A comparison between different traffic noise forecasting methods and experimental data

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The growing importance of noise pollution produced by urban road traffic needs a correct assessment of the acoustic climate of more or less extended built-up areas. According to what is stated in European Noise Directive 2002/49/EC the environmental noise indicators, based on equivalent sound pressure levels, should be measured or preferably calculated through computation methods. For this reason the accuracy of the results made through the methods must be carefully evaluated before using these estimated values for achievement of strategic noise maps. Several computational methods, based on different parametric algorithms, are available for the calculation of equivalent sound pressure levels. In this paper has been made a comparison between the results obtained from the most important and diffused forecasting codes as the French NMPB, the English CTRN and experimental results analysed for different urban traffic conditions.
Then a comparison between data coming from small-medium cities and metropolitan cities has been made, this to test general applicability of abovementioned systems. To conclude is showed an innovative method using statistical levels as descriptors for traffic made noise.

1   INTRODUCTION

The study of overall acoustic characteristics of urbanized areas needs, for a correct evaluation of events that occur, an in-depth experimental measurement campaign. On the basis of these sampled data is possible to draw several acoustic descriptors, which change depending on analyses aim.

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In order to verify the presence of events that may cause troubles to population, together with time histories are used other typical descriptors such as: effective value levels, maximum and minimum sound pressure levels, equivalent continuous sound pressure levels, single event sound pressure levels and percentile levels[1-2].

In Europe forecasting analyses, to accomplish prevention policy and noise effects reductions, are executed through the ordinances contained into the Directive 2002/49/CE which is about the determination and the management of environmental noise. It is based on consideration regarding annoyance and sleep disorders and it provides for the evaluation of noise exposure levels by mapping the studied area through a number of methods equal for all the member States.

The forecasting analyses are extremely useful to show, before construction of infrastructures and city-planning transformations are completed, the possible scenarios caused from those planned activities. Nevertheless it cannot always obtaining the expected results especially in the planning of acoustic reclamation. The worst and most frequent mistakes may occur when these actions involve very busy streets.

Is well-known road traffic is the main source of noise in urban areas. Usually all reclamation interventions in these places aim to reduce vehicular flows or at realizing screening systems to protect sensible targets. Scenarios, obtained from simulations assuming adequate remodeling of traffic, show that in theory is possible to obtain satisfactory results; in the practice, instead, they are not reached even after the realization of those interventions. Failure to achieve the prefixed goals is usually due to mistakes made during setting of parameters and analyses phases. To be more specific traffic is not the only annoying sound source, and therefore errors made during individuation of other sources may lead to wrong results.

2 ANALYSES IN URBAN SCENARIOS

The possible causes of mistakes in traffic noise data analyses can be highlighted examining the measurements done in an urban area characterized by elevate vehicular flows.

Percentile level usage allows portraying source peculiarity, its influence on overall sound characteristics of the area, the presence of singular noise events, even in order to identify a possible intervention to mitigate noise pollution effects[3].

Along with traditional statistical descriptors, the minimum level L_{Amin} and the maximum level L_{Amax} of sound pressure can be used. Since their evolution they can provide some useful indications about the peculiarity of the phenomenon being tested.

The evolution of vehicular traffic is controlled through the analyze of A-weighted percentile level L_{A10}; whereas analyzing the trend of residual noise (L_{A95} or L_{A99}) and that of L_{Aeq} is possible to detect changes in the acoustic climate.

The change of L_{A50} values highlights variation in the road traffic volume, and its comparison with others percentile levels shows convulsive traffic periods that increase sound pressure levels and determinate the trend of the acoustic characteristic of area.

The presence of sound sources permanently active in the analyzed time period it can be evaluated through the study of minimum sound pressure level. On the other hand, the study of L_{Amax} trend, compared to L_{Aeq}, it can be useful to show the presence of singular events particularly noisy[4].

The area which analyses is referred to it is shown in Fig.1. The real time analyzer was placed over a terrace, on 4 meters from ground level height, it was set to sample Fast, A-weighted, sound pressure levels. The street above, object of this study, is one-way road.

For instance, studying the results obtained during the night reference time (Fig.2, from 22^{00} to 06^{00}) on 24th April 2012, is possible to observe that the percentile level L_{A10}, main descriptor in

representing traffic evolution, fell gradually between 22^{00} and 01^{00} of the next day. The analyses of L_{A99} and L_{Aeq} trends allow recognizing possible variation in sound characteristics of the area: in the case taken as example, is possible to observe a reduction of these indicators. That means the transition from day reference time sound climate conditions to night sound characteristic conditions. Contemporary decrease in L_{A10}, L_{A99} and L_{Amin} values shows how the acoustic climate of studied area depends on vehicular traffic only, as proved by amplitude distribution chart, not shown for brevity.

