Research Article

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Strategic noise mapping in Athens International Airport: A tool for balanced approach & health effects evaluation

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Abstract: Athens International Airport (A.I.A) is the first major transportation infrastructure in Greece with the participation of the private sector, a pioneer international Public-Private Partnership. Environmental protection is a priority, and AIA, is committed to protect the environment and preventing or lessening negative impacts, through a comprehensive Environmental Policy and Procedures. Within this framework, AIA has already carried out the study for Strategic Noise Map (SNM) and the Noise Action Plan (NAP) for the Aircraft Noise. According to the European Directive 49/2002 the study should be repeated every 5 years. This research article focuses on the comparative study for the latest SNMs 2017 & 2019 (ECAC Doc.29) and for 2019 (executed by the new methodology CNOSSOS-GR), for the respective traffic data 2016 & 2018, and presents the results of the acoustic model in order to create the Strategic Noise Maps for L_{den} & L_{night} indicators. With a view to implementing the legislation, an analysis of aircraft mix for every year (except helicopters, military and other specific flights) was carried out in accordance with the categorisation provided for in the relevant recommendation of the Committee of 6 August 2003 and the European Commission adopted Directive 2015/996. The potential health effects were further analyzed using the World Health Organization (WHO's) Disability Adjusted Life Year's (DALY's) metrics for aircraft noise in relation to the exposure of the population based on the results of alternative comparative Strategic Noise Maps. The aim of the study is to show how the combination of both the implementation of the European Directive 2002/49 and 2015/996 and the DALY approach is an analysis tool for the evaluation of the acoustic environment. As we can observe in the results, the overall findings are significantly lower in the case of SNM 2019 (executed by the new methodology CNOSSOS-GR) than in the others.

Keywords: aircraft noise, Strategic Noise Mapping, DALY metric, environmental noise

List of acronyms

A/C	Aircraft
AIA	Athens International Airport
ANP	Aircraft noise and performance
AzB	Anleitung zur Berechnung von Larmschutzbereichen/Instructions on the calculation of noise protection areas
DALY	Disability-adjusted life year
DW	Disability weight
ECAC	European civil aviation conference
EU	European Union
HA	High annoyance
HSD	Highly sleep disturbed people
IATA	International air transport association
ICAO	International civil aviation organization
IHD	Ischemic heart disease
L_{den}	Day-evening-night equivalent sound level
L_{night}	Night equivalent sound level
NAP	Noise action plan
RW	Runway
SNM	Strategic noise map
WHO	World Health Organization
YLD	Years lost due to disability
YLL	Years of life lost

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Figure 1: The Airport

Table 1: Airport characteristics

Operation since:	**2001**
Runways:	2, approximately 4km each
Main Terminal Building:	4 levels, 14 passengers' embarkation bridges, 150.000 sqm.
Satellite Terminal Building:	10 gates for passenger's embarkation
Aircraft traffic (max capacity):	65 landings and take-offs per hour
Passenger Traffic 2006:	15.1 million passengers
Cargo Traffic 2006:	120.200 tones
Aircraft Traffic 2006:	**191.000 movements**
Passenger Traffic 2011:	14.4 million passengers
Cargo Traffic 2011:	86.000 tones
Aircraft Traffic 2011:	**173.000 movements**
Passenger Traffic 2016:	20.0 million passengers
Cargo Traffic 2016:	88.500 tones
Aircraft Traffic 2016:	**189.137 movements**
Passenger Traffic 2018:	24.2 million passengers
Cargo Traffic 2018:	96.500 tones
Aircraft Traffic 2018:	**217.098 movements**

1 Introduction

The Athens International Airport (Figure 1) is responsible for the operation, management and development of the new Athens International Airport "Eleftherios Venizelos" at Spata [1]. Is the first major transportation infrastructure in Greece with the participation of the private sector, a pioneer international Public-Private Partnership. The airport has been operating since March 2001 (Table 1) and is located 33 km northeast of central Athens under the ICAO code: LGAV and IATA: ATH. Hereafter are some of the main functional and physical characteristics of the Airport, such as the airport reference point and the associated runways:

- Geographic Latitude/Longitude: 37.56.12.12N/ 23.56.40.20E;
- Altitude: 94 m MSL;
- Runways: 03R/21L: 4000 m and 03L/21R: 3800 m.

Environmental protection, especially concerning the acoustic environment, is a priority, in order to protect the environment, preventing or lessening negative impacts, through a comprehensive Environmental Policy and Procedures. Within this framework, AIA has implemented the recent maximum permissible limits as per the Greek legislation and according to the European Directive 2002/49/EC [2] for both road, rail and airport environmental noise indexes, L_{den} (24 h) and L_{night} (8 h), defined as follows [3]:

a) Noise index L_{den} (24 h): 70 dB(A).
b) Noise index L_{night} (8 h): 60 dB(A).

