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ANALYSIS OF NOISE ABATEMENT MEASURES ON EUROPEAN AIRPORTS

Abstract: *Air traffic noise is one of the major constraints of airport development. Many airports recognized noise problem long ago and have introduced a variety of measures to reduce its impact. The number and types of the introduced measures differ between airports. In order to determine the most influential factors for the introduction of noise abatement measures in airport surroundings, the research presented in this paper examined 248 European airports. By analyzing the correlation of specific characteristics related to airports (number of runways and aircraft operations, distance from the city and the population of the city that it serves, gross domestic product (GDP) per capita) and the number of introduced noise abatement measures, five hypothesis were examined: the higher number of aircraft operations causes the introduction of a higher number of noise abatement measures (NAMs); the higher number of runways will affect the introduction of a higher number of NAMs; airports that are closer to the settlement will introduce a higher number of NAMs; the higher population in the vicinity of the airport will affect the introduction of higher number of NAMs; the higher GDP per capita will affect the introduction of a higher number of NAMs. The results of analysis has shown that number of NAMs introduced doesn't have significant functional relationship with observed factors, except in some certain cases.*

Key words: noise, european airports.

INTRODUCTION

Aircraft noise is considered as one of the most influencing limiting factors of air traffic development, especially airports. Due to increase of population in cities and their territorial expansion, cities become more closer to airports, which parallel with air traffic growth, results in increase of number of people affected by negative noise effect.

Various organizations at the global level discuss possible solutions to the problem of air traffic noise. In September 2001, within the Resolution A33-7 [1], International Civil Aviation Organization (ICAO) has presented the policies and programs based on the so-called "Balanced approach" of aircraft noise management. In the guidelines for the application of a "Balanced approach", ICAO has recognized the need that the solution for noise problem should be discussed separately at each airport in accordance with the specific characteristics of the observed airport [2]. The guidelines are general and do not require an accurate and uniform application for all airports. However, the same solution can be applied if similar noise problems are identified at airports [2]. The Balanced Approach recommends that noise policy should not target single solutions but use any combination of solutions as the most appropriate option to solve the causes of problems [3] [4].

Many airports recognized noise problem long ago and have introduced a variety of measures to reduce its impact. Since 1999, Boeing maintains a database of airports around the world that implemented measures to reduce noise impacts [5]. The database contains basic information about airports and description of noise abatement measures implemented on specific airport.

Based on data from Boeing's database, Netjasov [3] provides an overview of the measures implemented at airports around the world showing their frequency and diversity. Due to ever-increasing volume of air traffic in the world, it was shown that the number of airports that are facing the problem of noise is increasing and that the number of airports that are introducing some measures to manage noise is increasing [3].

Although there are similarities between airports that are introducing some of the noise abatement measures, the number and type of applied measures are very different among them. In addition to all the previous knowledge of the subject, the question that remains open is [3]: what are the most influential factors for introduction of certain measures? The aim of the research presented in this paper is to analyze and show if the correlation between number of noise abatement measures introduced and specific characteristics related to airports (factors) exist thus to answer this question.

This paper is organized as follows. Section 2 describes types of measures that airports are introduced in order

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to reduce noise impacts. Particular emphasis was placed on noise abatement measures applied by the airports in Europe. Section 3 explains the research methodology, the main questions that motivated the study, the starting point for research, as well as a database based on which the survey was conducted. By analyzing the correlation of specific characteristics related to airports and the number of introduced noise abatement measures (NAMs), based on data collected for European airports, Section 4 provides the discussion of results obtained. Section 5 contains conclusions and future research directions.

NOISE ABATEMENT MEASURES

According to Boeing database, airports around the world have introduced ten different noise abatement measures so far [3] [5]:

1. Noise Abatement Procedures - referring to the procedures, i.e. on the arrival and departure trajectories, as well as recommended flying techniques.

2. Engine Run-Up Restrictions - referring to the restrictions on the engine testing (usually the specific facilities and location at the airports are intended for that) and the use of ''reverse thrust'' in landing.

3. Preferential Runways - referring to the runways predefined for arrivals and departures in case of airports with multiple runways (if traffic, weather and safety conditions permit).

4. Airport Curfews - referring to the time intervals in which takeoff or landing are not allowed for some or all types of aircraft (usually time intervals during the night or weekend) and they can be changed seasonally (summer, winter).

5. Noise Charges - referring to the additional charge to airlines whose aircraft exceed the allowable values of noise as well as additional charge to companies using older types of aircraft (louder), where the amount of charge can vary with the time of the day (e.g. more expensive during the peak period) and the weight of the aircraft (e.g. more expensive for the heavier aircraft).

6. APU Operating Restrictions - referring to the prohibition of the APU (Auxiliary Power Unit) use while the aircraft is on the ground and recommends the use of fixed or mobile GPU (Ground Power Units).