The presence of sound sources different from traffic is to exclude also because L_{Amin} trend is erratic and it is synchronous with L_{A10} trend; in addition to this it is practically coincident with L_{A99} values. L_{A50} trend, the statistical descriptor giving information about traffic volume, in the considered period plummets. It means that traffic flow plunge and this influence the decrease of L_{A10} as well. These results are confirmed again by hourly L_{Aeq} trend, it is practically always parallel to that of L_{A10}.

Analyses of some descriptors trend, such as L_{Amin} and L_{A99}, allow obtaining information about active sound sources within the considered reference time. Let us consider, for instance, graph shown in Fig. 3, which is related to night reference time of 22nd April 2012. In this period, between 3^{00} and 4^{00}, the descriptor L_{Amin} moves horizontally, it indicates the presence of a sound source, characterized by low values of noise, which is always active, even when other sources are absent. L_{99} trend, and even that of L_{A95} (not showed in Fig. 3) are both constant and therefore they confirm the presence of a particular source having constant emission. This source, in the very next time interval, stops to be active. This process is highlighted by the minimum level value that rises gradually.

The analysis of Fig. 3 shows that, between 3^{00} and 4^{00}, L_{Aeq} value becomes bigger than that of L_{A10}. This basically means that, during this time period, some impulsive events are present and these influence strongly the value of the equivalent continuous level.

Figures 4 and 5 demonstrate the presence of these events (for the sake of brevity just a couple of them is shown as example).Some other interesting information can be found in the comparison between L_{Amax} and L_{Aeq} trend.

In Fig. 6 is shown the trend of percentile levels during the day reference time (from 06^{00} to 22^{00}) on 24th April 2012.

It is possible to notice how, in different time interval, the descriptor L_{Amax} hits extremely high peaks. Many of them influence the value of the equivalent continuous level, whereas others do not have any effect on the overall sound characteristics. For instance in the first group it is possible to find the value reached at 15^{00}. On the other hand, a possible example of the second type can be found at 9^{00}, 11^{00} and 17^{00}. These are very short singular events that cannot influence equivalent level value, whereas the other phenomenon mentioned above is composed of events repeated many time in the analyzed period, as highlighted in picture 7, showing the same time period with a different time pace (15 minutes). It is possible to conclude by saying that analyses with smaller time rate allow much more detailed study of the phenomenon being tested.

These short analyses show how and what mistakes can be done when literature forecasting models are used: in more than 90% cases within the whole studied period, road traffic is not the only disturbing source. Moreover, sound pressure levels depend on driving stile of motorists, as it is pointed out analyzing maximum pressure levels trend. It is impossible to take into account these aspects when forecasting models are utilized; therefore results are affected by these indeterminations.

These models provide results having a wide enough variation field (usually ±3 dB), therefore it indicates the possibility that the sound pressure levels of area is contained within that range of values.

This means that forecasting analyses can be used without problems to study effects on overall acoustic characteristics made by modification and intervention done, but they must be utilized carefully when remediation interventions have to be planned yet. In these cases is better to use data coming from experimental measurements.

2.1 Comparison between medium-sized cities and a metropolitan one

In the last few years has been organized some measurement campaigns in chief town of Calabria Region, Italy and in the Italian capital. Nowadays measurement campaigns in Rome-Italy are taken again. Sampled data obtained in this period has been used to verify possible differences between sound pressure levels measured in a metropolis and those sampled in medium-sized cities such as Calabria ones.

From a qualitative point of view results are basically equivalent; they differ just for the sound pressure level values measured that are strongly influenced by traffic volume, obviously wider in some streets of Rome-Italy in particular hours of the day than that survey in the other cities.

For instance, in Fig. 8 is shown the trend of the above mentioned percentile levels recorded in Viale XXI Aprile, in the center of Rome, Italy, during the night reference time on 30th April 2012. Qualitatively the results are very similar to those recorded in the smaller city of Rende (CS), Italy, and therefore they can be commented in the same way. It is possible to notice how the data regarding Rome presents an increase in the percentile levels values due to the bigger dimension of traffic phenomena.

2.2 Roundabout and traffic lights surveys

Statistical analyses can be used also to evaluate noise impact of some town planning solutions. They are useful, for instance, to evaluate effects produced by introduction of roundabouts instead of traffic lights along greatly busy streets.

Figures 11 and 12 show the results obtained from analyses carried out in an urban street in Rende (CS), Italy, and with a lot of traffic. In Fig. 9 has been reported the microphone positions, placed near a roundabout and other near a traffic light. In Fig. 10 is shown traffic trend considering the difference between light, heavy vehicles and motorcycles. In the roundabout traffic is more intense because of a link road with West part of the city affected by elevated traffic levels. Nevertheless the equivalent continuous sound pressure level measured near the roundabout [65.5 dB(A)] is less than that measured in the same period near the traffic light [66.5 dB(A)] that, in addition, is concerned with a smaller number of vehicular transits.

