain greenhouse gases (N_2O, CO_2, and CH_4), polluting gases (NO_x, CO, NMVOC and SO_2), particulate matter PM_{10} and $PM_{2.5}$, and metals such as arsenic, chromium, copper, nickel, selenium and zinc.

Light pollution is a phenomenon linked to the dispersion of light into the atmosphere with particular impacts related to excessive consumption of energy and the conservation of species of birds whose migratory route is altered by the exposure to light radiation.

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[3] WHO, World Health Organization

In the following paragraphs are shown some of the main aspects related to noise pollution and the emission of contaminants into the atmosphere for Civil Aviation, with particular attention to the description of the phenomena, the relevant legislation and mitigation policies.

1.1 Airport noise pollution

The technological development has brought significant improvements to reduce the noise of a single event but, given the volume of the system, the noise still remains a problem of major importance.

The factors that contribute to airport noise are:

- type of aircraft and flight configuration;
- number of aircraft operations;
- routes trajectory;
- weather and environmental conditions of the examined zone.

The current approach to the problem is based on four fundamental aspects:

- reduction of noise to the source;
- adoption of specific operating procedures for noise abatement;
- land use planning compatible with the airport infrastructure;
- operational restrictions.

A more detailed distinction leads to a classification of noise reduction in active defensive measures:

- reduction of noise with the development of more silent aircraft;
- introduction of noise abatement procedures for take-off and landing.

and passive defensive measures:

- limitations of aircraft movements;
- regulation and planning of urban development areas in the vicinity of airports;

- use of sound absorbing materials for soundproofing and sound insulation of buildings;
- imposition of additional taxes on companies that use noisy aircraft.

Noise impact can be defined by the detection at fixed points or through noise contours that join points with the same noise level. The firsts can be measured experimentally while the seconds are estimated through mathematical models.

Downstream from the choice for the acoustic index of reference for a certain scenario, there is the determination of metric that can describe a single event, as may be the flight of single air plane.

Annoyance is proportional to the exposure to the total noise energy, frequency-weighted, received over a period of time equal to the duration of the sound. This assumption leads to the determination of:

- The Effective Perceived Noise Level, EPNL, which is derived from LPNT.

Another acoustic descriptor non frequency weighted and not influenced by sound duration is:

- The Sound Exposure Level (Single Event or Sound Exposure Level), SEL, derived from SPL.

1.2 The international regulatory framework and the Italian

ICAO is the reference international body for the air transportation sector since 1944, when it was founded with the Convention on Civil International Aviation. Among the various Annexes to the Convention we mention the Annex 16, *Environmental Protection*, which covers all aspects of the environmental impact. This document is divided into two volumes: the first regards noise, the second the emission of polluting substances.

The first volume of Annex 16 is divided into three parts. The first contains general definitions, the second standards, recommendations and guidelines for the certification of various categories of aircraft. The third gives recommendations for the uniformity of measurements in monitoring, the use of a reference metric and the definition of procedures for noise abatement.

In Italy airport noise issues are governed by the Framework Law N^{o} 447, October 26 1995.

In addition to general definitions, this law defines the reference values[4]. It specifies the tasks of State, Regions, Provinces and Municipalities and it is introduced for the first time the obligation to determine and plan noise reduction mitigation activities.

Among the key acts of legislation relating to the aviation industry's the most important is the Ministerial Decree of October 31 1997 "Airport noise methodology of measurement", an implementing decree of the Framework Law 447 of October 26 1995. This decree introduces a method that, consistently with the international standards, establishes noise detection techniques, defining measurement criteria and procedures for noise reduction.

The fundamental technical aspects are contained in Appendices A and B in which are defined the airport noise evaluation index (LVA) and the procedures for the implementation of measures.

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[4] Limit values are in the implementing decrees

It also sets up Airport Commissions, one for each airport, which serve to define noise abatement procedures and to determine the acoustic zones. Its members are ENAC the Airport Authority, ENAV the Air navigation Service Provider, airport operator, local authorities (Region, Province, adjacent municipalities), the Ministry of Environment and ARPA, regional protection Agency. Specifically after the establishments of NAP, Commission carries out airport zoning plan dividing the territory into three areas:

- Zone A, in which the LVA values do not exceed 65 dB (A) and there are no limitations on building permits;
- Zone B, in which the values of LVA should not exceed 75 dB (A) and agricultural and industrial activities as well as services (ensuring adequate sound insulation) are permitted;
- Zone C, in which the values of LVA may exceed 75 dB (A), and for only activities related to airport services are permitted.

Out of these three areas the LVA value should not exceed 60 dB (A).
The airport noise evaluation index, LVA, is defined as:

$$L_{VA} = 10\,Log\left[\frac{1}{N}\sum_{j=1}^{N} 10^{\frac{L_{VA\,j}}{10}}\right] dB\,(A)$$

Where N is the number of days in the period of observation of the phenomenon and LVAj is its daily value. N is always 21 three weeks in the year of analysis, each chosen within the following periods:

- October 1st - January 31th;
- February 1st - May 31th;
- June 1st - September 30th;

The daily value (LVAj) is determined by the relation:

$$L_{VA\,j} = 10\,Log\left[\frac{17}{24}\cdot 10^{\frac{Lva_d}{10}} + \frac{7}{24}\cdot 10^{\frac{Lva_n}{10}}\right] dB(A)$$

LVA$_D$, is its daytime component:

$$L_{Ad} = 10 Log\left[\frac{1}{T_d}\sum_{i=1}^{Nd} 10^{\frac{SEL_t}{10}}\right] dB(A)$$

In which Td = 61,200 (the duration in seconds of the daytime period), N$_d$ is the number of operations and SEL$_i$ is the level of the i-th single event level of individual flight.

LVA$_N$ is its night-time component:

$$L_{VAn} = \left[10 Log\left(\frac{1}{T_n}\sum_{K=1}^{N_n} 10^{\frac{SEL_k}{10}}\right) + 10\right] dB(A)$$

where Tn = 25,200 s, N$_n$ the number of operations. It shows that for the night time there is an addition of 10 dB on each event to take account of the greater disturbance.

Outside of the three areas, it is in force the decree 14/11/97 "Determination of the limits of sound sources" which requires compliance with the limits of municipal acoustic map. In this case the reference metric is the Equivalent Sound Level, Leq, generally defined by the equation:

$$L_{EQ} = 10\ Log\left(\frac{1}{T}\int_0^T \frac{p^2(t)}{p_0^2}\,dt\right)$$

Noise monitoring systems are regulated according to the decree of the Ministry of the Environment May 20, 1999 that also introduces three indexes (Ia, Ib, Ic) that synthetically describe airport impact on the surrounding areas..

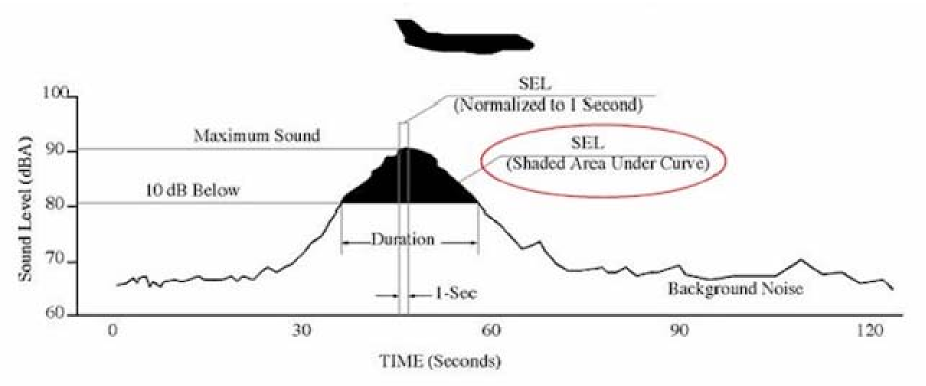

Figure 1, SEL scheme.

1.2.1 Noise Charge

The noise charge is one of the main mitigation tools to reduce the impact of airport noise. Airport operators pursued the charge introduction with the aim to develop procedures to control and mitigate noise. In the seventies the first airports to use noise charges were the airports of Frankfurt, London (Heathrow and Gatwick) and Manchester. Nowadays they are also enforced in other airports such as Paris CDG, Amsterdam and the Swiss airports. They are still not applied In Italy.

Generally, taxes increase according to the noise generated by the aircraft but also according to its weight, because the heavier airplane is usually the noisier. Some countries define a maximum noise threshold above which the aircraft pays a fee per single operation, while others divide aircrafts into noise categories with different taxation or incentives[5]. Several mathematical formulas exist to calculate the noise charges so the airlines meet, for the same aircraft, different taxes depending on the country where they operate. For example below are described the noise charge system of two major European airports: London Heathrow and Amsterdam Schiphol.

In 2003 the Dutch government established an airport charge system that also considers the aircraft noise. For this purpose aircrafts are divided into three categories (A, B, C) based on Chapter 3 of ICAO annex 16 and charged accordingly.

Heathrow has a similar charge per system. It also considers the parameter MTOW (Maximum Take Off Weight). Since 2006 the following classification is applied:

Table 1, Heathrow noise charge based on noise certification.

Chapter 2 *or without certification*	1537.50 GBP
Chapter 3 *marginal complying*	768.75 GBP
Chapter 3 – *Base fee*	512.50 GBP
Chapter 3 *QC 0.25, 0.5, 1 or* **Chapter 4**	461.25 GBP

During nighttime (00:00 to 03:30) taxes are increased by a factor of 2.5.

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[5] Raquel Girvin" Aircraft noise abatement mitigation strategies" Journal of Air Transport Management Volume 15, issue 1, January 2009.

1.3 Emissions of contaminants into the atmosphere: General Aspects

The atmosphere is the gaseous envelope surrounding the Earth. The gas mixture that makes up the atmosphere, is composed approximately of 78% nitrogen, 21% oxygen and the remaining fraction of all other substances (argon, CO_2, ...).

Air pollution is a situation in which there are substances in the atmosphere (gases of various types, aerosols and particles of varying grain size) at concentrations higher than those naturally present in the air and can produce potentially harmful effects on human health, quality of life, plants, wildlife, landscape, on materials, artefacts and works of art.

Excluding natural events, such as explosive volcanic eruptions, the cause of pollution is the set of human activities, particularly industrial ones (in which combustion processes play an important role) and road and air transport.

The latter, while contributing only for 2-3% of global emissions, plays a predominant role in the development strategies of each country. It is therefore crucial to lead the growth of this business by following a logic of sustainable development able to reduce impacts on the environment, both locally and globally. In the sector of Civil Aviation, an environmental issue such as air quality in the proximity of airport infrastructure has seen a big increase in interest from the population so that, at Community level, very important decisions were taken to mitigate these impacts. For example, we mention in July 2008 the introduction by the European Union of the Emissions Trading Scheme for the aviation industry and the project CleanSKY, intended to facilitate the design of cleaner, quieter and more efficient aircrafts. The European Commission expects that the project will reduce by 2020 the emissions of carbon dioxide (CO_2) by 50%, the nitrogen oxide (NO_x) by 80%, while halving the external noise caused by aircraft operations. Nevertheless, the continued growth of the system (*Eurocontrol* estimations, due to the current financial crisis, have been revised downward, but the growth rate is anyway 2-3% per annum[6]) drives to seek new solutions to reduce consumption energy resources and the contribution to climate change factors.

Current technological advances in the field of design and engineering of propulsion, although significant, are not able to limit the increase in emissions associated with the Civil Aviation sector and thus this is not a sustainable business today. In general terms, the impact on air quality of the aviation sector can be determined on the base of the aircraft fuel consumption.

Should not be neglected other aspects, difficult to quantify, such as the formation of so-called "contrail", the condensation wakes which impede the free path of solar radiation and the direct effect at high altitudes of nitrogen oxydes on ozone destruction.

The water steam formed during combustion of fuel is the main component of "contrail" which generates in specific weather conditions (relative humidity not less than 70%, temperatures below 40 degrees and height of at least 8,000 meters). Although these trails absorb a fraction of the sunlight, and thus prevent their arrival on earth, they retain and reflect the infrared output that would otherwise get lost in space, and thus feed the heating of the Earth's surface. Not all the water steam form contrails, but the water itself is a greenhouse gas able to trap infrared radiation. Each molecule of water is in fact able to capture more heat and survive longer at these altitudes than at sea level.

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[6] IPCC instead has raised its estimate of the total contribution of Aviation to the greenhouse effect, which would amount to 4.9% by reviewing the previous estimate which stood at 3%.

1.4 Air pollutants

The substances emitted by human activities are numerous and of different types; traditionally it is set a division into primary and secondary pollutants. The first category includes compounds present in the emissions which affect directly on human health: these are carbon monoxide, nitrogen monoxide, hydrocarbons, sulphur dioxide and particulate matter. The second contains those substances derived from the result of reactions between primary pollutants, or between primary pollutants and natural components of the atmosphere.

Air pollutants emitted from activities associated with airport infrastructure are generally the following:

CO, carbon monoxide is a colorless, odorless, flammable and very toxic gas. It forms during the combustion of organic substances, when it is incomplete due to lack of air. Environmental effects are considered negligible, while the effects on humans are particularly dangerous. This is due to the formation with the hemoglobin of blood of a compound physiologically inactive, the carboxyhemogoblin, which prevents the oxygenation of tissues. At low concentrations it causes headaches, weakness and dizziness. At higher concentrations it can be fatal;

THC, total hydrocarbons, by this term are indicated all the hydrocarbon products. Hydrocarbons are organic compounds containing only carbon and hydrogen atoms. A rough classification divides them into aromatic hydrocarbons, saturated and unsaturated hydrocarbons. The simplest is methane CH4;

NMHC, they are all non-methane hydrocarbons. The reason for this separation is that the methane in the atmosphere tends to be present in significant quantities (ppb 1700-1800) while the others are present in much lower concentrations, in the order of 1 ppb;

VOCs, volatile organic compounds include groups with different chemical and physical behavior. They are classified as VOC both hydrocarbons containing only carbon and hydrogen elements (the best known is benzene, C_6H_6), and compounds containing oxygen, chlorine or other elements, such as aldehydes, ethers, alcohols, esters, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). This category contains also harmful agents released from solvents, degreasers, etc. .;

NO_x is a generic acronym that collectively identifies all the nitrogen oxides and mixtures thereof. To reduce NO_x emissions is essential that the combustion occurs as evenly as possible, avoiding spikes in temperature. It is therefore necessary to determine a compromise with the carbon monoxide that is formed at low temperatures of flame;

SO_x, is a generic acronym that identifies collectively all the oxides of sulphur. They are among the main causes of acid rain (sulphuric acid formed - including nitrogen oxides in contact with water may give away to acidification, but their contribution is less);

PM_{10} and $PM_{2.5}$, identify the emissions of small particulate size. Particles with aerodynamic diameter less than 10 microns are indicated with PM_{10}, those with diameters less than 2.5 microns are indicated with $PM_{2.5}$ and these are the most dangerous because they can go deep into the lungs.

It is not possible to say based on an estimate of emissions which of these are major pollutants because their degree of hazard and toxicity are very different, and they have also to be taken into account other factors that contribute to the phenomenon of air pollution (e.g. time of persistence in the atmosphere and the consequent accumulation, the natural removal, etc...).

Civil Aviation emissions are not just limited to the exhaust of aircraft engines. To study the air quality of an airport you must consider the following sources:

- aircraft operations (takeoffs and landings);
- road and rail traffic at the airport;
- airport infrastructures (GSE, APU)

The aircraft emissions are the products of the fuel combustion both in the main engines and in auxiliary power units (APUs) during the flight and in ground movements.

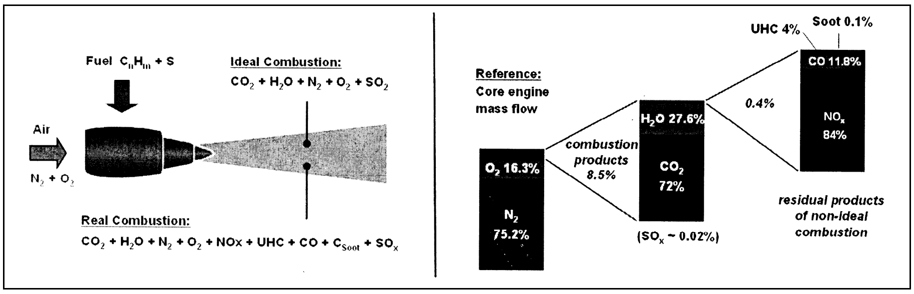

Figure 2, Aircraft engine combustion process (left) and percentage proportion of emissions during cruise phase (right).

1.5 Environmental reference regulations

The Italian legislation on air pollution has been aligned with the indications contained in the European Community Directive 2008/50/EC "Relative to the ambient air quality and cleaner air for Europe" through the approval of Legislative Decree 155 of August 13, 2010. With this text are also repealed all previous legislation from DPCM March 28, 1983 until the recent Legislative Decree 152/2007 putting together in one standard general strategies, the parameters to be monitored, the mode of collection, the evaluation levels, the limits, critical levels and the target values and quality criteria.

Earlier in Italy the definition of air pollution was extracted from the contents of DPR 203/1988, DL 352/1999 and Decree 60/2002. According to the DPR 203 for air pollution is meant *"Any modification of the normal composition or physical state of atmospheric air, due to the presence therein of one or more substances in quantities and characteristics likely to affect the normal environmental conditions and clean air; to constitute a danger or damage directly or indirectly the human health, to damage recreational activities* *and any other legitimate uses of the environment, to modify ecosystems and biological resources and public goods and private ....".*

The limits set by legislation in force, refer to values of concentration, both as a limit not to exceed and as statistical values to be respected.

The guideline value is a level set according to a criterion in order to maintain a good standard of air quality, where it is reached, or an improvement in general conditions through the study and adoption of preventive measures.

At Community level the Directive 96/62/EC mentions the "Evaluation and management of air quality." This directive establishes the framework within which operate the air quality assessment and management according to criteria harmonized in all countries of the European Union, leaving to "daughters" directives the definition of the technical operating parameters specific to each pollutant. In particular, the Directive establishes:

- pollutants on which to intervene, some already regulated (SO_2, NO_2, PTS, PM_{10}, Pb, O_3) new ones (Benzene, CO, PAHs, Cd, As, Ni, Hg);
- the criteria used to determine the air quality objectives for pollutants and monitoring requirements (limit values, target values, alarm threshold, margin of tolerance);
- the criteria for evaluating air quality in the two stages;
- the preliminary assessment to divide the territory into zones according to various regimes of air quality;
- The assessment used to get information on each pollutant and to monitor compliance with limits;
- cases in which must be implemented contingency plans and the maintenance plans;
- the obligation of Member States to establish a system of quality control and to ensure the quality of data collected;
- mechanisms for public information.

The main changes compared to the old rule are that while the current limit values refer to the protection of health and hygiene of people. In the new directive, they also provide for the protection of the environment. The current levels of attention and alarm have become "alarm thresholds". The target value (in the new directive now only associated with ozone so far) does not match the target of quality already established by Italian law. In Italy it was implemented through Legislative Decree No 351, 4 August 1999 "Implementation of Directive 96/62/EC on the assessment and management of ambient air quality".

More recently through the Ministerial Decree No 2 April 2002 60 have been transposed Directives 1999/30/EC and 2000/69/EC, which set new limit values in air concentrations of sulphur dioxide, carbon monoxide, nitrogen dioxide, PM_{10}, lead, benzene and carbon monoxide.

For each of these pollutants it exists in the decree a summary that describes the origin, effects, places limits on concentrations, the situation in Italy for compliance with the new limit values and possible actions with respect to urban areas.

1.5.1 Airport rules

Aircraft Emissions of NO_x, HC and CO are regulated in ICAO Annex 16, "Environmental Protection, Volume II, Aircraft Engine Emissions". The published limits, valid for the certification of aircraft, are reviewed periodically by the CAEP. From January 2008 they are in force those provided in the CAEP 6, which are intended to be further strengthened with the enactment of the CAEP 8.

These standards are reproducing series of landing and takeoff plane cycle (LTO, Landing Take-Off Cycle) of both jet and propeller engine. The LTO cycle simulates the condition of the air operations below 3,000 feet altitude, which roughly approximates the height of mixing layer of atmosphere. Thus Emissions at higher altitudes such those on cruise phase are not covered by current standards. Annex 16 contains the procedures for performing measurements.

ICAO also mentions the Document 9889 "Airport Air Quality Guidance Manual" which includes all the results of the assessments for the air quality at airports. It specifies emissions of NO_x, HC, CO, CO_2, SO_x and fuel consumption at each LTO phase for 52 aircraft.

The document also refers to the recent European Community Directive No. 50/2008 which sets out the objectives and deadlines for reducing the concentration of particulates in the atmosphere and the Directive 101/2008, which includes the sector within the European Emissions Trading Scheme (ETS).

1.6 Airport air pollution mitigation

As for noise, to mitigate the impact of contaminants in the atmosphere generated by aeronautical activities, is necessary to refer to a multi-level approach based on three aspects:

- introduction of policies to reduce pollution;
- reduction emissions at the source;
- introduction of operating procedures.

For the first time, in addition to the introduction of the ETS system, the most significant project is CLEAN SKY, a partnership between the EU and the aviation industry, which has the aim of increasing the environmental sustainability of the industry improving performance of the aircrafts both in terms of noise and gas emissions. In detail the project objectives are:

- reduction of fuel consumption and CO2 emissions by 50% in terms of passengers/kilometer;
- reduction of NO_x emissions by 80%;
- reduction of perceived noise by 50%;
- substantial lessening of environmental impacts on the production chain.

Reducing emissions at the source coincides with a reduction in fuel consumption. These lines of research are considered strategic by manufacturers and airlines for savings in economic terms given the high price of traditional fuels.

Projects are under development for the creation of a new generation of aircraft with innovative solutions in the fuselage and aerodynamic, but the primary aspect is the engine. In recent years efforts have been made in the design of new jets that will improve the performance, with reduced fuel consumption. There are two main technologies;

Geared Turbo Fan engine types based on a traditional pattern that allow the decoupling of the various mechanical parts, optimizing the air speed and *Openrotor* engine in which the fan is located outside the nacelle. The latter has impressive results in terms of fuel consumption reduction, but at present does not improve the acoustic impact.

Another line of research concerns fuels, in particular synthetic fuels and new second-generation biofuels (not competing with food crops) which are already at an advanced stage of testing on aircraft. The two most common resources for biofuel production are plants rich in sugar and bio-derived oils. Crops rich in sugar and starch can produce ethanol that can be a fuel or an additive. It is considered a first generation biofuel since it competes with food crops for available land. Moreover it does not meet eligibility requirements in terms of performance and security. Conversely, bio-oils derived from plants like algae, jatropha, camelina alofitee can be processed and used directly as fuel or chemically treated to obtain jet fuel or high quality diesel. These are the second-generation biofuels. Compared to fossil fuels, biofuels produce less CO_2 emissions in their life cycle. The amount absorbed during the growth of the biomass of the plant is roughly equivalent to the amount generated by the aircraft engine. This allows biofuels to be considered carbon neutral in their life cycle. But there are still emissions related to production, techniques for harvesting, transport to the refinery. When these factors are counted, it is estimated that biofuels reduce CO_2 emissions by 80% compared to fossil fuels (camelina even the 84%). Biofuels contain few impurities such as sulphur and therefore also the emissions of sulfur dioxide are limited.

The Civil Aviation dependence on fossil fuels is the cause of a variety of fluctuations including variations related to the price of fuel and problems with supply.

Biofuels are not tied to particular mining areas such as the production of petroleum, but can be produced in various parts of the world according to the demands of the sector.

Fuels are one of the largest operating costs for the aviation sector. Fluctuations in fuel prices prevent long-term strategic planning. The second-generation biofuels can also bring benefits to poor countries where arid land, unsuitable for food cultivation, offer ideal condition for this kind of feedstock.

1.6.1 Emission charge

Airport tax on emissions of pollutants has been developed more recently than the noise charge. In fact, they have been introduced for the first time in Switzerland in 1997 and the following year in Sweden, where aircraft are divided according to the characteristic of their own emissions (five and seven classes for Switzerland for Sweden). In 2003 a working group of the European Civil Aviation Conference (ECAC) has created the so-called "formula ERLIG" that provides a methodology for the calculation of the emissions of NO_x, starting from the engine of the aircraft. The total quantity of NO_x emissions of an engine is calculated from the values measured by the ICAO for each LTO cycle phase;

$$NOxAircraft(Kg) = Number\ of\ \ Engines * \sum\nolimits_{LTOphase} (time(s) * fuelflow(kg/s) * NOx(g/kg)/1000)$$

Where *time* is the duration of the phase, the *fuelflow* is the fuel consumption of the phase and *NOx* is the emission factor.

If the engine emissions for HC per LTO cycle exceed the 19.6 g/kN certified value, the relevant NO_x are then linearized with the formula:

$$Emission\ value = a * NOxAircraft$$

Where:

a = 1 if the average HC DP / FOO is less than or equal to 19.6 g/kN

a> 1 if the average HC DP / FOO is greater than 19.6 g/kN, with a maximum value equal to a = 4.

The tax based on the model ERLIG was introduced in 2004 in Sweden and London Heathrow, Gatwick in 2005, Frankfurt and Munich in Germany in 2007.

Heathrow has a NO_x emission charge which is about 1.10 GBP per kilogram of pollutant, as registered on the database "Aircraft's Ascertained NO_x Emission".

1.7 The environmental certification of aircraft

Regarding noise, the reference document is the ICAO Annex 16, Volume I. Limits depend on the type of aircraft, in particular on the type of engine and the maximum takeoff weight (MTOW), and on the date of the initial request for certification.

The certification procedure for noise determines the Effective Perceived Noise Level (EPNdB) for takeoff and landing operations in three specific spots called reference noise measurement points. The EPNL is an indicator constructed from measurements of sound pressure level for 24 third-octave bands through a process that takes into account spectral irregularities and duration of the event.

To evaluate landing operations the measurement point, simply called "Approach", is placed under the trajectory at 2,000 meters from the threshold. To evaluate take-off operations there are two reference noise measurement points. The first, called "Flyover" is placed under the trajectory at 6,500 meters from the start of roll, the second, called "Lateral" is that point at 450 meters from the runway where the highest level is measured (several measuring stations parallel to the runway must be deployed).

