LIFE NEREIDE: INNOVATIVE MONITORING ACTIVITIES ON IMPLEMENTATION URBAN SITES

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The LIFE NEREiDE project wants to demonstrate the use of new porous asphalt pavements and low noise surfaces composed by recycled asphalt pavements and crumb rubber from scrap tires, achieving specific benefits on resource efficiency and noise pollution. In particular, it wants to achieve better acoustical, allowing a significant reduction of noise in urban areas and health improvement. The new pavements will be laid in two urban areas in Tuscany, and will be tested with innovative instrumentation. The selection of urban areas has been performed and the procedure will be described in this paper. The effectiveness of the new pavements will be evaluated by measurements of surface characteristics, acoustical properties and by surveys submitted to the exposed population. The criterion used to evaluate the effectiveness is based on a before-after evaluation of the surfaces acoustical properties as well as the comparison with other traditional porous asphalt pavements. Thus, a side objective is to develop new techniques to monitor performances of new pavements in order to improve the reliability of the results. Differences between performances of surfaces must be evaluated on site with techniques able to rate them also in urban context, in this paper specific challenges will be described. In fact, to monitor performances, the CPX and the pass-by method will be used to measure the noise produced by tires rolling on the reference pavements and on the innovative ones. The pass-by will be adapted to the urban reality, minimizing the confounding factors. New evaluation methods of sound absorption will be developed and validated, allowing a better reliability of monitoring results, helping the choice between new asphalts with better performances. Guidelines on monitoring activities will be developed in order to upgrade and to improve the methods currently available to assess the effectiveness of low noise road surfaces in urban areas.

Keywords: low noise pavements, CPX, Pass-By, urban noise

1. Introduction

The project LIFE NEREiDE (Noise Efficiently REduced by recycleD pavEments) [1] wants to investigate the use of new porous asphalt pavements and low noise surfaces composed by recycled asphalt pavements and crumb rubber from scrap tires. These materials will be mixed with binders at warm temperatures to produce warm mixture asphalt pavements with specific benefits:

1) to reduce the disposal of waste materials, that by this way will be recycled, and to reduce the use of virgin materials (promote resource efficiency and waste management);

2) to achieve acoustical performance better than those currently available, allowing a significant reduction of noise in urban areas and health improvement;

3) to improve safety in urban areas by obtaining draining and good textured surfaces;

4) to improve air pollution due to asphalt laying.

The new pavements will be laid in 2 selected urban areas in Tuscany, and will be tested with standard and innovative methods. The project is expected to lay a first site 2400 m long, with 6 different 400 m long stretches, and a second site 2800 m long made of different mixtures including rubber from end-of-life (including PERS technology) and recycled asphalts improving waste management and enhancing resource efficiency policies.

The effectiveness of the new pavements will be evaluated by measurements of surface characteristics, acoustical properties and by surveys submitted to the exposed population. The criterion used to evaluate the effectiveness is based on a before-after evaluation of the surfaces acoustical properties as well as the comparison with other traditional porous asphalt pavements. This paper is focused on the project's side objective of developing new techniques to monitor performances of new pavements in order to improve the reliability of the results. Differences between performances of surfaces must be evaluated on site with techniques able to rate them also in urban context. The effectiveness of new asphalts will be monitored also with reference to the subjective response to noise before and after the intervention.

The experimental activities will lead also to the development of specific guidelines to be used by Road Administrations in order to upgrade and to improve the methods currently available to assess the effectiveness of low noise road surfaces in urban areas.

The dissemination of these guidelines will enhance the use of such surfaces at EU level and the achievements of the main aims in other contexts.

The project will allow to reduce the urban noise pollution in the selected sites by at least 5 dB (A), compared to traditional pavements, and 2 dB (A) compared to the other traditional low emission noise asphalt pavements. This effect will be measured in terms of LDEN and in terms of L_{CPX} indicator [2] (see LIFE performance indicators). This will improve citizens' health in terms of LDEN and therefore DALY indicator [3]: in fact, in Tuscany, it is estimated that actually there are 7000 DALY due to noise and 90% of them are due to road traffic noise. So a decrease of the DALY is expected after the project. In the project these new surfaces will be applied in urban sites where noise limits are exceeded and mitigations are planned so an improvement on people life quality is expected in terms of noise exposure. In any case, an improvement of sound quality perception is foreseen and it will be evaluated through the about 700 surveys performed. The expected benefit will be evaluated by a Life Cycle Assessment of the used materials and their efficiency by a holistic analysis aiming the evaluation of noise impact on population, including subjective evaluations, psychoacoustical, acoustical and structural properties. An evaluation of air pollution sustainability in the laying of these special surfaces will also be carried out.