In the roundabout the overall sound characteristic is solely due to road traffic (as highlighted by L_{Amin} and L_{A50} trend), whereas in the other position, in some time period, there are other sources different from vehicular traffic. For instance, it is possible to notice that in the first period of measures (from 12^{15} to 12^{45}) traffic flow is stable in the roundabout, whereas it is erratic, even with a smaller number of vehicles, near the traffic light that slows down the flow.

It is possible to conclude by saying that statistical analyses can be used also to examine efficaciousness of the solutions adopted to regulate urban traffic flow.

3   FORECASTING MODELS

Harmful effects produced by noise pollution are determined using composed indicators defined in the norm ISO 1996-2:1987. These levels are the day-evening-night level L_{den}

(measured from 6^{00} to 6^{00} of the following day), the long-term average sound level A-weighted $L_{Aeq,LT}$ (determined on the totality of day reference time in a calendar year), the night level L_{night} (measured from 22^{00} to 6^{00} of the following day) that is the long-term continuous equivalent level A-weighted, determined on the totality of night daily period in a calendar year, the day level L_{day} (from 06^{00} to 20^{00}) and the evening level $L_{evening}$ (from 20^{00} to 22^{00}). The last two are the long-term continuous equivalent level A-weighted determined, respectively, on the totality of day and evening daily reference time in a calendar year. It can be measured as follows:

$$L_{den} = 10 \log \frac{1}{24}\left[12\left(10^{\frac{L_{day}}{10}}\right) + 4\left(10^{\frac{L_{evening}+5}{10}}\right) + 8\left(10^{\frac{L_{night}+10}{10}}\right)\right],$$ (1)

The European Directive 2002/49/CE relating to the assessment and management of environmental noise, prescribes that, if no national forecasting method there is, the French «NMPB-Routes-96 (SETRACERTU-LCPC-CSTB) » has to be used as official forecasting model in road traffic noise provisional analyses.

This method allows calculating sound pressure levels produced by vehicular noise, up to a distance of 800 meters from roadway and 2 meters above ground level. It permits sound emission estimation and sound propagation determination. For all details, please refer to the norm.

Another calculation model, based on CRTN (Calculation of Road Traffic Noise) method, is used to forecast sound pressure levels caused by vehicular traffic in streets distant less than 300 meters from sounder and with wind speed up to 2.5 ms^{-1}. Sound pressure levels distribution, for flowing traffic above 100 vehicles/hour, can be approximate to a Gaussian distribution. This model, developed in the United Kingdom in 1975, allows valuating and foreseeing statistical percentile L_{A10} in dB(A). Calculated with suitable formula, L_{A10} value, for flowing traffic is expressed through the following:

$$L_{A10} = 10 \log Q + 33 \log (v + 40 + \frac{500}{v}) + 10 \log (1 + \frac{5P}{v}) - 27.6 ,$$ (2)

$$L_{A10} - L_{Aeq} = 3 ,$$ (3)

where Q is the total number of vehicles per hour [n/hour], v is the vehicles average speed [kmh^{-1}] and P is heavy-vehicles rate [travel empty > 1525 kg].

The equivalent continuous sound pressure level obtained through Eqn. (3) holds an error, that in 95% of analyzed cases, is contained in a range of $\pm$ 2 dB.

In the reality, relations between L_{A10} and L_{Aeq} is more complex, even because road traffic rarely moves flowing and sound propagation can be disturbed by reflection effects of buildings and ground. A theoretical study, made for FHWA in the United States, has showed that differences between L_{A10} and L_{Aeq} values is included in the range 1 $\div$ 5 dB(A). For this reason the firm belief that Eqn.(3) can be used has been reinforced into scientific community. All the levels calculated trough CRTN model are expressed as L_{A10}.

To verify reliability of forecasting models calculated data, surveys were executed for 24 hours in the medium-sized city of Crotone (KR), Italy. Experimental data were obtained positioning the microphone in different places, on a height of 4 meters from roadway. Analyses are referred to average road traffic condition shown in Fig.13. For sake of brevity only one measurement point is shown; it is indicated, in the same picture Fig.13, as A point. In it was recorded L_{Aeq} values equal to 68 dB(A) during the day reference time and equal to 63 dB(A) during the night one.

Simulations were done on the map of considered area, positioning measurement instrumentation 4 meters high from the ground, and they are referred to average urban road traffic conditions. In Fig.14 is shown the sound map during day reference time obtained with NMBP method. In this time the light-vehicles flow fluctuated between 1800 and 2600 vehicles per hour, while in the same period the heavy-vehicles flow was between 40 and 115 vehicles per hour. It is possible to notice how the equivalent continuous level is equal to 75 dB(A) and how near measuring point this level is between 70 and 75 dB(A), whereas the value given by experimental data is equal to 68 dB(A).