As mentioned, in general, the limits at each point vary with the weight of the aircraft. In the case of the "Flyover" the number of engines is also considered, allowing four engine aircraft to be noisier than two engine ones[7].

In order to reduce aircrafts emissions, ICAO has introduced standards that require the engine certification for the emissions of major pollutants: soot, carbon monoxide, unburned hydrocarbons and nitrogen oxide.

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[7] Originally jet and turboprop aircraft with MTOW larger than 5,700 kilograms were classified in two stages of certification corresponding to two chapters of Annex 16, Chapter 2 (with higher levels for older and noisier technologies) and Chapter 3 (with lower levels). In March 2002 the rule was revised and a new chapter, Chapter 4, had been added. In effect since January 1, 2006, the new standard imposes the reduction by 10 EPNdB of the aggregated value of the levels for all the measuring points compared to that of Chapter 3.

The reference document is the ICAO Annex 16, Volume II, Environmental Protection - Aircraft Engine Emissions.

Emissions shall be measured with standardized test conducted on a test-bed in reference to a landing and takeoff cycle (LTO cycle). It describes a complete cycle of arrival and departure, including therefore the approach procedures, starting from 3,000 feet, taxiing from the runway to the gates, taxiing to the runway from the gate and take off up to an altitude of 3,000 feet.

Table 2, Series of benchmarks for LTO.

Mode	**Thrust (%)**	**TIM (min)**
Take-Off	100	0.7
Climb	85	2.2
Approach	30	4.0
Taxi/Ground Idle	7	26.0

Although Annex 16 distinguishes between subsonic and supersonic aircraft, these are not discussed in this document. Below are briefly presented the most significant aspects of the document.

To measure the soot, the so-called “smoke”, it was introduced the Smoke Number, SN, which assures a value between 0 and 100 and is determined on the basis of the stain produced on a test filter from the reference mass of the sample of exhaust gas.

The Annex 16 requires that:

$SN \leq \min [83.6 (F\infty)-0.274; 50]$

Where the parameter $F\infty$, the rated output, indicates the maximum available thrust at sea level. Concerning the emissions of pollutants for civil subsonic aircraft with a maximum thrust of more than 26.7 kN, produced after 12/31/1985, CO and unburnt HC limits are expressed as:

$$\frac{D_P}{F_\infty} \leq 118 \quad g/kN$$
for CO;

$$\frac{D_P}{F_\infty} \leq 19.6 \quad g/kN$$
for UHC;

Where Dp is the mass of pollutant emitted during the LTO cycle. For nitrogen oxides the certification requirements are more complicated and are expressed according to the date of manufacture of the engine, the maximum thrust available at take-off and the pressure ratio between the inlet and outlet of the compressor (*reference pressure ratio*, πC)[8].

Besides the values established in Annex 16 were reviewed by CAEP which periodically updates them by placing more stringent limits. Updates are identified by the name of the committee that defines them: the original limit has been updated with the CAEP 2, which has over the years turned into CAEP 4 and CAEP 6 (next to be defined is the CAEP 8). CAEP has hypothesized the new limits by assuming a percentage reduction from previous values, so, for example, the CAEP 2, for values of pressure ratio of 30, is lower than the original limit by 20%, CAEP 4 is lower than the latter by 16% and finally the CAEP 6 is lower than the CAEP 4 of 12%.

Specifically the original limits refers to models with production beginning prior to 31.12.1985 or production of single engine prior to 12.31.1995 and requires:

$$\frac{D_P}{F_\infty} \leq 40 + 2\,\pi_C \quad g/kN$$

CAEP 2 limit (models with production beginning next to 31.12.1985 or after the production of single engine 12.31.1995) requires:

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[8] Annex 16 makes a dual classification, considering both the date of first production series engine (*date of manufacture of the first individual production model*), and the date of manufacture of the engine under investigation (*date of manufacture of the individual engine*), to consider possible changes (e.g. development kit, typically at the combustion system) of the engine.

$$\frac{D_P}{F_\infty} \leq 32 + 1.6\,\pi_C \quad g/kN$$

Models with production beginning later than 31.12.2003 (in this case the production date of the single engine examined is no longer taken into account) are divided into two periods: the first prior to 12/31/2007, which meets the requirements imposed by the CAEP 4 and the second after 12/31/2007 which meets the requirements imposed by the CAEP 6. Limits are expressed according to different pressure ratio and rated output intervals.

For example, for models produced within the period 31-12-2003/31-12-2007 (CAEP 4), if the pressure ratio is less than 30, it is required:

$$\frac{D_P}{F_\infty} \leq 19 + 1.6\,\pi_C \quad g/kN$$

with more than 89.0 kN maximum thrust;

$$\frac{D_P}{F_\infty} \leq 37.572 + 1.6\,\pi_C - 0.2087\,F_\infty \quad g/kN$$

with a maximum thrust between 89.0 kN and 26.7;

if the pressure ratio is between 30 and 62.5:

$$\frac{D_P}{F_\infty} \leq 7 + 2.0\,\pi_C \quad g/kN$$

with more than 89.0 kN maximum thrust;

$$\frac{D_P}{F_\infty} \leq 42.71 + 1.4286\,\pi_C - 0.4013\,F_\infty + 0.00642\,\pi_C \cdot F_\infty \quad g/kN$$

with a maximum thrust between 89.0 kN and 26.7;

if the pressure ratio is higher than 62.5:

$$\frac{D_P}{F_\infty} \leq 32 + 1.6\,\pi_C \quad g/kN$$

For the sake of simplicity the other cases are not reported.

Based on the values measured during certification, the manufacturer shall indicate the Emission Factors which are calculated according to the generic formula:

$$EI_{Pollutant} = \frac{mass\ in\ grams}{fuel\ mass\ in\ kg}$$

In this way it is created a database (constantly updates) of the emissions of different type of aircraft engines that have already gone into production. The British Civil Aviation Administration (CAA) is responsible for managing the physical database[9].

The database is structured on two levels featuring a section, “Individual Datasheet Engine”, that lists, classified by manufacturer (AlliedSignal, Allison Engine Company, Rolls Royce Corporation, AO “Aviadgatel”, BMW Rolls Royce, CFM International, ZMBK), individual certification datasheets and a section, “Emission Databank”, where it is possible to download the complete database of all models of engine.

Individual Engine Datasheet presents:

The general characteristics of the engine (engine identification, ID number, engine type, bypass ratio, pressure ratio and rated output) and the “Regulatory Data” showing data measured for each pollutant and Smoke Number of DP/F∞.

Measured data power settings (F∞ %), “Times in mode” (minutes), fuel consumption (Kg/s) and especially the CO, HC and NO_x emissions factors (g/kg fuel) for each LTO phase. Emissions in term of total mass is also provided.

Other informations report weather conditions in which the tests were carried out (pressure, temperature and relative humidity), the characteristics of the fuel used (specifications – type of fuel H/C ratio of hydrogen and carbon atoms in the molecular structure; AROM% - percentage of aromatic hydrocarbons) and the status of the engine production, any correction with respect to the atmospheric condition of certification, the manufacturer, the tests manager, place and date of tests.

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[9] available at http://www.caa.co.uk section Safety Regulation, Human and Environmental Issue.

Chapter 2: Methodology

2.1 Mathematical Models

To achieve the objectives of the study, the following activites have been carried out through the use of simulation models to calculate the environmental impact of airports:

- Noise analysis, with INM model, for the three major Lombardy airports (Milan Malpensa, Milan Linate and Bergamo Orio al Serio) considering three yearly operational scenarios, 1999, 2004 and 2008:
- Emission inventory for these scenarios, with EDMS model;
- Dispersion scenario simulation for Milan Linate airport, through the use of AERMOD Gaussian model (EDMS) and, only in the preliminary phase for Milan Malpensa, through the use of a lagrangian model (LASPORT).

2.2 Integrated Noise Model INM

The Integrated Noise Model is an international standard for the analysis of airport noise. It has been developed by FAA for more than twenty years and is used by more than 700 organizations around the world.

INM algorithms are based on SAE technical norms. The most important is SAE AIR 1845 "Procedure for the Calculation of Airplane Noise in the Vicinity of Airports" which describes a model for the calculation of flight profiles and noise levels (SEL) at receivers.

INM can calculate several noise metrics at single location points or widen the calculation on a grid of receivers to obtain a noise map.

The calculation is carried out using the "Noise Power Distance Data", NPD. It is a database that provides for each aircraft noise curves expressed in function of receptors-source distance and thrust setting. NPD curves are built on sound levels at ten distances (200, 400, 630, 1.000, 2.000, 4.000, 6.300, 10.000, 16.000 and 25.0000 feet). There is also a limited set of thrust values. For different values of distance and thrust logarithmic and linear interpolation are respectively applied.

So if thrust value P lies between P_i and P_{i+1}, contained in NPD database, for a given distance value, we have:

$$L(P) = L(P_i) + [L(P_{i+1}) – L(P_i)] [(P-P_i) / (P_{i+1} –P_i)]$$

Instead given d, a distance between two (d_i e d_{i+1}) of the ten distance tabulated, we have;

$$L(d) = L(d_i) + [L(d_{i+1}) – L(d_i)] [(\mathrm{Log}\ d – \mathrm{Log}\ d_i) / (\mathrm{Log}\ d_{i+1} – \mathrm{Log}\ d_i)]$$

By this two equations we obtain the level of the considered metric for each thrust/distance combination.

Flight profile, reproduced in the model by the union of 2D trajectory and vertical profile, is divided in segments that describe a single phase of flight[10]. INM calculates noise level for each segment and applies acoustic corrections. Then, an iterative process calculates noise levels taking into account all the segments for all the operations in the scenario.

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[10] Take-off ground roll, Climb, Acceleration, Descent, Level, Landing and Decelerate.

2.3 Dispersion of pollutants models

Due to the continuous increase of air pollution, many researches have focused on atmospheric dispersion models, as they allow the prediction of environmental impacts generated by human activities. They have become an extremely useful tool for air quality analysis, preliminary assessment of potentially polluting sources, environmental management and even monitoring.

Air quality standards should not be exceeded, especially in densely populated areas. Environmental control is conducted with monitoring systems but, where monitoring is absent or inadequate, models can make up for it. It is clear that models are an approximation of reality, and hence their predictions may disagree with measures. This difference can be quantified in terms of statistics as comparing different models applied to the same case.

Some kind of models express a relation between the pollutant concentration on the ground and its emission flow on the basis of statistical report. They ignore the physical mechanisms that underlie the diffusion of the pollutants. However they provide useful predictions in not highly variable situations.

Other models, those that will be described herein, have the ambition to understand and simulate the main physical processes that affect the dispersion of pollutant in the atmosphere in every condition. Models could be classified according to various criteria.

From a physical point of view models are divided in: Eulerian models, Lagrangian models and Gaussian models.

Eulerian models are defined by the integration of the diffusion equation which, given initial conditions and three dimensional wind fields (u_i) and turbulence (K_i)[11] calculates concentration values in every three dimensional space position and in subsequent time intervals.

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[11] i=1,2,3

In general, the equation is solved on a fixed grid, calculating $C^n_{j,\ k,\ l}$ concentration value for each node in the point of coordinates < j, k, l > and at the instant n.

$$\frac{\delta C}{\delta t} + u_i \frac{\delta C}{\delta x_i} = \frac{\delta}{\delta x_i}\left(K_i \frac{\delta C}{\delta x_i} \right) + S + R$$

Where $\frac{\delta C}{\delta t}$ is the time derivative, $u_i \frac{\delta C}{\delta x_i}$ is the transportation term, $\frac{\delta}{\delta x_i}\left(K_i \frac{\delta C}{\delta x_i} \right)$ the diffusion term, S the source term that represent the pollutant flow and R the transformation/removal term representing the chemical reaction in the compartment.

To obtain a good resolution for concentration field a rather dense grid is required, depending on how much complex are the ground conditions.

The main difficulty encountered in the use of this model is the impossibility to describe in a simple way the terms related to turbulence. Normally this problem is overcome by establishing a proportionality between turbulence terms and the spatial variations in the pollutant concentration. This proportionality is expressed in mathematical terms by K_i parameters. Depending on the complexity degree with which these parameters are defined (i.e. expressions of the first, second, third order or more) there are different type of models.

Eulerian models are well suited for analysis in which the transformation/removal term R is not negligible. Given the chemical reaction speed of the pollutant, which depends to a large extent on its concentration, the model easily calculates, for each node of the grid cell, the amount of pollutant removed or generated.

Lagrangian models calculate the dispersion through the motion of fictitious particles whose trajectories allow to define the field of concentration of the emitted substance. Basic hypothesis is that the particle path simulated represent, on average, real trajectories of air masses that have the same position at the initial time. Therefore as their real motion is the result of interaction of wind average motion and its turbulence, the motion of fictitious particles is calculated to parameterize these natural processes. Instantaneous concentration for a pollutant can be approximated by:

$$\frac{\partial c}{\partial t} + \sum_{j=1}^{3} u_j \frac{\partial c}{\partial x_j} = \sum_{j=1}^{3} \left\{ \frac{\partial}{\partial x_j} \left[K_j \frac{\partial c}{\partial x_j} \right] \right\}$$

Where u is the instantaneous speed. Speed values due to turbulence are obtained from the measure of variances in wind speed components in the same particle position point. Lagrangian models allow to use measured data available (wind speed), a strong advantage over Eulerian models that require a turbulence data parameterization in order to derive the diffusion coefficient K. Particles models are also preferred for the greater facility in reproducing the source term. It is possible to simulate all kind of sources (linear, point, areal), every dimension (by varying the initial volume in which particles are generated), as well as continuous or time varying emissions and even instantaneous (generating an appropriate number of particles at each time step) producing different scenarios evolution.

Several studies have verified these models at both mesoscale and local scale. Models validation with tracers measurements have shown that ground concentrations are in good agreement with experimental data, even in particular weather conditions, as in cases of convective instability, wind calm and others generally considered not easy to simulate.

Gaussian model is, by far, the simplest and most used in current practice to simulate the dispersion of pollutants. Gaussian model is based on a simple formula that describes the three-dimensional concentration field generated by a point source under constant meteorological and emission conditions.

$$C(x,y,z)=\frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left\{\exp\left[\frac{-(z-H_s)}{2\sigma_z^2}\right]+\exp\left[\frac{-(z+H_s)}{2\sigma_z^2}\right]\right\}+Cf$$

This equation is obtained as an analytical solution of the differential diffusion equation assuming that:

- Ki diffusion coefficients are constant;
- Wind speed is constant in time and space;
- Source term is independent of time;
- Transport of pollutants in x-direction due to turbulence is negligible compared to that due to the wind.

The correspondence between short term predictions for ground concentrations and experimental data are not satisfactory, however reliable estimates can be compared to the maximum absolute and may therefore be useful to describe the worst possible scenario. If meteorology of the site does not present frequent vertical inhomogeneity and characteristics of the source are known, estimates of average concentrations over long periods (annual and seasonal) can be in good agreement with measured values. Gaussian model in fact cannot be applied in uneven flow conditions, like complex terrain or typical evolutionary phenomena as breeze cycle formation. This is due to the model basic hypothesis of uniformity and stationarity for both meteorology and emissions.

2.3.1 Emissions and Dispersion Modelling System (EDMS)

The Emission and Dispersion Modelling System was developed by EPA in the 80s to assess the impact on air quality resulting from airport activities. Subsequently the software was completed by the FAA (Federal Aviation Administration) in collaboration with the U.S. Air Force (USAF) following the guidelines proposed by EPA. This model is one of the few tools specifically designed for the assessment of air quality around airports. It produces the emissions inventory generated by an airport and can simulate their distribution calculating concentrations in the surrounding areas. Since 2004 the software uses EPA AERMOD model to calculate dispersion of pollutant from point, linear, area and volume sources.

From a structural point of view, EDMS is essentially composed of an emission factors database, an integrate dispersion model and a report generator. The system includes emission data for different airport sources in an airport such as aircraft (for different flight phases), power and thermal plants, incinerators and fuel oil tanks etc.

With regard to the wind, the stability and the ground surface, the model assumes the hypothesis of horizontal homogeneity. The current version does not take into account the effects of temperature inversions at low altitude. EDMS can operate in different mode. Screening method requires user manual input for meteorological data. Detailed method uses meteorological data series and needs airport layout definition. Thus the model calculates emission inventory.

Dispersion analysis is performed starting from emission inventory and geometry of sources. The concentrations of pollutant are calculated in a user defined network of receptors. Key parameters are wind, turbulence and classes of atmospheric stability.

Simulation is based on the following steps:

- The user characterizes the various emission sources in the study. Upon completion of this phase EDMS can calculate the emission inventory;
- Modelling the dispersion is a more complex procedure and requires much additional information. In particular;
    - infrastructure coordinate;
    - aircraft data (type, engine, number of operations, flights frequency);
    - operational profiles.

LTO cycle is divided into six phases (approach, taxi in, gate, taxi out, takeoff, climb out). The emissions of pollutant vary depending on the specific phase and its duration. For each pair of aircraft/engine and for each LTO cycle phase EDMS uses a series of emissions factors. Emission are calculated by determining the duration of each phase (*time in mode,* TIM) that can be modified if necessary. If the user chooses to perform a "*Performance based*" calculation, TIM are determined through the abovementioned SAE AIR "Procedures for the Calculation of Aircraft Noise in the vicinity of airports"[12]. Otherwise opting for a second option "*ICAO/USEPA default*" method TIM are given by a standard database.

GSE (*Ground Supporting Equipment*) can be simulated in association with the aircrafts, or as independent object. Their emission are calculated using NONROAD2005 model, which is based on EPA emission factors determined on the basis of fuel usage, average load, type of brakes and age of the vehicle.

Another important source is APU which can be associated with the individual aircraft in the analysis (Emission calculation is based on LTO

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[12] Aircraft operational profile are calculated by EDMS using the algorithm provided by SAE AIR 1845, deducing basic parameters from the European Database BADA, Base of Aircraft Data.

cycles) or simulated as independent source. In any case the user should define its operating time (before take-off and after landing). Other sources are “*Stationary Sources*”, “*Training fire*”etc.

In addition to airport activities, EDMS reproduces road traffic to and from the airport. Vehicles emission factors are calculated by EPA MOBILE 6.2 model which considers the traffic flows , the average speed along the path, the year of manufacture, altitude and average temperature.

At the end of the input phase, EDMS calculates emission inventory for single pollutant, distinguishing single sources and, with regards to aircrafts emissions, the single LTO phases.

To simulate dispersion of pollutant EDMS processes weather files through AERMET. Specifically weather data are measured at the ground (*surface data*) and at different altitudes (*upper air data*).

Orographic data are not mandatory for the model but contribute greatly to improve the simulation. They are processed through AERMAP.

2.3.2 LASPORT

LASPORT is a model, developed in Germany by Janicke Consulting Environmental Physics, for the quantification of emissions and the calculation of the dispersion of pollutants due to airport activities. LASPORT performs the dispersion calculation through a particle lagrangian model, LASAT. The model simulates the following physical process:

- transport due to the average wind field and dispersion in the atmosphere;
- sedimentation of heavy aerosols and their deposition on the ground;
- wash out, dry deposition and chemical reactions of the first order.

Daily operations can be considered either individually through a movement journal or in a more general form grouped by aircraft model. Other sources considered by the model are: auxiliary power units, ground power units, airside supporting structures, vehicular traffic (internal and external) and other sources (represented by points, lines and volume).

Emissions, as for EDMS, for each LTO phases, are calculated from emission factors and its duration. Default times for single LTO phase are shown in table 3:

Table 3, Time in mode for LTO phase.

LTO Phase	**t (min)**
Idle	26
Approach	4
Climb out	2,20
Takeoff	0,7

LTO cycle is extended by default to a height of 914 meters (3000 feet) above the ground. Emissions at higher altitudes do not affect for local air quality and are not simulated.

For emission inventory, LASPORT provides different levels of simulation. For a complete simulation it is necessary to reproduce airport layout. LASPORT allows to import maps representing the airport, through which simulate runways, taxiways and gates as well as departure routes (arrivals are fixed). Taxiway are created for each combination of runway/position area. Also APU, GSU, GSE can be inserted in the model via GUI mode model.

Outside the airport motorway (for road traffic) are defined by a sequence of points (*marker points*).

Dispersion calculation takes into account the dynamics of engine exhaust gases, the ascent of thermal plume and the chemical reaction of NO into NO_2. Pollutant analysed by the model are: $NO_{x,}$ CO, O_3, VOC, PM. Dispersion is carried out on the basis of meteorological data series processed and entered by the user. Generally they contain hourly average values of wind speed, direction and stability class of Monin Obukhov. These values are calculated from the global and net solar radiation values. LASPORT, contrary to EDMS, consents the use of generic formats (i.e .csv). Regional Environmental Protection Agency, ARPA, provides meteorological data from stations in proximity of Airports.

Once completed input data phase, LASAT can simulate dispersion based on hourly averages, as statistical analysis or a graphic.

LASAT defines output results according to European regulation.

For each grid cells, LASPORT stores the daily average values and the long term average values of n higher concentrations (*maxima*) and the number of exceedings of threshold limits.

Results can be read both in tables and histograms representing the distribution of the concentration values

Chapter 3 Synthetic indexes for noise and emissions of pollutant related to Italian airport system

In order to assess the impact of aircraft operations on local environment, we have developed two indexes, the first one describing airport noise, while the second one the emissions of the major pollutants. Aspects related to vehicular traffic in proximity of airports and supporting activities for air traffic (mostly passengers shuttle, catering services and supply) and airport infrastructure are deliberately omitted from the index calculation.

The subject of this study is the evolution of air traffic and its related environmental impacts in the Italian airport system during the ten years period 2000-2008. Quantification of the impact is based on aircraft certification values, established 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 overlooked, however also emissions of SO_2, PM and CO_2 are considered in the index definition.

3.1 General aspects

The main source of noise and emissions of pollutant at airports is represented by aircraft engines, especially during take-off and landing operations, with peaks during the phase of take-off. Obviously, these issues are dependent on both the growth of air traffic and the type of fleet operating at the airport.

This study concerns aircrafts with a mass exceeding 5,700 kg and turbine engines. These types of aircraft are divided in two sections: propellers (*Turboprop*) and turbojet engines (*Turbojet*). Piston engines aircrafts (helical-internal combustion) are ignored due to their limited impact.

A first characterization recognizes that in Commercial Aviation, which includes all the flight operations carried out by sector companies (scheduled operations performed by airlines and unscheduled operations carried out by cargo and charter operators), most of fleets are made up by large turbojet aircrafts even if turboprop aircrafts are largely used in the regional sector (less than 100 passengers). In General Aviation, that includes all private flights (leisure or business aviation), aircraft fleets are made up by small turboprop or turbojet aircrafts. Over the years, both solutions have experienced a significant technological development with high level of efficiency regarding fuel consumption and environmental mitigation. More radical was the development for turbojet with the introduction of turbofan. This category of engines provides more efficiency in combustion due to the increase in bypass ratio bringing benefits both for noise, thanks to lower jet speed (noise is proportional) and emissions in the atmosphere, due to lower air mass, at the same level of thrust, that is involved in thermodynamic cycle of combustion. This has an effect on the amount of fuel needed to generate thrust.

The major turbojet engines manufactures are Pratt&Witney, Rolls Royce (associated with MTU AERO engines in the International Aero Engines), and General Electric (associated with Snecma in CFM international consortium). They mostly produce high-by pass turbofan for high and medium thrust segment.

3.2 The database for noise and emissions of pollutants

In order to determine indexes for noise and emissions of pollutant an environmental dataset has been created to collect all the necessary information. Noise certification values are taken from EASA[13] (Type-

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[13] EASA database is composed of turbojets (JETS) and heavy propeller (PROPS heavy), http//easa.eu.int/ws_prod/c/c_tc_noisephp.

certificate data sheet for noise, TCDSN) and FAA[14] (Advisory circular 36) datasets. Engine emissions certification values are taken from ICAO Engine Emissions Databank[15].

A MS Access file was created to collect all the available data and facilitate their elaboration through the use of query, pivot tables and more complex calculation using VBA scripts.

A preliminary phase concerns the collection and the rearrangement of certification values, then the index elaboration has been conducted through two alternative processes. The first one called "Standard" does not use aircraft registration information (purchased from specialized institutes) and is based on information freely available. The second one, called "Advanced", uses instead an engine statistics, developed on data from the International Register of Civil Aircrafts, IRCA.

Operational data concerning the airports traffic are taken from the Official Airline Guide, OAG, which collects a large amount of scheduled data from airports open to civil air traffic.

To qualify, specifically for each operation type (departure or arrival), the environmental features of the operating fleet, for each OAG aircraft described in terms of model and MTOW, have been identified its certification noise levels and engine pollutants emissions.

OAG data were imported (Table OAG_data, 222 record) extracting aircraft models (SPECIFICACFTNAME), present in the analysis period, and their maximum take-off weight (MAXTAKEOFFWEIGHT, kg) not considering in this phase the number of flight movements.

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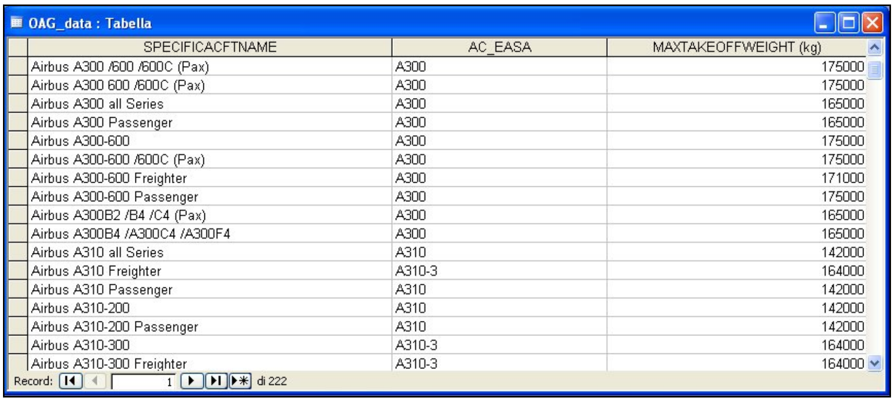
[14] http://www.faa.gov/about/office_org/headquarters_offices/aep/noise_levels.

[15] http://www.caa.co.uk/default.aspx?catid=702.

