Ante operam noise monitoring within LIFE NEREiDE: methods and results

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Summary
LIFE NEREiDE is an EU funded Project aiming to the implementation of new low noise surfaces made of recycled materials as rubber from end of life tyres (ELTs) and recycled asphalts (RAP). The objective is to mitigate noise exposure with green technologies achieving better acoustical, psichoacoustical and safety properties. This paper is focused on reporting results of *ante operam* noise measurement campaign carried out within the first period on the different stretches of implementation of new pavements and to show pro and cons of selected indicators and measurement protocols. Results are reported according to different parameters: CPX values, environmental noise values at roadside in terms of different indicators and SPB values with a new method for urban pass by. In fact, a side objective is to establish methods to evaluate pavements efficiency with methods that can be easily implemented in urban context. In particular, a new protocol for urban Pass-By has been developed in order to produce similar index to SPB as established in ISO 11819-1 without the need of manned measurements. This method showed a good agreement with measured noise levels and provided models for each vehicle category that are able to establish the contribution of each one and therefore to allow the evaluation of the pavements. The analysis allows also establishing that the *ante operam* noisiness of the first site with six stretches is quite homogeneous. Not only CPX values are comparable but also environmental noise values are similar. Therefore, mitigations will influence the noisiness of the sites depending on relative flows; influence of each new pavement can be evaluated as ante/post differential values starting from a homogeneous pavement and site condition (no relevant differences depending on weather, ground effects and road profile were found at least on *ante operam* values).

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1. Introduction

European Union policies lead to the implementation of the Directive 2002/49/EC (END), which requires the adoption of action plans by the Member States, based upon noise mapping results, "with a view to preventing and reducing environmental noise where necessary and particularly where exposure levels can induce harmful effects on human health and to preserving environmental noise quality where it is good". Urban noise is in fact one of the main problem reported by citizens and the World Health Organization has repeatedly pointed out the health risks associated with exposure to noise. A recent document by WHO European Centre for Environment and Health [1] reported methods to evaluate these effects on exposed population. The "Noise in Europe 2014" report of the European Environment Agency [2], collecting data received by EU Commission due to the EU Directive, provided data to confirm that road traffic is the most dominant source of environmental noise with an estimate of 125 million people affected by noise levels greater than 55 dB(A) L_{DEN} (day-evening-night level), and 40 million of that leaving near main roads.

In Tuscany, the implementation of the END allowed to estimate the exposed population in several agglomerations (Pisa, Firenze, Livorno, Prato) to different noise sources (road, rail, aircraft). A local study [3] highlighted the value of the DALY in each agglomeration according the YLD (years lived with disability) due to noise exposure. Overall 7000 DALY are assessed in Tuscany and 90% is due to road traffic noise. Beside this study, the road traffic exposure is critical also along regional roads outside the agglomerations and there are several sites in the region where actions are planned (including more than 20000 people leaving over 55 dB(A) L_{DEN}). All the foreseen actions include the renewal of the pavement.

The realization of low noise asphalt pavements that are soundproofing is one of the most popular solutions to mitigate noise pollution in urban areas. In fact, in these areas it is not possible to install acoustical barriers, and the installation of soundproof windows is much more expensive; particularly this latter solution doesn't solve the problem because in many buildings windows are open in summer and people are still annoyed.

The LIFE NEREiDE project wants to demonstrate the use of new low noise emission asphalt pavements and low noise surfaces composed by recycled asphalt pavements and crumb rubber from scrap tires. The new pavements will improve the actual performances reducing annoyance in urban context, with a particular attention to the disturbance perceived by population.

Low Noise Pavements (LNPs) are an interesting and economical solution where traffic noise reduction is necessary since rolling noise emissions for passenger cars are already predominant at urban speeds (30-50 km/h) [4]. A comprehensive analysis of the types of LNP used in some of these EU-countries is reported in the ERA-NET FTP2 project [5], which identified critical factors in processes, activities and regulations that may affect the acoustical performance of LNP.