7. Noise Level Limits - refers to the allowed noise values in certain points of the noise monitoring system (usually per operation), the excess which leads to additional charges (or fines) applied to airlines.

8. ICAO Annex 16 Chapter 3/Chapter 2 Restrictions - refers to the prohibition of flying for the aircraft that are certified in accordance with Chapters 2 and 3 of ICAO Annex 16, Volume 1.

9. Operating Quotas - refers to the limit of the number of commercial operations at the annual or seasonal (summer, winter) level as well as the limited number of actual arrivals and departures during peak hours.

10. Noise Budget Restrictions - refers to the process of giving the time interval for the landing and taking off (slot allocation) in order to meet the defined criteria (e.g. the annual number of operations) and approved overall noise level (noise total volume).

Analyzing Boeing's database it was found that 603 airports applied some of the NAMs in the year 2009. In 2010, the number of airports increased to 630.

In this paper, a special emphasis was given on NAMs that European airports applied. According to Boeing's database, the number of European airports that applied some of the NAMs was 231 in 2009 and 246 in 2010.

Distribution of number of NAMs introduced per airport in Europe for years 2009 and 2010 is shown on figure 1.

From the figure 1 it can be seen that in both years, roughly 60% of airports are introducing one to four NAMs and 25% five to six NAMs. Only 1% of the observed airports have implemented all ten analyzed measures.

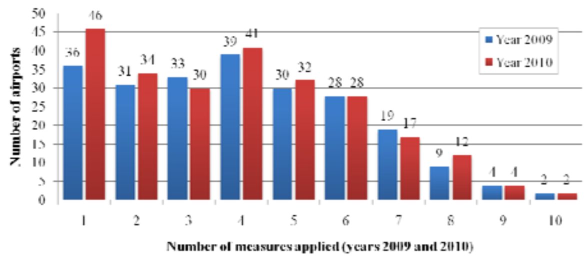
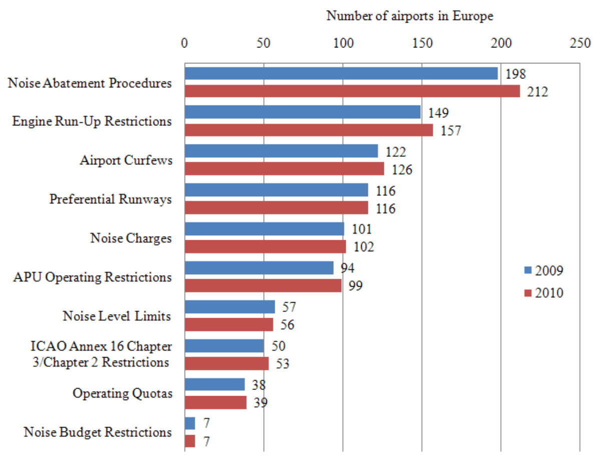


Figure 1 *Distribution of number of NAMs introduced per airport in Europe for years 2009 and 2010 (based on date from [5])*

Comparison of frequency of NAMs (ten previously mentioned) at European airports in years 2009 and 2010 is given in figure 2. The most common measures applied are Noise Abatement Procedures followed by Engine Run-Up Restrictions. Only seven airports have applied Noise Budget Restrictions.



Figur 2 *Distribution of number of airports in Europe that introduced certain noise reduction measures in years 2009 and 2010 (based on date from [5])*

RESEARCH METHODOLOGY

Number of introduced NAMs significantly differs among airports. In order to analyze characteristics of airports or their surroundings that are leading to different resolution of noise problem, first step in this research was to determine potential measurable factors that are presumed to have influence on introduction of NAMs.

Research starting point

Netjasov [3] stated that intuitively it is expected that airports with more aircraft operations (landings and take-offs), higher percentage of heavier aircraft in the fleet mix, closer to the settlements, greater population densities surrounding it, will implement more measures. However, in many cases, it seems that reasons for noise measure introduction are somewhat different [3]. Some of the reasons may be regulations concerning noise, citizen complaints or level of awareness of environmental protection.

To what extent will the airport surroundings be exposed to noise depends on many factors, and the most important are [6]:

- airport characteristics (number of takeoffs and landings, the distribution of traffic throughout the day and night, etc),
- fleet mix (types of aircraft that are using the airport),
- shape and characteristics of departure and arrival procedures, and
- airport location (topography).

Fleet mix, shape and characteristics of departure and arrival procedures, and airport location have a major impact on the creation and propagation of noise. However, in this study, they have not been taken into account because of the unavailability of operational data for a large number of the observed airports and the fact that procedure usage depends on current day meteorological and/or traffic situation.

It is necessary to consider distance from the airport to the city, because settlements closer to the airports are more exposed to noise. Airports with more runways have more options for designing different procedures for takeoff and landing in order to reduce noise and because of that, it is decided to consider the impact of number of runways on introduction of NAMs.

