ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

TECHNIQUES TO MEASURE THE EUROPEAN L_{DEN} NOISE INDICATOR FOR MAJOR SOURCES IN COMPLEX URBAN ENVIRONMENTS

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Abstract
The European Environmental Noise Directive 2002/49/EC introduces the concept of an "yearly averaged" noise indicator, one value for each relevant environmental source, for down to 50 dB of each L_{den} caused by the specific source. Within the framework of the European IMAGINE project, techniques are under development to measure these long term values, either to check the validity of noise maps or to get input values to produce new ones. An environmental noise test measurement campaign was performed, to test several techniques to identify these L_{den} values within a complex urban environment. The selected site included four sources: a major road, a major railway line, a major airport and a small industrial plant. Of the two main techniques that are commonly taken into account, long and short term measurement, in this work the second one is used because of its feasibility and correctness. The short term measurements use a new meteorological classification to group the measured data under several propagating conditions, and allow to extend the L_{den} measurement to a whole year after averaging the propagation variation and not only the source variations, as it was mainly done in the past.

INTRODUCTION

After the introduction of the European Noise Directive 2002/49/EC (END) many effort have been spent to provide technical guidelines in order to help the end user in the implementation of the END requirements. Along with the definition of the L_{den} noise indicator, one of the most pressing requests is the definition of noise maps for a very large scale and distinguished by noise source. In order to help accomplishing this task for the 2007 round the European Commission Working Group – Assessment of

Environmental Noise (WG-AEN) published its second position paper called "Good practice guide for noise mapping" [1]. Although no doubt exists that such a relevant task could only be accomplished by means of numerical models, measured noise levels can add to the quality of noise maps, because they tend to have better credibility than computed levels. Although a general expertise exists all around Europe regarding measurement techniques, a recent survey [2] shown that there is comparatively little experience of measurements in full conformance with the Directive. The IMAGINE European project [3] took into account the above facts and provided a specific task devoted to the definition of guidelines for monitoring and measuring noise levels [4].

The guideline describes how to determine L_{den} and L_{night}, as defined by the END, by direct measurement or by extrapolation of measurement results by means of calculation. The measurement method is intended to be used outdoors as a basis for assessing environmental noise and to verifying the quality of predictions. In order to check applicability of the proposed guidelines and to provide further information about its use, specific measurements campaigns are running at present. In this work we outline some of the outcome of this experience that can be useful both for noise measuring task and for input data required in numerical production of noise maps.

THE MEASURING SETUP

The measurement site has been set up in Pisa in an area influenced by four main sources: a major road, a major railway line, a major airport and a small industrial plant. The site is located in a medium density residential area and a sketch of the measurement setup is illustrated in figure 1.