The new pavements will be laid in two selected urban areas in Tuscany and will be tested for effectiveness by measurements of surface characteristics, acoustical and psychoacoustical properties and surveys submitted to the exposed population. The criterion used to evaluate the effectiveness is based on a before-after evaluation (*ante/post-operam* comparison) of the surfaces acoustical properties as well as the comparison with other traditional porous asphalt pavements.

A significant amount of literature can be found, reporting on experimental test sections which were monitored along time; the SILENCE project [6] was carried out in order to be able to describe the time of development of noise emission by studying different pavement types used in Europe. Different studies demonstrated that applying the standard monitoring techniques is not enough to establish reliable results and different surfaces are not easily comparable. Therefore, new measurement protocols and methods are developed from standard ones within the project in order to provide institutions with data of reliable monitoring campaigns.

Moreover, there are few experiences in which the effects of mitigation measures (and even less on asphalts) were tested against people perception. Therefore, the project also aims to provide new guidelines and templates for new measurements methods including psychoacoustical indicators. In

fact, the project aims to develop new asphalts not only able to reduce noise level but also suitable to improve perceived noise: it is demonstrated that at the same level different distributions of frequencies can change annoyance in exposed people.
In this paper the *ante operam* acoustical results in first implementation site is reported, together with results of innovative measurement method for vehicle noisiness at roadside.

2. Methods

Monitoring actions are focused on evaluating new surfaces efficiency and are conceived as *ante/post operam* analysis at the two sites; therefore, four acoustical measurement sessions are foreseen:

- *Ante operam* 1st site spring-summer 2017;
- *Ante operam* 2nd site spring-summer 2018;
- *Post operam* 1st site spring-summer 2018;
- *Post operam* 2nd site spring-summer 2019.

In this paper measurement methods to be applied in all the sessions are described together with *ante operam* results at first site.

2.1. Standard measurements

The evaluation of noise at roadside by means of a continuous monitoring station is needed to estimate people exposure according to Italian law requirements in terms of average energy received (Daytime L_D and Nocturnal L_N levels). Moreover, the evaluation of the European noise indicators L_{DEN} and L_{night} is one of the main methods recognized by LIFE programme to rate the outcomes of the project.
All the above levels are intended to be A-weighted levels. In addition to those parameters, C-weighted levels are measured and elaborated in order to verify effects of pavements on noise quality. The A-weighting follows the frequency sensitivity of the human ear at very high noise levels. Differently, the C-weighting scale is quite flat, and therefore includes much more of the low-frequency range of sounds than the A scale. The evaluation of low frequency components through the difference between A and C weighted levels provides indications to be correlated to people surveys [7]. A further parameter that is calculated from data acquired with monitoring stations is the "NA" parameter, referring to the Number-of-events Above a Specified Level having a sound average energy exceeding a specified level. Such level is identified as an annoyance threshold and in several airport noise studies it's quoted as the N70 index (events above 70 dB(A)). Finally, DALY [1] will be elaborated from acquired L_{Aeq} data and population data, since it might be a project performance indicator in terms of health improvements.

In addition to noise level at monitoring stations, noise from road surfaces can be analysed as noise generated by the road/tire interaction and pavement absorption. The road/tire noise is well represented through the Close Proximity Method (CPX) defined by the ISO 11819-2 (2017) [8] that will be performed in each measurement session over all the old and new surfaces stretches.
The close-proximity (CPX) method aim at:

- noise characterization of road surfaces, with the main purpose of checking compliance with a surface specification;
- checking the acoustic effect of maintenance and condition;
- checking the longitudinal and lateral homogeneity of a road section;
- the development of quieter road surfaces and research on tire/road interaction.