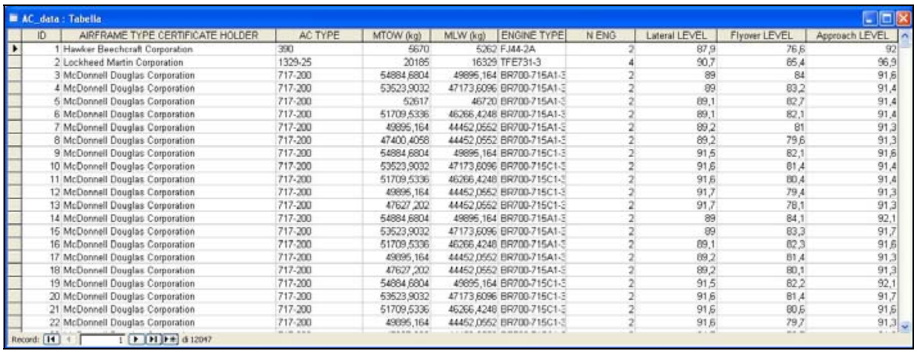


SPECIFICACFTNAME	AC_EASA	MAXTAKEOFFWEIGHT (kg)
Airbus A300 /600 /600C (Pax)	A300	175000
Airbus A300 600 /600C (Pax)	A300	175000
Airbus A300 all Series	A300	165000
Airbus A300 Passenger	A300	165000
Airbus A300-600	A300	175000
Airbus A300-600 /600C (Pax)	A300	175000
Airbus A300-600 Freighter	A300	171000
Airbus A300-600 Passenger	A300	175000
Airbus A300B2 /B4 /C4 (Pax)	A300	165000
Airbus A300B4 /A300C4 /A300F4	A300	165000
Airbus A310 all Series	A310	142000
Airbus A310 Freighter	A310-3	164000
Airbus A310 Passenger	A310	142000
Airbus A310-200	A310	142000
Airbus A310-200 Passenger	A310	142000
Airbus A310-300	A310-3	164000
Airbus A310-300 Freighter	A310-3	164000

Figure 3, Example of aircraft models present in the study.

EASA and FAA noise datasets presents technical specifications, regarding engine details and performance, useful to characterize the fleet. Specifically FAA database was used to integrate McDonnell Douglas DC-09, DC-08 and Boeing 707 data not present in EASA database. For each aircraft the following have been collected; manufacturer (AIRFRAME TYPE CERTIFICATE HOLDER), aircraft model (AIRFRAME TYPE DESIGNATION, reduced to AC TYPE), maximum takeoff weight (MTOW), type of engine (ENGINE TYPE DESIGNATION, reduced to ENGINE TYPE), number of engines (NUMBER OF ENGINES, reduced to N ENG) and acoustic certification data (NOISE LEVELS (EPNdB) Approach Level, Lateral Level, Flyover Level).

From a first verification of available data emerged the lack of information such as the number of engines (absent in EASA database) necessary to calculate emissions for Heavy propeller (since certification values are referred to a single engine). The results of this process, a total of 12.047 records were collected in the table AC_data.



ID	AIRFRAME TYPE CERTIFICATE HOLDER	AC TYPE	MTOW (kg)	MLW (kg)	ENGINE TYPE	N ENG	Lateral LEVEL	Flyover LEVEL	Approach LEVEL
1	Hawker Beechcraft Corporation	390	5670	5262	FJ44-2A	2	87,9	76,6	92
2	Lockheed Martin Corporation	1329-25	20185	16329	TFE731-3	4	90,7	85,4	96,9
3	McDonnell Douglas Corporation	717-200	54884,6804	49896,164	BR700-715A1-3	2	89	84	91,6
4	McDonnell Douglas Corporation	717-200	53523,9032	47173,6096	BR700-715A1-3	2	89	83,2	91,4
5	McDonnell Douglas Corporation	717-200	52617	46720	BR700-715A1-3	2	89,1	82,7	91,4
6	McDonnell Douglas Corporation	717-200	51709,5336	46266,4248	BR700-715A1-3	2	89,1	82,1	91,4
7	McDonnell Douglas Corporation	717-200	49896,164	44452,0552	BR700-715A1-3	2	89,2	81	91,3
8	McDonnell Douglas Corporation	717-200	47400,4058	44452,0552	BR700-715A1-3	2	89,2	79,6	91,3
9	McDonnell Douglas Corporation	717-200	54884,6804	49896,164	BR700-715C1-3	2	91,5	82,1	91,6
10	McDonnell Douglas Corporation	717-200	53523,9032	47173,6096	BR700-715C1-3	2	91,6	81,4	91,4
11	McDonnell Douglas Corporation	717-200	51709,5336	46266,4248	BR700-715C1-3	2	91,6	80,4	91,4
12	McDonnell Douglas Corporation	717-200	49896,164	44452,0552	BR700-715C1-3	2	91,7	79,4	91,3
13	McDonnell Douglas Corporation	717-200	47627,202	44452,0552	BR700-715C1-3	2	91,7	78,1	91,3
14	McDonnell Douglas Corporation	717-200	54884,6804	49896,164	BR700-715A1-3	2	89	84,1	92,1
15	McDonnell Douglas Corporation	717-200	53523,9032	47173,6096	BR700-715A1-3	2	89	83,3	91,7
16	McDonnell Douglas Corporation	717-200	51709,5336	46266,4248	BR700-715A1-3	2	89,1	82,3	91,6
17	McDonnell Douglas Corporation	717-200	49896,164	44452,0552	BR700-715A1-3	2	89,2	81,4	91,3
18	McDonnell Douglas Corporation	717-200	47627,202	44452,0552	BR700-715A1-3	2	89,2	80,1	91,3
19	McDonnell Douglas Corporation	717-200	54884,6804	49896,164	BR700-715C1-3	2	91,5	82,2	92,1
20	McDonnell Douglas Corporation	717-200	53523,9032	47173,6096	BR700-715C1-3	2	91,6	81,4	91,7
21	McDonnell Douglas Corporation	717-200	51709,5336	46266,4248	BR700-715C1-3	2	91,6	80,6	91,6
22	McDonnell Douglas Corporation	717-200	49896,164	44452,0552	BR700-715C1-3	2	91,6	79,7	91,3

Figure 4, AC_DATA table.

Data Regarding pollutants emissions come from ICAO Engine Emissions Databank[16] which is freely available and kept up to date from CAA. It contains for each engine model and for each phase of the LTO cycle, the emission factors of HC, CO, NO_X as well as the fuel consumption.

ICAO Database has been arranged to isolate the two main phases of LTO cycle, departure and arrival.

As shown in chapter two, LTO cycle is divided into four phases; take off, (0.7 minutes), climb out (2,2 minutes), approach (4 minutes) and idle composed by two sub phase, taxi in (7 minutes) and taxi out (19 minutes). To determine the emissions for each engine, Take-Off, Climb Out and Taxi Out amounts have then been combined to account for departure operations while Approach and Taxi In amounts have been combined to account for arrival operations.

Since emission factors are the quantity (grams) of pollutant emitted for 1 kg of fuel burned, for each phase (or subphase in the case of taxiing), they have been multiplied by the duration and by the fuel flow.

$$EI_{Phase}(g/Kg)\cdot DURATION_{Phase/Subphase}(s)\cdot FUEL\ FLOW_{Phase}(Kg/s)$$

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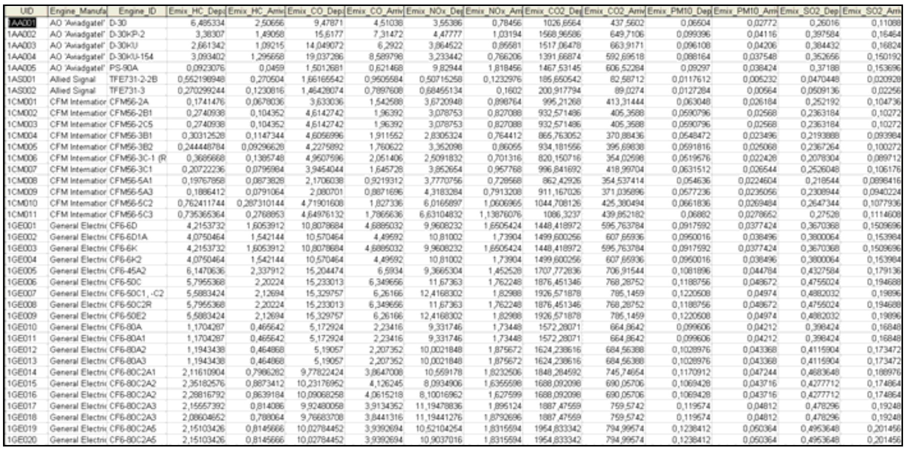
[16] ICAO Emission Databank does not provide emission factors for turboprop aircraft. It’s possible to obtain them from Swedish FOI, http://www.foi.se/FOI/templates/startpage____4.aspx.

Furthermore, it have been computed the production levels of CO_2 by multiplying, for each phase of the LTO cycle, the amount of fuel burned by the stoichiometric coefficient of 3.157 (CO_2 kg per fuel kg) of chemical combustion reaction. Similarly the emissions of PM_{10} and SO_2 have been calculated (their coefficients are set respectively to 0.2 g/kg and 0.8 g/kg as in Dings et al. 2003, Sutkus et al. 2001).

Calculation correctness is verified by comparing the sum for each LTO cycle of the two operations with total values in database (LTO Total Mass). Data processed are shown in the following table (Emix_Dep_Arr_(Kg)_DB).



UID	Engine_Manufa	Engine_ID	Emix_HC_Dep	Emix_HC_Arri	Emix_CO_Dep	Emix_CO_Arriv	Emix_NOx_Dep	Emix_NOx_Arr	Emix_CO2_Dep	Emix_CO2_Arriv	Emix_PM10_Dep	Emix_PM10_Arri	Emix_SO2_Dep	Emix_SO2_Arr
1AA001	AO 'Aviadgatel'	D-30	6,485334	2,50656	9,47871	4,51038	3,55386	0,78456	1026,6564	437,5602	0,06504	0,02772	0,26016	0,11088
1AA002	AO 'Aviadgatel'	D-30KP-2	3,38307	1,49058	15,6177	7,31472	4,47777	1,03194	1568,96586	649,7106	0,099396	0,04116	0,397584	0,16464
1AA003	AO 'Aviadgatel'	D-30KU	2,661342	1,09215	14,049072	6,2922	3,864522	0,85581	1517,06478	663,9171	0,096108	0,04206	0,384432	0,16824
1AA004	AO 'Aviadgatel'	D-30KU-154	3,093402	1,295658	19,037286	8,589798	3,233442	0,766206	1391,66874	592,69518	0,088164	0,037548	0,352656	0,150192
1AA005	AO 'Aviadgatel'	PS-90A	0,0923076	0,0459	1,5012681	0,621468	9,82944	1,818456	1467,53145	606,52284	0,09297	0,038424	0,37188	0,153696
1AS001	Allied Signal	TFE731-2-2B	0,552198948	0,270504	1,66165542	0,9505584	0,50715258	0,1232976	185,650542	82,58712	0,0117612	0,005232	0,0470448	0,020928
1AS002	Allied Signal	TFE731-3	0,270299244	0,1230816	1,46428074	0,7897608	0,68455134	0,1602	200,917794	89,0274	0,0127284	0,00564	0,0509136	0,02256
1CM001	CFM Internatior	CFM56-2A	0,1741476	0,0678036	3,633036	1,542588	3,6720948	0,898764	995,21268	413,31444	0,063048	0,026184	0,252192	0,104736
1CM002	CFM Internatior	CFM56-2B1	0,2740938	0,104352	4,6142742	1,96392	3,078753	0,827088	932,571486	405,3588	0,0590796	0,02568	0,2363184	0,10272
1CM003	CFM Internatior	CFM56-2C5	0,2740938	0,104352	4,6142742	1,96392	3,078753	0,827088	932,571486	405,3588	0,0590796	0,02568	0,2363184	0,10272
1CM004	CFM Internatior	CFM56-3B1	0,30312528	0,1147344	4,6056996	1,911552	2,8305324	0,764412	865,763052	370,88436	0,0548472	0,023496	0,2193888	0,093984
1CM005	CFM Internatior	CFM56-3B2	0,244448784	0,09296628	4,2275892	1,760622	3,352098	0,86055	934,181556	395,69838	0,0591816	0,025068	0,2367264	0,100272
1CM006	CFM Internatior	CFM56-3C-1 (R	0,3685668	0,1385748	4,9507596	2,051406	2,5091832	0,701316	820,150716	354,02598	0,0519576	0,022428	0,2078304	0,089712
1CM007	CFM Internatior	CFM56-3C1	0,20722236	0,0795984	3,9454044	1,645728	3,852654	0,957768	996,841692	418,99704	0,0631512	0,026544	0,2526048	0,106176
1CM008	CFM Internatior	CFM56-5A1	0,19767858	0,0873828	2,1706038	0,9219312	3,7770756	0,728568	862,42926	354,537414	0,054636	0,0224604	0,218544	0,0898416
1CM009	CFM Internatior	CFM56-5A3	0,1886412	0,0791064	2,080701	0,8871696	4,3183284	0,7913208	911,167026	371,036896	0,0577236	0,0236056	0,2308944	0,0940224
1CM010	CFM Internatior	CFM56-5C2	0,762411744	0,287310144	4,71901608	1,827336	6,0165897	1,0606965	1044,708126	425,380494	0,0661836	0,0269484	0,2647344	0,1077936
1CM011	CFM Internatior	CFM56-5C3	0,735365364	0,2768853	4,64976132	1,7865636	6,63104832	1,13876076	1086,3237	439,852182	0,06882	0,0278652	0,27528	0,1114608
1GE001	General Electri	CF6-6D	4,2153732	1,6053912	10,8078684	4,6885032	9,9608232	1,6505424	1448,418972	595,763784	0,0917592	0,0377424	0,3670368	0,1509696
1GE002	General Electri	CF6-6D1A	4,0750464	1,542144	10,570464	4,49592	10,81002	1,73904	1499,600256	607,65936	0,0950016	0,038496	0,3800064	0,153984
1GE003	General Electri	CF6-6K	4,2153732	1,6053912	10,8078684	4,6885032	9,9608232	1,6505424	1448,418972	595,763784	0,0917592	0,0377424	0,3670368	0,1509696
1GE004	General Electri	CF6-6K2	4,0750464	1,542144	10,570464	4,49592	10,81002	1,73904	1499,600256	607,65936	0,0950016	0,038496	0,3800064	0,153984
1GE005	General Electri	CF6-45A2	6,1470636	2,337912	15,204474	6,5934	9,3665304	1,452528	1707,772836	706,91544	0,1081896	0,044784	0,4327584	0,179136
1GE006	General Electri	CF6-50C	5,7955368	2,20224	15,233013	6,349656	11,67363	1,762248	1876,451346	768,28752	0,1188756	0,048672	0,4755024	0,194688
1GE007	General Electri	CF6-50C1, -C2	5,5883424	2,12694	15,329757	6,26166	12,4168302	1,82988	1926,571878	785,1459	0,1220508	0,04974	0,4882032	0,19896
1GE008	General Electri	CF6-50C2R	5,7955368	2,20224	15,233013	6,349656	11,67363	1,762248	1876,451346	768,28752	0,1188756	0,048672	0,4755024	0,194688
1GE009	General Electri	CF6-50E2	5,5883424	2,12694	15,329757	6,26166	12,4168302	1,82988	1926,571878	785,1459	0,1220508	0,04974	0,4882032	0,19896
1GE010	General Electri	CF6-80A	1,1704287	0,465642	5,172924	2,23416	9,331746	1,73448	1572,28071	664,8642	0,099606	0,04212	0,398424	0,16848
1GE011	General Electri	CF6-80A1	1,1704287	0,465642	5,172924	2,23416	9,331746	1,73448	1572,28071	664,8642	0,099606	0,04212	0,398424	0,16848
1GE012	General Electri	CF6-80A2	1,1943438	0,464868	5,19057	2,207352	10,0021848	1,875672	1624,238616	684,56388	0,1028976	0,043368	0,4115904	0,173472
1GE013	General Electri	CF6-80A3	1,1943438	0,464868	5,19057	2,207352	10,0021848	1,875672	1624,238616	684,56388	0,1028976	0,043368	0,4115904	0,173472
1GE014	General Electri	CF6-80C2A1	2,11610904	0,7986282	9,77822424	3,8647008	10,559178	1,8232506	1848,284592	745,74654	0,1170912	0,047244	0,4683648	0,188976
1GE015	General Electri	CF6-80C2A2	2,35182576	0,8873412	10,23176952	4,126245	8,0934906	1,6355598	1688,092098	690,05706	0,1069428	0,043716	0,4277712	0,174864
1GE016	General Electri	CF6-80C2A2	2,28816792	0,8639184	10,09068258	4,0615218	8,10016962	1,627599	1688,092098	690,05706	0,1069428	0,043716	0,4277712	0,174864
1GE017	General Electri	CF6-80C2A3	2,15557392	0,814086	9,92480058	3,9134352	11,19478836	1,895124	1887,47559	759,5742	0,119574	0,04812	0,478296	0,19248
1GE018	General Electri	CF6-80C2A3	2,08604652	0,788064	9,76683708	3,8441316	11,19441276	1,8792696	1887,47559	759,5742	0,119574	0,04812	0,478296	0,19248
1GE019	General Electri	CF6-80C2A5	2,15103426	0,8145666	10,02784452	3,9392694	10,52104254	1,8315594	1954,833342	794,99574	0,1238412	0,050364	0,4953648	0,201456
1GE020	General Electri	CF6-80C2A5	2,15103426	0,8145666	10,02784452	3,9392694	10,9037016	1,8315594	1954,833342	794,99574	0,1238412	0,050364	0,4953648	0,201456

Figure 5, Emix_Dep_Arr_(Kg)_DB table.

3.2.1 Introduction to standard procedure

Standard procedure developed noise levels and quantity of pollutant emitted by aircraft without I.R.C.A. statistics but simply calculating average value for the different engine options. It was therefore assumed that aircrafts could be powered by all their engines with which they had been certified. In this way environmental impacts were calculated by averaging all the possible aircraft/engine configurations. The First step of the procedure consisted in connecting OAG_data and AC_data tables through the model type and maximum takeoff weight.

Specifically MTOW parameter was used to improve this association, excluding possible wrong combinations (e.g. in case of extended range, ER, versions): criterion selection has been set so that AC_data maximum take-off weight can be in a range of 3% from the OAG table values (MAXTAKEOFFWEIGHT field). We opted for a threshold of 3%, meaning that a model which satisfies a relationship of name similarity is excluded from the calculation whether it presents a certification MTOW value that differs for more than 3%, from that in the OAG table. The following table describes the case of Airbus A320 model. The first records are not considered because their MTOW is too different from the sample data while the last two (in bold) are accepted.

Table 4, Selection of sample data.

AIRFRAME TYPE CERTIFICATE HOLDER	**AC TYPE**	**SPECIFICACFTNAME**	**MTOW (kg)**
Airbus	A320-111	A320-211	66000
Airbus	A320-111	A320-211	68000
Airbus	A320-111	A320-211	66000
Airbus	A320-111	A320-211	68000
Airbus	A320-111	A320-211	68000
Airbus	A320-111	A320-211	66000
Airbus	A320-111	A320-211	68000
Airbus	A320-111	A320-211	68000
Airbus	A320-111	A320-211	68000
Airbus	**A320-211**	**A320-211**	**76500**
Airbus	**A320-211**	**A320-211**	**77000**

The elaboration result is stored in table AIRCRAFT_DATASET, which is the master table of the study.

ID	AC TYPE	AC_EASA	SPECIFICACFTNAME	MTOW (kg)	MAXTAKEOFFWEIGHT (kg)	ENGINE TYPE	N ENG
3	717-200	717-200	Boeing 717	54885	55000	BR700-715A1-30	2
3	717-200	717-200	Boeing 717-200	54886	56000	BR700-715A1-30	2
4	717-200	717-200	Boeing 717	53524	55000	BR700-715A1-30	2
4	717-200	717-200	Boeing 717-200	53524	55000	BR700-715A1-30	2
9	717-200	717-200	Boeing 717	54885	55000	BR700-715C1-30	2
9	717-200	717-200	Boeing 717-200	54886	56000	BR700-715C1-30	2
10	717-200	717-200	Boeing 717	53524	55000	BR700-715C1-30	2
10	717-200	717-200	Boeing 717-200	53524	55000	BR700-715C1-30	2
14	717-200	717-200	Boeing 717	54886	56000	BR700-715A1-30	2
14	717-200	717-200	Boeing 717-200	54885	55000	BR700-715A1-30	2
15	717-200	717-200	Boeing 717	53524	55000	BR700-715A1-30	2
15	717-200	717-200	Boeing 717-200	53524	55000	BR700-715A1-30	2
19	717-200	717-200	Boeing 717	54886	56000	BR700-715C1-30	2
19	717-200	717-200	Boeing 717-200	54885	55000	BR700-715C1-30	2
20	717-200	717-200	Boeing 717	53524	55000	BR700-715C1-30	2
20	717-200	717-200	Boeing 717-200	53524	56000	BR700-715C1-30	2
41	737-200	737-200	Boeing 737-200 /200C /200QC (Passenger)	53800	52000	JT8D-15	2
41	737-200	737-200	Boeing 737-200 Passenger	53800	52000	JT8D-15	2
42	737-200	737-200	Boeing 737-200 /200C /200QC (Passenger)	53800	52000	JT8D-15 ADV	2

Figure 6, AIRCRAFT_DATASET table.

3.2.2 Noise levels calculation

Average noise levels are calculated by considering for each aircraft of the OAG dataset all the combination of weight and engine selected with the previous control procedure. This process was easily realized calculating the average values for three fields (Approach LEVEL, Lateral LEVEL, Flyover LEVEL) and collecting results in table "Standard_Average_Levels". The following table shows the values calculated for two of the most common aircraft models of Commercial Aviation.

Table 5, Standard procedure – Average noise levels (EPNLdB) for A320 and B737 families.

Aircraft type	Approach_Level	Lateral_Level	Flyover_Level
Airbus A320	95,6	93,2	85,9
Airbus A321	96,6	96,1	89,5
Boeing 737-200	96,4	96,5	90,9
Boeing 737-300	98,9	90,6	84,6
Boeing 737-400	99,3	91,8	86,8
Boeing 737-500	98,2	89,8	81,8
Boeing 737-600	95,7	90,5	85,1
Boeing 737-700	96,0	93,4	84,3
Boeing 737-800	95,9	94,1	83,9

3.2.3 Emissions of pollutants calculation

Regarding pollutants emissions, likewise to noise study, certification values (Emix_Dep_Arr_(Kg)_DB table) have been associated to the aircraft dataset. In this case it has been set a similarity relation between engine data (ENGINE TYPE field) of AIRCRAFT_DATASET table and its analogue (Engine_ID field) of Emix_Dep_Arr_(Kg)_DB table.

The calculation of emissions for each record (aircraft, weight, engine) is performed multiplying the quantity of each pollutant (HC, CO, NO_X, CO_2, PM_{10}, SO_2) by the number of engines, then the average values of emissions has been calculated for each OAG aircraft over the different MTOW and engine/combinations, and collected in Standard_Average_Emissions table. The tables below show the results for A320 family and Boeing 737 family both for departure and arrival.

Table 6, Standard procedure –Average emissions (kg) for A320 e B737 families, departure.

Aircraft	**HC**	**CO**	**NOX**	**CO2**	**PM10**	**SO2**
Airbus A320	0,807	7,899	8,308	1867,132	0,118	0,473
Airbus A321	0,703	7,277	12,248	2155,541	0,136	0,546
Boeing 737-200	1,970	7,205	6,348	2077,775	0,132	0,527
Boeing 737-300	0,501	8,507	6,701	1866,084	0,118	0,429
Boeing 737-400	0,436	8,052	7,419	1957,878	0,124	0,470
Boeing 737-500	0,513	8,584	6,605	1853,222	0,117	0,470
Boeing 737-600	0,986	8,154	5,616	1613,259	0,102	0,409
Boeing 737-700	0,738	6,744	8,381	1874,371	0,115	0,475
Boeing 737-800	0,582	6,101	9,399	1959,592	0,124	0,497

Table 7, Standard procedure – Average emissions (kg) per A320 e B737 families, arrival.

Aircraft	**HC**	**CO**	**NOX**	**CO2**	**PM10**	**SO2**
Airbus A320	0,627	4,430	1,759	776,245	0,049	0,196
Airbus A321	0,450	3,777	2,204	872,886	0,055	0,221
Boeing 737-200	0,847	3,361	1,367	866,463	0,055	0,220
Boeing 737-300	0,191	3,541	1,724	790,921	0,050	0,200
Boeing 737-400	0,167	3,357	1,860	824,681	0,052	0,209
Boeing 737-500	0,195	3,571	1,706	786,308	0,050	0,199
Boeing 737-600	0,452	3,758	1,551	688,263	0,043	0,174
Boeing 737-700	0,371	3,219	1,930	778,598	0,049	0,197
Boeing 737-800	0,270	2,769	2,061	806,912	0,051	0,204

3.2.4 Introduction to advanced procedure

To improve the reliability of the process maximizing the accuracy in the aircraft engine association, information from I.R.C.A. have been taken into account.

Thus I.R.C.A. database table has been imported in the MS Access file and rearranged in a single table containing model type (CELLMODEL), aircraft manufacturer (CELLMANUFACTURER), maximum takeoff weight (MTOW), engine type (ENGINE MODEL) and engine manufacturer (ENGINE MANUFACTURER). This table is composed by 494.452 records. Unfortunately data recorded by I.R.C.A. are sometimes imprecise and lacking in some areas and it was therefore necessary to make some corrections. Some records in CELLMANUFACTURER field were manually corrected, then in order to limit the size of the table and to focus on the objectives of the study, only the aircraft present in the OAG dataset were selected for the procedure besides engine names have been corrected to match ICAO codes. Other corrections have been carried out to improve I.R.C.A. lack of detail. For example, to the engine code “CFM56 Series” have been associated in more specific engine codes according to information obtained from specialized sources.

Table 8, CFM56 Series engines.

