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Traffic Noise Assessment of Developing Urban Arias in Greece – The City of Athens Case

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Abstract. This paper describes a statistical method for assessing disturbance in distinctly populated arias due to traffic noise elaborating the concept on noise events. Traffic noise assessment is usually produced using (L(A)eq) levels for every hour which correspond to a continuous stationary noise source equivalent to the non-stationary sound pressure levels actually measured in an acoustic environment. It is obvious that this index is not taking in to account differences of the (L(A)eq) levels or noise events occurring in the time interval of one hour. In addition to using the A-weighted equivalent continuous sound level L((A)eq), as an index of annoyance this approach uses additional parameters such as: the amplitude difference between the sound pressure level of noise events in comparison to the background noise, the number and the frequency of occurrence of events and the short time spectral characteristics of noise. The method detects events and classifies according to the disturbance they may cause. The developed method was used to assess disturbance from road traffic noise of major motorways in the city of Athens, Greece as well as railway and air traffic noise. Several noise descriptors were either measured or calculated and used to evaluate the disturbance caused by transportation noise.

1. INTRODUCTION

The aim of this investigative research is to create a tool for the control of noise pollution, in areas that produce high levels of environmental noise, in order to be used by local authorities. This tool consists of a digital system that accumulates and processes noise information from a variety of measurements. With this tool the acoustical perception is compared with actual

measurements and indexes. Finally the reasons and the characteristics of noise are clarified while the results of various researches are compared.
The Acoustics Measurement Laboratory, created at the National Technical University of Athens (NTUA), is used for pilot measurements, the analysis of data and the prediction of acoustic pollution. The method is based on a digital system that processes measurements and a database for various areas with noise problems.
The data are collected after on-the-spot measurements in the area or older measurements which have been taken from credible sources (for example older measurements, noise charts/maps, environmental acoustics researches, maps of older land use). Certain areas of the city of Athens as well as others (rural and non-rural) were chosen for pilot measurements. The criteria used to chose these areas was based on which areas had records of noise pollution in the past.

2. IMPACT OF ENVIRONMENTAL NOISE

The noise levels that are connected to sources of environmental noise are most likely not to produce acoustic anomalies (with exception music from amplifiers and living close to a building sight) but can definitely create secondary negative reactions to ones health. These are usually the increase in stress levels, sleep deprivation and difficulties in communication and completing certain duties, due to the annoyance of noise.
Many researchers examine the affect of various types of environmental noise for example traffic noise, noise from airplanes or trains. Most of these use a questionnaire technique which states the percentage of people who were affected by each type, the level of noise and period of exposure time in relevance to sleeping disorders, annoyance, production of speech and difficulties in functioning. The problem with coming up with a definite conclusion is that different types of noise has been measured with different parameters, L(A)eq, L(A)10,Ldn and different positions (interior or exterior of buildings) and by different researchers. Some studies have been done in laboratories and controlled spaces which by itself may affect the person being examined. The various forms of impact that environmental noise may have are connected. For example a sleeping disorder can create a feeling of fatigue while the fatigue can create stress due to the fact that the person is too tired to function properly. That is why these different impacts must be discussed individually.
In the range of noise produced by transport there are different reactions to different types of transport (car, train, and plane) even though these may have the same noise levels and are measured using the same parameters. It was observed that as noise levels increased the people being examined were annoyed with airplanes and cars more than trains.

3. NOISE MEASUREMENTS AND ANNOYANCE REACTIONS

The ability that noise has to produce annoyance depends on many physical characteristics, including the sound pressure levels and spectral characteristics as well as the changes of both of these during a period of time. Relationships between exposure to sound and reactions to different types of transport noise portray clearly that noise can create different types of annoyance. The same type of noise like the one in rural areas around airports may produce different reactions and annoyance levels in different countries.
Annoyance due to noise in a community is different depending on the type of activities that produce the noise. During daytime annoyance is created by activities that produce noise levels below L(A)eq 55 dB(A) or medium type annoyance by activities producing noise