Comprehensive analysis of legislation was not conducted in this paper, but the impact of one EU directive on introduction of NAMs was shown. Number of citizen complaints on noise was not considered in this paper because for most airports data do not exist or are not found in the available databases. GDP per capita is used as a measure of level of awareness of environmental protection. The assumption in this paper is that developed countries, which have a higher GDP per capita, are more concerned about the negative impact of noise than less developed countries.

From all of the assumed factors, for further analysis, the following have been adopted:

- number of aircraft operations (take-offs and landings) on the airport,
- number of airport runways,
- distance from airport to the settlement,
- population in the vicinity of the airport,
- GDP per capita of the country where the airport is located.

Based on the presented research starting points, hypothesis that will be examined in this study are the following:

1. The higher number of airport operations causes the introduction of a higher number of NAMs.
2. The higher number of runways will affect the introduction of a higher number of NAMs;
3. Airports that are closer to the settlement will introduce a higher number of NAMs;
4. The higher population in the vicinity of the airport will affect the introduction of higher number of NAMs;
5. The higher GDP per capita will affect the introduction of a higher number of NAMs.

Design of database

To determine functional relationship between proposed factors and number of NAMs, it is primarily necessary to collect data about these factors for each airport that has applied at least one of the NAMs.

The basis for this research was Boeing's database of airports that implemented NAMs [5]. The research was conducted on the data set for years 2009 and 2010.

The data about the number of applied NAMs and number of runways for each observed airport were obtained from Boeing's database [5] (grass runways were excluded). Number of aircraft operations is taken from EUROCONTROL's STATFOR Interactive Dashboard [7]. STATFOR database takes into account only IFR flights. GDP per capita (in dollars) for every country was taken from World Bank website (http://data.worldbank.org/indicator/ NY.GDP.PCAP.CD) .

For the purposes of this research, proximity to the settlement was defined as distance from airport to center of a city that airport serves. For most airports, the data about distance to city center and cities that airport serves, was taken from Wikipedia. For some airports, website www.distance.to was used for estimation of distance to the city center. For airports serving several cities, the average distance from the cities was calculated according to the following formula:

$$d_{avg} = (\sum_{i=1}^{n} d_i \cdot P_i) / \sum_{i=1}^{n} P_i \quad (1)$$

where: d_{avg} is average distance from the cities, d_i is distance from city i to the airport, P_i is population in city i, n is number of cities.

Since the distance from the noise source limits impact of noise, the following assumption was made: the impact of noise on residents near the airport is only relevant in the radius of 20 km from the airport. However, since this assumption can significantly affect the result of the research, in the first case, all the cities that airports serve are taken into account, while the second case takes into account only cities that are located within a radius of 20 km from the airport. This principal was applied only with airports that serve several cities. For airports that serve only one city, the distance from the city center was taken, regardless of the fact that city is located in the radius of 20 km from the airport. Collecting data about city population was carried out from two sources. For most cities, the data about population was taken from EUROSTAT, and for some of them that were not available, the data was taken from Wikipedia.

DISCUSSION OF RESULTS

In order to examine the five above-mentioned hypotheses, the correlation between the proposed factors and the number of NAMs was determined, based on the collected data.

For the same set of data, for the average distance from airport to the city centre and city population, two cases were considered, depending on whether they take into account all or only cities that are located within a radius of 20 km from the airport. The results of statistical analysis for year 2010 are shown in **Table *1***. Statistical indicators that were analyzed are the correlation and determination coefficients, as well as statistical significance.

Table 1. *Results of statistical analysis for year 2010*

			Correlation (Dependent variable - Number of NAMs)		
			Pearson correlation coefficient (r)	Coefficient of determination (r^2)	Sig. (1-tailed)
Independent variable	Number of aircraft operations (in thousands)		0.503	0.253	0.000
	Number of airport runways		0.352	0.124	0.000
	Average distance	All cities	0.173	0.030	0.003
		Within 20 km	0.144	0.021	0.012
	Population (in thousands)	All cities	0.261	0.068	0.000
		Within 20 km	0.238	0.057	0.000
	GDP per capita (in thousands)		0.183	0.034	0.002

Functional relationship between the dependent variable number of NAMs and two independent variables (the number of aircraft operations and the average distance from airport to the city) is given in figure 3. From the figure 3, large dispersion can be seen, which is also characteristic for the other independent variables. For the majority of independent variables, positive dependence is found, which is in accordance with all of the hypotheses, except in the case of distance. From the figure 3, it can be seen that with the increase of the average distance, the number of implemented NAMs also increases, which contradicts the hypothesis regarding distance.

The highest coefficient of determination, but still insignificant, was obtained for the number of aircraft operations (R^2=0.253), while for the number of runways it was 0.124, which can be seen from table 1. For the other independent variable, the coefficient of determination was less than 0.07.