This result allows some remarks: considering the usage of those data from an environmental-planning point of view the method gives acceptable results. Indeed, considering that uncertainty of model is ±3dB, there is a substantial correspondence between experimental and theoretic data. On the other hand, as regards its employment in individuation of remediation actions to protect sensible receptors – procedure activated when is studied the acoustic climate caused by work being planned and when are indicated interventions for protection – it is useful remind that results carried out from simulations can be used to highlight the particular type of intervention to do, but they are not good enough for dimensioning of protection systems. Therefore experimental data are necessary to complete further steps in planning.

In Fig. 15 is reported the sound map in night reference time; is possible to notice that on street axis the equivalent continuous level is louder than 65 dB(A), it is between 60 and 65 dB(A) close to the measurement point, whereas experimental data value is equal to 63 dB(A). All the consideration made above can be considered still confirmed.

The analyses made with CRTN model are shown in Fig. 16 (related to the level L_{A10} on 18 hours based, from 06^{00} to 24^{00}) and in Fig. 17 (related to the level L_{A10} from 12^{00} to 13^{00}). In the first one L_{A10} value on the street axis is between 68 and 72 dB(A), whereas according to the experimental data the equivalent continuous level is equal to 68 dB(A). Considering that to obtain L_{Aeq} level is necessary subtracting 3 dB to L_{A10} value and that model uncertainty is equal to ±3 dB, even in this case there is a substantial correspondence between experimental end theoretical data.

In the second picture the value of L_{A10} is 76 dB(A) on the street, holds between 68 and 72 dB(A) and the experimental value is equal to 68.5 dB(A). Even here all the above mentioned consideration is valid.

4   CONCLUSIONS

The aim of this work is to damp enthusiasm in the immoderate use of forecasting models for urban traffic noise simulation. As it is possible to notice through the numerous examples and data presented in the whole paper, they can be a powerful way to conduct environmental analyses in the prevision of overall sound characteristics of an area, but on the other hand they are too vague and their results are affected by too many uncertainties to be used as the only devices to plan any type of noise remediation. Indeed when a remediation plan should be done it is better to schedule it by using data coming from experimental measures rather than rely on forecasting methods only. The measurement campaigns allow knowing a greater number of information that may lead to more accurate and efficient planning choices.

Another aspect coming out from this work is the substantial equivalence between urban road traffic in medium-sized cities and metropolitan ones. The traffic is the main source of noise, obviously the sound pressure levels depends on traffic volume, but even in the medium-sized cities they reach values above 65 dB(A), that are close to those measured in big cities such Rome.

To conclude it is possible to affirm that the substitution of traffic lights with roundabouts, where possible, allows a traffic flow less congested, decreasing sound pressure levels and

reducing the environmental noise pollution.