Engine
CFM56-5B8/P
CFM56-5B9/P
CFM56-5B5 o 5B5/P
CFM56-5B6 o 5B6/P o 5B6/2P
CFM56-5A4 o 5A4/F
CFM56-5A5 o 5A5/F
CFM56-5B7 o 5B7/P
CFM56-5A1 o 5A1/F
CFM56-5A4 o 5A4/F
CFM56-5A3
CFM56-5B4 o 5B4/P o 5B4/2P
CFM56-5B1 o 5B1/P o 5B1/2P
CFM56-5B2 o 5B2/P
CFM56-5B3 o 5B3/P o 5B3/2P
CFM 56-5C2

CFM 56-5C3
CFM 56-5C4
CFM 56-5C2
CFM 56-5C3
CFM 56-5C4
CFM 56-3B1, 3B2, 3C1
CFM 56-3B2, 3C1
CFM 56-3B1, 3C1
CFM 56-7B24, 7B26, 7B27

Vice versa, specific cases have seen the lack of engine models in emissions database. Substitution have been identified on the basis of engine technical features and performance. For example Pratt & Whitney JT8D-5 has been replaced by JT8D-9 for analogy in thrust values. After this review phase, I.R.C.A. data have been associated to the OAG dataset (also in this case through aircraft model name and weight[17]) with the result of a 17,702 records table we proceeded to the selection of data on which to evaluate the environmental impacts.

In this way noise levels and pollutants emissions have been calculated taking into account the statistics obtained from the IRCA database. Table 9 shows an example for the Airbus A320 aircraft.

Table 9, IRCA engine statistics for Airbus A320.

Engine model	IRCA frequency
CFM 56-5 A1	6.9%
CFM 56-5A3	12.3%
CFM56-5B/4P	1.3%
CFM 56-5B4	6.0%
CFM 56-5B4/2P	5.0%
CFM 56-5B4/P	7.3%
V2500-A1	8.0%
V2527-A5	48.5%
V2527E-A5	4.7%

---

[17] Same criterion of 3% MTOW range threshold is adopted as in standard procedure.

3.2.5 Emissions and noise levels calculation

Average values of noise levels and departure and arrival pollutant emissions for each OAG aircraft model, have been calculated taking into account the engine statistics.

Specifically instead of calculating the average of noise levels and emissions over all the possible engine/weight configurations, only those available in I.R.C.A. database have been accounted, on the basis of their frequency.

The procedures was carried out using VBA scripts.

The study was completed appending noise levels and emissions of those aircrafts that were not found in I.R.C.A. and were processed in standard procedure.

Final tables were called "Advanced_Average_Levels" for noise and "Advanced_Average_Emissions" for pollutant emissions.

Table 10, Advanced procedure – Average levels (EPNLdB) for A320 e B737 families.

Aircraft	Approach _Level	Lateral _Level	Flyover_Level
Airbus A320	95,1	92,5	85,4
Airbus A321	96,4	96,4	88,8
Boeing 737-200	96,4	96,7	90,7
Boeing 737-300	99,0	90,3	85,0
Boeing 737-400	99,3	91,8	86,8
Boeing 737-500	97,9	89,7	81,7
Boeing 737-600	95,7	91,2	84,8
Boeing 737-700	96,0	92,8	85,0
Boeing 737-800	95,9	93,6	84,1

Table 11, Advanced procedures – Averaged emissions (kg) for A320 and B737 families, departures.

Aircraft	HC	CO	NO_X	CO_2	PM_{10}	SO_2
Airbus A320	0,304	4,600	9,031	1897,544	0,120	0,481
Airbus A321	0,691	5,955	13,569	2223,442	0,141	0,563
Boeing 737-200	2,083	7,437	6,519	2113,807	0,135	0,539
Boeing 737-300	0,538	8,756	6,337	1818,882	0,115	0,461
Boeing 737-400	0,439	8,076	7,376	1952,482	0,124	0,495
Boeing 737-500	0,450	8,136	7,326	1944,997	0,123	0,493
Boeing 737-600	0,682	5,843	6,670	1663,070	0,105	0,421
Boeing 737-700	0,626	5,627	8,350	1831,835	0,116	0,464
Boeing 737-800	0,554	5,192	9,636	1933,948	0,123	0,490

Table 12, Advanced procedures – Averaged emissions (kg) for per A320 e B737 families, arrivals

Aeromobile	**HC**	**CO**	**NO$_X$**	**CO$_2$**	**PM$_{10}$**	**SO$_2$**
Airbus A320	0,167	2,168	1,861	798,132	0,051	0,202
Airbus A321	0,404	3,130	2,367	903,636	0,057	0,229
Boeing 737-200	0,898	3,494	1,396	882,989	0,056	0,224
Boeing 737-300	0,205	3,640	1,656	773,699	0,049	0,196
Boeing 737-400	0,168	3,367	1,852	822,674	0,052	0,208
Boeing 737-500	0,172	3,390	1,844	820,124	0,052	0,208
Boeing 737-600	0,254	2,483	1,719	705,211	0,045	0,179
Boeing 737-700	0,234	2,340	1,936	766,332	0,049	0,194
Boeing 737-800	0,207	2,126	2,128	800,127	0,051	0,203

3.3 Noise index LVAyear

As for noise impact, the next phase has seen the evaluation of the different airport scenarios by the development of a single synthetic indexes.

As a first step in its definition, we converted the Effective Perceived Noise Levels (EPNL) of the noise certification in the Sound Exposure Level (SEL). The latter is the most common metric to represent noise events, since it expresses the sound energy produced by 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 using INM to determine their difference at three certification measurement points in order to be able to convert the EPNL values of the database into SEL values. However, in order to minimize errors arising from 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 the following table.

Table 13, 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

This table was then imported to MS Access file to calculate for each certification reference point the annual evaluation level of airport noise, LVA year, according to Italian airport noise regulation[18] that can be expressed as:

$$LVA_{year} = 10\,LOG\left[\frac{1}{3600\cdot 24\cdot 365}\sum 10^{\frac{SEL+W}{10}}\right] = 10\,LOG\left[\sum 10^{\frac{SEL+W}{10}}\right] - 74.988$$

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

LVA year values for each airport have been calculated joining together OAG airport data, the aircraft noise levels table and that shown in table 13.

In order to obtain a synthetic index for the single airport, the energetic mean of the values of the three measurement points has been calculated. The fact that departures are doubly represented in relation to arrivals (Flyover and Lateral Measurement Point) can be considered acceptable, since the former causes more annoyance to people living nearby the airport infrastructure than the latter.

The index of airport noise is therefore:

$$LVA_{year\ AVG} = 10\,LOG\left[\frac{1}{3}\sum_{punti} 10^{\frac{LVA_{year}}{10}}\right]$$

---

[18] We consider an annual period instead of 3 weeks as required by the decree.

3.4 Local Air Pollution Index, LAP

In order to compute the total emission of pollutant p produced by aircraft *i* (Q_{pi}) during the LTO cycle, the following equation (similar to equation presented in paragraph 3.2) has been applied:

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

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

Hence, multiplying Q_{pi} by the number of flights made by aircraft *i* in airport *A* ($\bar{n}_1(i\,A)$) , we get the total amount of pollutant *p* (kg) produced in one year at the same airport:

$$\bar{Q}_{pA} = \bar{n}_{iA} \times Q_{pi}$$

To aggregate these data into a single index, representing the LAP produced by each airport, we consider the cost (of damage) imposed by each pollutant (c_p). Such estimates are provided by Dings et al. (2003).

The cost of LAP used in this contribution is equal to 4 Euro/kg for HC and 9 Euro/kg for NO_x. Carbon monoxide (CO) emissions from aircraft operation do not appear to result in substantial health effects and therefore a cost estimate for emission of this gas is assumed equal to 0 Euro/kg (Dings et al.. 2003; Givoni and Rietveld. 2010).

The Local Air Pollution (LAP) index is obtained, for each airport, as the sum of the kg produced of each pollutant weighted for the relative cost of damage:

$$LAP_A = \sum_{p=1}^{n} c_p \times \bar{Q}_{p\,A}$$

3.5 Fleet mix age estimation

To get a useful information for further development of the environmental indexes, a final elaboration has been done to calculate the average age of the fleet operating on an airport. Key parameter was the date of the engine certification test, taken as indicative of the age of the aircraft powered by it. The year of certification was included in the tables previously described and on the basis of the difference with 2008 (the most recent year of analysis), it has been determined the age of each possible aircraft/engine configuration.

Chapter 4 Mathematical models to asses noise and emissions of pollutant from airport activities; the case of Lombardy three major airports

The study is based on the definition of three cases, concerning the three Lombardy major airports (Milan Malpensa, Milan Linate and Bergamo Orio al Serio), respectively divided in three operational scenarios simulating average air traffic conditions for 1999, 2004 and 2008 years.

For each airport, for all the reference periods, noise analysis was performed with INM model. As output INM produces maps describing the scenario, identified according to Italian regulation, and noise levels in receptor points. Some of these have been set at the same measurements points of the ICAO annex 16 certification tests. In this way, results are used for the comparison with the Noise index LVAyear, previously described. Substance emissions in the atmosphere were estimated with EDMS model. Emission inventory were performed for all the case studies. Dispersion study is carried out only for Milan Linate case due to lack of official weather data in a compatible format with EDMS requirements. On a preliminary phase, a dispersion study with LASPORT model was made as scenario test and it has been described in the paragraph at the end of this chapter.

To compare emission inventory results with values from LAP index it’s necessary to separate the emissions of aircraft operations from the other airport sources. External emissions related with airports like road traffic and commercial activities are deliberately ignored in this phase.

4.1 The study airports: Milan Malpensa, Milan Linate and Bergamo Orio al Serio

Milan Malpensa (LIMC, ICAO code) is the second Italian airport in terms of number of passengers and total number of aircraft operations[19]. It has two terminals, the main one and the secondary one where also LCC operate.

Its configuration consists in two parallel runways referred as *35R-17L* and *35L-17R*. To increase airport capacity, Malpensa airport operator S.E.A[20]. has formally asked for the approval of a third runway project.

Regarding ATM (*Air Traffic Management*) in normal operational conditions, not influenced by traffic peaks, aircrafts take off and land at runways 35. Generally runways 17 are in use during night-time specific weather conditions influenced by wind direction and wind speed. A complete overview of airport technical data, is published in ENAV *AIP Italia AD 2 LIMC*.

These airport documents are the basis for the modelling activity.

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[19] E.N.A.C. data.

[20] SEA Group is Milan airport operator also for Milan Linate, SACBO s.p.a. is Bergamo Orio al Serio airport operator.

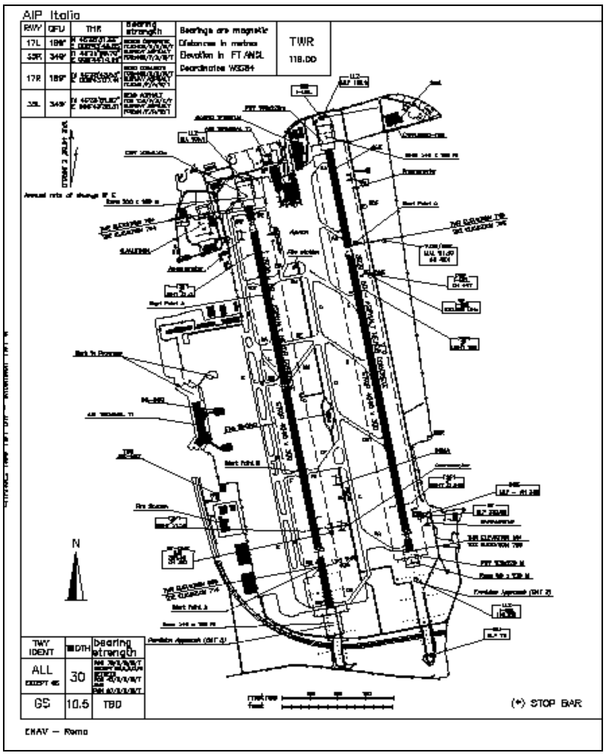

Figure 7, Milan Malpensa from AIP AD 2 LIMC 1-2.

Milan Linate (LIML, ICAO code) is the third Italian airport in terms of aircraft movements[21] either for domestic and international flights. Due to its proximity to Milan and the other towns in the area, Linate is a historic environmental case, subject of several studies regarding noise impact on territory and population. It has two runways[22], but only *36-18* is used by Commercial Aviation. Generally take offs and landings occur on runway 36.

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[21] 91907 movements by Commercial aviation in 2010, Assaeroporti http://www.assaeroporti.it/defy.asp.

[22] Runway 35-17 is not simulated in the study.

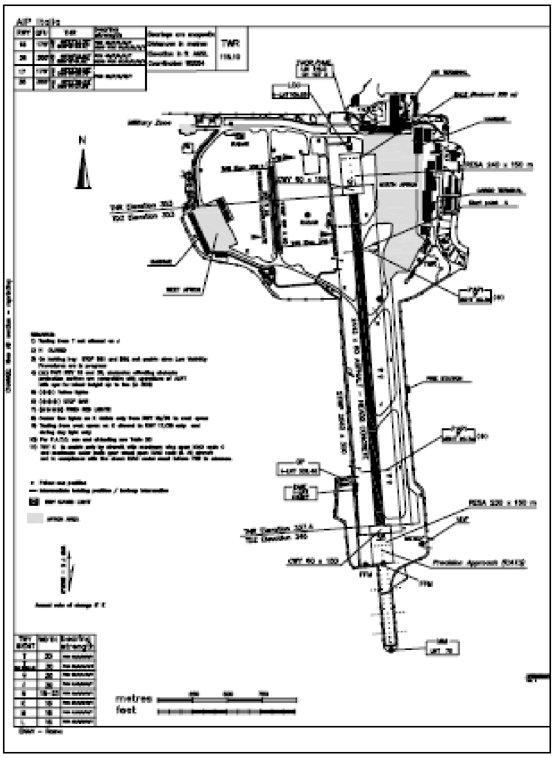

Figure 8, Milan Linate from AIP AD 2 LIML 1-2.

Bergamo Orio Al Serio (LIME, ICAO code) is the third airport of Milan system. During the last ten years Bergamo Orio Al Serio increased significantly its number of movements and passengers. This growth is characterized by the LCC flights that changed traffic the status of the airport from regional condition to short haul international airport. It has one runway referred as 10-28. Another small runway, 12-30, is now used as taxiway or for General Aviation.

Actual configuration sets runway 28 both for aircraft take offs and landings.

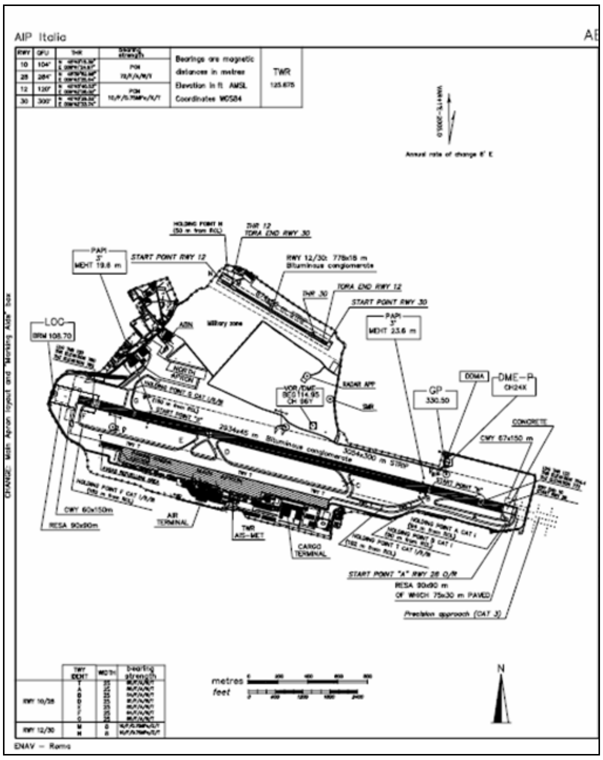

Figure 9, Bergamo Orio al Serio airport from AIP AD 2 LIME 1-2.

4.2 Operational Data

The dataset used both for noise analysis and emission inventory is taken from the same source, OAG database, used for indexes definition in chapter 3. The number of movements simulated for airports in the three traffic scenarios is represented in Figure 10. Traffic data were compared with data published by Assaeroporti.

Based on one of the most common classification, aircraft have been grouped by: wide-body, narrow-body, regional jets and propeller.

Scenarios data showed specific trend in the number of operations provided at the three airports. Milan Malpensa presents a slight decrease in operations from 1999 to 2008 due to some external factors like Italy’s flag carrier airline, Alitalia, de-hubbing process.

Milan Linate experiences a peak of air traffic in 2004 while Bergamo Orio al Serio shows a constant increase reaching in 2008 more than 50.000 annual movements.

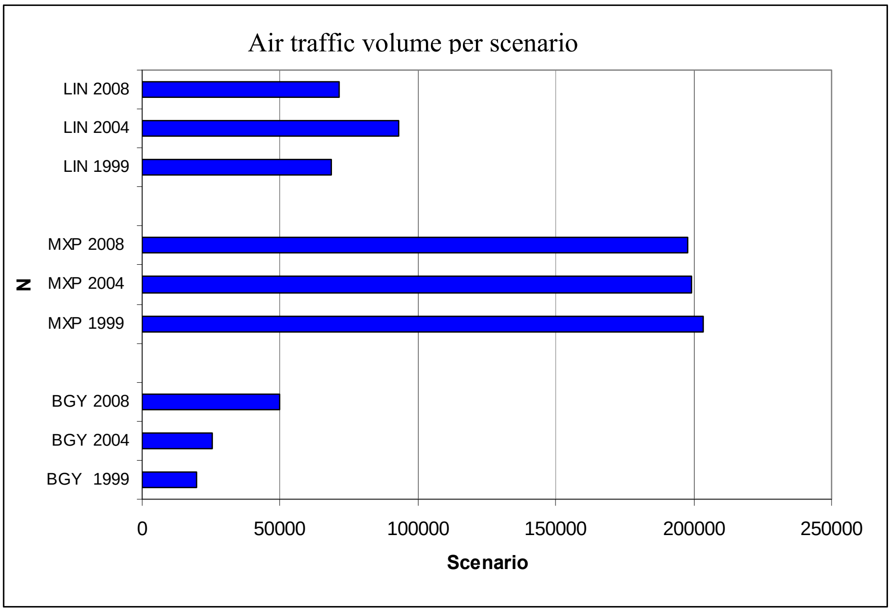

Figure 10, Number of aircraft operations for single traffic scenarios.

Fleet mix, together with the total number of aircraft operations, is a key component in determining the environmental impacts of an airport. The graphs below describe for each airport the fleet mix for 2008[23] (Figure 11, 13, 15) and the evolution, in percentage, of the aircraft categories for the years 1999, 2004 and 2008.

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[23] Scenarios graphs for 1999 and 2004 are present in appendix 1

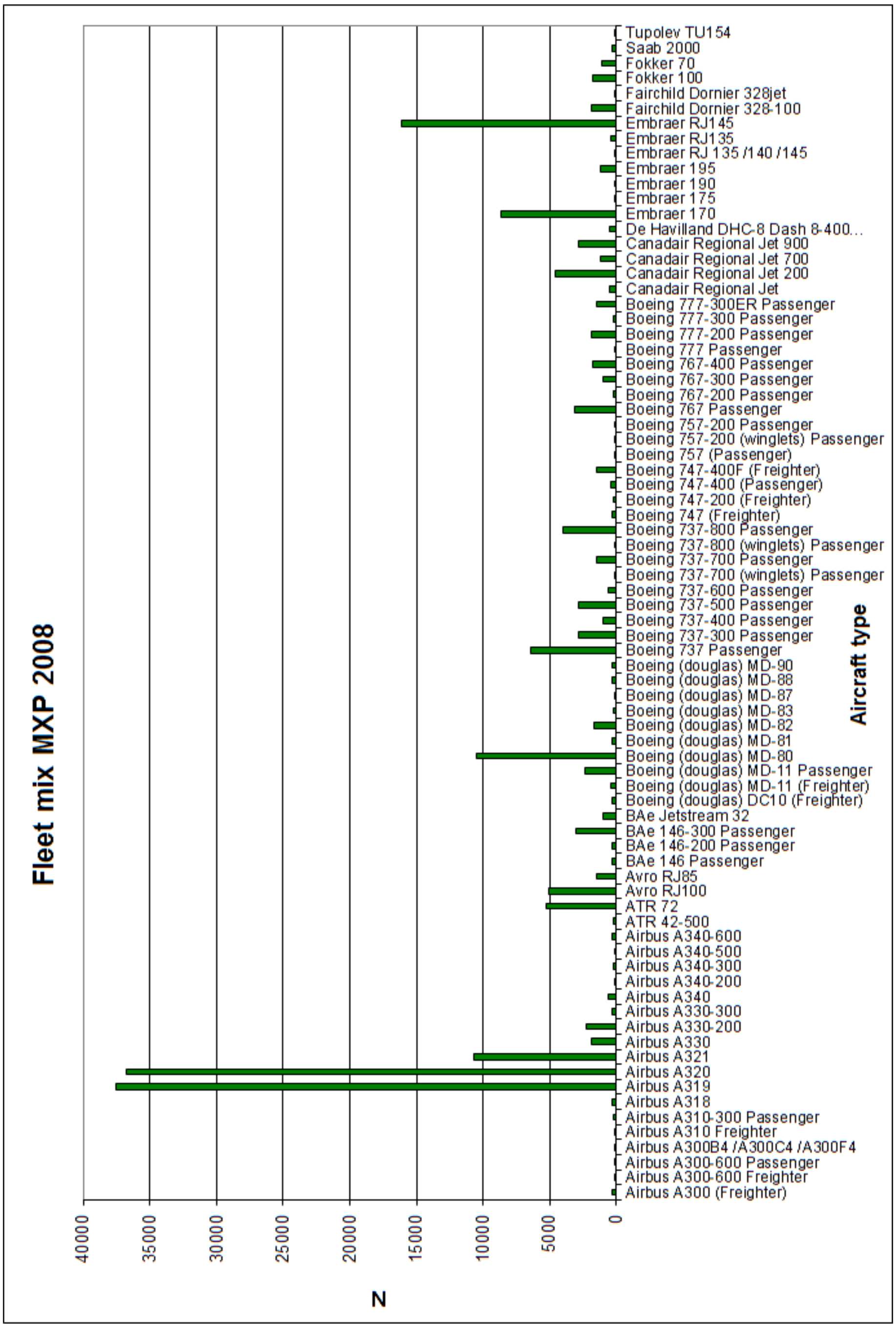

Figure 11, MXP fleet mix for scenario 2008.

Milan Malpensa has seen the progressive replacement of McDonnel Douglas MD80 with narrow body aircraft like Airbus A320 and Boeing 737 also with a significant increase in Regional models like Embraer 145, generally serving Central Europe major hubs like Frankfurt, Munich and Paris CDG. Malpensa is the only Lombardy airport for Intercontinental flights with a presence of wide body aircraft like Airbus A330, Boeing 747, Boeing 777 and Boeing 767.

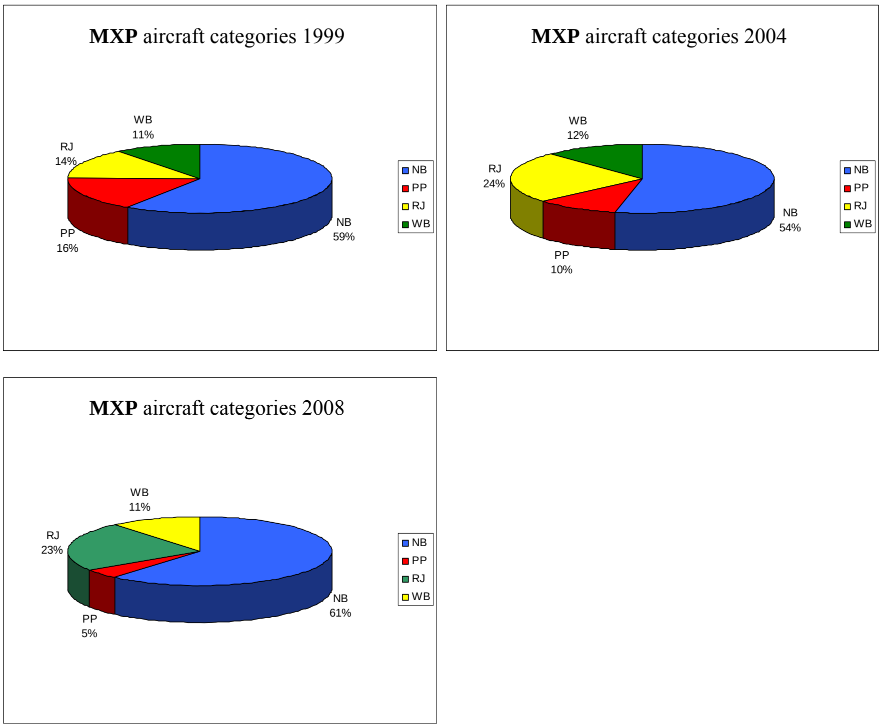

Figure 12, MXP percentage of aircraft groups.

Narrow body aircrafts make up the major component in Malpensa fleet mix. After a low decrease in 2004, in 2008 this category recovered the 1999 level (around 60% of total operations). Wide body aircrafts component is constant during period in analysis while Propellers decreased of about 11 points in favour of an equivalent growth of Regional jet.

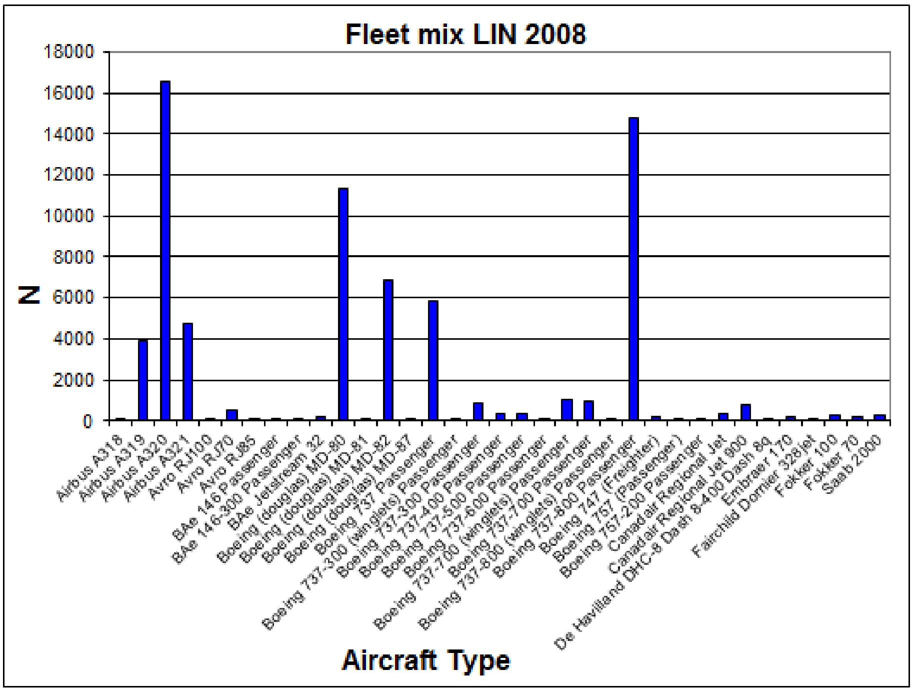

Figure 13, LIN fleet mix for scenario 2008.