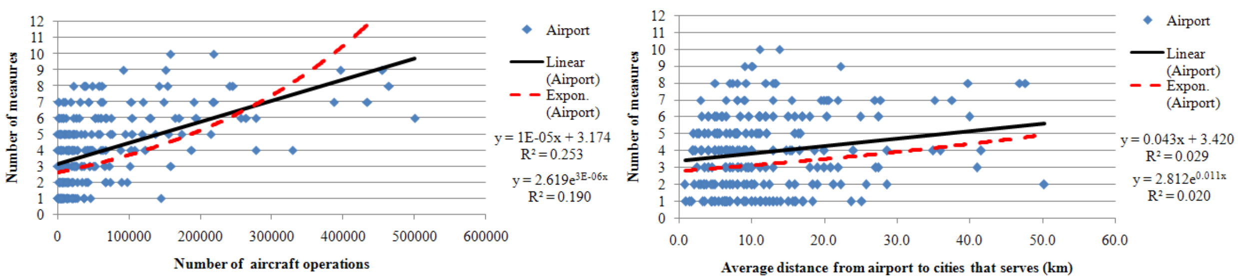


Figure 3 *Correlation between number of NAMs introduced and specific characteristics related to airports (year 2010)*

4.1. Multiple linear regression

In order to examine correlation between all five proposed factors and the number of introduced NAMs, backwards multiple linear regression was conducted. In the first step, five independent variables entered the model:

- number of aircraft operations (in thousands)
- number of airport runways,
- average distance: all cities (in km),

- city population (in thousands),
- GDP per capita (in thousands).

As a final result of multiple linear regression, only the number of aircraft operations and GDP per capita showed statistical significance. The correlation coefficient with the dependent variable (the number of NAMs) was 0.531, indicating a moderate functional relationship between these variables. The coefficient of determination was 0.282, which means that the number of aircraft operations and the GDP per capita explains 28% of variability of the dependent variable number of NAMs.

Linear regression based on strategic noise maps data

In 2002, the European Parliament and Council adopted Directive 2002/49/EC relating to the assessment and management of environmental noise, which among other things, requires the development of strategic noise maps and action plans for airports with over 50,000 takeoffs and landings per year, in order to reduce the environmental noise. Strategic noise mapping is defined as the presentation of data on an existing or predicted noise situation in terms of a noise indicator, indicating breaches of any relevant limit value in force, the number of people affected in a certain area, or the number of dwellings exposed to certain values of a noise indicator in a certain area [8].

In this paper, an additional analysis was conducted based on data from available strategic noise maps for 73 European airports. Unlike average distance and city population, which were used in previous analyzes, the number of people exposed to different bands of noise indicators L_{den} and L_{night} was used in this analysis. For noise indicators L_{den}, the number of people outside agglomerations and including agglomerations is shown in the noise bands by 5 dB steps, starting from 55dB. For noise indicators L_{night}, only the number of people outside agglomerations is shown, in the noise bands by 5 dB steps, starting from 50 dB.

As in previous analyzes, dependent variable was number of NAMs, and 16 independent variables were analyzed. The correlation between the independent variables and the number of NAMs in year 2009 was determined through linear regression analysis (**Table 2**). Pearson correlation coefficient shown in **Table 2** take values between -0.11 and 0.28, and indicates that the relationship between the dependent and independent variables is very weak, almost non-existent. For three independent variables, negative correlation was shown. That is because for most airports, the number of people exposed to noise bands over 75 dB for L_{den} and over 70 dB for L_{night} equal to zero (these values correspond to the noise close to the runway) and a few airports that have this value above zero, applied the number of NAMs under the average.

Most of the independent variables did not show statistical significance. The number of people exposed to noise bands over 55 dB, over 65 dB and total number of people for L_{den} including agglomerations, are three independent variables that showed statistical significance. However, correlation coefficient for these three variables is around 0.28, indicating that the correlation between variables is not significant, while the coefficient of determination is little less than 8%.

Table 2. *Results of statistical analysis (regarding strategic noise maps)*

			Correlation Dependent variable (Number of NAMs)		
			Pearson correlation coefficient (r)	Coefficient of determination (r^2)	Sig. (1-tailed)
Independent variable (Population)	Outside agglomerations	55-59 L_{den}	0.152	0.023	0.102
		60-64 L_{den}	0.074	0.005	0.269
		65-69 L_{den}	0.057	0.003	0.317
		70-74 L_{den}	0.055	0.003	0.322
		> 75 L_{den}	-0.091	0.008	0.223
		total L_{den}	0.122	0.015	0.152
		50-54 L_{night}	0.132	0.018	0.135
		55-59 L_{night}	0.128	0.016	0.142
		60-64 L_{night}	0.012	0.000	0.461
		65-69 L_{night}	-0.065	0.004	0.293
		> 70 L_{night}	-0.111	0.012	0.177
		total L_{night}	0.130	0.017	0.137
	Including agglomerations	> 55 L_{den}	0.281	0.079	0.009
		> 65 L_{den}	0.280	0.078	0.009
		> 75 L_{den}	0.141	0.020	0.122
		total L_{den}	0.278	0.077	0.009

Cluster analysis

For the purpose of grouping and detailed analysis, the observed airports are divided into smaller sets that have similar characteristics.