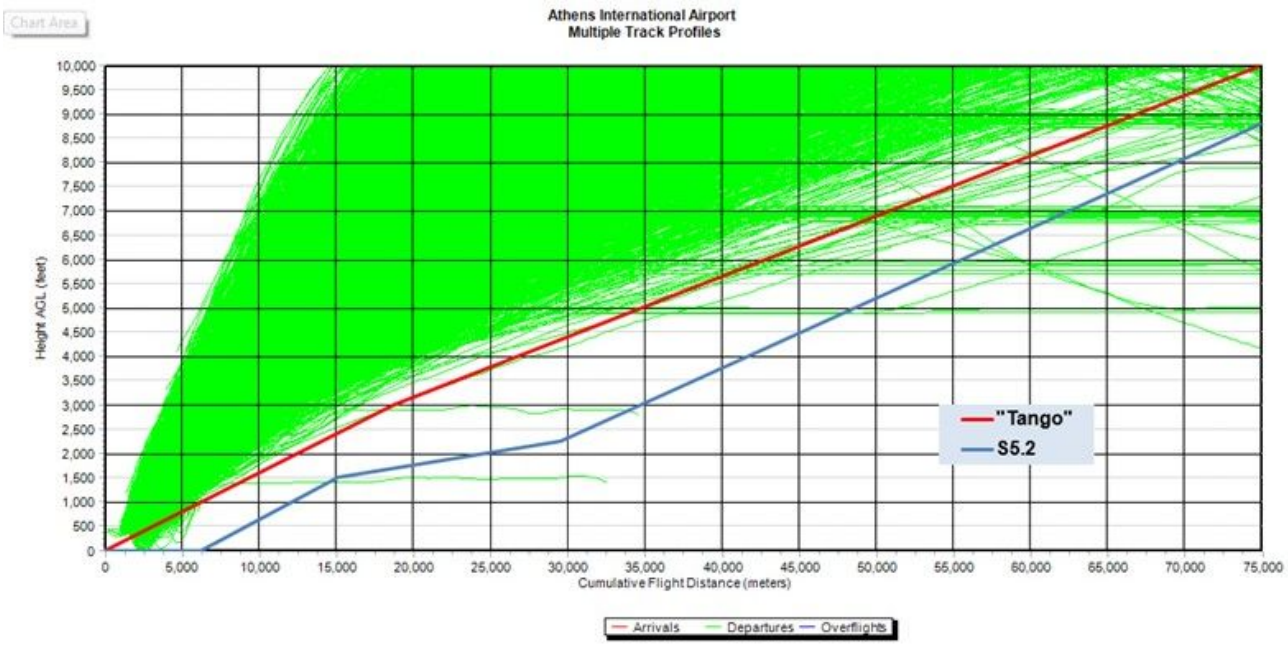


Figure 2: Actual flight paths *VS* AzB

2 Traffic data, Aircraft mix and flight paths

In Table 2 hereafter we present the categorization in accordance with the Recommendation of the Committee of 6 August 2003 (2003/613/EC) and the relevant database "AzB-08" [4]. The total movements are compared by traffic category according to AzB, for 2006, 2011, 2016 & 2018. In order to make the appropriate DTM acoustic modelling, the total volume of traffic throughout the year was used, then the aircraft were allocated per runway and aircraft mix for all 3 different time periods as defined by the legislation.

Taking into account the radar dispersion, representative 3D flight paths in the greater impact area of approximately 20 km^2, as well as density maps from the Noise Monitoring System (NOMOS), were selected in order to select the correct flight paths per runway and landing/take-off.

For departures from runways 03L and 03R, two (2) distinct flight paths per runway (on the horizontal level) were determined in order to optimally cover the affected geographical area. Regarding the actual longitudinal profiles, all movements (especially for RW 03R) for the year 2016 are compared with the suggested profiles as per AzB aircraft data base category. It was established that the actual climbing is far more increased compared to all AzB relevant paths ensuring that the model takes into account the worst-case scenario for the aircraft linear sources, regarding the proximity to ground level. In Figure 2 a comparison of actual recorded longitudinal flight paths *vs* AzB theoretical flight path for the most common aircraft category 5.1 *vs* Tango procedure is shown for all 2016 take offs on Runway 03R.

The Environmental Noise Directive (2002/49/EC) requires EU Member States to determine the exposure to environmental noise through strategic noise mapping and to elaborate action plans in order to reduce noise pollution, where necessary. On 19 May 2015, the European Commission adopted Directive 2015/996 establishing common methods of noise assessment in accordance with Directive 2002/49/EC of the European Parliament and of the Council Directive 2015/996 [5] shall remain in force on the L_{den} and L_{night} values as determined by calculation at the assessment sites, in accordance with the method laid down in Chapter 2 of Article 6 of Directive 2002/49/EC and the data described in Chapter 3. In addition, measurements shall be carried out in accordance with Chapter 4 of Article 6 of Directive 2002/49/EC. Aircraft noise is evaluated by everyone, and therefore exposure to noise is one of the most frequent complaints of populations living nearby International Airports [6]. Aircraft noise modelling is different from the other three noise sources (road & railway traffic, industrial) in several specific aspects. The Aircraft Noise and Performance (ANP) database has been developed to fulfil the requirements of ECAC Doc.29 and both are used in the EU airports to calculate environmental noise. ECAC Doc. 29 3rd Edition was introduced in CNOSSOS-EU

Table 2: Traffic categories according to database AzB* for 2007, 2012, 2017 and 2019 SNM (helicopters, military and other special flights not included)