2. Implementation context

A preliminary analysis is necessary to drive Regione Toscana in the selection of the two sites within all available ones from its action plan, since many places need mitigation but a limited budget is available and a long stretch is needed for such a project in each site. The first step of this action is the description of candidate sites to be chosen within this list.

The description quantifies the limits overcoming and identifies influence of other sources (secondary roads, industrial activities, railways, airports and heliports and commercial activities) and the presence of sensitive buildings like schools and hospitals, accessibility [2].

2.1. The selection of candidate sites

The selection of implementation sites is performed following the list of most prioritized sites from the regional action plan according the Italian regulations. The sites with Italian priority index over 1000 are considered.

The consequent list is sufficiently long to require a proper filtering procedure in order to obtain sites in dense urban context where the needed 400 m long stretches are viable. In particular, a site for 6 stretches and a site for 7 stretches are needed. The filtering procedure not only considers the sites accessibility and other parameters to be evaluated on site, but it also considers some other facets as the possibility of merging near sites.

The procedure starts from a shapefile with sites requiring mitigation on SR (regional roads) provided by the Regione Toscana and continues following these steps:

1. Sites on highways are excluded. Carrying out measurements with the due safety will result a complex task and they are not compliant with dense urban requirements.
2. If the sum of sites length on a specific SR is less than 2400 m, all sites on that SR are removed from the list.
3. Isolated sites (no other sites nearby on the list on the same SR) shorter than 2400 m are removed from the list.
4. Sites that can be merged together are provided with a unique code.
5. Sites with merged length less than 2400 m are removed from the list.
6. New merged sites are presented to Regione Toscana and eventual reasons for their exclusion are declared by Regione Toscana.

The last step of the procedure is conceived to verify if some of the sites mitigations have been already funded or awarded and if other eventual modifications of the territory prevent the selection of the sites.

After the filtering procedure, the selected sites are visited and analysed in order to define single pavements stretches. On-site visits and maps analysis of the candidate sites should verify the eventual presence of other sources, roundabouts and traffic lights, buildings amount at both sides, sensitive buildings. A further step in office includes action plan analysis to check AADT (annual average daily traffic) flows, speed limits, total inhabitants exposed to exceeding noise levels, total inhabitants, noise levels and total priority of merged sites.

2.1.1. Results of filtering procedure

The shapefile provided by Regione Toscana contained 111 sites with priority higher than 1000. Six of them have been immediately excluded due to their inaccessibility. Afterwards, the isolated sites are removed and the filtering procedure has led to 13 sites to be presented to Regione Toscana.

Some sites have been excluded from the list after consulting Regione Toscana, since they have been already totally or partially funded and some sites were excluded being repaved in 2013 for UCI Road World Championships.

In **Table 1** the notes after step 5 implementation.

The sites on SR 66 have been visited to verify pavement status. Visits confirmed the pavements' renewal with the consequent lowering of the noise levels respect to ones leading to the inclusion in the mitigation sites list.

At the end of the procedure, the following sites were analysed:

- SR 71_2: Castiglion Fiorentino, Vitiano, Rigutino, Policiano and Il Matto
- SR 71_3: Terontola, Riccio, Ossaia, Vallone and Camucia
- SR 325_1: Mercatale, San Quirico
- SR 439_2: Pian del Quercione, Bozzano and Quiesa (Massarosa already realized)

The visited sites were described and parameters reported in technical sheets. Some notes are added based on local observations and other information available.

The identified sites with observations and noise maps were sent to Regione Toscana leading to the final decision on implementation context as reported in the following paragraph.

Table 1: Results of Regione Toscana consultation

Site code	Location	Notes
SR66_2	Olmi – Casini – Catena – Seano -Poggetto	Repaved in 2013
SR66_3	Poggio a Caiano - Sant'Angelo a Lecore	Repaved in 2013
SR66_4	San Piero a Ponti	Repaved in 2013
SR71_2	Castiglion Fiorentino – Vitiano – Rigutino – Policiano – Il Matto	To be visited
SR71_3	Terontola - Riccio - Ossaia - Vallone - Camucia	To be visited
SR325_1	Mercatale - San Quirico	To be visited
SR325_2	La Briglia – Il Fabbro - Carmignanello	Already realized at buildings
SR435_1	Pescia – Borgo a Buggiano – Santa Lucia	Already realized at buildings
SR439_2	Pian del Quercione – Massarosa – Bozzano - Quiesa	Partially realized, To be visited
SR439_3	Capannoli	Already realized at buildings

2.2. Final implementation sites

Following candidate sites analysis, the implementation context is defined in the SR 439_2: Pian del Quercione, Bozzano and Quiesa for the first implementation site with 6 stretches and in SR 71_2: Castiglion Fiorentino, Vitiano, Rigutino, Policiano and Il Matto for the 7 stretches site.