This method evaluates different road surfaces with respect to their influence on traffic noise, under conditions when tire/road noise dominates. The interpretation of the results essentially applies to free-flowing traffic passing by at constant speeds from 40 km/h and upwards, where tire/road noise is assumed to dominate.
The CPX measurements can be carried out using a trailer towed by a separated vehicle or a self-powered vehicle (as in this project). The method uses two microphones placed at 0.2 m from the axis of the wheel and 0.1 m above the road surface. The microphones position is chosen in proximity to the tire/road contact, aiming to evaluate only the road-tire noise without the influence of noise coming from the engine and the exhaust system of the car.
The energy-based average sound level spectra for the two microphones, normalized at reference temperature and tire hardness by a simple correction procedure and at reference speed by a logarithmic regression between levels and speed data, is called "tire/road noise CPX Level" (L_{CPX}).
Finally, the road surface is characterized averaging all the 20 m long segments, while the standard deviation around the mean is an indication of the homogeneity.
Both absolute and differential L_{CPX} values [9] will be analysed in the *post operam* dataset in order to

compare special pavements to reference one measured in the same weather conditions.
An adapted protocol for measurement and data post-processing was developed to improve the suitability of the CPX method within the LEOPOLDO project [10].
Following [10], data analysis in the post-processing phase is based on the spatial resolution of three tire circumferences (about 5.84 m, dependent of tire radius) long segments and the sound pressure level Lp_i associated to the i-th segment is estimated by fitting experimental data by the well-known logarithmic relationship with speed data.
The fit is calculated for each segment, for each third octave band level in the frequency range of 315 to 5000 Hz.
Finally, the overall A-weighted equivalent sound pressure level, at the reference speed, associated to the i-th segment, $L_{CPX,i}$, is obtained through the A-weighted energy-based sum of the third octave bands estimated levels, as required by the ISO 11819-2 [8].
The $L_{CPX,i}$ levels versus distance are used to characterize the road surface installation through its homogeneity and the averaged noise levels on all segments.
The pavement absorption will be evaluated for the new porous surfaces using both standard methods as ISO 13472-2 method [11] or ISO 10534-2 method [12] and an innovative method still under development within LIFE NEREiDE.

2.2. Innovative approaches

A method aimed at evaluating road surface performances in terms of energy perceived at roadside is the Statistical Pass By (SPB) [13]. Unfortunately, this method is applicable under strict environmental surrounding conditions that are almost never realized in urban context. Therefore, an urban statistical pass by method is established.
As described in Deliverable B10 [14] the new procedure requires the use of a monitoring station placed at roadside at a known distance from centreline and a microphone at 4 m height. Sound level meter should be set in order to acquire the L_{eqA} Fast 50 ms and the Third octave band spectrum.
The monitoring station should be positioned in such a way that the angle of sight of the road is maximised without going too far from centreline, otherwise noise levels at station might be too low and events could be not clearly identifiable from background noise.
In addition to monitoring station, a traffic counter system should be installed at roadside. The traffic counter should be set and positioned in order to acquire traffic data of both lanes and to acquire vehicles' length accurately to identify different vehicles categories. The device should be positioned such that measured speeds are reasonably the same of ones in front of monitoring station.
The analysis is performed matching traffic counter flows with noise data. In particular, a time interval between consecutive passages is fixed to identify candidate passages.
All traffic data are loaded into a calculation spreadsheet: the events that are identified on traffic counter are highlighted by conditional formatting on the spreadsheet. Analogous conditional formatting is performed over vehicles length returned by traffic counter to discriminate vehicles categories. Single candidates are verified on the noise time history and noise average spectrum is acquired in the L_{AFmax}-10 dB time interval. Thus, if 10 dB are not available, the event is discarded. The analysis spreadsheet developed under this project is able to count valid events per direction and categories such that it is possible to stop analysis as soon as minimum requirements are fulfilled However, a 20% more is recommended in order to allow removal of possible outliers.
Average spectrum is then copied together with speed and direction in order to collect all events and fit them against speed as explained above.
The analysis with binning technique [10] provides regression of SEL values and each frequency bands as function of speed.
If a sufficient number of events is acquired (at least 100 light vehicles and 30 heavy vehicles), SPB index (SPBI) is estimated according the ISO standard (low speed roads). Finally, attention should be paid to the estimation of heavy vehicles parameters, differentiating light and heavy trucks if the latter category can be easily visible as outlier in a plot of *SEL vs speed*.
Comparison of urban pass by of different stretches might be difficult due to local urban different conditions. For this reason, before reporting data, a distance correction is needed to analyse them at a reference distance, chosen equal to the one of the official standard SPB (7.5 m from the centreline, 1.2 m above the ground). Therefore, a linear correction is applied to acquired spectrum and the fits are performed on corrected data before reporting them on data sheet.