5   ACKNOWLEDGEMENTS

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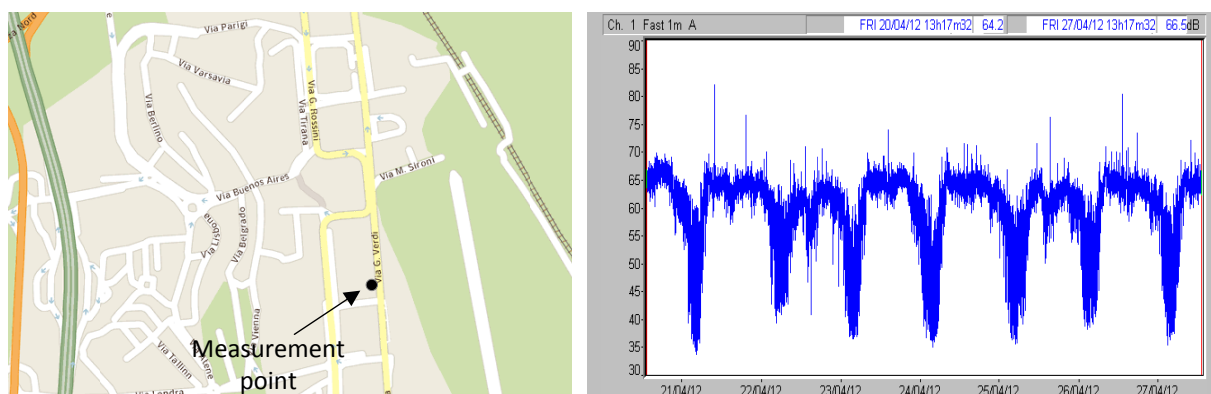
Fig. 1 – Map of measurement place (Via G. Verdi, Rende (CS) – Italy) and SPL time history
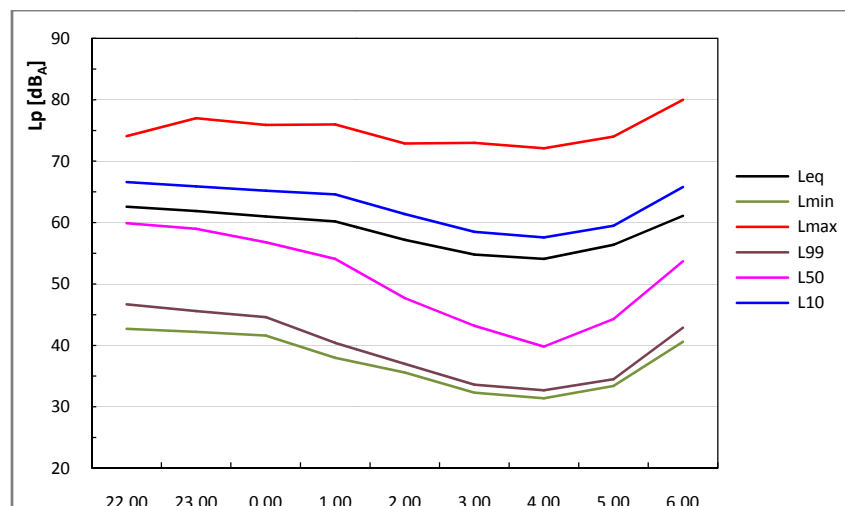
Fig. 2 – Percentile levels during night reference time (20.04.2012)
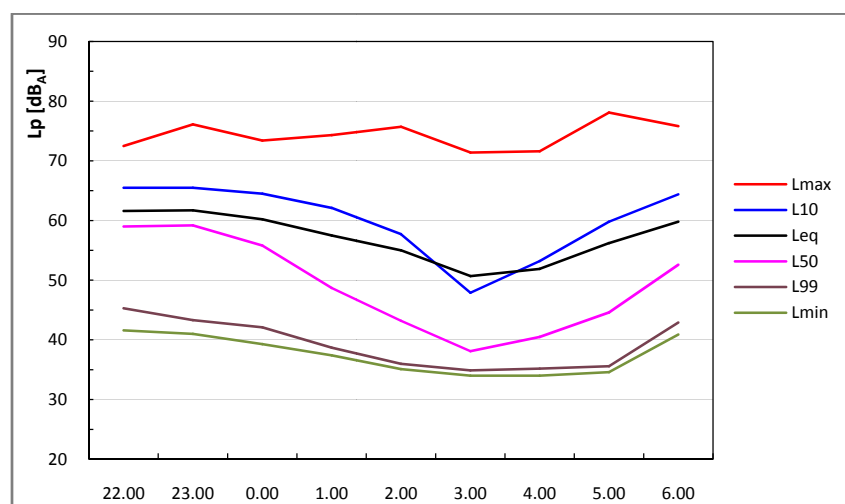
Fig. 3 – Percentile levels during night reference time (22.04.2012)
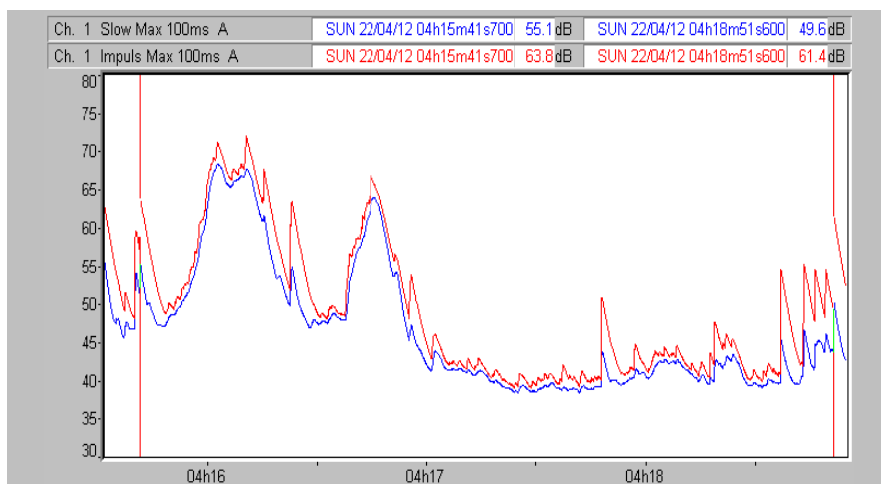