levels below L(A)eq 50 dB(A). The sound pressure levels during nighttime must be 5-10 dB lower than at daytime. Noise that includes intense frequencies in the lower region demands even lower levels. For noise with interruptions it is important to take into consideration the higher pressure levels as well as the amount of noisy events.
The day-night index (L day-night, LDN), is taking into account that high levels of noise are more disturbing during the sleep cycle. For the evaluation of this index 10dB are added to the SPL measurements for the night period from 23:00 to 07:00 hours. This index is also using a statistical average of SPL levels every hour. Again, in this case, differences of the (L(A)eq) levels or noise events in measurements are not represented from the index.
For traffic noise assessments other indexes have been proposed and used in order to include disturbances during the sleep cycle such as the Noise Pollution Level, Lnp [1] and the Traffic Noise Index, TNI [2]. Laboratory studies of the sleep cycle conclude that the most important parameters for sleep disturbance are the noise level and the number of noise events. For the estimation of sleep disturbance it has been proposed that these parameters can be used as independent variables instead of estimating one single index [3].
In this work a method is proposed for automatic event detection in traffic noise signals producing an estimate of the event's disturbance. The algorithm determines events according to the difference between the sound pressure level of the event and the background noise L(A)90 level. Spectral characteristic of the event are also taken into account. Analysis in time-frequency also can be used. This approach detects events that occur in frequency bands. This is implemented by using time-frequency decomposition of the noise signal in frequency bands [4] and then applies the detection algorithm in each band individually. For this purpose a recursive realisation of the Short Time Fourier Transform [5] is used.

4. THE SLEEP FUNCTION AND DISTURBANCE

Sleep function disturbance is one of the most common reasons of annoyance because at this stage people have no resistance. As a result, the last 20 years researchers found out the noise affects on sleep. Sleep as a phenomenon is very complicated. It may be concerned that sleep consists of sequences circles lasting 90 minutes and composed of the following stages. Stage 1 is mediated between awaking and sleep. Stage 2 becomes after stage 1 and is the limit line of sleep. Sage 2 leads to sleep. Stages 3 and 4, known also as Delta sleep, are the deepest stages of sleep and the most revival. Stage 5 or REM (Rapidly Eye Movement) is the most active stage of sleep where dreams happen.
Different studies representations and methods cause difficulties to support that a specific noise level product a specific reaction about annoyance sleep. Important differences are mentioned between studies taking place in real acoustic environments and studies in a laboratory.
In spite of the problems about noise influence on sleep, investigations came to a conclusion. Abel describes a number of laboratory and home researches and reports that in almost every case increased level of noise caused disturbance in quality sleep, as a short time of sleeping, more times awaking, and slipping between different levels of sleep [6].
Studies about sleep disturbance report that the increase of level 1 has been affected by traffic noise major sound level 50-60 dB(A) and the number of events and the high level of noise are affected more by the equivalent level according to sleep disturbance [7], [8].
The influence of noise is also depended on the time of sleep when the event happens. As time is passing it is easier for the sleep function to be disturbed. Ohrstrom studies report that

between awaking and sleep the number of noise events is more important than the high level of noise, while the high level is relative on the possibility of awaking [9].
Except noise, many other elements affect quantity and quality of sleep. As the age, the family condition and how much deep or soft is someone's asleep. Fear is another reason for sleep annoyance [10].

5. EXTRACTING EVENTS FROM TRAFFIC NOISE SIGNALS.

Noise events are extracted on the time domain using energy changes of noise signals and the time instances when the event happens are determined. Events are assigned to have more energy than the background noise, considering that the background noise level is non stationary, so that fluctuations of noise are intended.
The extracted events are characterized by the term of the time and relative intensity. The difference between the noise pressure level of the event and the background noise makes the relative intensity.
The disturbance caused by transportation noise is highly associated with the number, amplitude and frequency content of noise events [11]. Noise events are detected in the time domain using the fluctuations of the energy of the signal as an index to where an event occurs. Events are defined as having double energy of the background noise. The values of background noise are calculated using variable time intervals.
Event detection in transportation noise signals is usually employed to evaluate sleep disturbance. Sleep disturbance caused by transportation noise includes increased sleep latency, shorter duration of sleep, increased number of awakenings and abnormal shifts in sleep stages resulting in symptoms such as tiredness and slow reaction for the person. According to Horonjeff et al. it is probable the difference between the background noise level and event noise levels rather than the absolute event level that is of importance for awakenings [12]. Following this approach the difference between the level of the detected events and the background noise level is calculated.
The decomposition of an event in time-frequency [ ] shows the allocated spectra ingredients and the relative of time term. So events can de distinguished in harmonics, wide and narrow spectra.