At Milan Linate Boeing 737 family has the highest frequency in the 1999, 2004 scenarios. In 2008, Airbus A320 overtook it with more than 16.000 yearly operations.

Unlike in Milan Malpensa, in Milan Linate the percentage of MD81 and MD82 aircraft is still high. Alitalia use this family of aircrafts to provide a secondary connection with other Italian cities. Its impact in terms of noise and pollutant emissions is considerable higher than other aircraft of the same category.

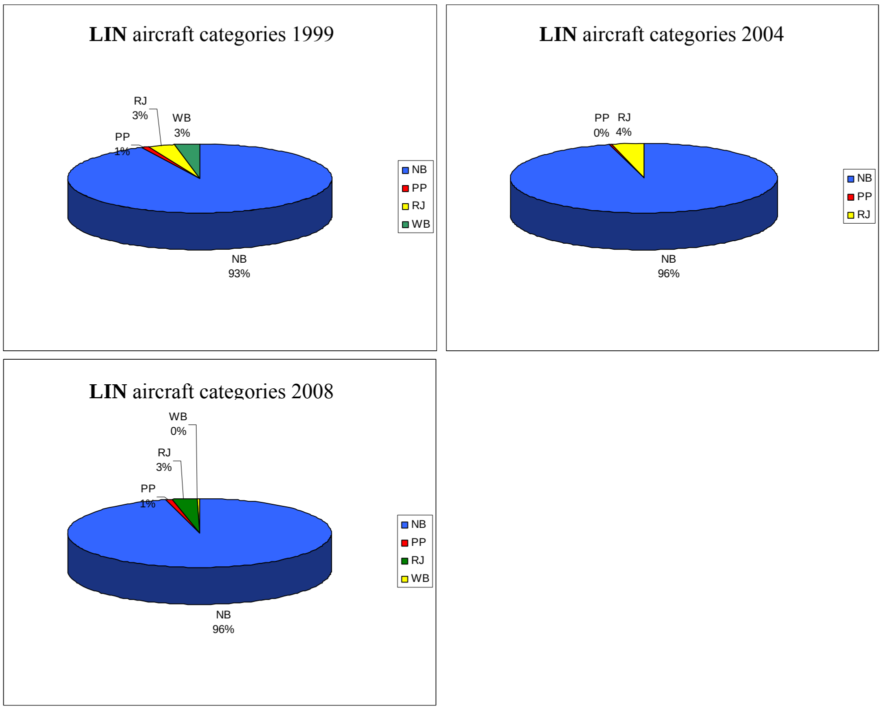

Figure 14, LIN percentage of aircraft groups.

As shown in the previous graphs, Linate fleetmix is characterized by a high percentage (around 95%) of narrow body aircrafts. The second group are regional jet with a constant value of 3%. This composition is typical of city airports like Linate with flights operating on short and medium tracks.

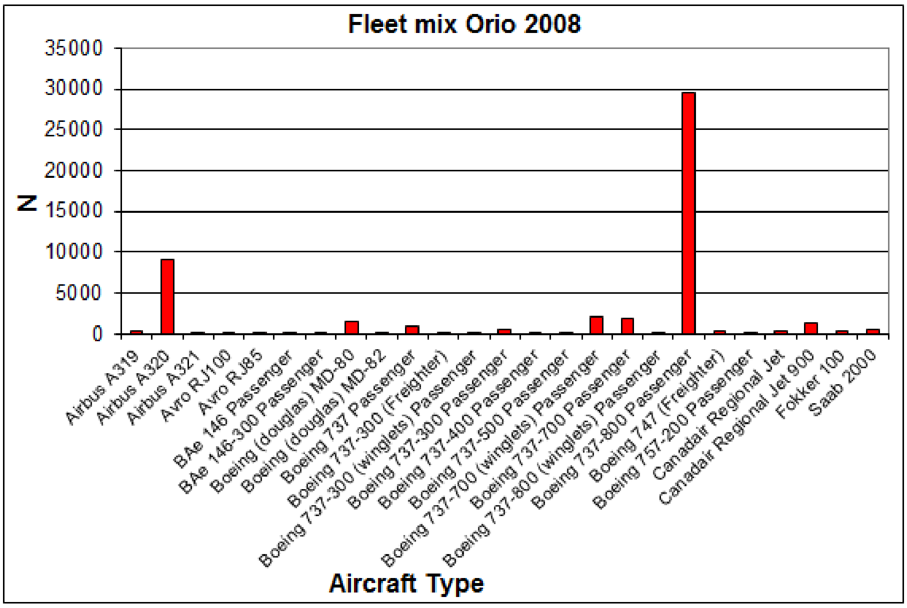

Figure 15, BGY fleet mix for scenario 2008.

Bergamo Orio al Serio has a fleet mix similar to Milan Linate. Substantially it consists of medium aircrafts like Airbus A320, plus a minority component of small aircrafts like Canadair Regional Jets (CRJ), Fokker 100 and Saab 2000. Boeing 737-800 has the highest frequency as results of his use by LCC Ryanair.

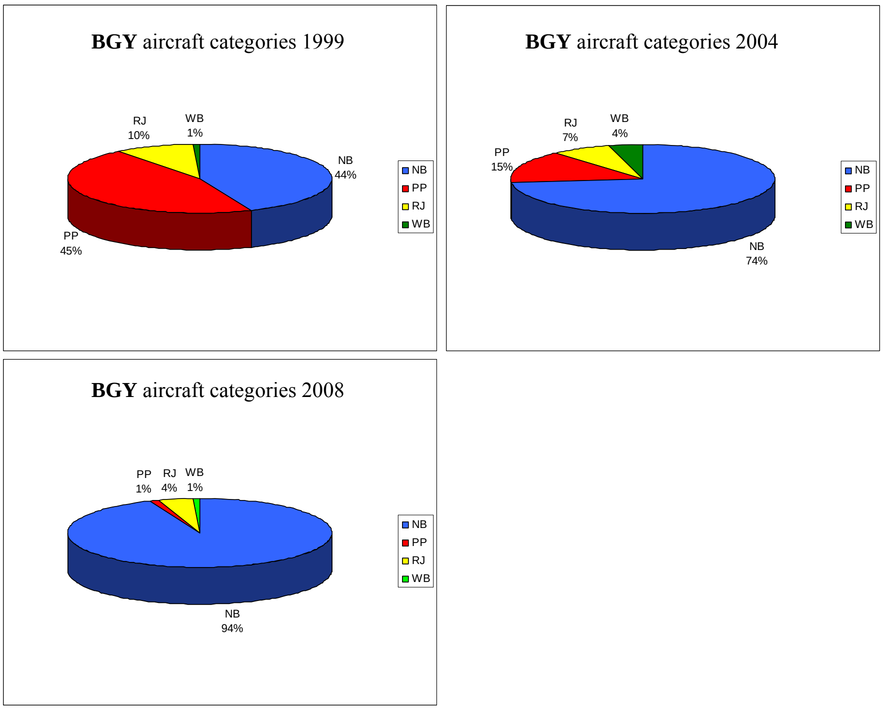

Figure 16, BGY percentage of aircraft groups.

The trend described in these graphs representing the evolution of aircraft groups operating at Bergamo Orio al Serio results very interesting. Starting from a regional condition in 1999, characterized by a percentage of Propeller and Regional jet of more than 50%, Bergamo shows a progressive replacement of this category with narrow body aircrafts. An impressive increase of 50% of narrow body operations from 1999 to 2008 brings the groups composition to percentage similar to Milan Linate.

Consequently, it is easy to understand that Bergamo Orio al Serio, due to a strong increase both in terms of number of movements and evolution of the fleet, has seen during this ten years period the growth of his environmental impacts in a major percentage compared to the other Lombardy airports.

4.3 Noise Analysis

Airport INM models have been reproduced according to AIP informations, specifically those at AD sector for LIML, LIME and LIMC. They concern airport and airspace layouts (SIDs and STARs).

At each airport, among the different scenarios, there are no layout differences except for Bergamo Orio al Serio where new SID have been implemented to reduce noise impact.

To simulate airspace, lacking radar tracks for the entire period of analysis, departure and arrival routes have been defined according to AD publication. Practically SIDs and STARs 2D projections are reproduced in the model taking into account AIP requirements and basic principles of flights. For instance, turning radius is calculated from the aircraft bank angle values and speed according to the formula:

$$tg(\varphi) = \frac{v^2}{g \cdot R}$$

For Commercial Aviation, bank angle is usually contained within 25° while for General Aviation it could have higher values that consent the possibility of tighter turns. During initial climb phase, the most significant in terms of noise, it is assumed for all the aircrafts in the simulations a value of speed of 180 knots and a bank angle of 15°. In order to compute flight lateral dispersion around departure routes, it was introduced a model described in ECAC CEAC DOC 29. Equation model is modified as follows;

- for routes with turns lower than 45°:
    - $s(y) = 0{,}055\ x - 0{,}150$ with $2{,}7\ \text{km} \leq x \leq 30\ \text{km}$;
    - $s(y) = 0{,}2185$ km with $x > 30$ km;

- for routes with turns higher than 45°:
  - $s(y) = 0{,}128\ x – 0{,}42$ with $3{,}3\ km \leq x \leq 15\ km$;
  - $s(y) = 0{,}5144\ km$ with $x > 15\ km$.

ECAC model identifies seven subtracks, a central one and three symmetrical pairs in respect to the backbone. Air traffic is distributed over the subtracks as shown in table 14 where subtrack geometry is specified as well.

Table 14, Subtracks and percentage distribution.

Subtracks	**Percentage distribution (%)**
ym - 2.14 s(y)	3
ym – 1.43 s(y)	11
ym - 0.71 s(y)	22
Ym	28
ym + 0.71 s(y)	22
ym + 1.43 s(y)	11
ym + 2.14 s(y)	3

Landing operations were instead modelled as straight vectors aligned to runway from a distance of 15 nautical miles. No lateral dispersion has been considered because, generally, landing operations are well aligned with instrument landing system, ILS, tracks.

Aircraft weight (stage parameter) is essential to compute vertical profiles. For departures it has been calculated following INM model that establishes a direct relation with the flight length. For arrivals there is just are one single stage class.

Fleet operating at the airports has been divided into four groups, distinguished according to size and engine characteristics.

These groups are:

- HEAVY, equal to Wide Body;
- LARGE, equal to Narrow Body;
- RJ, Regional Jet, small aircraft category;
- PP, Propeller, turboprop aircraft;

As general input parameter, weather conditions for all the scenarios simulated are:

- temperature = 15°C;
- pressure = 1013 bar;
- wind speed = 2 knot;
- relative humidity = 70%;

INM can provide noise levels calculated with different families of acoustics metrics. DNL is the metric we used to calculate noise contours and LVA at the certification points. Noise contours describing acoustic climate provides a range between 45 dB(A) and 75 dB(A), although for the regulation are only significant 60, 65 and 75 dB (A) contours.

4.4 Emission Inventory

First phase of the study was the airport layout creation with a procedure similar to noise analysis. For Milan Linate case the same layout was used also for dispersion study.

Routes, runways, taxiways and aircraft parking areas were defined. Information and geographic coordinates necessary to the simulation were found in AIP, as for the noise study. In this phase, emission inventory was performed for aircraft and secondary source providing flight support service as APU and GSE. As introduced before, road traffic to and from the airports were not simulated.

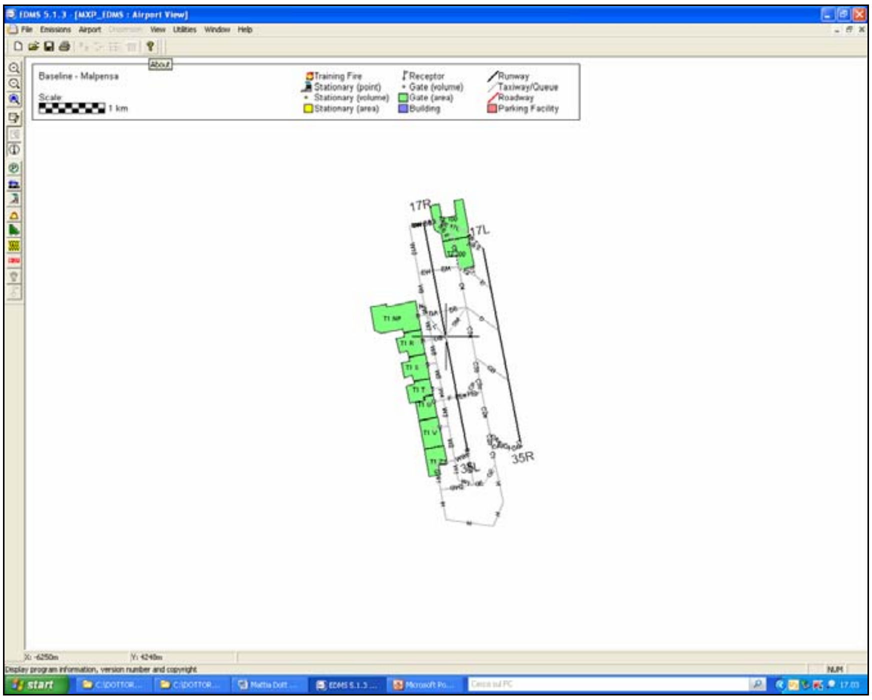

Figure 17, EDMS layout for Milan Malpensa.

The methods of calculation selected are “*Performance Based (SAE 1845)*” and “*Sequence modeling*”. EDMS calculate vertical profile and established specific times for each phase of theLTO cycle. On the basis of weather parameters values it has been used the following default data:

- temperature = 13,54°C;
- pressure = 98780,90 Pa;
- wind speed = 5 km/ht;
- relative humidity = 68,9%.

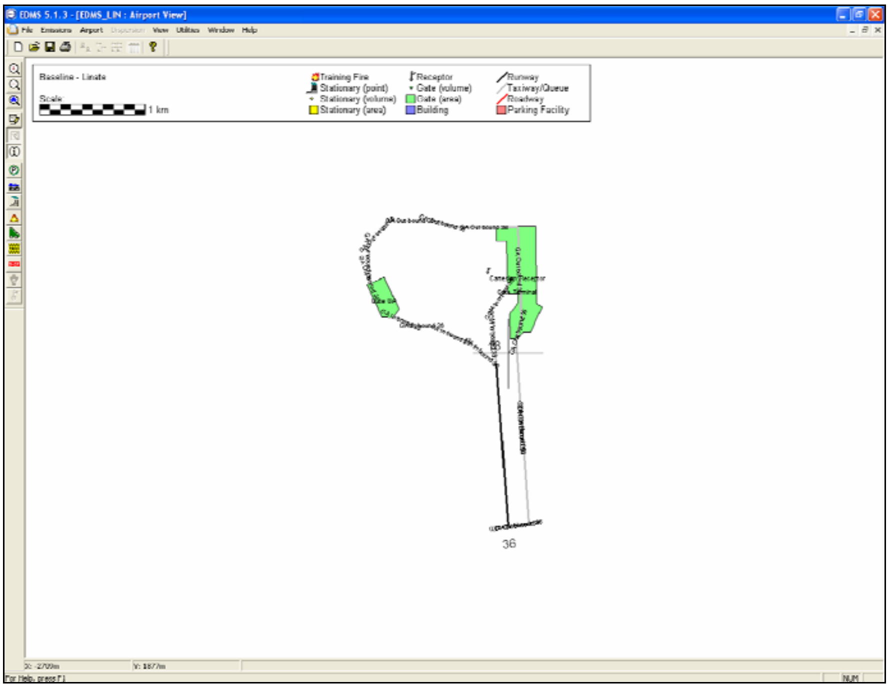

Figure 18, EDMS layout for Milan Linate.

Air traffic data input required the determination of the total annual LTO cycles performed by single type of aircraft. Starting from OAG data, one LTO cycle is obtained adding two separate operations of take-off and landing. An accurate check has been carried out to select only those categories of engines that have been considered to calculate the LAP index in order to proceed to a correct comparison between the results.

A gate has been assigned to every aircraft in the sample. For Milan Malpensa case, that has several parking facilities, not having official gate data, the assignment has been done on the basis of the characteristics of the aircraft and its operational frequency. Once finished the scenario definition, EDMS produces a file describing all the input parameters used in the simulation.

As output the model provides the quantity of pollutants emitted from the aircraft. Results are easily exportable to continue the procedure of results analysis and validation.

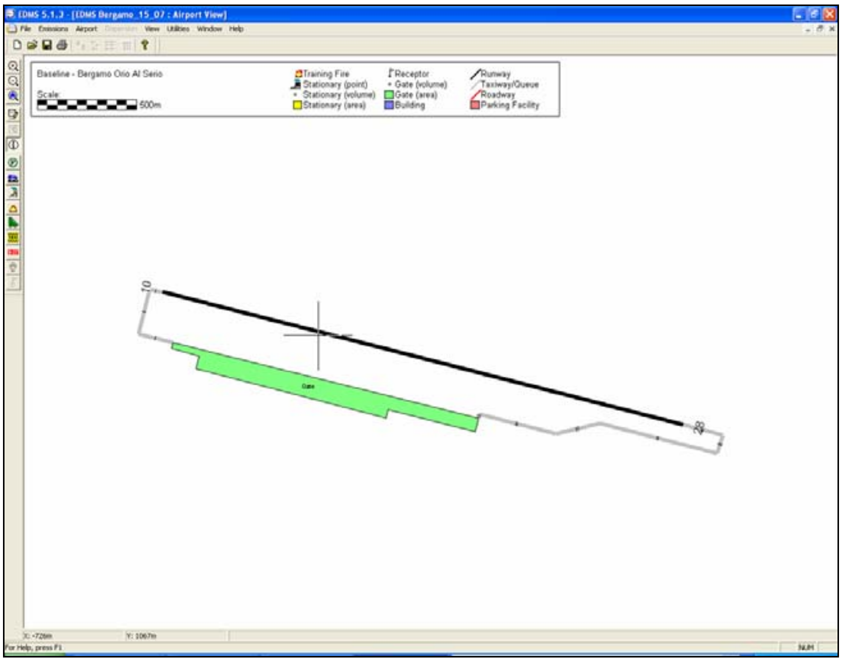

Figure 19, EDMS layout for Bergamo Orio al Serio.

4.5 EDMS Dispersion study

This study is based on the simulation of the dispersion of pollutants emitted at Milan Linate airport relatively to the 2004 traffic scenario (Airport layout and data are the same used in the emission inventory).

To better understand the difficulties encountered to model dispersion of pollutants it is necessary to focus on the influence of meteorological conditions. In fact they regulate the speed at which pollutant are transported and dispersed in the air. They define the volume in which pollutants are dispersed.

A key parameter is the height of the mixing layer that is the altitude of the first thermal inversion, the upper limit of the dispersion. As default this parameter is set to 914 feet.

Another effect of weather on dispersion of pollutants is its influence on chemical reactions speed that causes the formation of secondary pollutants, such as ozone.

To calculate concentration AERMOD requires surface weather data as well as those of vertical measurements with radiosondes.

Surface weather data were supplied by NOAA (*National Oceanic and Atmospheric Administration*). Data from atmospheric soundings (upper air data) were retrieved at *NOAA/ESRL Radiosonde Database*.[24] No elaboration of this data is needed.

Input phase is conducted through the use of AERMET wizard tool that allows easy entry and error check. Once finished AERMET can create the input file for AERMOD.

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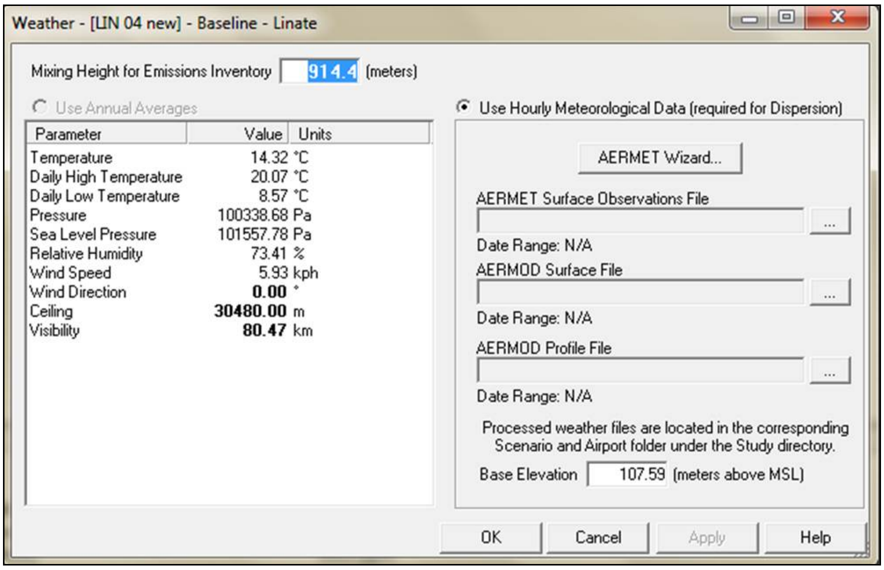
[24] http://esrl.noaa.gov/raobs/


Weather - [LIN 04 new] - Baseline - Linate

Mixing Height for Emissions Inventory 914.4 (meters)

○ Use Annual Averages

● Use Hourly Meteorological Data (required for Dispersion)

Parameter	Value	Units
Temperature	14.32	°C
Daily High Temperature	20.07	°C
Daily Low Temperature	8.57	°C
Pressure	100338.68	Pa
Sea Level Pressure	101557.78	Pa
Relative Humidity	73.41	%
Wind Speed	5.93	kph
Wind Direction	**0.00**	°
Ceiling	**30480.00**	m
Visibility	**80.47**	km

AERMET Surface Observations File

Date Range: N/A

AERMOD Surface File

Date Range: N/A

AERMOD Profile File

Date Range: N/A

Processed weather files are located in the corresponding Scenario and Airport folder under the Study directory.

Base Elevation 107.59 (meters above MSL)

Figure 20, Aermet Wizard tool

4.6 LASPORT simulation

The study with LASPORT model to assess airport impact in terms of emissions and dispersion of pollutant has been carried out for Milan Malpensa just as a preliminary test. Simulation procedure is quite similar to that of EDMS. Runways, position areas, taxiways and motorways have been defined according to AIP publications. Scenarios in analysis are the year 2006, 2007 and 2008.

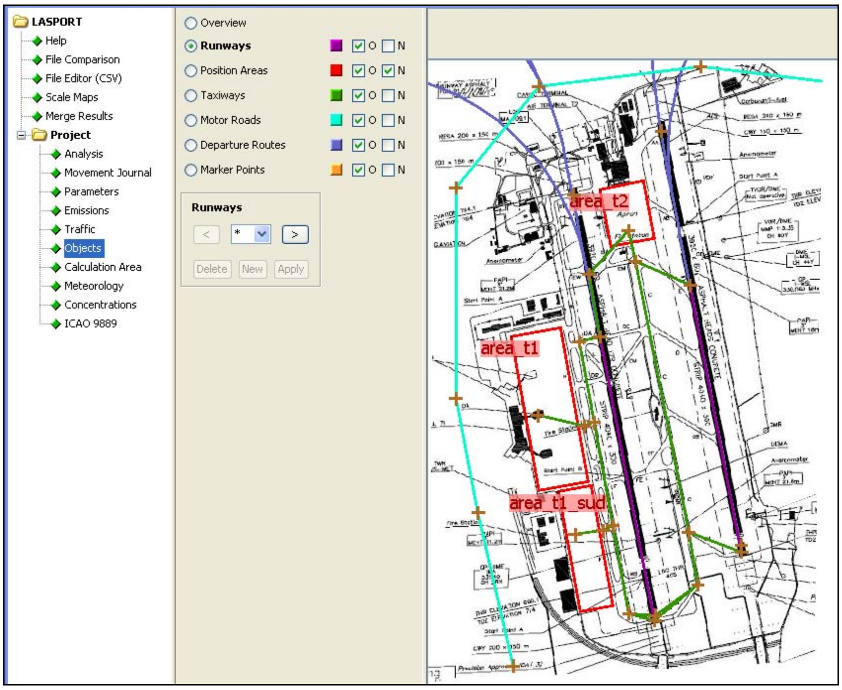


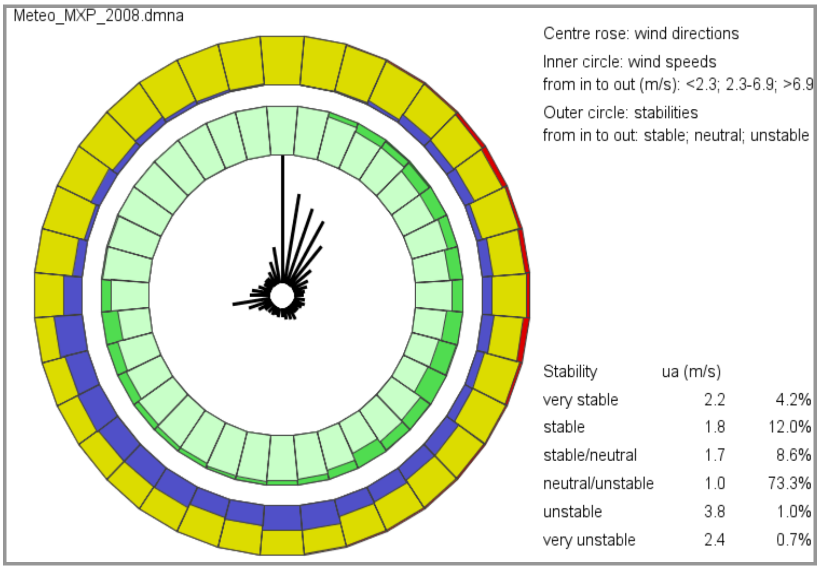
Figure 21, LASPORT layout for Milan Malpensa.