SNM	P1	P1.1	P1.3	P1.4	P 2.1	P 2.2	S 5.1	S 5.2	S 5.3	S 6.1	S 6.2	S 6.3	S 7	S 8	TOTAL YEAR
2007	4.805	0	0	0	39.134	399	25.662	97.100	3.953	10.667	176	2.395	303	0	**184.594**
(data 2006)	2,6%	0,00%	0,00%	0,00%	21,2%	0,2%	13,9%	52,6%	2,1%	5,8%	0,1%	1,3%	0,2%	0,00%	100,0%
2012	1.807	0	0	0	38.284	347	12.963	108.323	496	6.242	366	376	269	0	**169.473**
(data 2011)	1,1%	0,00%	0,00%	0,00%	22,6%	0,2%	7,6%	63,9%	0,3%	3,7%	0,2%	0,2%	0,2%	0,00%	100,0%
2017	1690	0	0	0	40426	32	9818	123193	94	7152	138	364	54	0	**182.961**
(data 2016)	0,92%	0,00%	0,00%	0,00%	22,1%	0,02%	5,37%	67,33%	0,05%	3,91%	0,08%	0,20%	0,03%	0,00%	100,0%
2019	2	4	117	120	51.445	0	10.291	140.343	52	8.748	156	0	164	184	**211.626**
(data 2018)	0,00%	0,00%	0,06%	0,06%	24,31%	0,00%	4,86%	66,32%	0,02%	4,13%	0,07%	0,00%	0,08%	0,09%	100,0%

AzB category*	Representative A/C type	Annex 16 Chapter
P 1 to P 1.4	Ultralight & MTOM from 2t up to 5.7 t	
P2.1 - P2.2	DHC-7/-8, F-50, ATR 42, F-27, HS748 with MTOM > 5.7 t	3/10
S5.1	BAE 146, ARJ, CRJ	3
S5.2	A319/320/A321, B757-200, B737-300...-800	3
S5.3	MD-8x, B737/B727 with Hush-Kit	3
S6.1	A300, A310, A330, B767, B777	3
S6.2	DC-10, MD-11, DC-8-70, Boing C-17	3
S6.3	A 340-200, -300. -500, -600	3
S7	B747-100, -200, -300, -400, Antonov An-124	3
S8	A-380 MTOM > 500 t	4

Table 3: Aircraft mix categories at Athens International Airport according to ANP database

Aircraft Type	A/C	Aircraft Type	A/C
717200	3627	A380-841	158
737800	27153	CL601	2014
747400	44	CNA55B	1046
757300	117	CNA560XL	2169
767300	1761	DC1040	228
767400	440	DC8QN	322
74720B	94	DHC8	21726
757RR	7	DHC830	20906
767CF6	400	DO328	243
7773ER	2193	EMB175	1240
7878R	735	EMB195	1142
A319-131	9522	F10065	1194
A320-232	61582	HS748A	8814
A321-232	24467	LEAR35	986
A330-343	12177	MD11GE	112
A340-211	4753	MD82	17
A340-642	211	MD83	27

method for aircraft noise prediction. In the modelling context, a flight path is a full description of the motion of the aircraft in space and time. Together with the propulsive thrust (or other noise related power parameter), it is the information required to calculate the noise generated. Concerning the new aircraft mix of 2018, as part of the adaptation to the ANP database (CNOSSOS-EU), we proceeded initially to small-scale grouping of the AzB aircraft categories characterized by the worst-case scenarios and the most favorable ones at the noise level of the AzB database selection options. Especially for the application method of ANP database to the acoustic environment, the method used to group aircraft (assessing the appropriate aircraft mix), is briefly as follows:

1. The A/C database was categorized based on the AzB database for the flights of year 2018 with the aim of establishing a comparative aircraft typology background and categorization method. All available track data from the previous SNMs and the latest track density data, as represented by the associated Noise Monitoring System per threshold/process/time period, were used to provide a real scenario of noise mapping and comparison of airline fleet.
2. The most representative A/C type was selected in the sub-categories of AzB based on the table (ACFT_ID - ANP_DB) for use in the noise modeling program based on the worst and most favorable noise characteristics (Spectral Class), MTOW and A/C Class in each category, and based on the real A/C mix of AIA. In case of no A/C in the ANP, the selection was based on the features and the proposed solution by NP v2.2 Aircraft substitutions - jets & heavy props - Eurocontrol.
3. The following table is a motion analysis and categorization of aircraft.

The table above is based on the easy-to-use approach, with the aim of avoiding the use of AzB categorization and the performance of aircraft that do not appear in the ANP database with other similar of the worst emission, which is exemplary referred hereafter to as “CNOSSOS-GR” aircraft mix approach and ensures a reduced number of aircraft types aiming at a considerable computational time economy.