6. KIFISSIAS AVENUE ACOUSTIC ENVIRONMENT

The Olympic Stadium region has been chosen as a pilot area for noise traffic assessment. The measurements were concentrated along crossing Kifisias Avenue (a main road artery linking the suburbs with the city centre having three lanes plus one lane for local traffic each direction) which is a characteristic example of main road arteries in Athens. This road crosses residential, business, trading areas and the Olympic Stadium complex. In general, it is a reconstructed area for the Olympic Games of 2004, so it is interest to study the consequences to the acoustic environment.
The research of the differentiation of rates recorded between day and night periods is very interesting. The day period is set at 16 hours (07:00-23:00) while the night period is 8 hours (23:00-07:00). These rates which provide information concerning the equivalent noise levels as well as background noise levels and the maximum noise levels are shown in table 1

Table 1

Average noise levels for night and day periods from Kifisias Avenue

L(A)eq		**L(A)90**		**L(A)max**	
Day	**Night**	**Day**	**Night**	**Day**	**Night**
71	70	67	65	82	79

It seems that the level of noise is increased during the day but the differentiation of rates between day and night is small. This means that both during daytimes and nighttimes the level of noise is quite high. The equivalent noise level can be seen to be high both day and night while the differentiation between the numbers found is only 1 dB. The level of background noise is also perceived to be high both day and night while at night time its level decreases by 2 dB. These facts obviously provide us with a very high overall noise level both day and night. The research concerning the differentiation of rates of noise levels can be done for these set time periods: night (24:00-06:00), morning (06:00-12:00), noon (12:00-18:00) and afternoon (18:00-24:00).
The rates of the equivalent noise levels (background and overall noise levels) can be seen in table 2

Table 2

Average noise levels for the periods of night, morning, noon and afternoon from Kifisias Avenue

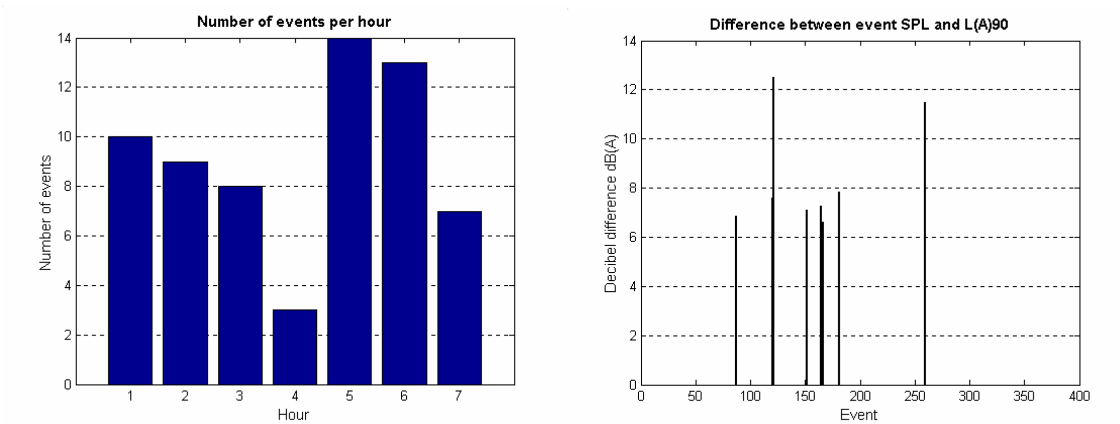
Period	**Index**		
	L(A)eq	**L(A)90**	**L(A)max**
Night (24:00-06:00)	70	65	79
Morning (06:00-12:00)	72	67	84
Noon (12:00-18:000	71	65	83
Afternoon (18:00-24:00)	72	68	81

It seems that the level of noise is increased during all the periods and not many differences can be observed. Therefore the levels of noise are increased during the morning and afternoon and less at night. The only differentiation between rates for certain time periods is between 2 dB (afternoon/morning and night) and 0 dB (noon and afternoon).
The background noise levels are also increased during all the time periods. Its maximum measurement was 68 dB(A) during the evening while its minimum 65 dB(A) at night and the noon. The biggest difference was between the equivalent noise level and the background noise levels which was 6 dB(A). On the other hand the maximum overall noise levels recorded 84 dB(A) during the morning.
It can be observed that the background noise level is quite higher than the limits set for comfortable communication. As a result the intelligibility of the speech is problematic and requires a higher vocal volume.