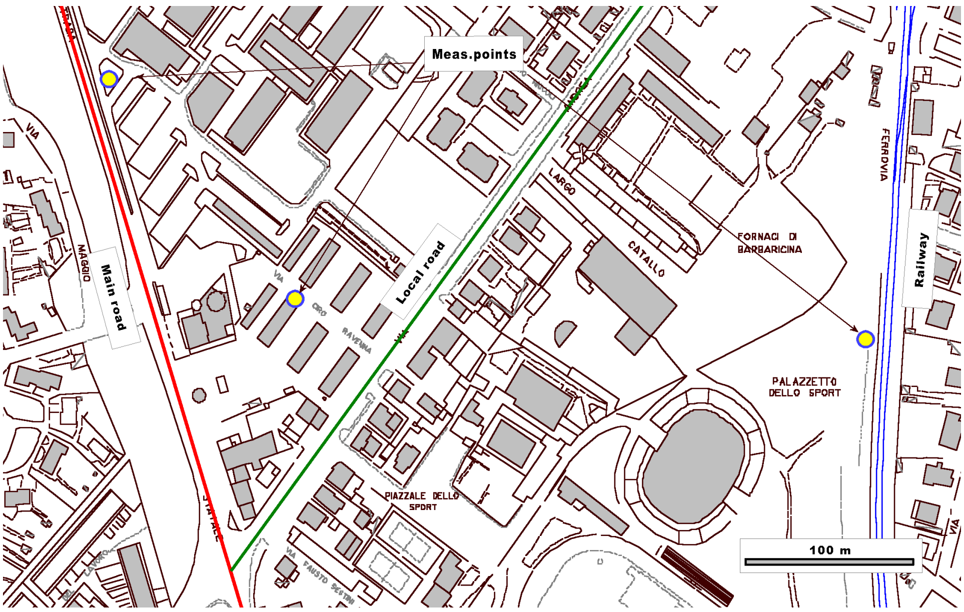

Figure 1 – Map of the measurements site

In order to evaluate noise levels produced by the two most relevant noise sources, two measurement equipments located rather close to the main road and to the railway line were used. A third monitoring station has been placed roughly in the middle between them, at a residential building. The three measuring stations were all able to record noise and noise levels for 7 days a week and 24 hours a day; two separate campaigns have been completed so far, for a total of about 2 months of uninterrupted monitoring.

Along with the noise monitoring, additional information has been acquired. The meteorological conditions were constantly inspected by means of an ultrasonic anemometer besides the use of three traditional meteo-stations. The traffic volume through the principal road was acquired using a laser traffic counter, providing information also about traffic composition and speed. The railway traffic was object of a specific measurement campaign, focused also on emission data, and consisting of a system for train passage detection and speed measurement along with a video recording device for off-line train type recognition.

PRINCIPLE OF OPERATION

The measurement principle developed in the IMAGINE project started with the evidence of two operation mainstreams: determination of L_{den} by means of long-term or short-term measurements. The former involve measurements during a time long enough to include variations in source operating and meteorological conditions. However it was highlighted that optimal duration of long-term measurement cannot easily be determined. The latter method involve measurements under specified source operating and meteorological conditions and the use of relevant prediction method in order to determine the L_{den} value.

The choice of the IMAGINE project was to promote the short-term measurement as the more correct and feasible, provided that appropriate consideration about measurement uncertainty is carried on along with the measurement data analysis. According to this principle the long-term L_{eq} is given by:

$$L_{Leq,long} = 10\ \log_{10}\left(\sum_{i=1}^{n} p_i 10^{<L_i>}\right) \tag{1}$$

where p_i is the frequency of occurrence of the *i-th* emission and meteorological conditions. The $<L_i>$ is determined by several measurements accomplished in the relevant *i-th* status according to the usual energetic mean of the measured $L_{i,k}$ values:

$$< L_i > = 10 \log_{10}\left(\sum_{k=1}^{n_i} 10^{L_{i,k}}\right) \tag{2}$$

Is worth noting that classification of source emission characteristics as well as propagation conditions is an unavoidable step also concerning the numerical mapping task and that most of the accuracy in assessment of noise level is related to the correctness in the determination of those parameters.

This approach come along with an uncertainty that is determined by several factors, most of them rather difficult to establish. However, a simple but generally accepted way to take these difficulties into account is to linearise the contribution of each source of uncertainty; in the present case, it is possible to express the final uncertainty as:

$$\sigma = \sqrt{\sum_{i=1}^{n} \left|\frac{\partial L}{\partial L_i}\right|^2 \sigma_{Li}^2 + \sum_{i=1}^{n} \left|\frac{\partial L}{\partial p_i}\right|^2 \sigma_{pi}^2} \quad (3)$$

Sensitivity coefficients can be evaluated analytically but their mathematical expression is omitted here; however in the following sections the above expression will be used in order to estimate the uncertainty associated with the reported assessment.

DATA ANALYSIS

In order to produce the results according to the principle stated in the previous paragraph, preliminary investigations have been performed about relevant sources and propagation conditions. The main objective was to provide useful indication on how to operate a classification in order to apply the stratification requested by the measurement principle. In view of the determination of the L_{den} indicator the measurement should take into account the period of the day (day-evening-night); for that reason data acquisition and subsequent analysis is based on an hourly time period. The local airport and the small industrial area were shown to be negligible for the purpose of this analysis and are not any longer considered.

Road traffic sources

The main road source is represented by the Italian national road SS 1, connecting several major urban centers on the Italian western coastline. Traffic has been extensively monitored for two days, in terms of volume, vehicle classification, speed and direction.

No significant differences were noted neither in direction (volumes are almost the same) nor in speed (around 50 km/h). Vehicle types were distinguished among cars, two wheelers and heavy vehicles; the total traffic volume is shown in table 1.

Classification of road traffic was performed in order to get an expected difference among different classes of about 4 dB; concerning the wheelers and the heavy vehicles higher contribution is taken into account weighting their relative volumes by a factor of 3.16 and 10 respectively (corresponding to a penalty of 5 and 10 dB).