3 The balanced approach to aircraft noise – The AIA’s action plan

The EU Environmental Noise Directive (EC/2002/49) and the associated Balanced Approach Regulation (EU 598/2014) [7]. aim at promoting the sustainable development of air transport through the reduction of aircraft noise pollution at airports. This legislation introduced the principle of a ‘balanced approach’ to aircraft noise man-

agement at airports, in line with ICAO guidance (Doc9829 AN/451). In this context, airports are encouraged to first assess the current state of noise by identifying specific issues using a combination of modeling and monitoring techniques. This should then be used by airports to establish a noise baseline, future targets and an accompanying action plan for noise management. This balanced approach consists of the following three main pillars:

(i) Reduction of noise at the source,
(ii) Land-use planning and spatial management policies and
(iii) Operating restrictions on aircraft type and movements.

In particular, the Noise Abatement Procedures include:

✓ Use of runways:

- Runway 21L closed for landings during 11pm – 7am.
- Runway 03R closed for departures during 11pm – 7am.
- Chapter 2 aircraft licensed to use the airport are excluded from runway 03R for take-offs or runway 21L for landings on a 24-hr basis. Also marginally accepted Chapter 3 aircraft are also not allowed to use runway 03R for take-offs or runway 21L for landings (since April 2012) on a 24-hr basis.
- Runway 03R is closed for all military aircraft for departures and runway 21L for landings on a 24-hr basis (implemented for 03R in April 2012 and 21L in December 2011).
- Deviations of the above may be allowed for flight security reasons during extreme meteorological phenomena or when airport's capacity and operational procedures made those deviations necessary.

✓ Use of reverse thrust
✓ Thrust Reduction and Acceleration for runways 03L and 03R during TO
✓ AIA's N*O*ise M*O*nitoring System (NOMOS) with 10 stations
✓ Public Complaint Management System
✓ Environmental Noise Reporting

4 The "Tango" take – off procedure

Since 2013, the 'Tango' AD2-LGAV-SID-4 on A.I.P GREECE has been assigned as first priority departure procedure to the North (03R) by the Hellenic Civil Aviation Authority instead of the "Juliet" AD2-LGAV-SID, which is shown in the following Figures 3, 4 below. This Standard Instrument Departure SID-4-LGAV was designed according to ICAO noise abatement considerations and mainly assigned by the appropriate ATC unit in accordance with the operational re-