In Fig. 1 an example of the noise maps available on the sites is reported for the 6 stretches site. Finally, in Table 2 characteristics of sites are summarized.

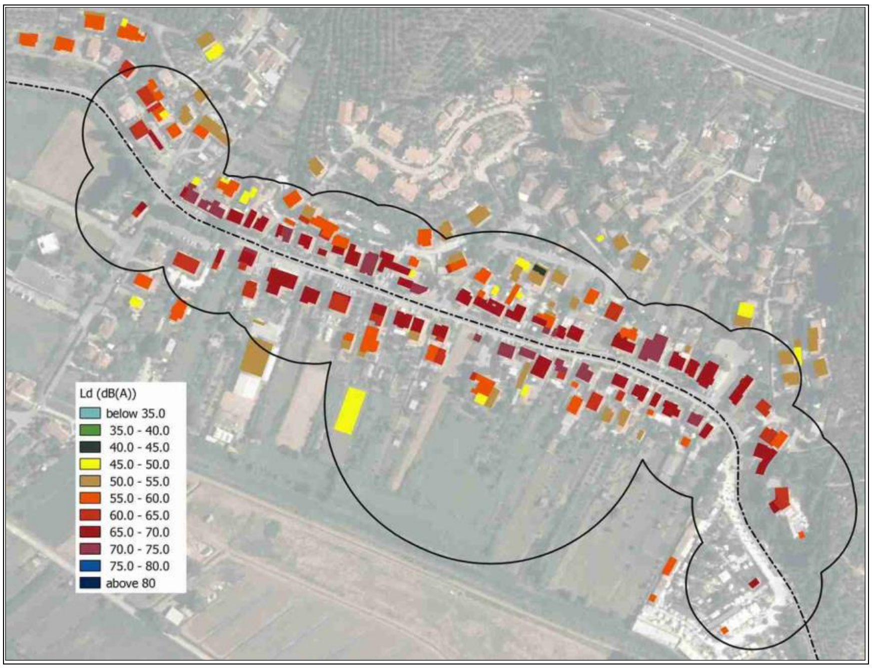

Figure 1: Noise map of L_{day} at buildings in Pian del Quercione.

Table 2: Implementation sites data

Sites	Inhabitants	Inhabitants exceeding limits	Sensitive buildings	AADT 2016		
				2-wheelers	Light Vehicles	Heavy vehicles:
SR439	1587	1131	4	370	13889	124
SR71	5963	2172	6	112	10783	248

3. Foreseen monitoring activities

In order to monitor performances, the Close Proximity Method (CPX) and the Statistical Pass-By method (SPB) will be used to measure the noise produced by tires rolling on the reference pavements and on the innovative ones. The pass-by will be adapted to the urban reality, minimizing the confounding factors. New evaluation methods of sound absorption on board of a mobile laboratory will allow to evaluate the absorption in a reproducible manner and without the use of destructive methods along the entire stretch. In addition, an evaluation of psychoacoustical effects on local population will be carried out. Surveys will be performed to evaluate annoyance and sleep disturbances differences produced by new surfaces. After a first round of implementation and monitoring, a second round will implement 7 different surfaces in another area in Tuscany to verify the lessons learnt and improving them by the use of recycled asphalts. A second monitoring stage will measure noise and structural properties to verify safety requirements and performances.

The minimum set of acoustical and psychoacoustical parameters needed to identify surface acoustical properties and to assess road surface performances will be established before the monitoring actions. The selected parameters will be measured in the monitoring campaigns ante-operam and post-operam. In the ante-operam campaigns, average values will be measured along the whole site taking into account the local conditions.

The ante-operam and post-operam monitoring campaigns will be carried on in two steps in order to monitor the pre-existing surfaces just before the substitution with the new ones and the new ones such that analysis of almost equally-aged surfaces can be performed. This will allow not only to have a reliable reference, but also to implement in the second step the lesson learnt in the first. It has to be considered that after the laying of each surface, at least three months are needed to the pavement to settle down before any measurement can be performed.

Moreover, an adjacent stretch that would not be replaced will be monitored in order to have a constant reference. In fact, some values may change due to seasonal and temperature local effects that could be controlled and adjusted only having a local reference value. The importance of having such a reference is justified by previous studies on CPX [5]. Absolute data and differential values as ante/post-operam and new surface vs reference one will be provided for each method (see Fig. 2).