Figure 1. Measurements positions (red circles) and stretches in Pian del Quercione (2 on the left) and Bozzano-Quiesa (4 on the right) in Massarosa municipality – first implementation site

3. Results

Measurements were carried out within May and June 2017 according to established protocols.
CPX data were acquired in two separate sessions for the two locations, Pian del Quercione and Bozzano-Quiesa, in Massarosa municipality. Data are elaborated for every single stretch. Environmental noise levels were acquired with monitoring stations placed in central points or at strategic places like schools. The location of the six continuous monitoring stations, one for each 400 m long stretch in which a different LNP will be implemented, is reported in figure 1.
Moreover, distance, average daily traffic flow (ADT) and speed are reported for each continuous station in table I.

Table I. Stations' positions.

Stretch	*Distance from roadside [m]*	*ADT*	*Speed [Km/h]*
1	1.5	5928	63
2	2.5	10560	49
3	3	10560	49
4	7.2	14160	57
5	2.5	20880	49
6	5	19920	39

Therefore, following data are acquired before action:

(1) Environmental noise values over each stretch including noise equivalent levels L_{Aeq} according to law at continuous station and European indicators, L_{C-A} values, NA values.
(2) CPX over each stretch and for each lane.
(3) U-SPB of 1st, 3rd, 5th, 6th stretches.

It must be specified that NA values have been calculated for night period (22.00 – 6.00) in order to correlate the values to eventual sleep disturbance outcomes. NA threshold has been fixed to *75 dB(A)* regardless the position of the monitoring station in order to have the same indicator over all stretches. In any case both L_{C-A} and NA values are to be evaluated, comparing *ante/post ratio*, that's why they are not reported in this paper.

3.1. Environmental noise levels

Table II reports L_{Aeq} for daytime (6.00 - 22.00 L_D) and nocturnal (22.00 - 6.00 L_N) periods and limits by law.

Table II. L_{Aeq} values for reference periods together with Italian noise limits.

Stretch	*L_D [dB(A)]*		*L_N [dB(A)]*	
	L_{Aeq}	*limit*	*L_{Aeq}*	*limit*
1	66.4	*65*	60.1	*55*
2	68.1	*65*	62.1	*55*
3	67.9	*50*	62.6	*55*
4	66.4	*65*	60.9	*55*
5	70.6	*50*	65.0	*55*
6	68.6	*65*	62.7	*55*

All points exceed limits both for residential buildings and schools. This confirms the need of mitigation actions.
Table III reports European indicators for Italian defined periods: L_{Day} (6.00 – 20.00); $L_{Evening}$ (20.00 – 22.00); L_{Night} (22.00 – 6.00).
Considering distance, flow and speed they can be elaborated obtaining L_{DEN} for a reference average

vehicle passing by at 50 km/h equal to 51.5 with a standard deviation of 0.7 between stretches.

Table III. L_{Aeq} European values [dB(A)].

Stretch	L_{Day}	$L_{Evening}$	L_{Night}	L_{DEN}
1	66.8	65.5	60.1	68.6
2	68.3	66.9	62.1	70.3
3	68.1	67.2	62.6	70.5
4	66.5	65.7	60.9	68.8
5	70.8	69.3	65.0	72.9
6	68.8	67.3	62.7	70.8

3.2. Close Proximity method - CPX

Table IV reports L_{CPX} (v = 50 km/h) for each stretch and direction.