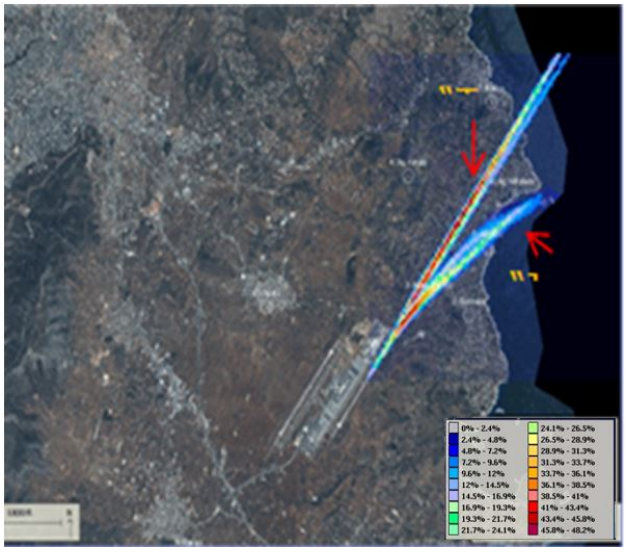


Figure 3: Juliet *vs* Tango

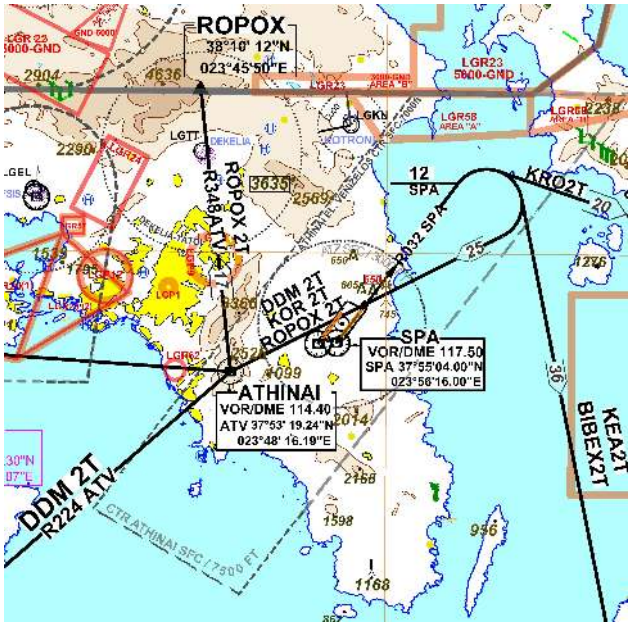
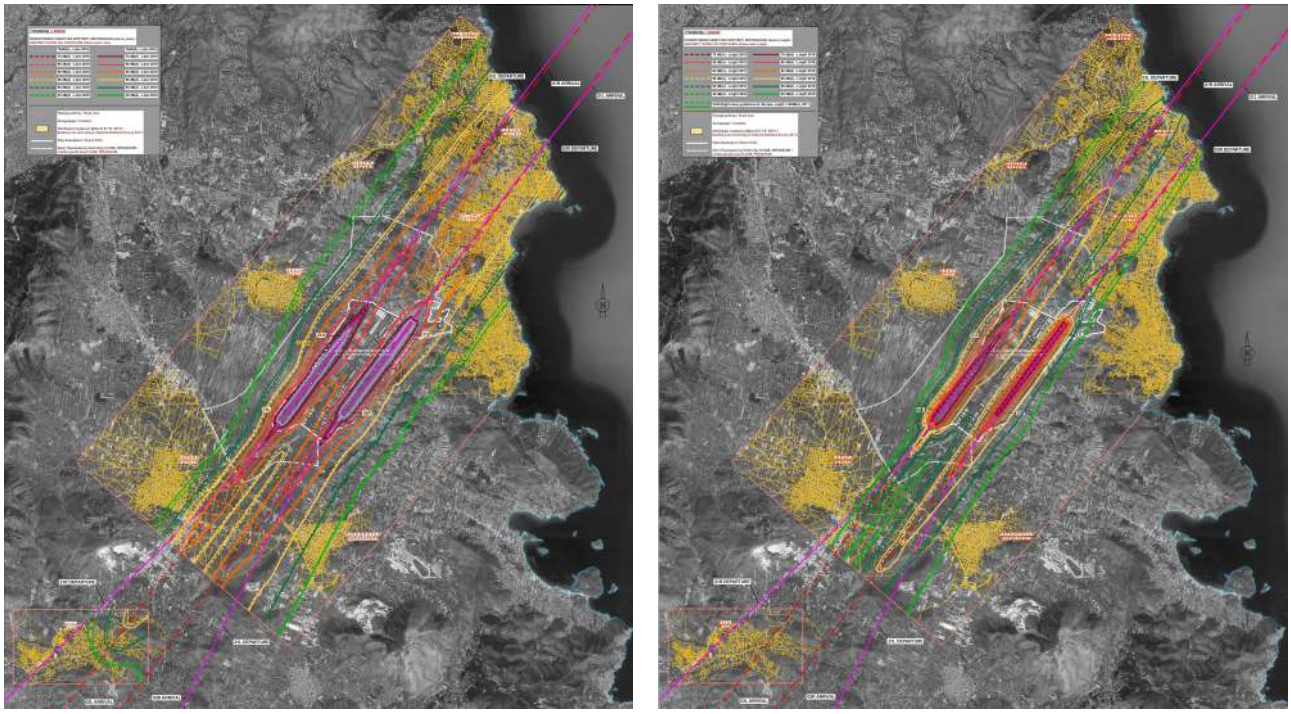


Figure 4: Tango procedure (HCAA / ANSP / AIS AIP Greece AIP GREECE - AD 2 LGAV)



(a) (b)

Figure 5: Comparison of SNM 2017 and 2019 (both based on ECAC.CEACDoc.29) for indexes L_{den} & L_{night}

quirements. The impact of this procedure has significantly contributed to the further A/C noise reduction of the wider region of Artemis by avoiding right turns in low altitude as pervious operation.

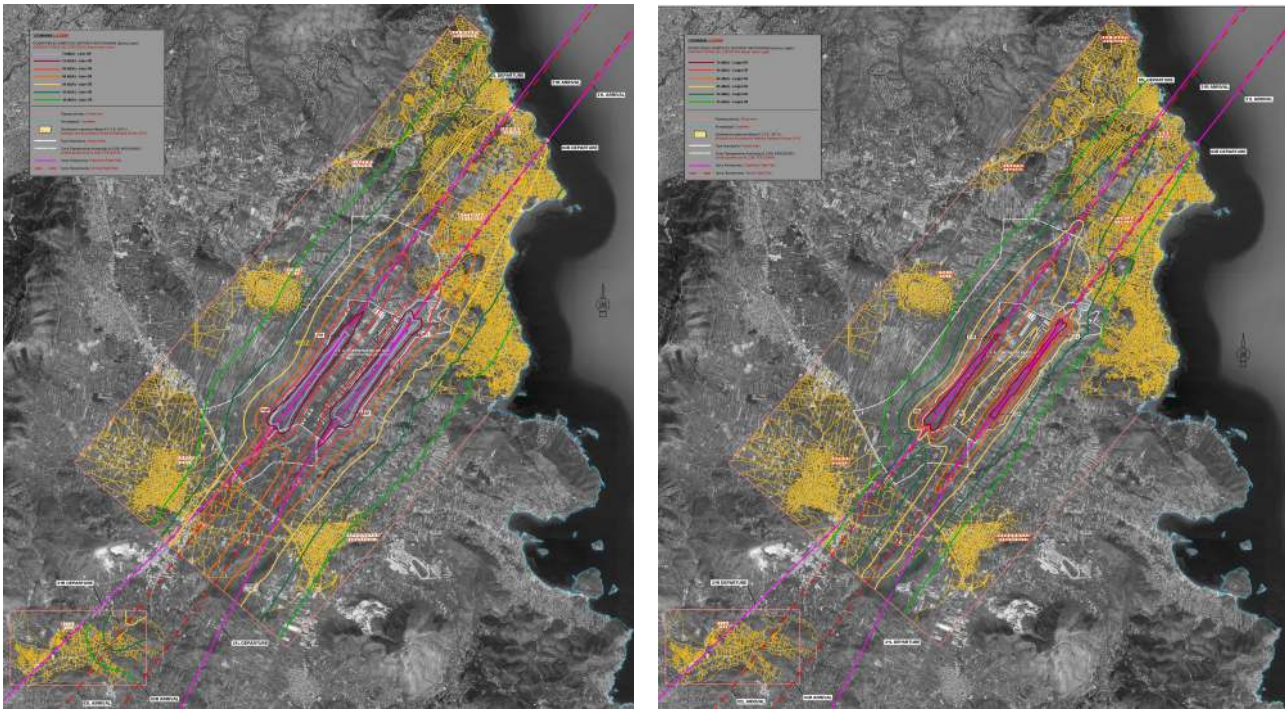
It is worth mentioning that despite the increase of aircraft movements, with the proper application of the Tango procedure, there are no significant negative effects on airborne noise, according to the computed isonoise curves of the legally permissible limits of environmental noise indicators: $L_{den} \leq$ 70 dB(A) and $L_{night} \leq$ 60 dB(A), with those levels to be confined within the airport limits for all SNM scenarios (see Figure 5 above).