7. DISTURBANCE CAUSED BY TRAFFIC NOISE EVENTS

On figure 1 traffic noise events are represented centralized for a period of one hour (a) or detailed (b) during 03:00 on Thursday 15/02/2001. At hourly diagrams on vertical axis we can see the difference between the level of events and the level of background noise and on the horizontal axis the time. Time appears as a sample. For each hour there are 360 samples, so the distance between 10 samples is corresponding in 8 minutes and 20 seconds.

On Thursday the time with the most noise events is 05:00 a.m. After 01:00 a.m. events were declining and become less at 04:00 a.m. (3 events) to increase vertically at 05:00 a.m. and following a decline line during 06:00 and 07:00 a.m. The inference is consistent on a working day. After 01:00 a.m. there is some traffic on the roads, while after 05:00 a.m. traffic increases. The most difference between events level and background noise are reported at 03:00 a.m., where background noise level is increased.

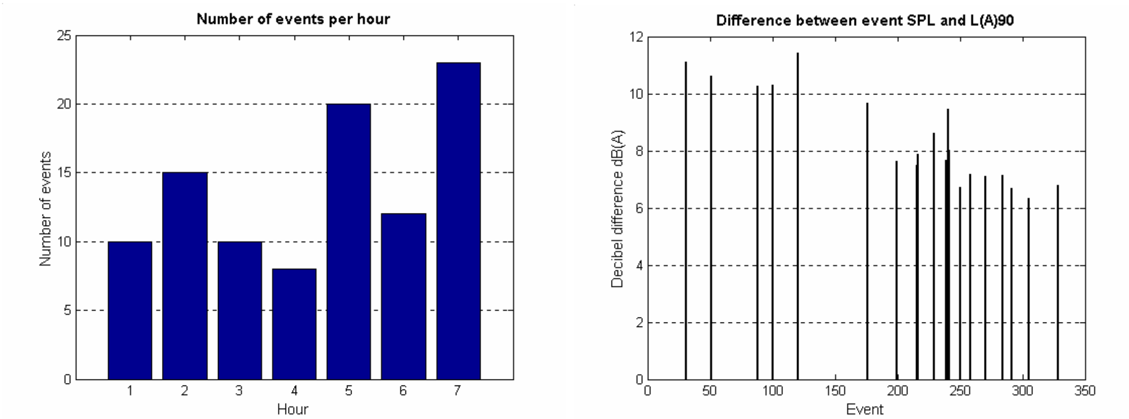


a) *b)*

Figure 1. Number of detected events per hour for the hours 01:00 a.m. to 07:00 a.m. Thursday (a) and the difference between SPL and L(A)eq of detected events for the hour 03:00 a.m. (b)

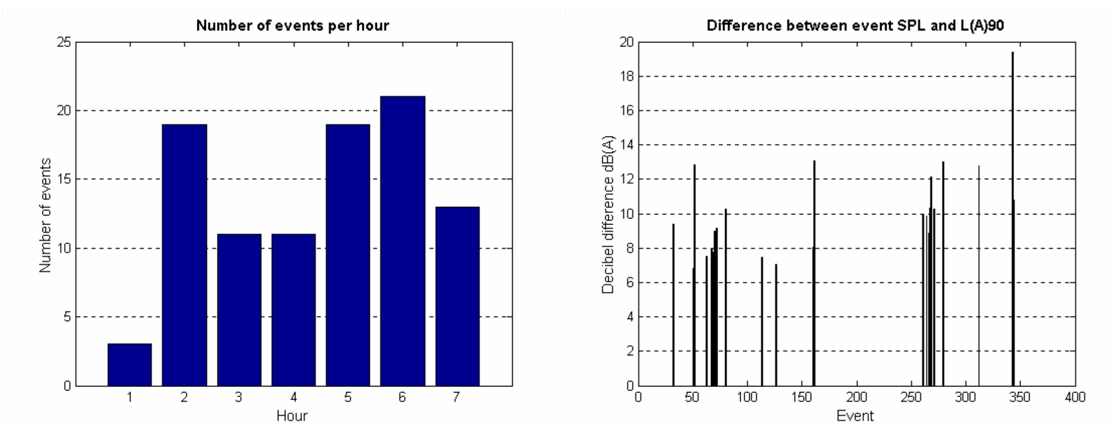
On figure 2 noise traffic events are represented centralized (c) and detailed during 05:00 a.m. (d) and 07:00 a.m. (f) on Friday 16/02/2001. Time with the more events is at 07:00 a.m. and 05:00 a.m. follows. Studying those two cases it clear that the events reported at 05:00 a.m. are independent, while at 07:00 a.m. there's a bunch of events caused by lanterns function.