Fig. 4 – SPL time history with time-weightings S_{Amax} and I_{Amax}
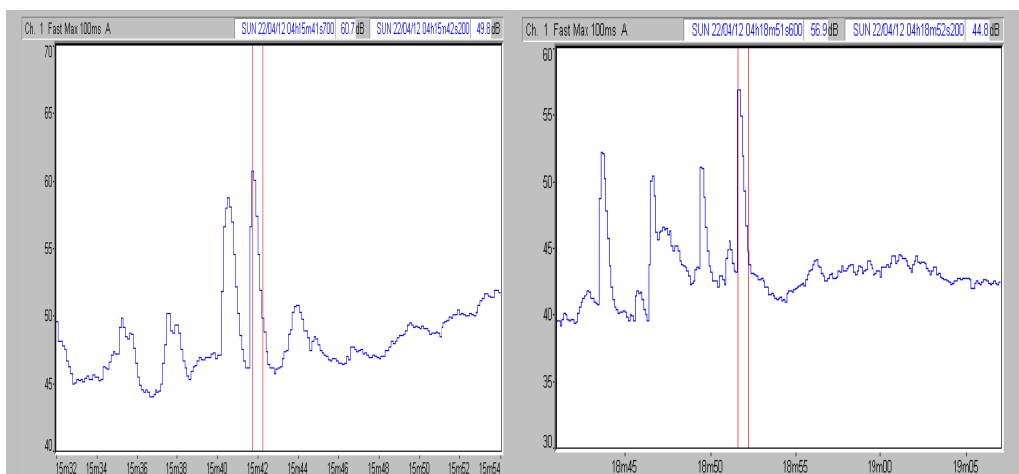
Fig. 5 – SPL time history with time-weightings F$_{Amax}$
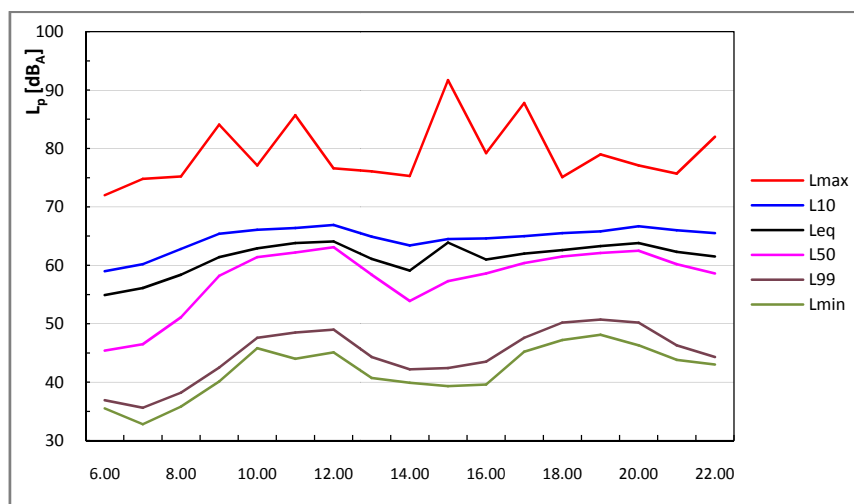
Fig. 6 – Percentile levels during day reference time (25.04.2012)
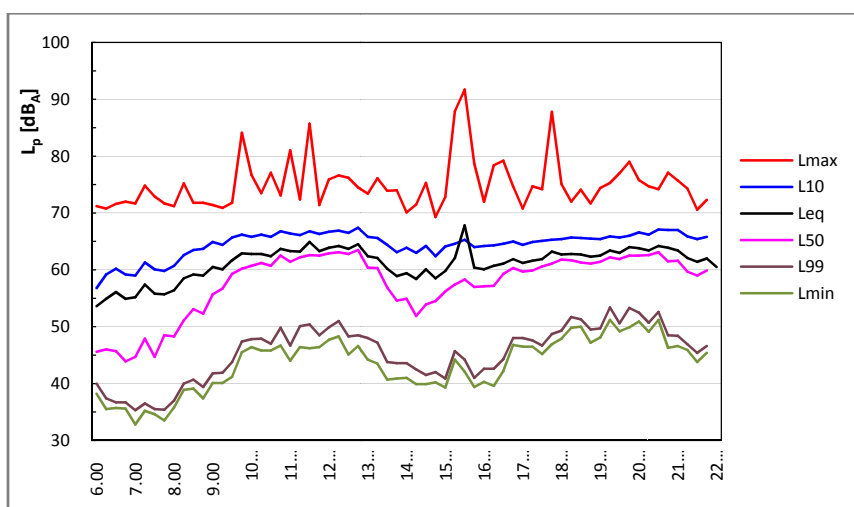
Fig. 7 – 15 minutes rate percentile levels during day reference time (25.04.2012)
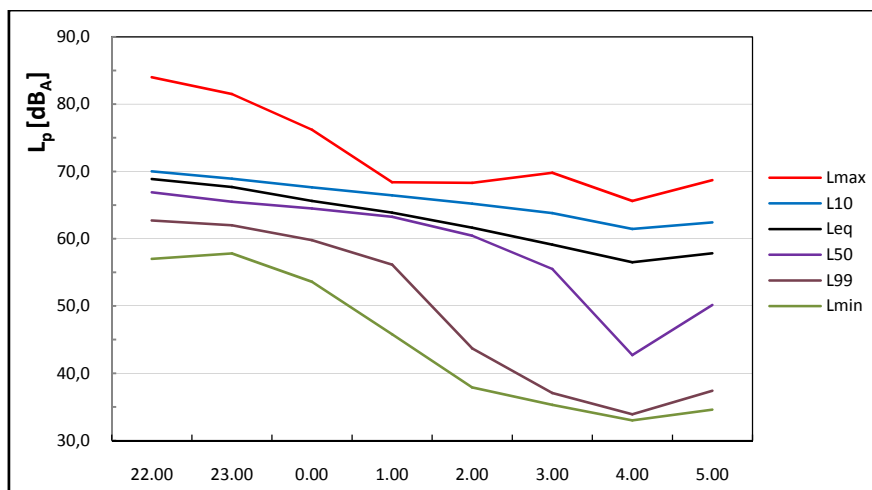
Fig. 8 – Percentile levels during night reference time in Rome (30.04.2012)