Differently from EDMS, also airspace has been simulated creating departure routes and assigning vertical profiles (for each group of aircrafts default values have been used). Configuration modelled set an equal use in percentage (50%) for runways 35R and 35L and a 33% for the three taxiways for each category of aircraft.

Emission inventory has been performed using *Actuals Time in mode* method with a maximum height of 914,40 m. Average taxi speed is 10 m/s (36 km/h), while the take-off waiting time is 4 minutes.

The first phase of the study consists in the creation of weather data. LASPORT contrary to EDMS permits the use of generic formats (i.e .csv). Regional environmental protection agency, ARPA, provides meteorological data from stations in proximity of Malpensa Airport (in particular from RRQA station in Somma Lombardo). Parameters measured are wind speed, wind direction, temperature and net/global radiation (used to calculate

Monin Obukhov stability class)[25]. Meteorological data can be represented with the graphs shown in Figure 22.



Stability	ua (m/s)	
very stable	2.2	4.2%
stable	1.8	12.0%
stable/neutral	1.7	8.6%
neutral/unstable	1.0	73.3%
unstable	3.8	1.0%
very unstable	2.4	0.7%

Figure 22, LASPORT meteorological file input graphs for Milan Malpensa.

Here are shown some of these preliminary results. Emission inventory expressed in tons/year for 2008 scenario is contained in Table 15.

Table 15, LASPORT emission inventory (tons/year).

	FB	**NOx**	**PM10**
Air Traffic	1.52347e+05;	2.73596e+03;	1.77553e+01
APU	1.10717e+03;	9.79967e+00;	3.00566e-01
Handling	1.44933e+03;	5.71361e+01;	3.86800e+00
Totale	154903e+05;	2.80289e+03;	2.19239e+01

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[25] Calculations has been carried out with VBA.

After emission calculation, dispersion simulation for NO_x, PM_{10} and Fuel Burned (FB) were performed to test LASAT model.

Concentration are calculated at each cell of the grid. Results can be expressed in table or in graphs as described below for NO_x.

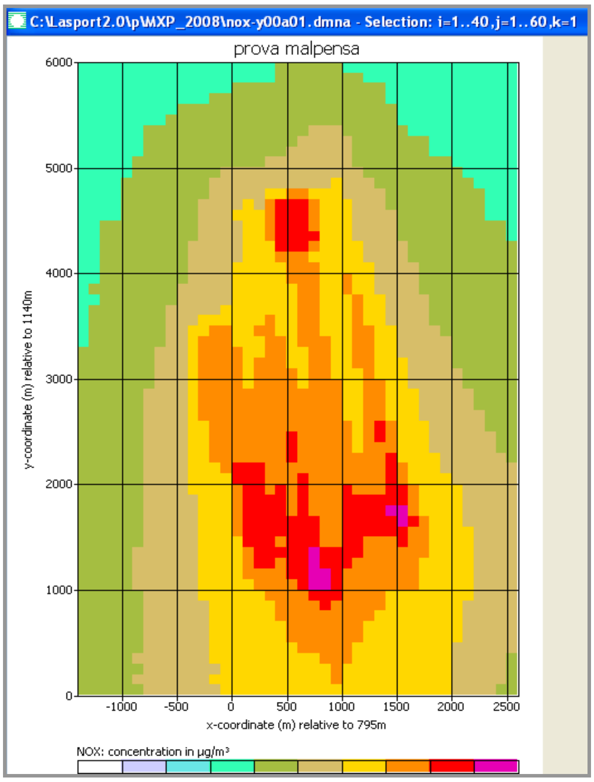

Figure 23, Dispersion graph for NOx. Variation in concentration is represented by different colors.

Chapter 5 Results

5.1 LVAyear and LAP indexes analysis

In order to investigate the influence of the airport fleet mix on the negative externalities produced by airport activities, we run two ordinary least squares (OLS) regressions. More in details, we intend to examine the effect of an increase in the number of airport flights made respectively by wide body aircrafts, regional jets and power propeller, given the total number of flights (i.e. we observe what happens if, for 1% of flights, narrow body aircrafts are replaced by one of the another aircraft category). The regressions estimated are the following:

$$\frac{LAP}{MOV} = \alpha_0 + \alpha_1 WB + \alpha_2 RJ + \alpha_3 PP + \varepsilon$$

$$LVA_y = \beta_0 + \beta_1 WB + \beta_2 RJ + \beta_3 PP + \omega$$

where WB is the percentage of flights made by widebody aircrafts, RJ is the percentage of flights made by regional jets and PP is the percentage of flights made by propeller aircrafts.

5.1.1 Descriptive statistics

This study has been focused on the 32 Italian major airports, observed in the period 1999-2008. Mean statistical values for Italian airport system are described in the Table 16.

Table 16, Italian airport system.

YEAR	LAP	MOVEMENTS	SEATS	LAP/MOV	LAP/SEAT	NOISE	NOISE/SEAT
2000	49.584.142	1.097.809	132.209.989	45.17	0.38	68.22	0.57
2001	48.875.779	1.091.179	131.179.838	44.79	0.37	68.26	0.57
2002	47.855.890	1.097.151	128.320.698	43.62	0.37	67.87	0.58
2003	51.040.162	1.156.525	137.766.897	44.13	0.37	67.92	0.57
2004	53.478.207	1.166.844	146.969.402	45.83	0.36	67.97	0.54
2005	55.154.265	1.184.757	150.509.122	46.55	0.37	68.11	0.54
2006	57.714.265	1.235.101	161.313.888	46.73	0.36	68.14	0.52
2007	61.432.213	1.345.697	178.341.092	45.65	0.34	68.25	0.52
2008	61.927.185	1.320.948	182.161.998	46.88	0.34	68.65	0.50

In this table, for each year of analysis, are shown total values for LAP and LVAyear (noise), total number of movements and seats and the average indexes values both for aircraft operation (LAP/MOV) and for seats (LAP/SEAT, NOISE/SEAT).

With regard to air pollution, we resolved to relate the environmental costs (in euro) to a single operation. Table 17 shows the values of the fleet mix while Table 18 shows fleet mix, LAP values (total, LAP/MOV and LAP/SEAT), the trend percentage for index and number of operations.

Table 17, Fleet mix in Italian airport related to 2008.

Airport	IATA code	WB	NB	RJ	PP
Alghero	**AHO**	**0.0%**	**95.1%**	**4.4%**	**0.6%**
Ancona	**AOI**	**0.0%**	**12.8%**	**7.4%**	**79.9%**
Brindisi	**BDS**	**0.0%**	**84.6%**	**15.2%**	**0.2%**
Bergamo	**BGY**	**0.8%**	**93.7%**	**4.2%**	**1.3%**
Bologna	**BLQ**	**1.0%**	**56.9%**	**25.7%**	**16.4%**
Bari	**BRI**	**0.2%**	**78.9%**	**19.5%**	**1.4%**
Cagliari	**CAG**	**0.0%**	**83.7%**	**2.8%**	**13.5%**
Rome Ciampino	**CIA**	**0.0%**	**99.2%**	**0.8%**	**0.0%**
Crotone	**CRV**	**0.0%**	**2.8%**	**97.2%**	**0.0%**
Catania	**CTA**	**0.0%**	**93.7%**	**5.4%**	**0.9%**
Rome Fiumicino	**FCO**	**8.0%**	**82.7%**	**6.3%**	**3.0%**
Florence	**FLR**	**0.0%**	**38.3%**	**37.0%**	**24.6%**
Forlì	**FRL**	**0.0%**	**99.9%**	**0.1%**	**0.0%**
Genoa	**GOA**	**0.0%**	**48.1%**	**35.7%**	**16.2%**
Milan Linate	**LIN**	**0.0%**	**96.9%**	**2.5%**	**0.6%**
Lampedusa	**LMP**	**0.0%**	**41.7%**	**0.0%**	**58.3%**
Milan Malpensa	**MXP**	**10.9%**	**61.3%**	**23.2%**	**4.6%**
Naples	**NAP**	**0.2%**	**72.7%**	**22.6%**	**4.5%**
Olbia	**OLB**	**0.0%**	**92.3%**	**5.1%**	**2.5%**
Perugia	**PEG**	**0.0%**	**49.7%**	**13.3%**	**37.0%**
Palermo	**PMO**	**0.2%**	**87.3%**	**4.4%**	**8.1%**
Pisa	**PSA**	**1.4%**	**74.3%**	**11.8%**	**12.4%**
Pescara	**PSR**	**0.6%**	**47.8%**	**13.8%**	**37.7%**
Reggio Calabria	**REG**	**0.0%**	**82.0%**	**1.5%**	**16.5%**
Rimini	**RMI**	**0.0%**	**60.8%**	**12.3%**	**26.9%**
Lamezia Terme	**SUF**	**0.3%**	**93.8%**	**5.9%**	**0.0%**
Turin	**TRN**	**0.0%**	**63.0%**	**23.7%**	**13.4%**
Trieste	**TRS**	**0.0%**	**30.3%**	**47.7%**	**22.0%**
Treviso	**TSF**	**0.0%**	**99.7%**	**0.3%**	**0.0%**
Brescia	**VBS**	**16.1%**	**75.4%**	**0.0%**	**8.5%**
Venice	**VCE**	**3.5%**	**72.8%**	**13.3%**	**10.4%**
Verona	**VRN**	**0.1%**	**65.7%**	**22.0%**	**12.3%**

Rome Fiumicino and Milan Malpensa, the two major Italian airports, have respectively a cost per operation of 72.25 and 67.87 euro. It is worth to be noticed that, in general, airports with a high level of LAP per movement are characterized also by a high percentage of narrow-body aircraft.

Due to this overview on the Italian airport system, we have the possibility to investigate data to compare different airports.

It will be now described an example of analysis of an airport related to environmental index LAP.

Table 18, LAP, LAP/MOV,LAP/SEAT for 2008 and traffic variation during analysis period

Airport	LAP	LAP/MOV	LAP/SEAT	LAP Variation 1999-2008	Aircraft movements Variation
Alghero	599.443	47.92	0.30	**78.5%**	**37.5%**
Ancona	119.202	17.47	0.24	**-4.0%**	**-18.9%**
Brindisi	447.165	42.38	0.31	**5.4%**	**69.1%**
Bergamo	2.512.747	50.68	0.30	**83.1%**	**151.0%**
Bologna	1.634.707	33.14	0.30	**0.2%**	**0.5%**
Bari	1.073.196	41.26	0.32	**26.1%**	**70.0%**
Cagliari	1.413.631	43.86	0.32	**3.6%**	**46.2%**
Rome Ciampino	1.678.860	49.91	0.28	**66.9%**	**1.160.7%**
Crotone	459	1.29	0.01	**-97.1%**	**-55.1%**
Catania	2.361.154	46.34	0.31	**-3.0%**	**42.7%**
Rome Fiumicino	18.685.561	55.29	0.37	**-0.3%**	**34.6%**
Florence	896.280	29.51	0.31	**48.8%**	**-1.7%**
Genoa	513.129	29.87	0.29	**30.4%**	**-23.4%**
Milan Linate	4.674.659	50.12	0.35	**-4.7%**	**36.3%**
Lampedusa	57.492	25.44	0.32	**58.4%**	**-20.5%**
Milan Malpensa	10.268.418	51.89	0.40	**-1.6%**	**-2.7%**
Naples	2.129.580	36.41	0.28	**-5.1%**	**39.2%**
Olbia	812.921	46.89	0.32	**7.8%**	**31.5%**
Perugia	31.022	33.90	0.29	**171.2%**	**-42.7%**
Palermo	1.897.498	43.82	0.31	**11.2%**	**21.4%**
Pisa	1.475.088	41.78	0.29	**42.3%**	**110.0%**
Pescara	143.313	27.31	0.29	**4.5%**	**210.3%**
Reggio Calabria	266.872	42.16	0.34	**-16.2%**	**2.2%**
Rimini	63.348	37.22	0.31	**48.6%**	**-42.9%**
Lamezia Terme	589.791	47.07	0.32	**3.1%**	**91.4%**
Turin	1.629.229	34.34	0.31	**-4.9%**	**32.0%**
Trieste	287.211	22.30	0.25	**-19.8%**	**28.3%**
Treviso	630.504	51.60	0.29	**27.5%**	**679.3%**
Brescia	393.626	79.91	0.64	**121.5%**	**53.3%**
Venice	3.115.177	42.46	0.32	**12.7%**	**36.1%**
Verona	1.074.962	38.37	0.32	**35.2%**	**44.6%**

To better explain the fleet mix influence on the values of the two indexes, we present the case of two airports with similar infrastructure characteristics and similar volumes of traffic; Bergamo Orio al Serio (LIME) and Catania Fontanarossa (LICC).

Figure 24 shows, for the two airports, 10 years trend of costs derived from of each pollutant and the annual composition of the fleet. Notice that, for both airports, NO_x is the family of pollutants with the highest cost, meaning that NO_x is the principal component of LAP index. Furthermore, LICC airport shows a nearly constant trend in the LAP index, while LIME airport shows an impressive increase from 37 euro in 1999 to 66.76 euro in 2008.

This is explained by the evolution in the fleet-mix of Bergamo, which turned from regional airport to LCC hub. As shown in Figure 24, this process has led to the progressive substitution of regional aircraft with narrow-body.

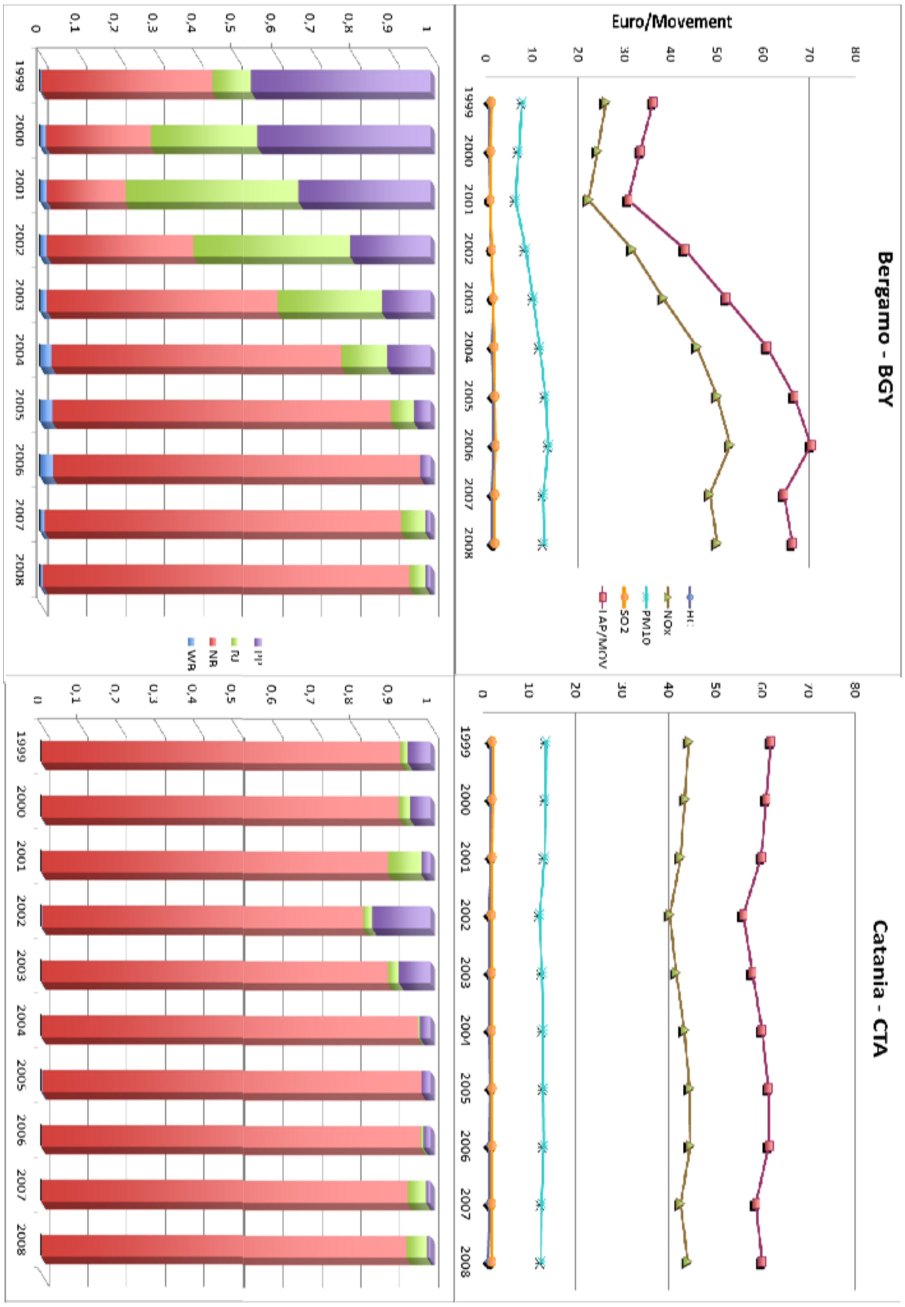

Figure 24, Bergamo Orio al Serio and Catania Fontanarossa airports pollutant trends and fleetmix compositions.

Concerning noise, since the LVA_{year} index is expressed in decibels (represented in a logarithmic scale), changes in the analysis period (1999-2008) result substantially low. However, for some Italian airports (such as Rome Ciampino, Bergamo and Pisa) the raise in traffic volumes and the changes in the fleet mix, with regional aircrafts progressively replaced by narrow-body aircrafts, have led to considerable increases in the noise levels. Table 19 shows results for 2008 with the fleetmix of each airport, the LVA_{year} index value (and its variation from 1999) and the values of LVAyear per seat (and their variation from 1999).

In order to better understand the differences in terms of noise among Italian airports we proceeded with a linearization of LVAyear levels.

Table 19, LVAyear2008, variation from 1999, LVA per seat 2008 and its trend.

Airport	**LVA$_{year}$ 2008**	**Variation LVA$_{year}$ 2008-1999**	**LVA/SEAT 2008**	**Variation LVA/SEAT 2008–1999**
Alghero	**53.35**	3.4	0.33	-0.24
Ancona	**42.77**	-4.5	0.58	-0.14
Brindisi	**52.14**	1.2	0.38	-0.04
Bergamo	**60.33**	5.9	0.36	-0.37
Bologna	**58.88**	-0.1	0.53	-0.05
Bari	**56.16**	0.4	0.43	-0.16
Cagliari	**57.11**	0.9	0.42	-0.01
Rome Ciampino	**58.58**	11.8	0.33	-0.08
Crotone	**35.16**	-6.2	0.39	0.03
Catania	**59.56**	0.6	0.39	-0.04
Rome Fiumicino	**68.65**	0.5	0.46	-0.02
Florence	**55.03**	0.9	0.57	-0.20
Genoa	**52.70**	1.0	0.51	-0.22
Milan Linate	**62.37**	1.1	0.44	0.00
Lampedusa	**42.33**	2.6	0.53	-0.13
Milan Malpensa	**66.68**	0.1	0.51	-0.01
Naples	**59.09**	1.1	0.46	-0.08
Olbia	**55.55**	1.0	0.38	0.01
Perugia	**39.51**	7.7	0.33	-0.56
Palermo	**58.17**	0.0	0.41	-0.09
Pisa	**58.50**	7.1	0.40	-0.14
Pescara	**46.93**	5.7	0.50	-0.04
Reggio Calabria	**50.71**	-1.1	0.41	0.02
Rimini	**43.18**	-5.3	0.36	-0.13
Lamezia Terme	**53.07**	2.7	0.36	-0.05
Turin	**57.60**	0.4	0.52	-0.02
Trieste	**50.38**	0.2	0.56	-0.09
Treviso	**53.03**	8.5	0.29	-0.08
Brescia	**55.56**	9.9	0.44	0.05
Venice	**60.53**	1.0	0.46	-0.08
Verona	**56.07**	3.0	0.47	-0.08

Due to the decibel mathematical properties, halving the sound energy corresponds to a decrease in sound level of 3 dB. Otherwise, doubling it is equivalent to an increase of 3 dB. This condition has been used for the LVAyear linearization. For example, if 80 dB represents the noise of an aircraft landing at the airport, 89 dB corresponds to the noise of 2^3 aircrafts (of the same type) landing at the airport simultaneously. In Table 20 LVA_{year} values are expressed in a linear scale. According to this specification, noise emitted at Rome Fiumicino airport (the noisiest airport in terms of LVA_{year}) is 2^{11} greater than the noise emitted at Crotone airport (i.e. the airport with the lowest LVA_{year}).

Table 20, LVAyear linearization

AIRPORT	IATA code	LVAyear	Difference	linearization
Alghero	AHO	53.35	18.19	2E6
Ancona	AOI	42.77	7.61	2E3
Brindisi	BDS	52.14	16.98	2E6
Bergamo	BGY	60.33	25.17	2E8
Bologna	BLQ	58.88	23.72	2E8
Bari	BRI	56.16	21.00	2E7
Cagliari	CAG	57.11	21.95	2E7
Rome Ciampino	CIA	58.58	23.42	2E8
Crotone	CRV	35.16	0.00	2E0
Catania	CTA	59.56	24.40	2E8
Rome Fiumicino	FCO	68.65	33.49	2E11
Florence	FLR	55.03	19.87	2E7
Forlì	FRL	50.09	14.93	2E5
Genoa	GOA	52.70	17.54	2E6
Milan Linate	LIN	62.37	27.21	2E9
Lampedusa	LMP	42.33	7.17	2E2
Milan Malpensa	MXP	66.68	31.52	2E11
Naples	NAP	59.09	23.93	2E8
Olbia	OLB	55.55	20.40	2E7
Perugia	PEG	39.51	4.35	2E1
Palermo	PMO	58.17	23.01	2E8
Pisa	PSA	58.50	23.34	2E8
Pescara	PSR	46.93	11.77	2E4
Reggio Calabria	REG	50.71	15.55	2E5
Rimini	RMI	43.18	8.02	2E3
Lamezia Terme	SUF	53.07	17.91	2E6

Turin	TRN	57.60	22.44	2E7
Trieste	TRS	50.38	15.22	2E5
Treviso	TSF	53.03	17.87	2E6
Brescia	VBS	55.56	20.40	2E7
Venice	VCE	60.53	25.37	2E8
Verona	VRN	56.07	20.91	2E7

Likewise, dividing the values of LAP index of each airport by the lowest value of LAP in our sample (Crotone airport), we were able to linearize the results and compare the indexes.

In this way, we are able to show that the local air pollution produced at Rome Fiumicino airport in 2008 (the airport with the highest LAP) is 2^{15} greater than that at Crotone airport, higher than that calculated for noise index (2^{11}).

This comparison is repeated for all the airports in our dataset. Table 21 shows an interesting relationship between the two indexes.

Table 21, Indexes comparison.

AIRPORT	LVAyear	LAP	Δ
Rome Fiumicino	11	15	4
Milan Malpensa	11	14	3
Milan Linate	9	13	4
Bergamo	8	12	4
Bologna	8	12	4
Rome Ciampino	8	12	4
Catania	8	12	4
Naples	8	12	4
Palermo	8	12	4
Pisa	8	12	4
Venice	8	13	5
Bari	7	11	4
Cagliari	7	12	5
Florence	7	11	4

Olbia	7	11	4
Turin	7	12	5
Brescia	7	10	3
Verona	7	11	4
Alghero	6	10	4
Brindisi	6	10	4
Genoa	6	10	4
Lamezia Terme	6	10	4
Treviso	6	10	4
Forlì	5	9	4
Reggio Calabria	5	9	4
Trieste	5	9	4
Pescara	4	8	4
Ancona	3	8	5
Rimini	3	7	4
Lampedusa	2	7	5
Perugia	1	6	5
Crotone	0	0	0

On average an airport, compared to the less “pollutant”, has an impact 2^4 times greater in terms of gas emissions than in terms of noise. However, some airports (e.g.Venice, Cagliari and Turin) show to be “more polluting than noisy” (2^5 versus 2^4), while other airports (i.e. Milan Malpensa and Brescia) show to be “more noisy than polluting” (2^3 versus 2^4).

5.1.2 Econometric statistics

We run two OLS regression models to obtain a statistical confirmation of the effect of airports fleet mix on both the LAP and the LVA_{year} indexes. The results of first regression model are shown in Table 22.

Table 22, LAP regression results.

Residuals:

Min	1Q	Median	3Q	Max
-27.683	-2.113	-0.068	1.515	103.306

Coefficient	Estimate	Std. Error
(Intercept)	64.174 (***)	0.601
WB	198.786 (***)	11.732
RJ	-45.903 (***)	1.753
PP	-51.505 (***)	1.427
NB	NA	NA

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Residual standard error: 6.953 on 352 degrees of freedom
Multiple R-squared: 0.8657
Adjusted R-squared: 0.8646
F-statistic: 756.3 on 3 and 352 DF. p-value: < 2.2e-16
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Notice that the adjusted R^2 of the OLS regression is 0.86, implying that our model can explain the 86% of the data variations of the cost derived by airport in terms of local air pollution[26].

As expected, the OLS regression results confirm that the LAP is negatively and significantly correlated with the percentage of regional jets and propeller

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[26] All the necessary tests have been performed to exclude both heteroscedasticity and autocorrelation of the residuals. Furthermore, a t test confirmed that the mean of the residuals is not statistically different from zero.

characterizing the airport fleet mix. More in details, airports with a large percentage of flights made by wide-body and narrow-body aircrafts produce more LAP per movement than airports where an higher component of regional and power propeller aircrafts. This result is consistent with the intuition given by the previous descriptive analysis.

The differences between regional and narrow-body stage lengths appears to be reducing; since regionals offer similar features but with smaller capacities, they can be used to replace narrow-bodies on routes that are normally served by mainline jets. This could be really interesting for those routes that are characterized by the penalty of empty seats. Considering that the environmental impact of a narrow body is usually greater than a regional, the idea to have flights with low load factors and higher negative externalities in terms of pollution and noise is extremely undesirable.