Table 1 – Hourly traffic volumes along the main road, in the North direction.

Time (h)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Traffic volume	-	-	-	-	*55*	*86*	*230*	*615*	*566*	*653*	*685*	*705*
Time (h)	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Traffic volume	*768*	*723*	*747*	*747*	*863*	*904*	*859*	*778*	*582*	*323*	*425*	*347*

Concerning traffic, missing data were obtained by parabolic extrapolation. The classification operated was compared with the acquisition taken at the near microphone in order to check its validity. According to this procedure, a resulting classification is reported in table 2.

Table 2 – Source operation condition classification of the main road.

Time (h)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Traffic volume	*B*	*C*	*C*	*C*	*C*	*C*	*B*	*A*	*A*	*A*	*A*	*A*
Time (h)	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Traffic volume	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*B*	*B*	*B*

Although this classification is obtained for the main road it can be also considered as a first approximation of the traffic circulating on the nearby local road; short term measurements performed along this noise source showed that its influence on the total noise acquired at the position near the buildings is rather low.

Railway traffic source

The railway is relatively far from the measuring point and the propagation path is screened from many buildings; as a result, the rail influence is rather low during day-time while it may influence the noise level assessed at the measuring point placed close to the buildings during night-time.

Train passages, speed and train type were measured extensively over a week. Train speed is rather slow along that part of railway line, as almost all measured speeds lie in the interval 40-60 km/h regardless of the train type. Table 3 report the overall traffic volumes summed up in four hours periods; the volume increase of passenger trains occurring during day-time is counterbalanced by the slight increase of freight trains noticeable during the night-time period, so that no relevant variation in noise emission is expected, as the latter is confirmed by measurements performed close to the rail. For the purpose of the application of the proposed method, no source classification seems therefore to be necessary.

Table 3 – Railway traffic mean volumes

Time (h)	**0 - 4**	**4 - 8**	**8 -12**	**12-16**	**16-20**	**20-24**
Freight	11	7	5	4	5	7
Pax	7	11	19	25	31	17

Propagation variables

Propagation variables were measured by means of an ultrasonic anemometer and elaborated with the aid of micro-meteorological theory in order to estimate the curvature radius R of the sound in the atmosphere; some information about this process can be found in references [4-7]. The ratio D/R, where D is the distance between the source and the receiver, has been used to propose a propagation classification according to the following scheme:

Table 4 – Classification of propagation conditions

Propagation class	D/R * 1000
M1 – Unfavourable	< - 40
M2 – Neutral	- 40 : 80
M3 – Favourable	> 80

Statistical occurrences of propagation classes have been therefore calculated for the propagation paths connecting the sources to the measuring point at the buildings. In the following table it can be noted that the meteorological conditions affect more evidently the railway because of its distance from the receiver. Despite of this classification, the presence of relatively high buildings in the area disturb the correlation between this indicator and the noise level at the receiver point.

Table 5 – Percentile occurrences of propagation classes over the time; the first block refers to the main road-to-houses propagation, the second to the railway-to-houses propagation.

Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
M1	12	17	13	14	4	7	12	7	10	10	15	21	25	25	18	21	17	14	10	15	8	7	11	12
M2	82	80	80	83	87	89	83	87	89	90	85	76	73	73	80	76	81	81	84	79	84	87	86	82
M3	5	3	6	3	9	5	5	6	2	0	1	3	2	2	3	3	2	5	6	6	8	6	4	6
M1	15	20	18	10	22	15	15	22	19	20	30	37	44	46	50	54	54	47	42	30	21	23	20	20
M2	43	41	40	48	44	48	47	47	51	58	47	37	32	28	26	18	23	28	24	37	43	48	44	43
M3	42	40	42	42	34	36	37	32	29	23	23	25	24	26	24	27	23	25	35	33	36	29	36	37

Noise classes population

Once the classification of the area has been performed, it was necessary to populate the emission-propagation classes accordingly; since a relevant classification was found only for the main road and the propagation condition, data stratification has been performed only on those two indicators, leading to a total of 9 classes. Along with the evaluation of the mean level, an indication of the uncertainty within the class is also reported in table 6 in order to proceed with the global uncertainty computation. Before those values could be used in Eq. (1), occurrences of frequencies of each class should be evaluated for each of the three-day periods indicated by the Directive. This information is summarized in the table 7.