Number of aircraft operations clusters

Distribution of the number of European airports that are grouped according to the number of aircraft operations in the classes of 50,000 operations is shown on figure 4.

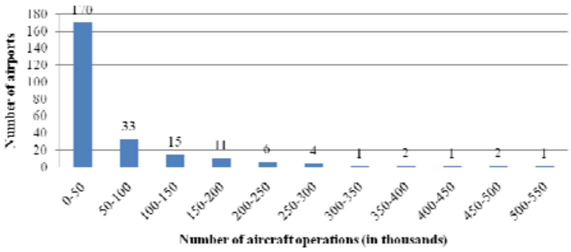


Figure 4 *Clustering European airports according to the number of aircraft operations (year 2010)*

From the figure 4 it can be seen that the largest number of airports have up to 50,000 operations, while only seven of the 246 airports have over 300,000 aircraft operations.

The observed airports are divided into three clusters. The first cluster makes 170 airports with up to 50,000 aircraft operations. The second cluster includes 33 airports that have between 50 and 100 thousand operations, while 43 airports with over 100 thousand operations makes the third cluster.

For each cluster, an analysis was conducted in order to determine the correlation between the number of NAMs and the number of aircraft operations for airports in the observed cluster. Scatter chart for the variables number of NAMs and the number of aircraft operations for airports belonging to the first cluster (up to 50,000 aircraft operations) is shown on figure 5.

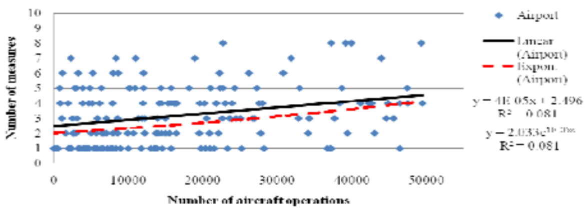


Figure 5 *Number of implemented NAMs as a function of number of aircraft operations (up to 50000, year 2010)*

From figure 5 it can be seen that positive dependence is obtained. The coefficient of determination is 0.081, indicating that the correlation between variables is not significant. Similar results were obtained for airports in the second and third cluster.

GDP per capita clusters

The observed sample is divided into clusters based on GDP per capita. Distribution of airports that are grouped according to GDP per capita in the classes of 10 thousand of dollars is shown on figure 6. It can be seen that the largest number of airports is located in countries that have a GDP per capita between 30 and 50 thousand of dollars.

The observed sample is divided into three clusters. The first cluster makes 62 airports that are located in countries with a GDP per capita up to 30 thousand of dollars. The second cluster includes 161 airport with a GDP per capita between 30 and 50 thousand of dollars, while 23 airports with a GDP per capita over 50 thousand of dollars makes the third cluster.

For each cluster, an analysis was conducted in order to determine the correlation between the number of NAMs and the GDP per capita for airports in the observed cluster. As for clustering according to the number of aircraft operations, similar results were obtained for all GDP per capita clusters. For this reason, only analysis for airports that belong to second cluster will be described here.

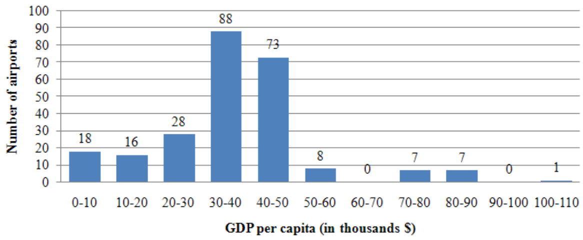


Figure 6 *Clustering European airports according to GDP per capita (year 2010)*

Scatter chart for the variables number of NAMs and the GDP per capita for airports belonging to the second cluster (between 30 and 50 thousand of dollars) is shown on figure 7.

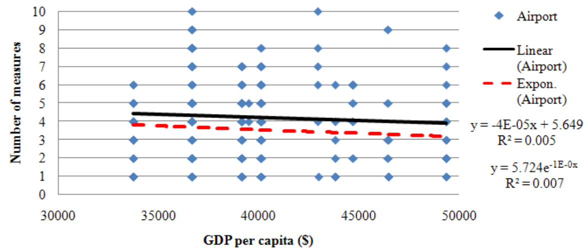


Figure 7 *Number of implemented NAMs as a function of GDP per capita (30000-50000$, year 2010)*

From figure 7 it can be seen that negative dependence is obtained, which contradicts the hypothesis that the higher GDP per capita will affect the introduction of a higher number of NAMs. The coefficient of determination is less than 1%, indicating that the correlation between variables is not significant.