5 Strategic noise maps - main results

The execution of Strategic Noise Map (SNM) and Noise Action Plans for the Athens International Airport (AIA), started at 2007 (1^{st} Round), based on ECAC.CEAC.Doc.29 (ECAC) methodology [8]. Recently AIA completed also the 3^{rd} Round for 2017 for both noise indicators L_{den} & L_{night} in accordance with the legislation 2002/49/EC Directive [9]. Moreover during 2019 the relevant SNM corresponding to the 2018 annual traffic data was also completed implementing both methodologies ECAC.CEAC.Doc.29 and the new methodology CNOSSOS-EU [10].

In the comparative Figure 7 (a and b) hereafter the isonoise curves of both 55 and 50 dB(A) for the relevant L_{den} & L_{night} indices are presented for all scenarios 2017, 2019 (ECAC) & 2019 (CNOSSOS-GR) along with the respective max. permissible limits as per the Greek legislation. defined above [6]. The population exposed to the different noise buffer zones of the L_{den} index of the study area must be categorized – according to the aforementioned institutional framework – in noise buffer zones higher than 55, 65 and 75 dB(A) respectively and at a height of 4,0 meters (± 0,20m) above the ground. The results for both methodologies ECAC.CEACDoc.29 and CNOSSOS-EU for the years 2017 & 2019 are presented in Figures 5 & 6 and Table 4 hereafter [11].

According to the results of all alternative SNMs, 0.0% of the population is exposed at noise levels above 70 dB(A) & 60 dB(A) respectively for the environmental aircraft noise indexes L_{den} & L_{night} as per the Greek legislation.

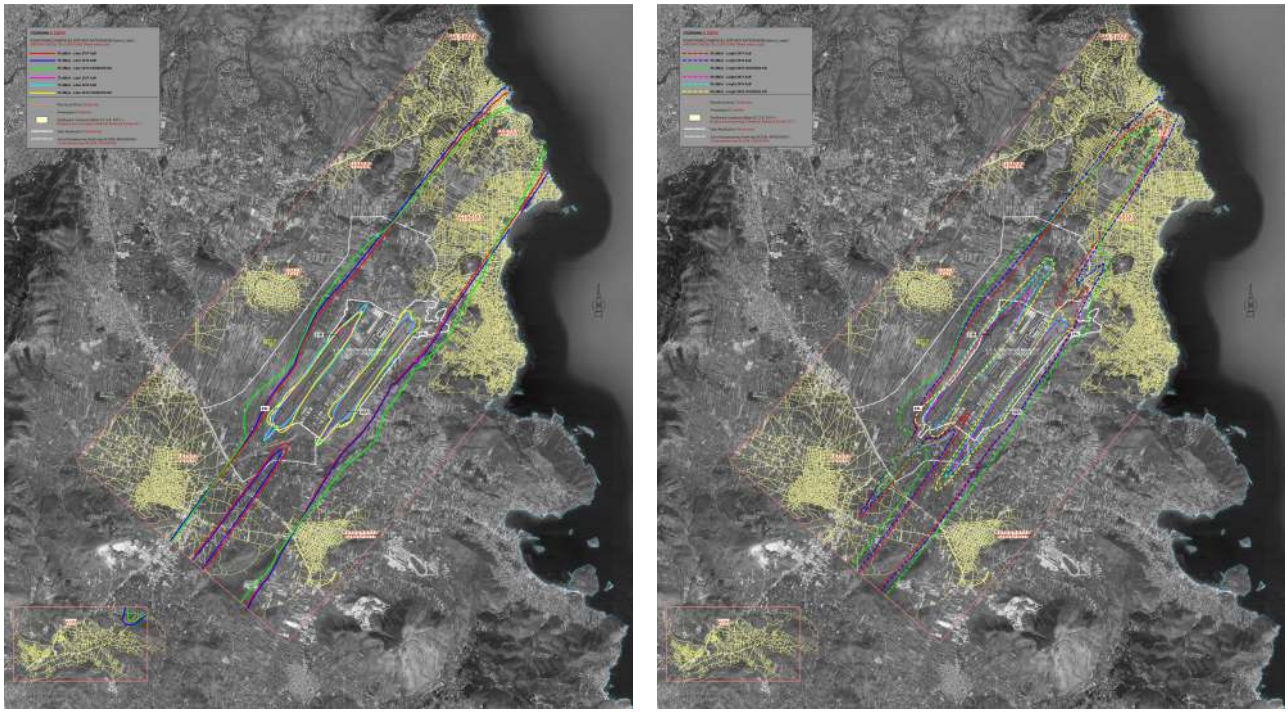


(a) (b)