Fig. 9 – Comparison between roundabout and traffic light, map of measurement points
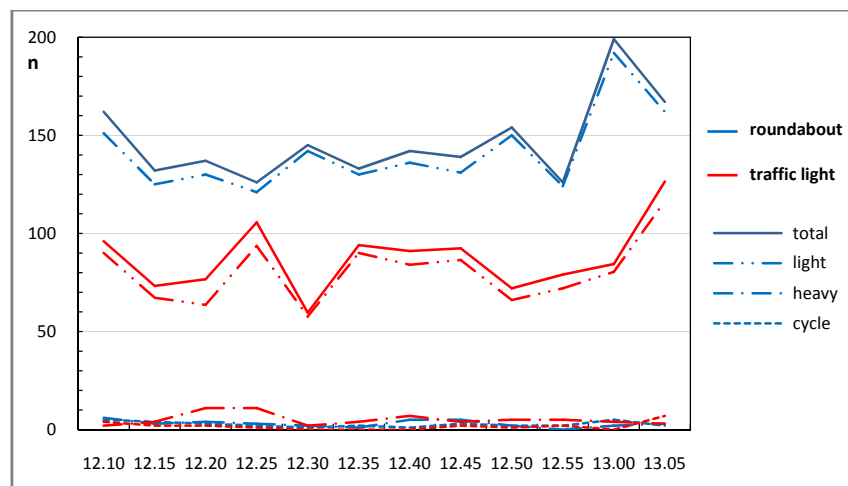
Fig. 10 – Number and type of vehicles passing at the roundabout and traffic light
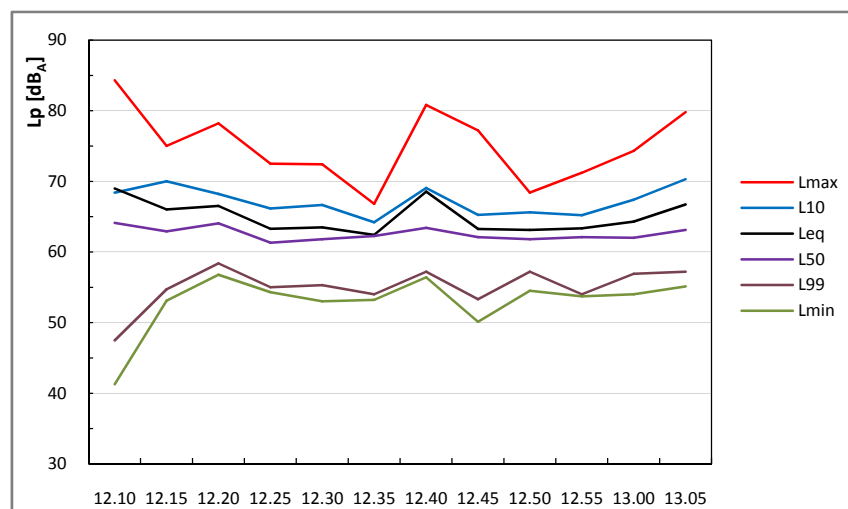
Fig. 11 – Percentile levels measured at the roundabout
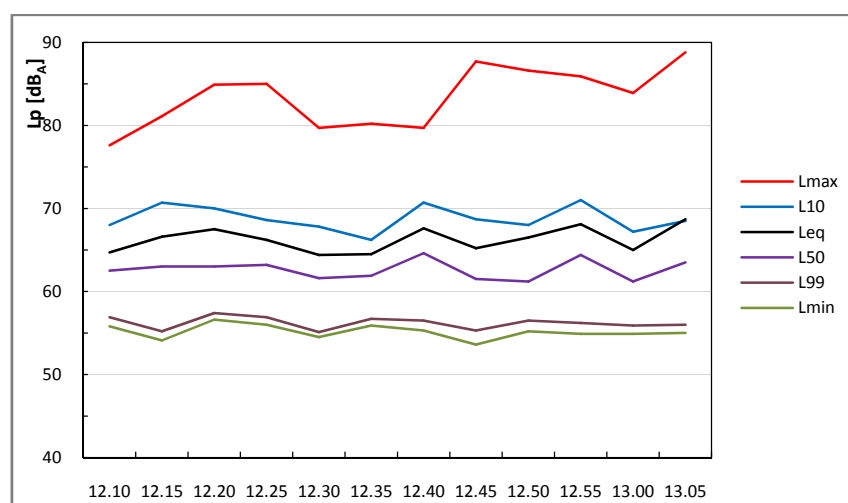
Fig. 12 – Percentile levels measured at the traffic light
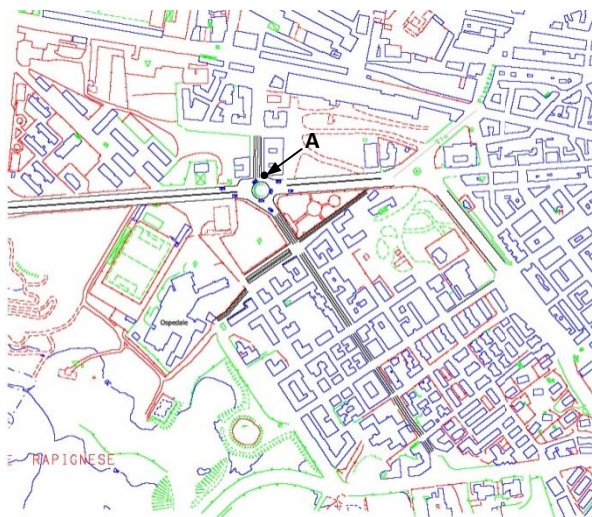
Reference time	Light vehicles [n/h]			Heavy vehicles [n/h]		
	average	max	min	average	max	min
Day	2400	2600	1800	90	115	40
Night	500	560	220	50	75	20