Clustering according to number of introduced NAMs

All airports within the sample can be grouped according to the number of applied NAMs in order to conduct detailed analysis and search for their common characteristics. Since the number of aircraft operations and GDP per capita are only two variables that showed any statistical significance in relation to the number of applied NAMs within the multiple linear regression analysis, further work will show the relationship of these two variables for airports with the same number of NAMs. Clustering according to number of introduced NAMs is shown in table 3.

For each group of airports, minimum and maximum values of number of aircraft operations and the GDP per capita are given and the percentage of airports that have applied certain NAMs.

Measures that were mainly applied by airports in each group are marked blue. For example, of all airports that have applied only one measure in 2010, 72% of them have implemented a Noise Abatement Procedures (NAP). In case of airports that have applied eight NAMs, each of them have applied Airport Curfews and Noise Abatement Procedures, while 92% of them applied the Operating Quotas, Engine Run-Up Restrictions and ICAO Annex 16 Chapter 3/Chapter 2 Restrictions. Due to the large overlap of ranges, it cannot be argued with great accuracy how much NAMs the airport should introduced on the basis of the number of aircraft operations at the airport and the GDP per capita of the country in which the airport is located.

Table 3 *The distribution of the number of NAMs on airports in Europe in 2010*

No. of NAMs 2010	No. of airports	No. of operations (minimum)	No. of operations (maximum)	Min GDP	Max GDP	APU	Curfew	NAP	Noise Budget	Noise Charges	Noise Limits	Pref Rwys	Quota	Run-Ups	Stg3-Ch3 Rest
1	46	6	145043	1632	86156	0%	7%	72%	0%	4%	2%	7%	0%	9%	0%
2	34	1624	97678	2974	86156	3%	12%	82%	0%	35%	0%	26%	0%	41%	0%
3	30	1105	159109	5843	86156	40%	43%	70%	0%	30%	0%	37%	3%	77%	0%
4	41	856	329343	6335	56486	46%	56%	98%	0%	32%	20%	59%	7%	78%	5%
5	32	794	214990	7670	70370	59%	81%	88%	0%	56%	31%	66%	19%	78%	22%
6	28	1145	500325	7670	102009	71%	86%	96%	0%	71%	54%	68%	14%	89%	50%
7	17	2271	433836	29863	86156	71%	88%	100%	12%	82%	35%	82%	53%	100%	76%
8	12	22721	464275	21382	56486	83%	100%	100%	17%	67%	83%	75%	92%	92%	92%
9	4	92683	455320	18867	46468	100%	100%	100%	25%	100%	100%	100%	75%	100%	100%
10	2	158162	218776	36703	42960	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

From the table 3 it can be seen that there are airports that have introduced only one NAMs, but have twice the GDP per capita of the airports that have introduced ten NAMs. Similarly, there are airports that have introduced three NAMs, but have more than 250,000 aircraft operations, while certain airports with less than 25,000 aircraft operations have introduce eight NAMs.

These differences indicate the existence of additional factors that, together with the initial two have influence on the introduction of NAMs. This is confirmed in the results of multiple linear regression analysis, which indicated that the number of aircraft operations and the GDP per capita explains only 25% of variability of the dependent variable number of NAMs.

Clustering by country

In this analysis, observed airports are grouped according to the country where they are located. In order to analyze influence of GDP per capita on number of NAMs per country, the number of implemented measures for each airport is not considered separately, but as the average value on country level.

Impact of GDP per capita on the average number of applied NAMs by European countries in 2010 is shown on figure 8.

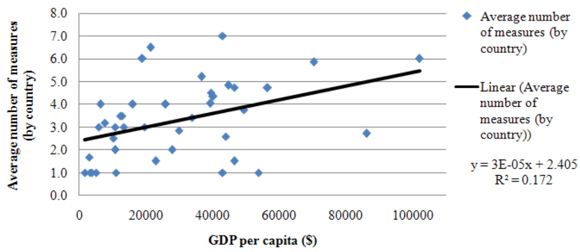


Figure 8 *Average number of applied measures by country as a function of GDP per capita (year 2010)*

Figure 8 shows linear dependence between variables. Coefficient of determination was 17%, indicating that the correlation between variables is not significant. Nevertheless, it can be seen that the impact of GDP per capita is much higher when the number of implemented measures is considered as the average value at the state level, in comparison with 3% coefficient of determination when the number of NAMs is considered separately for each airport.

The influences of the number of aircraft operations on the number of implemented measures for airports grouped by countries were also tested in this research. Due to the sample size, only countries with more than ten airports in the sample were analyzed and they are United Kingdom, Germany, France, Italy, Spain and Sweden. The results of analyzes for year 2010 are given in table 4.