Table 23 shows the results of the second regression model regarding LVAyear index. Notice that, in this case, the results have been obtained performing the White correction because the residuals of the original model were not homoscedastic according to the Breush – Pagan test.

Table 23, LVAyear regression results.

Residuals:

Min	1Q	Median	3Q	Max
-25.383	-3.889	1.412	5.697	11.661

Coefficient	Estimate	Std. Error
(Intercept)	56.2214 (***)	0.608
WB	74.1726 (***)	31.277
RJ	-10.9106 (***)	2.218
PP	-17.8658 (***)	1.405
NB	NA	NA

Residual standard error: 6.692 on 352 degrees of freedom

Multiple R-squared: 0.4293

Adjusted R-squared: 0.4244

F-statistic: 88.25 on 3 and 352 DF. p-value: < 2.2e-16

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

The adjusted R^2 of the second OLS regression is 0.42, implying that our model can explain 42% (i.e. a lower percentage than the previous model) of the costs derived by airports in terms of noise exposure. This result is not surprising, since the LVA_{year} index is influenced also by the number of movements (on the contrary, the LAP index has been divided by the number of movements and, consequently, it is not influenced by the traffic level at the airports).

However, the results confirm our expectations also in the case of noise: airports with a large percentage of flights made by wide-body and narrow-body aircrafts produce a greater LVA_{year} than airports with a larger component of regionals and propellers.

5.2 LVAyear e LAP validation based on comparison with Lombardy airport INM and EDMS scenarios

In order to estimate the capability of the developed tool to provide a good representation of the investigated scenarios, results have been compared with the outputs of models calculations.

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.

LVA levels at the certification measurement points have been calculated using INM, considering average daily scenarios while emissions inventories has been conducted using EDMS.

INM results have been directly compared with the LVAyear 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.

5.2.1 Noise

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 arrival and departures that the aircraft flies following a straight route, real flights occur at different runways over different STAR and SID routes.

In order to compare LVAyear 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 eventually runways, and processed as a specific INM case.

LVA levels, for each certification measurement point, have consequently been logarithmically summed up to obtain the final results to be compared with the LVAyear 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 (SIDs are constructed over 5 radials based on VOR radials[27]) 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 25) and Approach measurement points, and to the side of each runway, in the case of Lateral measurement point.

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

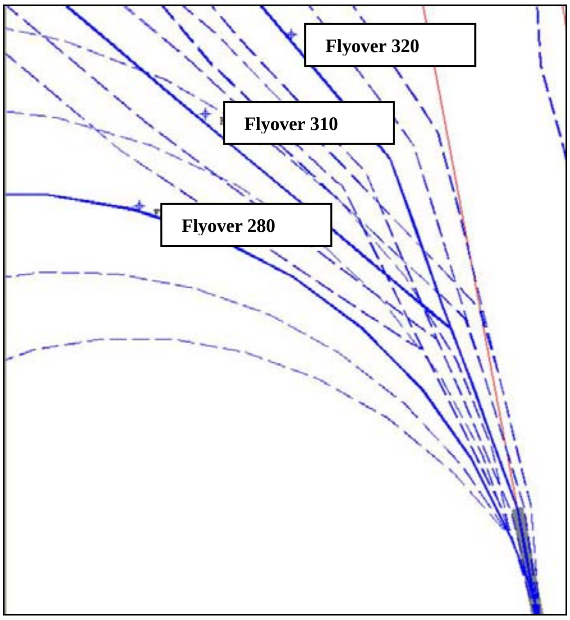


Figure 25, Flyover points for Milan Malpensa runway 35L.

Flyover, Lateral and Approach INM levels for 2008 scenario are showed in table 24.

Table 24, INM Noise Levels for specific exit radial

Radial	Lva (dBA)
Flyover 040	56,3
Flyover 280	49,7
Flyover 310	55,3
Flyover 320	58,1
Flyover 358	55,2
Lateral 040	63,5
Lateral 280	62,2
Lateral 310	62,5
Lateral 320	62,3
Lateral 358	63,4
Approach 35 L	65,0
Approach 35 R	65,0

In Table 25 are shown the logarithmical average values of Flyover, Lateral and Approach for the three scenarios. Results differ by less than 1 dB(A) from LVAyear.

Table 25, LVAyear comparison to INM noise levels.

MXP scenario	LVAyear	INM Levels	Δ
1999	66,6	67,3	-0,7
2004	66,0	67	-1,0
2008	66,7	67,2	-0,5

5.2.2 Emissions of pollutants

Regarding emission inventory, the results for each scenario simulation are shown in Table 26. The quantity of pollutants emitted by Lombardy major airports is expressed in terms of kg/year.

As abovementioned, EDMS results were transformed in LAP indexes (Table 26) using the same economic criteria of cost of pollutant.

Table 26, 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 26 for each airport scenario.

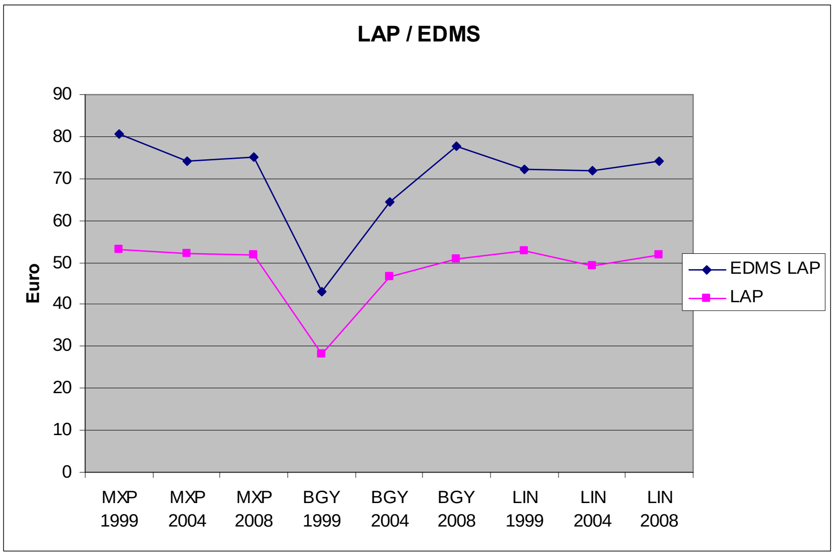


Figure 26, LAP comparison to EDMS scenario results.

As in the case of noise, EDMS provides higher results than the indexes values. Nevertheless as showed in the graph, the trend during the analysis period are very similar. That means 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.

This overestimation is largely due to the LTO default single phase times. 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 corrected to make them more adherent to the actual ones, not available at the moment.

5.2.3 Validation considerations

To get a complete overview of noise analysis, noise maps for the three airports have been calculated. 2008 scenario is showed in Appendix 2.
These maps, produced in compliance with Italian regulation, describe zone A, B, C of the airport zoning plan derived by LVA contour levels of 60, 65 and 75 dB(A).
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 distribution of noise, especially relatively to the residential areas.
In fact, LVAyear cannot describe the specific impact on single receptors and evaluate the influence of flight procedures on noise spatial distribution. Consequently LVAyear does not substitute INM in airport noise assessment.
Conversely LAP indexes can be thoroughly effective for the emission inventory calculation, provided that the same set of input data are used. As regards the evaluation of the impacts on the residential areas, as for the noise study, the dispersion model continues to be necessary to integrate LAP indexes in providing the concentrations levels of pollutants at receptors.

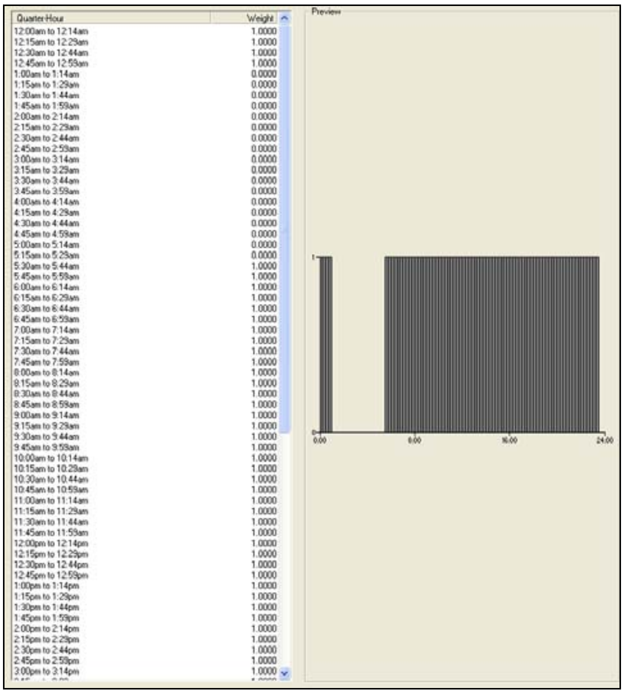
5.3 EDMS dispersion study results

The calculation of concentration levels is the final process of EDMS simulation. Dispersion is calculated starting from the emission inventory data. NO_x, HC, SO_x, CO and PM_{10} have been investigated on monthly basis. To properly reproduce the annual scenario, we used specific operational profiles in order to distribute the overall events on each month of the year, according to the data obtained by the Assaeroporti database.

Table 27, Monthly operational profile for 2004

Month	Frequencies
JAN	0,77
FEB	0,79
MAR	0,86
APR	0,81
MAY	0,89
JUN	0,89
JUL	0,94
AUG	0,71
SEP	1,00
OCT	0,85
NOV	0,83
DEC	0,71

In table 27, the 2004 monthly trend is illustrated. Each month represented in relation with the peak(occurred in September) in a scale that ranges from 0 to 1. Quarter hourly frequencies were assigned according to the usual Milan Linate daily operational profile with no flights during 23.30 p.m.-5.30 a.m period.



Quarter Hour	Weight
12:00am to 12:14am	1.0000
12:15am to 12:29am	1.0000
12:30am to 12:44am	1.0000
12:45am to 12:59am	1.0000
1:00am to 1:14am	0.0000
1:15am to 1:29am	0.0000
1:30am to 1:44am	0.0000
1:45am to 1:59am	0.0000
2:00am to 2:14am	0.0000
2:15am to 2:29am	0.0000
2:30am to 2:44am	0.0000
2:45am to 2:59am	0.0000
3:00am to 3:14am	0.0000
3:15am to 3:29am	0.0000
3:30am to 3:44am	0.0000
3:45am to 3:59am	0.0000
4:00am to 4:14am	0.0000
4:15am to 4:29am	0.0000
4:30am to 4:44am	0.0000
4:45am to 4:59am	0.0000
5:00am to 5:14am	0.0000
5:15am to 5:29am	0.0000
5:30am to 5:44am	1.0000
5:45am to 5:59am	1.0000
6:00am to 6:14am	1.0000
6:15am to 6:29am	1.0000
6:30am to 6:44am	1.0000
6:45am to 6:59am	1.0000
7:00am to 7:14am	1.0000
7:15am to 7:29am	1.0000
7:30am to 7:44am	1.0000
7:45am to 7:59am	1.0000
8:00am to 8:14am	1.0000
8:15am to 8:29am	1.0000
8:30am to 8:44am	1.0000
8:45am to 8:59am	1.0000
9:00am to 9:14am	1.0000
9:15am to 9:29am	1.0000
9:30am to 9:44am	1.0000
9:45am to 9:59am	1.0000
10:00am to 10:14am	1.0000
10:15am to 10:29am	1.0000
10:30am to 10:44am	1.0000
10:45am to 10:59am	1.0000
11:00am to 11:14am	1.0000
11:15am to 11:29am	1.0000
11:30am to 11:44am	1.0000
11:45am to 11:59am	1.0000
12:00pm to 12:14pm	1.0000
12:15pm to 12:29pm	1.0000
12:30pm to 12:44pm	1.0000
12:45pm to 12:59pm	1.0000
1:00pm to 1:14pm	1.0000
1:15pm to 1:29pm	1.0000
1:30pm to 1:44pm	1.0000
1:45pm to 1:59pm	1.0000
2:00pm to 2:14pm	1.0000
2:15pm to 2:29pm	1.0000
2:30pm to 2:44pm	1.0000
2:45pm to 2:59pm	1.0000
3:00pm to 3:14pm	1.0000

Figure 27, Quarter hourly operational profile

Concentrations have been calculated at six receptor, located at some residential areas around the airport. Results are shown in table 28.

Table 28, Monthly concentrations for 2004.

January 04	**Concentration (µg/m3)**				
RECEPTOR	**CO**	**NOx**	**PM10**	**SOx**	**HC**
Milano Linate	0.345008E+01	0.343340E+01	0.343797E-01	0.367252E+00	0.390856E+00
Novegro	0.407652E+00	0.521981E+00	0.489695E-02	0.506044E-01	0.467406E-01
Peschiera	0.715729E+00	0.141474E+01	0.113880E-01	0.114212E+00	0.794746E-01
Pioltello	0.293193E+00	0.411044E+00	0.363055E-02	0.362196E-01	0.329887E-01
Redecesio	0.361633E+00	0.340205E+00	0.387745E-02	0.397291E-01	0.459021E-01
San Donato	0.192490E+01	0.336458E+01	0.274008E-01	0.274543E+00	0.251675E+00
Segrate	0.731150E+00	0.100380E+01	0.100295E-01	0.996401E-01	0.814472E-01

February 04	Concentration (µg/m3)				
RECEPTOR	CO	NOx	PM10	SOx	HC
Milano Linate	0.457848E+01	0.415030E+01	0.414119E-01	0.467889E+00	0.530337E+00
Novegro	0.784699E+00	0.764985E+00	0.861646E-02	0.850406E-01	0.949811E-01
Peschiera	0.114411E+01	0.215980E+01	0.158103E-01	0.169854E+00	0.135920E+00
Pioltello	0.116255E+01	0.147433E+01	0.132607E-01	0.137627E+00	0.129508E+00
Redecesio	0.933350E+00	0.892668E+00	0.126777E-01	0.115062E+00	0.122072E+00
San Donato	0.148640E+01	0.296171E+01	0.235326E-01	0.241970E+00	0.188328E+00
Segrate	0.883369E-01	0.121314E+00	0.112314E-02	0.113729E-01	0.977638E-02

March 04	Concentration (µg/m3)				
RECEPTOR	CO	NOx	PM10	SOx	HC
Milano Linate	0.404817E+01	0.508113E+01	0.473125E-01	0.486320E+00	0.470170E+00
Novegro	0.394650E+00	0.422819E+00	0.469091E-02	0.447237E-01	0.547119E-01
Peschiera	0.121048E+01	0.189787E+01	0.159203E-01	0.162048E+00	0.146597E+00
Pioltello	0.317178E+00	0.184974E+00	0.206071E-02	0.258402E-01	0.328344E-01
Redecesio	0.421288E+00	0.405377E+00	0.413572E-02	0.413033E-01	0.562340E-01
San Donato	0.115472E+01	0.158454E+01	0.151628E-01	0.150404E+00	0.143260E+00
Segrate	0.372474E+00	0.526904E+00	0.295779E-02	0.429355E-01	0.410208E-01

April 04	Concentration (µg/m3)				
RECEPTOR	CO	NOx	PM10	SOx	HC
Milano Linate	0.533056E+01	0.549272E+01	0.518217E-01	0.553839E+00	0.619236E+00
Novegro	0.503571E+00	0.798043E+00	0.643747E-02	0.673114E-01	0.366811E-01
Peschiera	0.367536E+00	0.717568E+00	0.499116E-02	0.534111E-01	0.455252E-01
Pioltello	0.148832E+00	0.336340E+00	0.325921E-02	0.256022E-01	0.200812E-01
Redecesio	0.195906E+00	0.306181E+00	0.227725E-02	0.251274E-01	0.194053E-01
San Donato	0.287213E+01	0.504119E+01	0.378510E-01	0.397419E+00	0.320259E+00
Segrate	0.188180E-01	0.358996E-01	0.279619E-03	0.276398E-02	0.224626E-02

May 04	Concentration (µg/m3)				
RECEPTOR	CO	NOx	PM10	SOx	HC
Milano Linate	0.415110E+01	0.369174E+01	0.368934E-01	0.395245E+00	0.472818E+00
Novegro	0.246005E+00	0.282512E+00	0.321658E-02	0.292142E-01	0.322591E-01
Peschiera	0.147818E+01	0.283686E+01	0.217601E-01	0.226257E+00	0.175287E+00
Pioltello	0.442693E-02	0.191757E-01	0.142030E-03	0.126984E-02	0.561146E-03
Redecesio	0.144591E+00	0.265772E+00	0.266210E-02	0.226325E-01	0.164226E-01
San Donato	0.150101E+01	0.259291E+01	0.189267E-01	0.203409E+00	0.162047E+00
Segrate	0.438578E-01	0.909198E-01	0.814085E-03	0.711852E-02	0.594265E-02

June 04	Concentration (µg/m3)				
RECEPTOR	CO	NOx	PM10	SOx	HC
Milano Linate	0.328113E+01	0.231665E+01	0.262914E-01	0.287188E+00	0.362520E+00
Novegro	0.507507E+00	0.305942E+00	0.361497E-02	0.408785E-01	0.328067E-01
Peschiera	0.142717E+01	0.261225E+01	0.241744E-01	0.223497E+00	0.171857E+00
Pioltello	0.269816E-01	0.213527E-01	0.225193E-03	0.242819E-02	0.289549E-02
Redecesio	0.716165E+00	0.834576E+00	0.699180E-02	0.798997E-01	0.578899E-01
San Donato	0.131990E+01	0.154254E+01	0.145722E-01	0.155352E+00	0.154174E+00
Segrate	0.285573E+00	0.459310E+00	0.526146E-02	0.418420E-01	0.412544E-01

July 04	Concentration (µg/m3)				
RECEPTOR	CO	NOx	PM10	SOx	HC
Milano Linate	0.417497E+01	0.319441E+01	0.362659E-01	0.383188E+00	0.482906E+00
Novegro	0.109192E+00	0.130183E+00	0.130363E-02	0.127029E-01	0.142601E-01
Peschiera	0.867290E+00	0.162322E+01	0.134663E-01	0.134541E+00	0.957793E-01
Pioltello	0.278241E+00	0.448529E+00	0.429740E-02	0.405972E-01	0.340772E-01
Redecesio	0.759665E-01	0.563697E-01	0.660071E-03	0.668961E-02	0.699027E-02
San Donato	0.126704E+01	0.171155E+01	0.143399E-01	0.159126E+00	0.143235E+00
Segrate	0.208869E+00	0.186965E+00	0.125257E-02	0.181943E-01	0.199529E-01

August 04	Concentration (µg/m3)				
RECEPTOR	CO	NOx	PM10	SOx	HC
Milano Linate	0.134392E+01	0.255180E+01	0.276235E-01	0.286858E+00	0.379545E+00
Novegro	0.316495E+01	0.790532E+00	0.749033E-02	0.902512E-01	0.157566E+00
Peschiera	0.119005E+01	0.312002E+01	0.262639E-01	0.276780E+00	0.221359E+00
Pioltello	0.214421E+01	0.261472E-01	0.251103E-03	0.230667E-02	0.243588E-02
Redecesio	0.168447E-01	0.104241E+01	0.816898E-02	0.985442E-01	0.114557E+00
San Donato	0.104930E+01	0.152669E+01	0.140650E-01	0.143905E+00	0.134103E+00
Segrate	0.117431E+01	0.111263E+01	0.996777E-02	0.104135E+00	0.933239E-01

September 04	Concentration (µg/m3)				
RECEPTOR	CO	NOx	PM10	SOx	HC
Milano Linate	0.379739E+01	0.326921E+01	0.333253E-01	0.353137E+00	0.432807E+00
Novegro	0.698370E+00	0.110115E+01	0.881206E-02	0.881638E-01	0.772060E-01
Peschiera	0.891742E+00	0.158791E+01	0.132862E-01	0.133034E+00	0.100069E+00
Pioltello	0.138499E+00	0.187432E+00	0.166041E-02	0.183767E-01	0.142292E-01
Redecesio	0.606102E+00	0.583991E+00	0.453358E-02	0.612635E-01	0.557225E-01
San Donato	0.162393E+01	0.266254E+01	0.229089E-01	0.227743E+00	0.209874E+00
Segrate	0.543354E-01	0.415279E-01	0.388074E-03	0.488997E-02	0.620520E-02

October 04	Concentration (µg/m3)				
RECEPTOR	CO	NOx	PM10	SOx	HC
Milano Linate	0.435257E+01	0.470486E+01	0.445333E-01	0.470249E+00	0.480539E+00
Novegro	0.191838E+01	0.174975E+01	0.161199E-01	0.190528E+00	0.199230E+00
Peschiera	0.639664E+00	0.961361E+00	0.814108E-02	0.840313E-01	0.759608E-01
Pioltello	0.588028E+00	0.657606E+00	0.771733E-02	0.707151E-01	0.654932E-01
Redecesio	0.967699E+00	0.114557E+01	0.957776E-02	0.114100E+00	0.105441E+00
San Donato	0.191691E+01	0.314156E+01	0.247607E-01	0.268486E+00	0.235088E+00
Segrate	0.795393E-01	0.882106E-01	0.761785E-03	0.904635E-02	0.706095E-02

November 04	Concentration (µg/m3)				
RECEPTOR	**CO**	**NOx**	**PM10**	**SOx**	**HC**
Milano Linate	**0.284093E+01**	**0.281173E+01**	**0.272399E-01**	**0.296981E+00**	**0.299904E+00**
Novegro	**0.141269E+01**	**0.223469E+01**	**0.146576E-01**	**0.179360E+00**	**0.155193E+00**
Peschiera	**0.171220E+01**	**0.373145E+01**	**0.308963E-01**	**0.283602E+00**	**0.187374E+00**
Pioltello	**0.103639E+01**	**0.128638E+01**	**0.102174E-01**	**0.125345E+00**	**0.898778E-01**
Redecesio	**0.177543E+01**	**0.191060E+01**	**0.178695E-01**	**0.194548E+00**	**0.227736E+00**
San Donato	**0.198908E+01**	**0.347125E+01**	**0.265967E-01**	**0.282108E+00**	**0.232300E+00**
Segrate	**0.245154E+00**	**0.225965E+00**	**0.248213E-02**	**0.256877E-01**	**0.330017E-01**

December 04	Concentration (µg/m3)				
RECEPTOR	**CO**	**NOx**	**PM10**	**SOx**	**HC**
Milano Linate	**0.315114E+01**	**0.231247E+01**	**0.243428E-01**	**0.281117E+00**	**0.362629E+00**
Novegro	**0.250510E+01**	**0.256790E+01**	**0.269999E-01**	**0.283841E+00**	**0.266653E+00**
Peschiera	**0.799065E+00**	**0.141781E+01**	**0.105480E-01**	**0.109400E+00**	**0.974052E-01**
Pioltello	**0.364933E+00**	**0.433918E+00**	**0.485615E-02**	**0.441673E-01**	**0.479291E-01**
Redecesio	**0.189719E+01**	**0.234938E+01**	**0.228305E-01**	**0.234727E+00**	**0.244323E+00**
San Donato	**0.224033E+01**	**0.350257E+01**	**0.294217E-01**	**0.300575E+00**	**0.244644E+00**
Segrate	**0.179983E+00**	**0.221731E+00**	**0.146015E-02**	**0.191681E-01**	**0.137274E-01**

Chapter 6 Conclusions

The conceptual framework of this study has changed through the years of the PhD project. Starting from an integration between the mathematical models for airport environmental analysis, it has been turned in the creation of an easy and fast procedure to evaluate noise and air pollution around the airports through the calculation of the two indexes.

In fact since meanwhile important research projects, like SPADE[28], have studied models integration, it has been decided to direct the aim of the study to the definition of a procedure for a simple preliminary assessment of airports environmental impacts.

Indexes definition showed interesting results and significant possible future developments. They allow to identify the most polluting operations and assess the sustainability of an increase in traffic. It is also a useful tool to investigate the consequences coming from changes in the airport fleet mix. Indexes comparison gives also the opportunity to set the priority of interventions for each airport.

LAP index provides the cost of air pollutants emitted by aircrafts. The application of a regression model shows its relation with the airport fleet mix proving that airports with higher percentage of wide-body and narrow-body aircrafts produce more LAP than airport characterized by regional and propeller traffic.

LVAyear index provides the airport noise level. Regression analysis shows its relation with the airport fleet mix but in a lower percentage than LAP index, due to the intrinsic influence of number of aircraft movements in index structure.

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[28] Supporting Platform for Airport Decision-making and Efficiency analysis http://spade.nlr.nl/

Simulations performed with INM and EDMS model, considered as worldwide standard for these analysis, provide validation to our method with good results for the two fields. LAP index results underestimated compared to the EDMS emission inventory while a significant result has been obtained with INM validation. The difference between INM and LVAyear for Milan Malpensa case is only 0,5 dB(A) for scenario 2008, 0,7 dB(A) for 1999 and 1 dB(A) for 2004. Indexes performance could be improved if traffic data would be directly provided by Airport Operator. LAP index calculation could be more accurate obtaining real data as regards aircrafts and operational times.