Figure 6: SNM 2019 (CNOSSOS-GR) - Indexes L_{den} & L_{night}

Table 4: Population exposure at all 5 dB(A) buffer zones of L_{den} & L_{night} environmental noise indicators

Noise Zones dB(A)	Population exposure per noise index for: SNM 2017, 2019 (ECAC Doc.29) and SNM 2019 (CNOSSOS-GR)					
	L_{den} 2017 (ECAC) %	L_{night} 2017 (ECAC) %	L_{den} 2019 (ECAC) %	L_{night} 2019 (ECAC) %	L_{den} 2019 (CNOSSOS-GR) %	L_{night} 2019 CNOSSOS-GR) %
<45	53,7%	79,1%	50,7%	76,5%	41.1%	76.3%
45-50	12,8%	17,6%	14,6%	17,1%	22.6%	20.1%
50-55	12,6%	3,1%	11,4%	6,1%	16.8%	3.5%
55-60	18,7%	0,1%	19,0%	0,3%	16.6%	0,1%
60-65	2,3%	0.0%	4,2%	0.0%	2.7%	0.0%
65-70	0,0%	0.0%	0,0%	0.0%	0.1%	0.0%
70-75	0,0%	0.0%	0,0%	0.0%	0,0%	0.0%
>75	0,0%	0.0%	0,0%	0.0%	0,0%	0.0%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**



(a) (b)

Figure 7: Comparison of SNM 2017, 2019 (ECAC) & 2019 (CNOSSOS-GR) (a) L_{den} 55 dB(A) & 70 dB(A), (b) L_{night} 50 dB(A) & 60 dB(A)

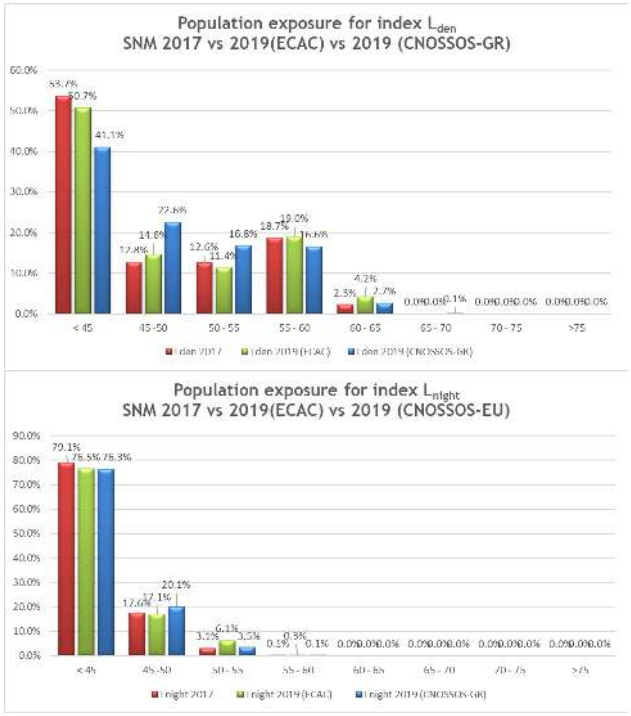


Figure 8: Population exposure for indexes L_{den} & L_{night}

6 Noise health assessment methodology – main results

According to World Health Organization (WHO) [12], the burden of disease is expressed in DALY's. Disability Adjusted Life Year or DALY combines in general population the time frame that people live with disabilities (YLD) and the time lost due to premature mortality (YLL):

$$\text{DALY} = \text{YLL} + \text{YLD}$$

The YLD is the number of incident cases (I) multiplied by a disability weight (DW) and an average duration of disability in years (L):

$$\text{YLD} = \text{I} \times \text{DW} \times \text{L}$$

The YLL corresponds to the number of deaths (N) and the Standard Life expectancy at the age in which death occurred (L):

$$YLL = N \times L.$$

The main results for the health burden of disease due to long term exposure to noise from aircraft are described in Table 5. As we can observe in the results, the overall findings are significantly lower in the case of SNM 2019 (as per the new methodology CNOSSOS-GR).

Table 5: Main results for the health burden of disease due to long term exposure noise from aircrafts

Strategic Noise Map (SNM)	2017 ECAC Doc.29	2019 ECAC Doc.29	2019 CNOSSOS-GR
Total Population	**79.487 as per 2011 census (all scenarios)**		
Cardiovascular (DALY per year)	1	2	5*
Annoyance (DALY per year)	77	89	74
Sleep disturbance (DALY per year)	16	32	0
Tinnitus (DALY per year)	1	1	1
Cognitive impairment in children (DALY per year)	199	230	190
Total DALY	**294**	**354**	**270**

** WHO BOD 2011, pg.27, Table 2.4, for road noise exposure: Exposure - response relationships of Cardiovascular disease relative risk (RR) according to different risk bands in L_{den}*

Figure 9: Noise regulation & WHO guidelines

These results according to the new methodology are explained by a more homogenic approach regarding the calculation of the exposed population with a more statistically correct distribution of the population to all building facades rather than to the most exposed facade as previously enforced (1^{st}, 2^{nd} & 3 rounds of 2002/49/EC directive), by implementing two representative cases, depending on the availability of data.