Table 6 – Mean noise level <L_i> (in dB_A) measured at the houses classified according with i-th emission-propagation conditions.

	Propagation class		
Traffic class	M1 – unfavourable	M2 – neutral	M3 – favourable
A – high	54.0 ± 0.2	54.5 ± 0.1	55.6 ± 0.2
B – medium	50.6 ± 0.2	51.1 ± 0.1	51.7 ± 0.3
C – low	48.8 ± 0.2	49.2 ± 0.1	50.3 ± 0.3

Table 7 – Percentage of occurrences of the nine emission-propagation classes distinguished by day period.

	Day			Evening			Night		
Classes	M1	M2	M3	M1	M2	M3	M1	M2	M3
A – high	15	82	3	6	88	6	0	0	0
B – medium	0	0	0	8	88	4	13	82	5
C – low	0	0	0	0	0	0	11	85	5

All the information needed to use Eq. (1) are now available and the application of that expression leads to the following result, where the global uncertainty reported have been computed according to the Eq. (3):

Table 8 – Values for road noise obtained at the receiver point, using the measurements and the described calculation procedure.

L_{day}	$L_{evening}$	L_{night}	L_{DEN}
54.5 ± 0.5	56.2 ± 0.4	53.3 ± 0.3	60.3 ± 0.2

RESULTS AND DISCUSSION

Although the effort spent in order to obtain valuable measurement data and correct elaboration of the L_{den} value, there are many possible sources of error in this process.

The most relevant is the fact that, at the present, it is rather difficult to separate the contribution of different sources. As a matter of fact this would make difficult to accomplish with the END requirements, but also to be reasonably sure that long unattended measurement sessions would not be affected by local noise sources unrelated with the one under investigation. During the execution of this experimental campaign we proposed to use two simultaneous measurement devices that perform correlation between recordings in order to clean acquired data from relevant disturbances; however this part of the work has not jet been completed, consequently it will not be presented here.

Another possible critical point is the extrapolation of a yearly-average from a reduced data-set as the one used for this article. This is undoubtedly a point we are aware of; for that reason a second measuring campaign has been already performed and other two campaigns are planned in the second half of 2006. In spite of the statistical significance of the measuring noise level, it has been already noted that most of the uncertainty is related to the source emission and noise propagation statistical information; this information is the same that should be fed into a numerical model for running a noise maps task. Therefore it seems to be of primary importance, both for numerical mapping and measurements, to provide increased accuracy about this kind of non-acoustical information.

CONCLUSIONS

In this paper a method to evaluate experimental data in order to asses L_{den} according to the Environmental Noise Directive was presented: part of this work is based on the proposed measuring protocol developed by the IMAGINE European project which is available on the project web site.

The principle of the method is the classification of emission-propagation conditions and acquisition of several noise data in each class; L_{den} is therefore obtained by composition of elementary values according to their relative frequency of occurrence. Particular attention is paid to the method concerning the determination of uncertainty of the assessed values.

There are still several parts of the measurement protocol which should be still developed; particularly some more information should be given on how to recognise different noise sources, but also a statistical verification of the significance of the acquired data. Data presented in this paper is therefore still preliminary while more experimental acquisition is running.

REFERENCES

[1] Working Group Assessment of Exposure to Noise, second position paper on “Good practice guide for strategic noise mapping and the production of associated data on noise exposure ”, http://europa.eu.int/comm/environment/noise/pdf/wg_aen.pdf

[2] “IMAGINE Project, Deliverable 2 – The State of the Art in Noise Mapping”, http://www.imagine-project.org/artikel.php?ac=direct&id=242

[3] IMAGINE Project web site, http://www.imagine-project.org

[4] “IMAGINE Project, Deliverable 5 – Determination of L_{den} and L_{night} using measurements”, http://www.imagine-project.org/artikel.php?ac=direct&id=380

[5] “Acoustics – Description, assessment and measurement of environmental noise”, ISO/DIS 1996-2 (2003).

[6] Gutenberg B., “Propagation of Sound Waves in the atmosphere”, J. Acoust. Soc. Am., 14, 151-155 (1942).

[7] Roland B. Stull, *An Introduction to Boundary Layer Meteorology* (Kluwer Academic Publisher, 1988).