Table IV. L_{CPX} (v = 50 km/h) values [dB(A)].

Stretch	*Direction: to Lucca*	*Direction: to Viareggio*
1	91.5 ± 3.6	92.0 ± 2.2
2	90.6 ± 2.7	92.5 ± 2.1
3	90.5 ± 3.1	92.0 ± 3.0
4	90.3 ± 1.4	90.1 ± 1.2
5	90.5 ± 1.6	92.0 ± 1.9
6	90.8 ± 2.3	91.4 ± 1.6

Ante operam surface is homogeneous through stretches, with a slight difference between two lanes that might be due to metal manholes located on Viareggio lane only.

3.3. Urban Statistical Pass By – U-SPB

The urban pass by protocol within this measurement campaign was applied only to stretches 1, 3, 5, 6 since time constraints did not allow using traffic counter for every stretch. Moreover, being the old pavement quite the same (see CPX results), it appeared not effective to measure *ante operam* pass by at each stretch.

Measurements with urban pass by technique as defined in Deliverable B10 were elaborated providing values of L_1 representing noisiness of a light vehicle passing by at 50 km/h at the reference distance (see Table V) and SPBI for urban roads (see Table VI) as defined in ISO 11819-1 starting from SEL fits and not from L_{Amax}.

It should be noticed that station at stretch 1 is located in a hilly point so direction to Lucca is raising and direction to Viareggio is descending, with higher average speed in sample and dominant rolling noise. In this direction it is possible to identify the greeter difference to L_{CPX} index, being about 20 dB. On the other hand, in stretch 6, with very low speeds and relevant power noise of passing by vehicles, the difference with L_{CPX} is the lowest, being about 14 dB.

Table V. Pass by Values L_1 [dB(A)].

Stretch	*Direction: to Lucca*	*Direction: to Viareggio*
1	73.7 ± 1.9	71.7 ± 2.7
3	76.1 ± 1.2	74.6 ± 0.5
5	74.7 ± 1.0	74.6 ± 0.6
6	75.7 ± 0.9	76.7 ± 0.8

Table VI. Pass by Values SPBI [dB(A)].

Stretch	*Direction: to Lucca*	*Direction: to Viareggio*
1	74.4 ± 1.6	72.1 ± 2.3
3	76.3 ± 1.4	75.2 ± 0.5
5	75.6 ± 0.9	75.8 ± 0.6
6	76.2 ± 1.1	77.4 ± 1.0

Moreover, SEL model parameters *a* (intercept) and *b* (slope) according to equation 1 for light vehicles, two wheelers and heavy vehicles were elaborated.

$$SEL = a + b \log\left(\frac{v}{v_0}\right), \quad (1)$$

where v_0 is the reference speed 50 km/h.

These last data allow estimating noise values based on traffic flows and will be deeply studied in further papers.

4. Conclusions

The *ante operam* analysis allows to establish that the noisiness of the six stretches is quite homogeneous. Not only CPX values are comparable but also environmental noise values are similar when corrected by distance from centreline and flows. At list 4 different flows classes have been found: 1st stretch with an average of about 250 vehicles/h/day and the mean speed higher than limit, 2nd and 3rd stretches with about 450 vehicles/h/day, 4th stretch with about 600 vehicles/h/day and mean speed higher than limit and finally 5th and 6th stretches with about 850 vehicles/h/day.

Therefore, mitigations will influence the noisiness of the sites depending on relative flows; influence of each new pavement can be evaluated as *ante/post*

differential values starting from a homogeneous pavement and site condition (no relevant differences depending on weather, ground effects, and road profile were found at least on *ante operam* values).
The new established method to derive pass by values in urban context provides a procedure able to define index of vehicles noisiness on the specific pavement and place. This allows a comparison of efficiency of new pavements in terms of noise at roadside.

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