Fig. 13 – Measurement point maps and traffic flow in Crotone (KR) – Italy

Fig. 14 – Overall sound characteristic map during the day reference time (NMPB model)

Fig. 15 – Overall sound characteristic map during the night reference time (NMPB model)
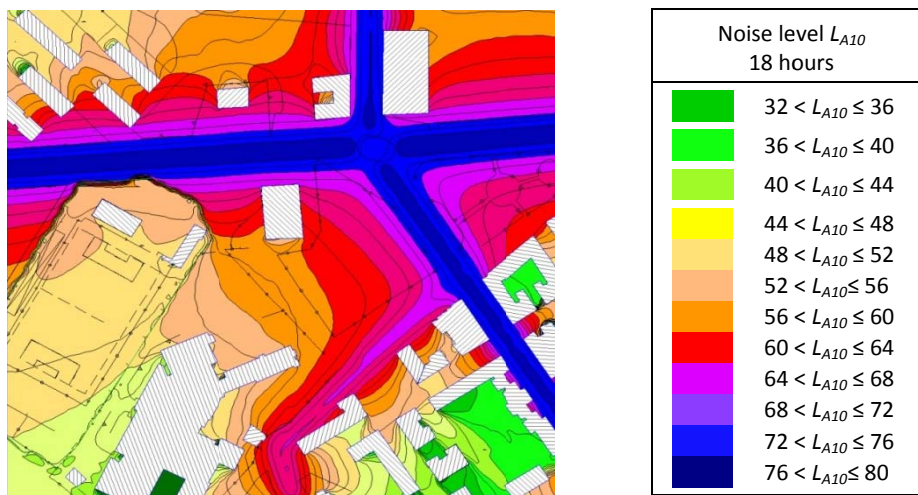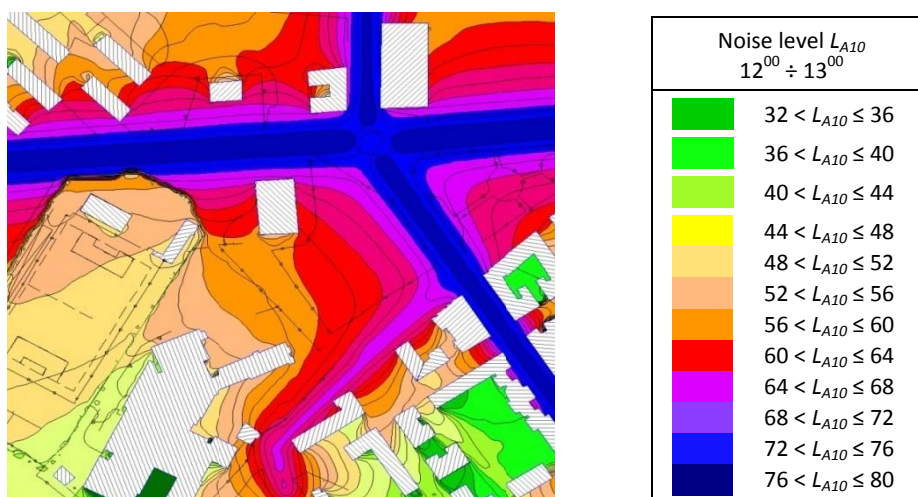
Fig. 16 – L_{A10} values maps on 18 hours (CRTN model)

Fig. 17 – L_{A10} hourly (12^{00} – 13^{00}) values maps (CRTN model)