Figure 9 hereafter also presents a comprehensive table of both Noise regulation and the recent WHO recommendations for the European region [13].

The assessment of the population exposure to environmental aircraft noise is based, according to 2002/49/EC, on corresponding of the population on a receiver point at 4 ± 0,20m m above the terrain level in the most exposed building facade of the given residential buildings. How-

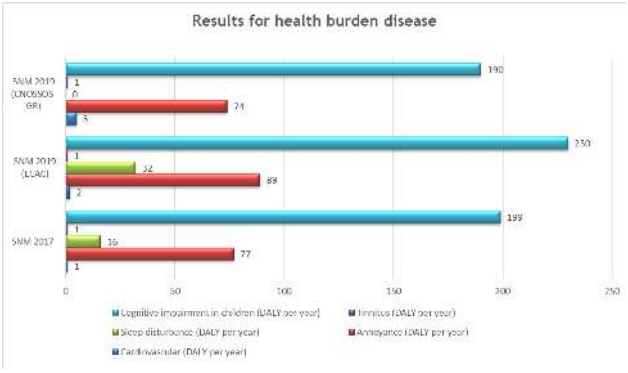


Figure 10: Main results for the health burden of disease

ever, the distribution of the inhabitants of a given building within Cnossos-EU methodology, two procedure cases respectively 1 and 2 are to be used as the most appropriate tools in order to evaluate the exposure to noise from land-based noise sources.

However, for aircraft noise, this approach is of a limited importance due to the particular form of the aircraft noise linear source (flight path) and the assignment of the total population of a given residential building is to be implemented to the nearest noise calculation point on the grid.

Although all these years lost due to air traffic cannot be a satisfying number, it can be considered as a small value.

7 Discussion and conclusions

The nuisance of environmental noise - in particular from the operation of the airport - is a growing concern and is accepted as a final point that can be taken as a basis for assessing the impact of noise on the exposed population, which in many cases can experience a variety of negative responses of an important level.

In many cases, as per the International Airport "Nikos Kazantzakis" at Heraklion in Crete, aircraft noise annoyance results are a very comprehensive evaluation tool towards an efficient noise action plan having an important impact to an eventual relocation of an airport.

Therefore, the influence at the inhabitants' acoustic comfort regarding aircraft operation is proven to be an important factor in the evaluation of the impact to local population [14, 15].

Ensuring a balanced approach to noise management in accordance with the International Civil Aviation Organisation (ICAO) should aim to maintain a balance between aviation needs as well as quality protection against aircraft noise.

Athens International Airport is the first international airport at European level that has calculated and compared aircraft noise levels with both European methodologies. Taking into account, the size of the airport remaining the major source of noise pollution sites, the noise emissions are quite comparable.

The main health effects on aircraft noise are comparable to the volume of the aircraft movement with a total of 294, 354 & 270 DALY respectively for three different case studies. The aim of the study is to show how the combination of both the implementation of the European Directive 2002/49 and 2015/996, as well as DALY's approach consists of a quality analysis tool to assess the healthy environment that ensures the assessment of all possible sources of noise in all areas possible, offering an opportunity to understand their impact on the population and, finally, to assess the extent of their impact as urban inconvenience. As we can observe in the results, the overall findings are significantly lower in the case of SNM 2019 (referred to the new methodology CNOSSOS-GR). The results show that annoyance represents the most widespread subjective response to noise, and noise judgment and the consequent disturbance are highly correlated with acoustical conditions inside classrooms [16].

As recently decided by the European Commission the amending of Annex III to Directive 2002/49/EC as regards the establishment of assessment methods for harmful effects of environmental noise, would be important for future research especially regarding especially high annoyance (HA), and high sleep disturbance (HSD).

However, in the case of railway and aircraft noise regarding ischemic heart disease (IHD), the population exposed above adequate L_{den} levels is estimated as subject to an increased risk of IHD, while the exact number N of cases of IHD cannot be calculated [17]. Sleep disturbance is part of the extra-authority effect of noise. It can be quantified objectively by number and duration of nocturnal awakenings, the number of sleep stage changes and modifications in their amounts [18].

Assessing the results of the SNM 2017 (Figure 7) compared to SNMs 2019 (ECAC Doc.29) and 2019 (CNOSSOS-GR) it is clear that the noise limits defined in JMD 211773 / 27-4-2012 are not exceeded and the updated Noise Action Plan incorporating among other restrictions the use of the "Tango" procedure is considered very effective.

In more detail, it seems that there is no population that is exposed above 60 & 70 dB(A) for L_{den} & L_{night}. Moreover, by combined these results with the results of DALY's, we can conclude, that despite the large increase in aircraft

movements, there is little impact on the acoustic environment.

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