On Saturday 17/02/2001 (figure 3) the numbers of events are especially decreased relative to the two days before. It's remarkable that the number of events are less at 01:00 a.m., decreases dramatically at 02:00 and remains low (more than 10 events) during 03:00 and 04:00 a.m. The appearance of high number of events during the morning hours on Saturday is relative to transfer after entertainment activities, because Saturday is a day of. Centralized (e) and detailed (f) diagram of Saturday's events is shown in figure 3.



c) *d)*

Figure 2. Number of detected events per hour for the hours 01:00 a.m. to 07:00 a.m. Friday (a) and the difference between SPL and L(A)eq of detected events for the hour 05:00 a.m. (b).



e) *f)*

Figure 3. Number of detected events per hour for the hours 01:00 a.m. to 07:00 a.m. Saturday (a) and the difference between SPL and L(A)eq of detected events for the hour 07:00 a.m. (b).

8. PROPOSALS FOR TRAFFIC NOISE ANNOYANCE REDUCTION IN THE CITY OF ATHENS AREA

The strategic confrontation of noise that is suggested to be applied to a community level is based on the perception of the problem as a sum of data, solution procedures and results. The assessment resulted in the following short and long term suggestions:

8.1 Short term suggestions

- One short term suggestion is the improvement of the design of the streets and junction, which means the quality of the road, the straightness of the streets, the use of barriers for the safety of sensitive areas.

- As a reference to traffic noise a very important role is played by the asphalt. Special types of asphalt that have pores produce lower levels of noise than the conventional non-pore type. Also this type of asphalt takes away water from its surface which is helpful as accidents caused by slippery roads are avoided. Also it stops the formation of ice.

- Another solution is the regulation of traffic lights according to a "free flow" system so traffic. Vehicles will move smoother and avoid unnecessary stopping and accelerating which it is a source of additional noise.

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- Sound barriers placed between noise sources and housing can lower noise levels considerately. The effectiveness of these barriers is dependent on the path of the sound.

- Creating a "green" (trees, bushes) zone between noise source and housing, not only has a noise reduction effect, but also affects the psychology of the people in that area.

- Lastly improving the soundproof of buildings in problematic areas may be one of the most effective solutions.

8.2 Long-term Suggestions

- Redesigning and renovating shopping malls is a necessary long term action. In Athens most of central arteries are inhabited by a mixture of land use activities, mainly residence and commerce. This situation creates traffic and parking problems and incurrence noise levels. An effective solution to this problem is to redesigne land use in certain areas by moving commercial activities together in special designated areas with parking facilities rather than developing commercial activities along central roads.

- The introduction of park and ride scheme by creating parking areas in the outskirts of the city and, at the same time, introducing regular public transport linking parking areas to the city centre or other public transport routes. This scheme, combined with strict parking regulations in the city centre can help minimise traffic and therefore noise during working hours.

9. CONCLUSIONS

A method to estimate disturbance of transportation noise due to noise events has been proposed. For the assessment of transportation noise disturbance we propose the use of the number of events and the difference between the event noise level and the background noise level as independent variables. Detection of events is based on the fluctuations of the energy of the signal. Detected events are analysed, identified and classified. The relation between different types of noise events and the disturbance caused by them to people should be further investigated.

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