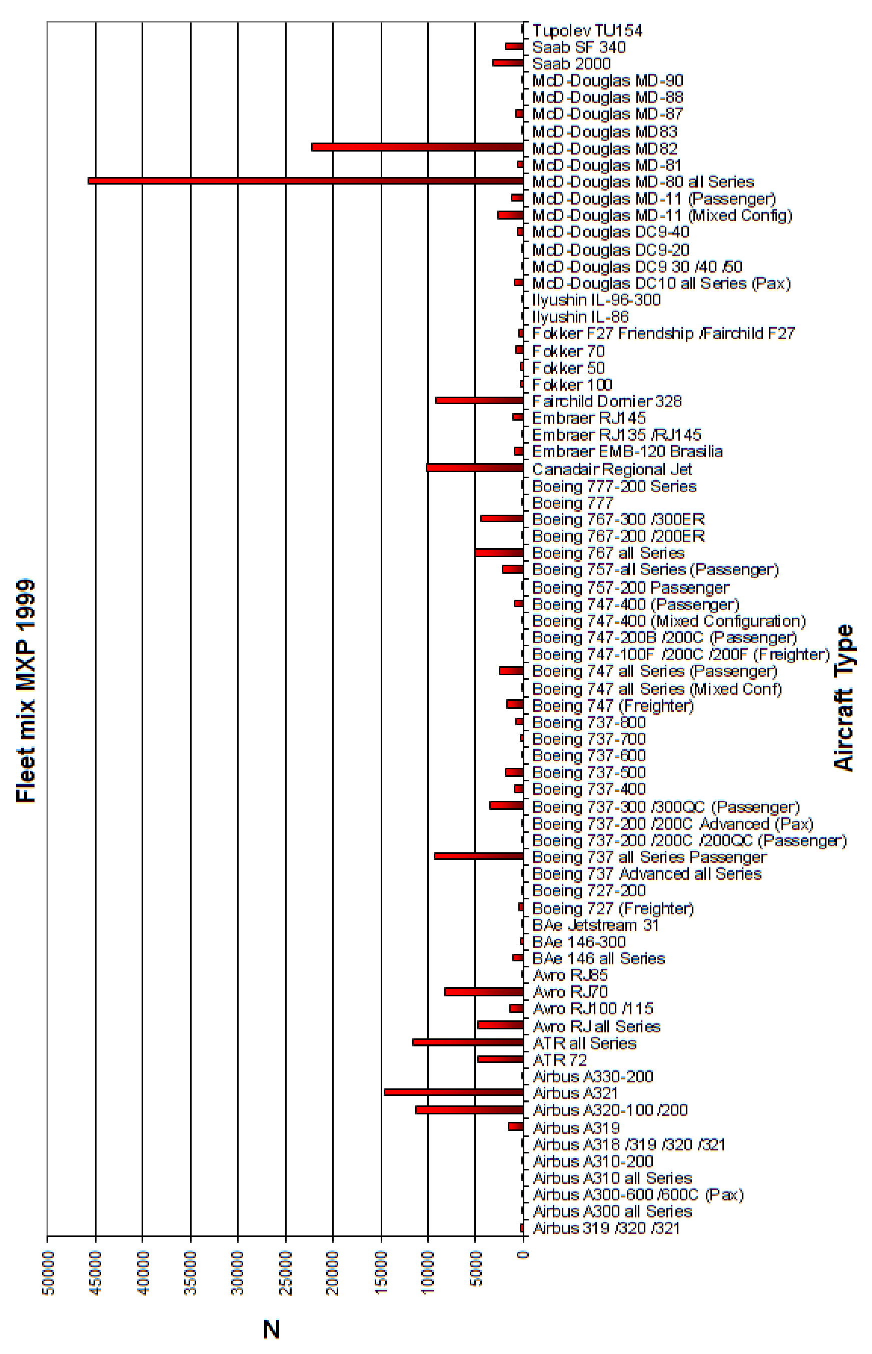
This procedure, tested at three Lombardy airports, can be applied to other airport systems in Italy as well as in Europe.

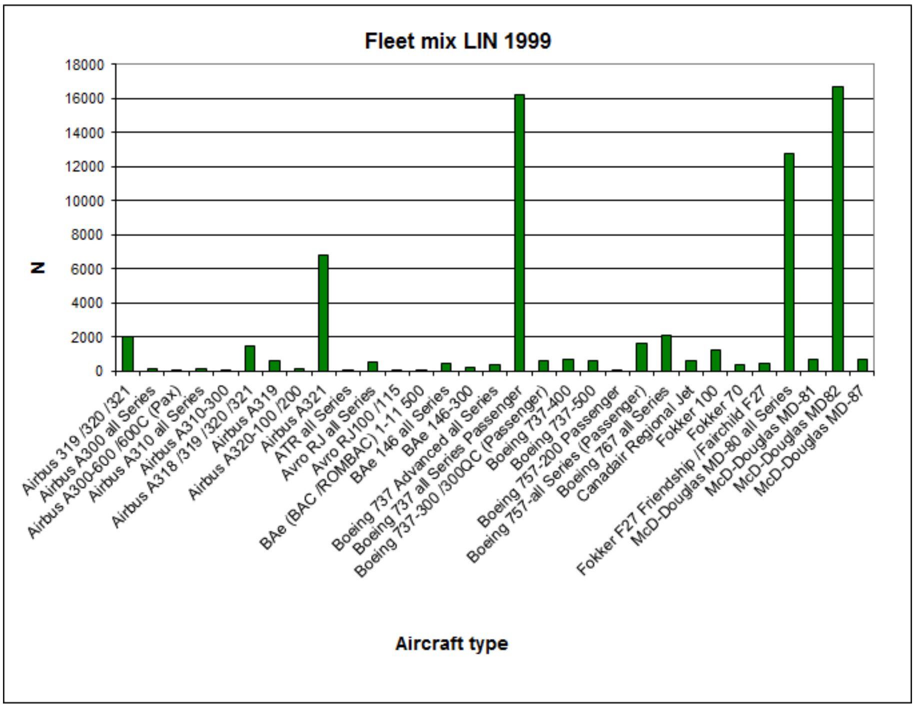
The flexible structure of the index/models simulation procedure makes it a useful tool for different research lines as population exposure study (integrating territorial analysis) and mitigation policies verification.

Other scientific fields like engineering and econometric analysis for airport benchmarking show interest to include environmental variables on their researches. Conversely this procedure can be integrated with analysis on charge systems, capacity and efficiency, and decision making processes.

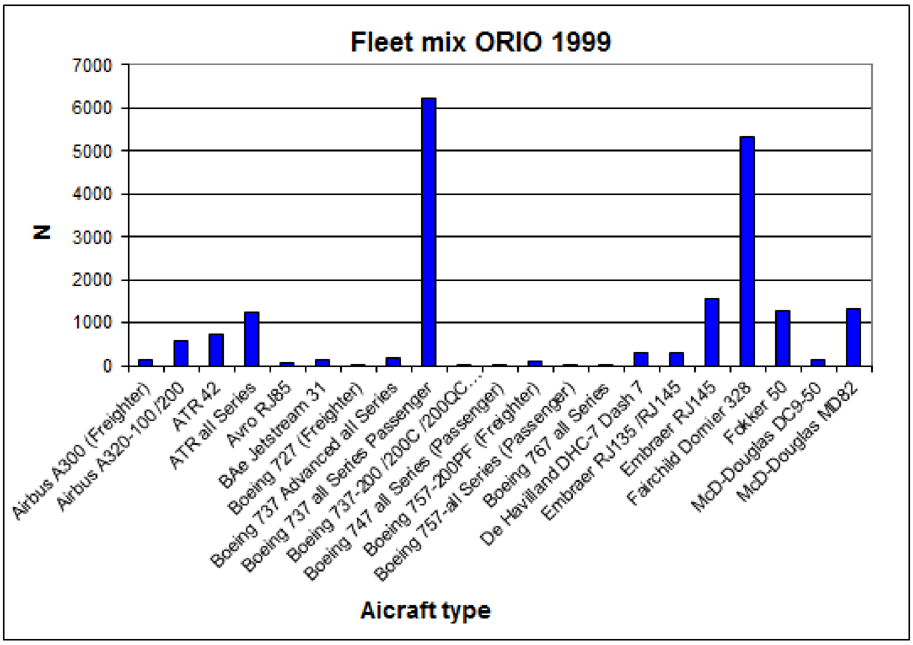
Appendix 1

Fleet Mix for 1999.



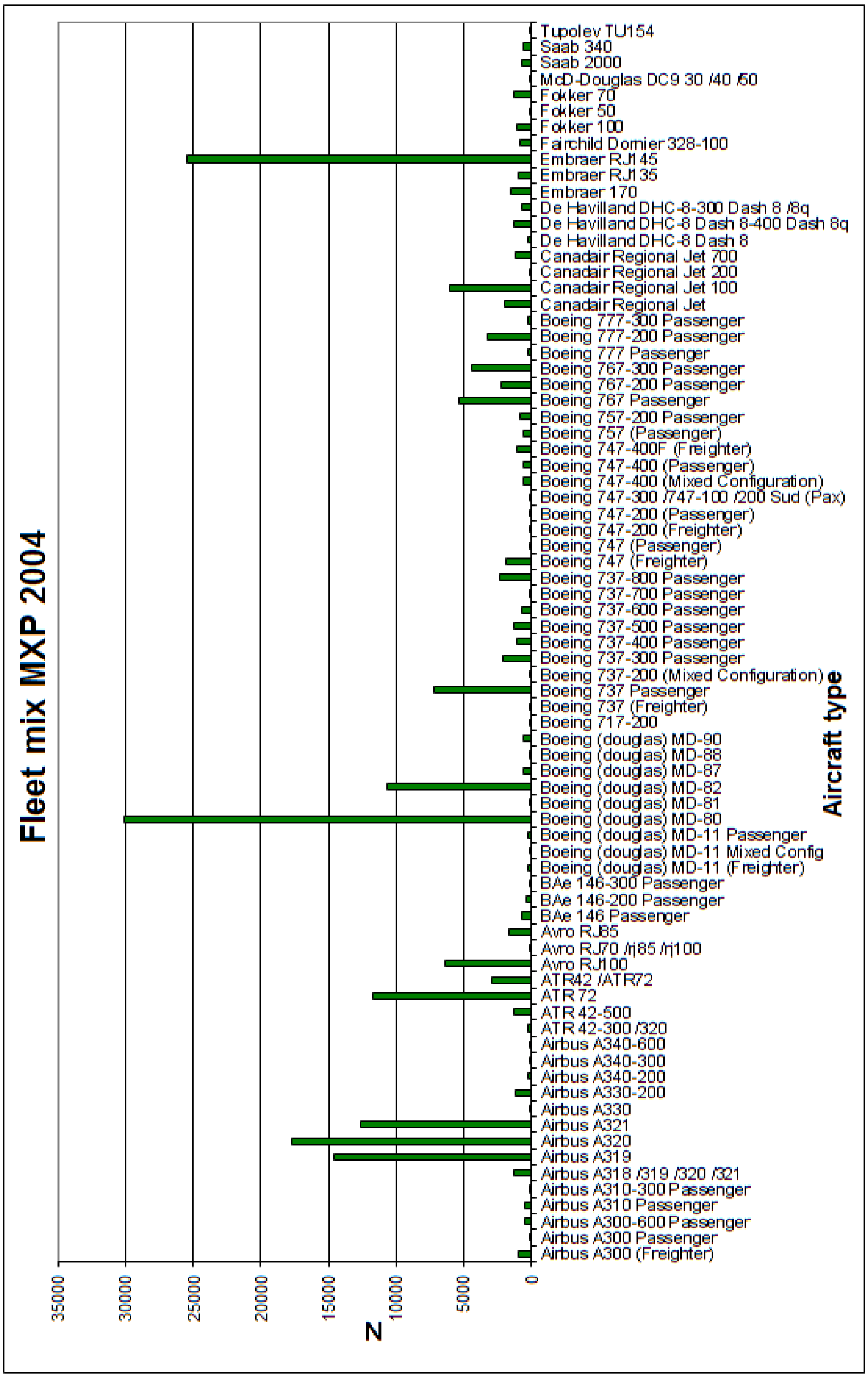


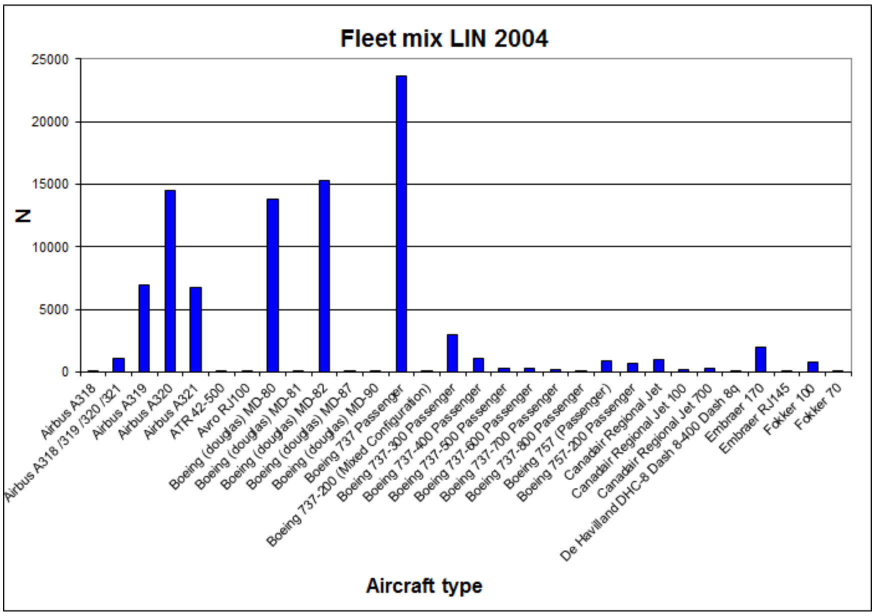
Fleet mix LIN 1999

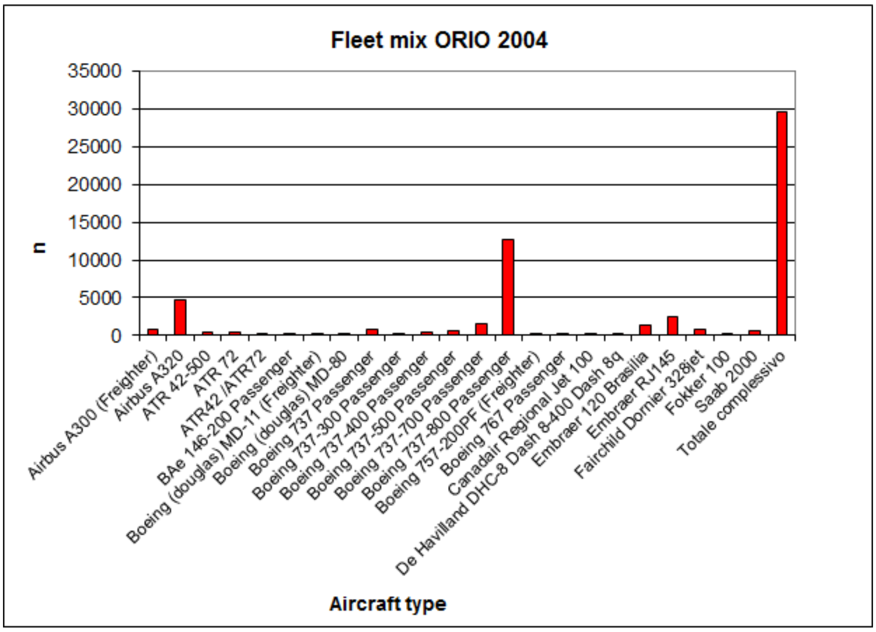


Fleet mix ORIO 1999

Fleet mix for scenario 2004

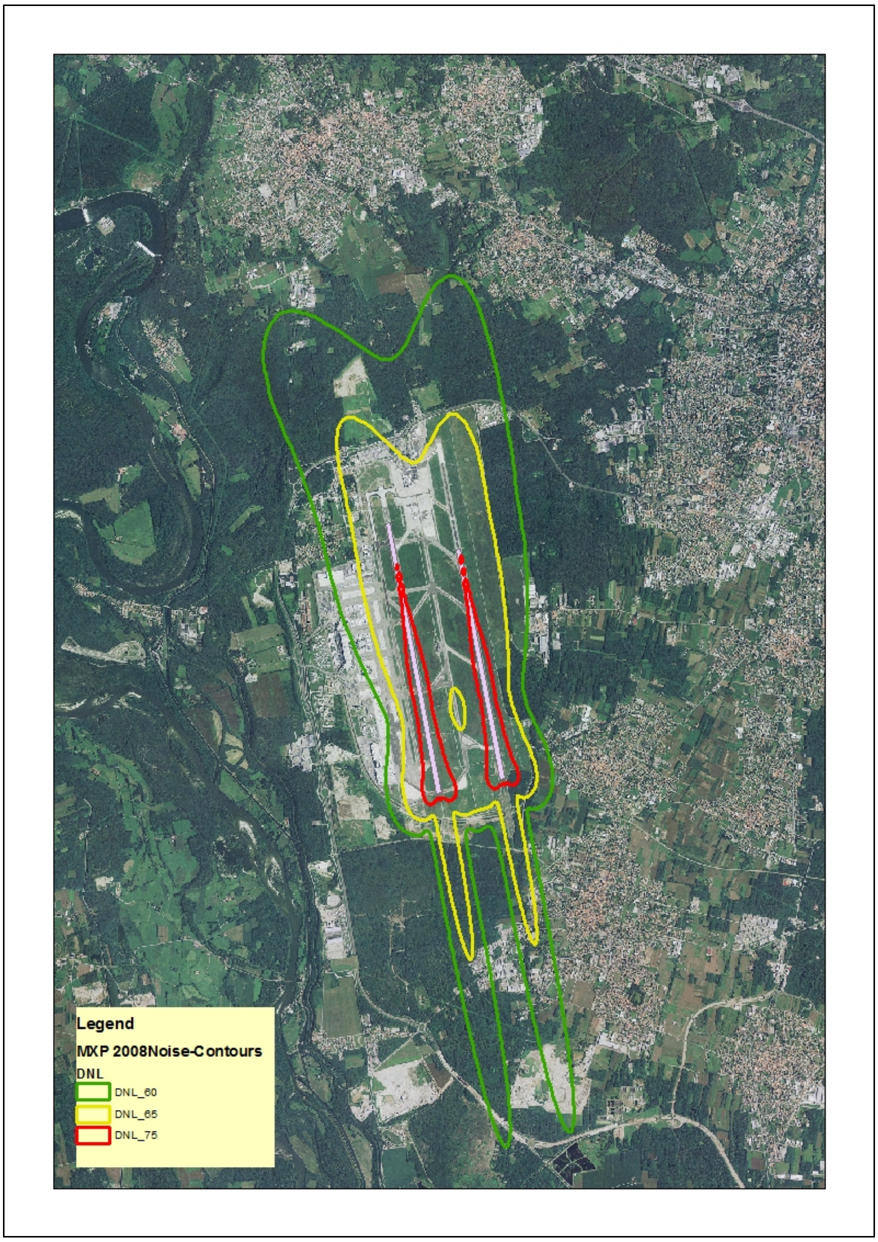


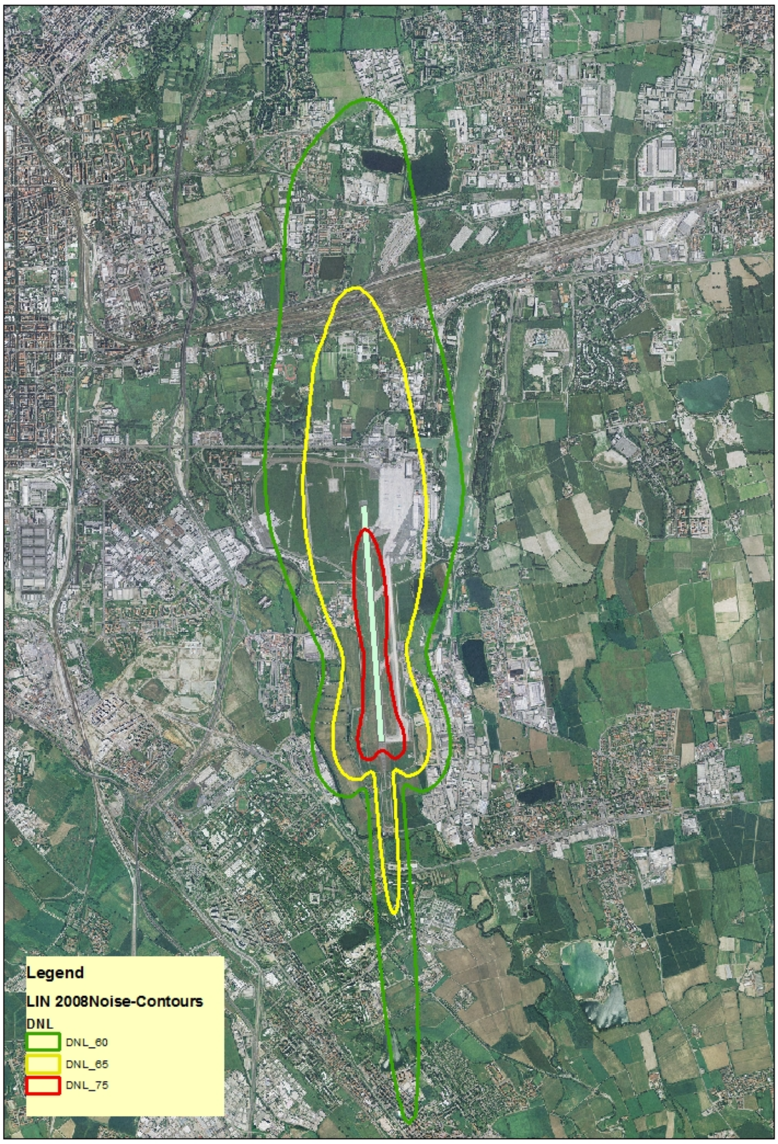

Fleet mix LIN 2004
25000
20000
15000
10000
5000
0
N
Airbus A318
Airbus A318 /319 /320 /321
Airbus A319
Airbus A320
Airbus A321
ATR 42-500
Avro RJ100
Boeing (douglas) MD-80
Boeing (douglas) MD-81
Boeing (douglas) MD-82
Boeing (douglas) MD-87
Boeing (douglas) MD-90
Boeing 737 Passenger
Boeing 737-200 (Mixed Configuration)
Boeing 737-300 Passenger
Boeing 737-400 Passenger
Boeing 737-500 Passenger
Boeing 737-600 Passenger
Boeing 737-700 Passenger
Boeing 737-800 Passenger
Boeing 757 (Passenger)
Boeing 757-200 Passenger
Canadair Regional Jet
Canadair Regional Jet 100
Canadair Regional Jet 700
De Havilland DHC-8 Dash 8-400 Dash 8q
Embraer 170
Embraer RJ145
Fokker 100
Fokker 70
Aircraft type

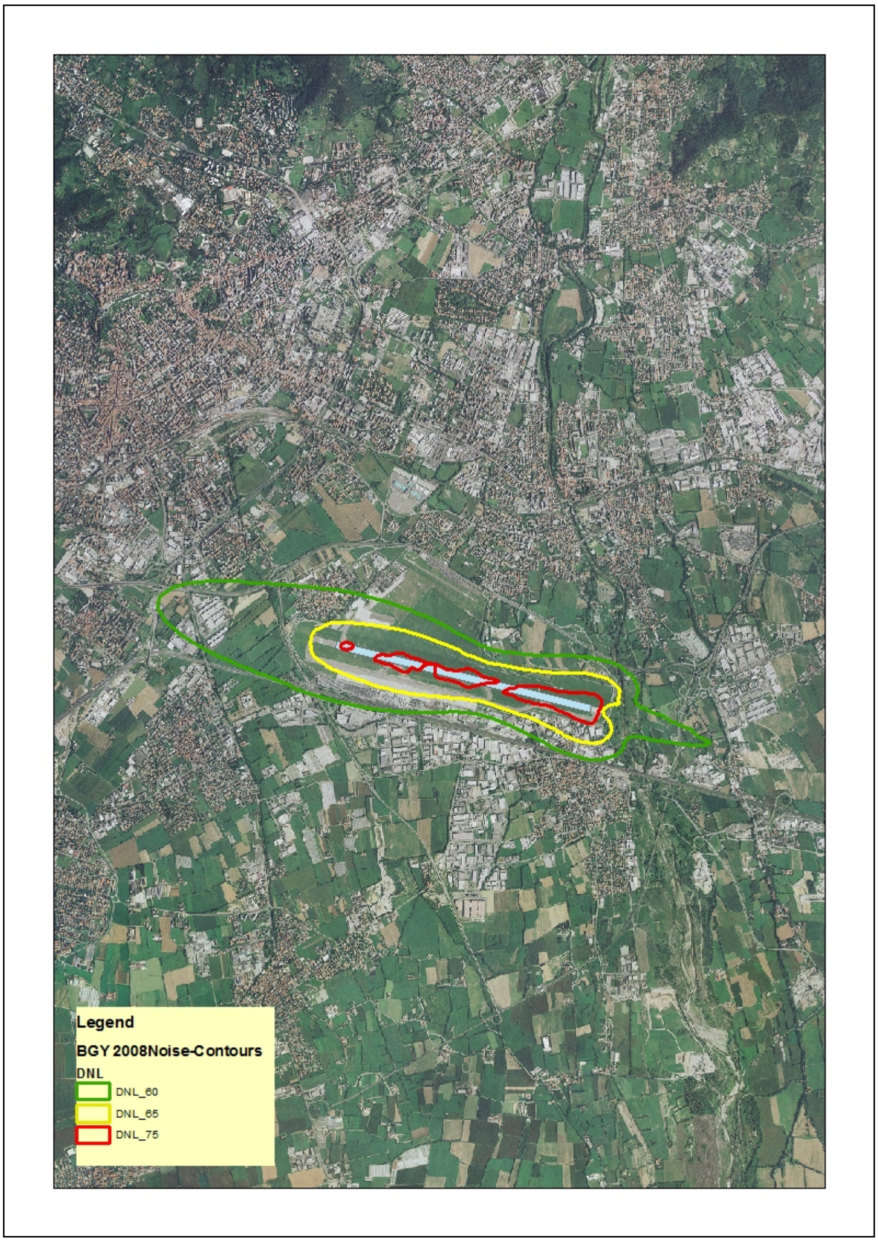

Fleet mix ORIO 2004
35000
30000
25000
20000
15000
10000
5000
0
n
Airbus A300 (Freighter)
Airbus A320
ATR 42-500
ATR 72
ATR42 /ATR72
BAe 146-200 Passenger
Boeing (douglas) MD-11 (Freighter)
Boeing (douglas) MD-80
Boeing 737 Passenger
Boeing 737-300 Passenger
Boeing 737-400 Passenger
Boeing 737-500 Passenger
Boeing 737-700 Passenger
Boeing 737-800 Passenger
Boeing 757-200PF (Freighter)
Boeing 767 Passenger
Canadair Regional Jet 100
De Havilland DHC-8 Dash 8-400 Dash 8q
Embraer 120 Brasilia
Embraer RJ145
Fairchild Dornier 328jet
Fokker 100
Saab 2000
Totale complessivo
Aircraft type

Appendix 2

Noise contours for 2008 scenario.




Legend
LIN 2008Noise-Contours
DNL
DNL_60
DNL_65
DNL_75


Legend
BGY 2008Noise-Contours
DNL
DNL_60
DNL_65
DNL_75

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