Table 4. *Correlation between number of aircraft operations and number of applied NAMs by country*

Country	No. of measures	No. of airports	Pearson correlation coefficient (r)	Coefficient of determination (r^2)
UK	193	37	0.512	0.262
Germany	126	29	0.607	0.368
France	101	25	0.517	0.267
Italy	82	24	0.453	0.205
Spain	57	20	0.848	0.719
Sweden	64	17	0.559	0.313

From table 4 it can be seen that functional relationship between number of aircraft operations and number of NAMs is the largest for airports in Germany and Spain. Correlation between number of aircraft operations and the number of applied NAMs for airports in Germany for year 2010 is shown on figure 9. Positive dependence is obtained. The coefficient of determination (R^2_1=0.368) obtained from this cluster analysis is greater than the coefficient of determination obtained on the basis of linear dependence tested on the entire sample (R^2_2=0.253), which was previously presented in the paper.

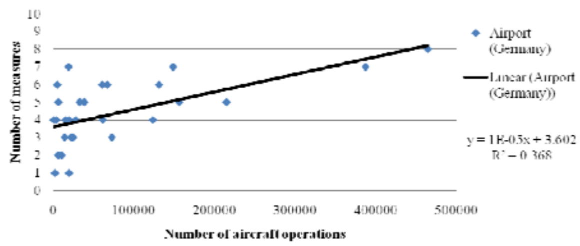


Figure 9 *Correlation between number of aircraft operations and the number of applied NAMs for airports in Germany*

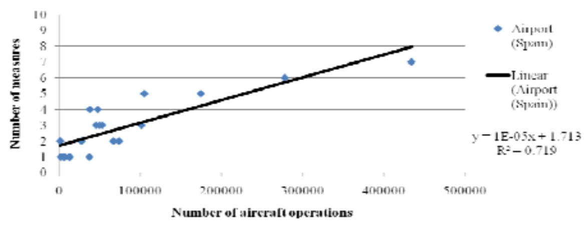


Figure 10 *Correlation between number of aircraft operations and the number of applied NAMs for airports in Spain*

Much greater difference was observed for airports in Spain (**Figure *10***). The coefficient of determination was around 72%, indicating a very good correlation between the number of aircraft operations and the number of NAMs implemented at airports in Spain.

Clustering regarding noise monitoring

Another analysis was conducted in this research. The aim was to determine the effect of Directive 2002/49/EC on the implementation of certain NAMs, since this directive also requires that all airports with over 50,000 aircraft operations per year have to introduce a noise monitoring system.

The analysis was based on assumption that most airports that have introduced a noise monitoring system (due to legal obligations or voluntary) will use this system to apply specific NAMs, such as Noise Level Limits or Noise Charges. Both measures include establishment of allowed noise values in certain points of the noise monitoring system (usually per operation) whose exceeding leads to additional charges (or fines) applied to airlines.

The second assumption was that the percentage of non-EU airports with over 50,000 aircraft operations, which applied the two aforementioned NAMs, would be much lower compared to airports located in the European Union, due to the lack of legal requirements for the introduction of noise monitoring system. This could to some extent, prove the impact of regulation on the introduction of NAMs.

The number and percentage of European airports with over 50,000 aircraft operations, which applied specific NAMs in 2010 is shown in table 5. Airports were grouped according to whether they were in the European Union or not.

From table 5 it can be seen that in 2010, 73% of EU airports has implemented Noise Charges, while 45% of them have applied Noise Level Limits. From all of the non-EU airports with more than 50,000 aircraft operations, 30% of them have applied two aforementioned NAMs.

From the results shown, in the case of Noise Charges it can be seen a clear difference between the airports which were located in the European Union and other European airports. The reason for that may be different regulation, but it is necessary to analyze the influence of other factors.

Table 5. *Clustering regarding noise monitoring, [5]*

Measures in Year 2010	EU (66 airports with more than 50000 aircraft operations)		Non EU (10 airports with more than 50000 aircraft operations)	
APU Operating Restrictions	37	56%	5	50%
Airport Curfews	48	73%	4	40%
Engine Run-Up Restrictions	61	92%	8	80%
Noise Abatement Procedures	63	95%	10	100%
Noise Budget Restrictions	5	8%	0	0%
Noise Level Limits	30	45%	3	30%
Noise Charges	48	73%	3	30%
Operating Quotas	17	26%	1	10%
Preferential Runways	42	64%	6	60%
ICAO Annex 16 Chapter 3/Chapter 2 Restrictions	30	45%	2	20%

CONCLUSION

Analysis of noise abatement measures, presented in this paper has shown functional relationship between the observed factors and the number of NAMs introduced at European airports. The research was conducted based on data from Boeing's database for years 2009 and 2010 for 248 European airports. For each airport, data on number of runways and aircraft operations, distance from the city and the population of the city that it serves, GDP per capita of the state in which airport is and the number of introduced NAMs were collected.

Examination of initial hypotheses was performed by testing the correlation between the five proposed factors and the number of introduced NAMs.

Linear regression analysis has shown that all the independent variables are statistically significant, but their association with the dependent variable is weak or almost nonexistent. Only the number of aircraft operations showed a moderate correlation with the number of NAMs, with coefficient of determination of 25%.

Using the backwards multiple linear regression, only the number of aircraft operations and the GDP per capita showed statistical significance, which explains about 28% of the variability of the dependent variable number of NAMs. Based on the obtained results it can be concluded that initial hypotheses were not confirmed.

Based on the information from strategic noise maps for 73 European airports, the correlation between the number of people exposed to different bands of noise indicators L_{den} and L_{night} with a number of NAMs introduced at the airport were analyzed. Also in this case, significant functional relationship between the tested variables was not found.

For the purpose of detailed analysis of introduced NAMs, the observed airports are grouped into specific clusters.

In the case of clustering according to number of aircraft operations, GDP per capita and number of NAMs, correlation coefficients obtained indicated a weaker relationship between variables in the clusters compared to the relationship within the whole sample.

Clustering by country has shown that correlation between average number of applied measures and GDP per capita for each country is not significant, but is much higher in comparison when the number of NAMs is considered separately for each airport. Correlation between number of aircraft operations and number of NAMs for airports in the same country has shown that coefficient of determinations are much higher than those obtained for the whole sample, which shows that at the state level there is a higher correlation between the observed variables. In case of airports in Spain, obtained results indicate that the number of aircraft operations explains 72% of the variability of the dependent variable number of NAMs.

Based on available data, additional analyzes was carried out in order to determine the impact of regulation on the implementation of certain NAMs. The results showed that in 2010, 73% of the airport in the European Union, which has over 50,000 aircraft operations applied Noise Charges on the basis of a noise monitoring system, compared to 30% of the non-EU airport. The reason for this may be the Directive 2002/49/EC, but it is necessary to analyze the influence of other factors.

In addition to analyzes described above, there are several ways to improve the conducted research. As each measure requires the involvement of some resources, analysis of the impact of the necessary resources for introduction of NAMs on the number of introduced NAMs may be the subject of future research. Comprehensive analysis of legislation and its impact on the introduction of NAMs is also planned.

Analysis of the sequence of introduction of NAMs based on Boeing's database for the period 1999-2010 may be useful for better understanding of this subject and may answer the question does airports follow a certain sequence of introduction of NAMs.

Based on this research, it was concluded that it is better to pay particular attention to each measure separately, because of its specificity. This means that future studies should focus on answering the question why airports are introducing certain measure at a certain point rather than to observe measures together.

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ANALIZA MERA ZA SMANJENJE UTICAJA BUKE EVROPSKIH AERODROMA

Emir Ganić, Feđa Netjasov, Obrad Babić

Rezime: *Buka vazdušnog saobraćaja trenutno predstavlja jedno od glavnih ograničenja njegovog razvoja, a naročito aerodroma. Mnogi aerodromi su odavno prepoznali problem buke i uveli različite mere za smanjenje njenog uticaja. Broj i vrste uvedenih mera se razlikuju među aerodromima. U cilju određivanja najuticajnijih faktora za uvođenje mera za smanjenje uticaja buke u okolini aerodroma, u ovom radu su prikazani rezultati istraživanja na uzorku od 248 aerodroma u Evropi. Analizom korelacije određenih karakteristika vazanih za aerodrome (broj poletno-sletnih staza, broj operacija poletanja i sletanja, udaljenost od grada koji opslužuje, broj stanovnika grada koji opslužuje, bruto domaći proizvod (BDP) po glavi stanovnika države u kojoj se nalazi) i broja uvedenih mera za smanjenje uticaja buke, testirano je pet hipoteza: veći broj operacija na aerodromu uslovljava uvođenje većeg broja mera za smanjenje uticaja buke; veći broj PSS će uticati na uvođenje većeg broja mera za smanjenje uticaja buke; aerodromi koji su bliži naselju će uvoditi veći broj mera za smanjenje uticaja buke; veći broj stanovnika u blizini aerodroma će uticati na uvođenje većeg broja mera za smanjenje uticaja buke; veći BDP po glavi stanovnika će uticati na uvođenje većeg broja mera za smanjenje uticaja buke. Rezultati testiranja su pokazali da broj mera za smanjenje uticaja buke nema značajnu funkcionalnu vezu sa posmatranim faktorima, osim u pojedinim razmatranim slučajevima.*

Ključne reči: mere za smanjenje uticaja buke, aerodromi.