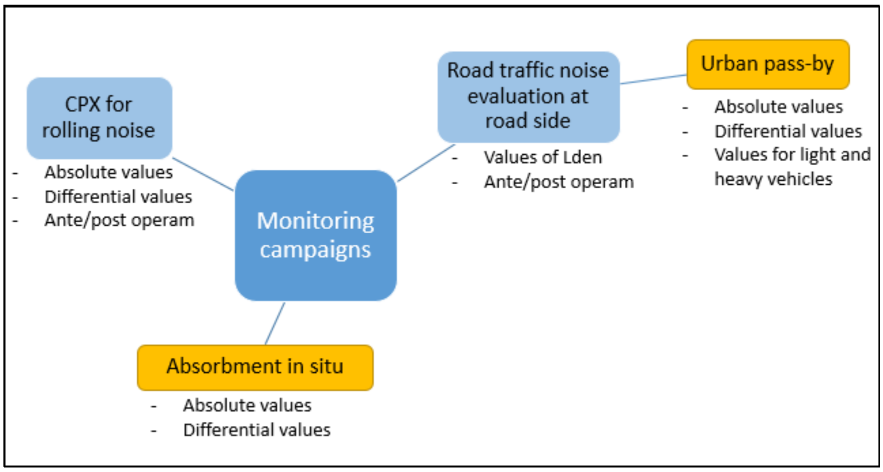

Figure 2: Noise monitoring campaigns, methods and values

These methods have to be adapted for the urban context, depending on the aim of their application, and new indicators are to be evaluated to better correlate results with data of environmental noise.

In addition to noise measurements, psychoacoustical evaluations will be carried out simultaneously. The objective is to select a set of reasonable parameters that could be then related to subjective annoyance. Surveys on the population living roadside will be carried out before and after the laying and further tests will be performed in laboratory environment.

In addition to acoustical properties, structural requirements will be also proofed by specific campaigns.

In the following, some details on innovative methods developments are provided

3.1. Innovative methods

3.1.1. Urban Pass By

One of the main objectives of the project is to achieve acoustical performance better than those currently available, allowing a significant reduction of noise in urban areas and health improvement. The reduction is performed through noise efficient asphalts whose performance should be monitored. To evaluate the performances several methods are already in use but none fits perfectly to the urban environment. This action aims to define a new measurement methodology to determine noise exposure levels of vehicles passing by a low noise emission pavement in urban context. In fact, SPB is an indicator of noise perceived for single vehicles and may help introducing policies for specific categories restriction or speed limits more than other methodologies acquiring the overall noise. The urban pass by methodology is intended to mix a simple noise measurement (easy to be performed with simple instrumentation and helping replication consequently) with SPB method (algorithms are intended to be developed to elaborate simple measurements in order to have data similar to SPB ones without being there during the measurement). The project aims to the evaluation of pavements and this action is needed to have a proper indicator of noise for each type of vehicle on pavements (which is impossible with CPX method). In fact, CPX allows the estimate of noise produced by a reference vehicle/tyre pair (single vehicle type/category) but fails provide indications for all vehicle categories. The most common methodology including several vehicles categories -the SPB – may be applied in urban context with several difficulties. In fact, not only the measurement requires free field condition in the proximity of measurement site (which is not at all common in urban context), but it also requires single vehicles passing by with a sufficient isolation time between the previous and the following ones. This is a very rare event in urban context, not only because roads needing mitigation have large flows, but also due to traffic lights, pedestrian crossing, roundabouts that group vehicles together. All these considerations led to the need of a new way of applying statistical pass by in urban context. The main objective of this action is to establish a measurement and an analysis procedure allowing to obtain data without manned measurements that will be used to monitor noise performances of new surfaces in the demonstration sites. In particular, night low traffic flows are considered as a relevant resource for statistical pass by data. In this way an indication of the noise heard by citizens when a single vehicle is passing by is estimated for each vehicle category. In fact urban pass by values will be representative of façade noise levels (which are the ones used for exposure estimation). This information not only provides a value for road pavement efficiency in the specific context, but also provides indications to policy makers for traffic route policies (freight banning times, bus routes, speed limits etc.) and also values to estimate people exposure to potential different traffic flows. A first phase will include the analysis of these measurements data to test several elaboration procedures in order to identify single passages (different techniques will be tested to relate noise data to vehicle categories like vehicle length, pattern recognition, and spectral analysis). All the already available data will have to be formatted according a common framework before they can be used for the purpose of the action, so a lot of work is foreseen to collect and format available data. In addition, new ad hoc measurements campaigns are foreseen to produce new data for testing different methodologies. In particular, the new measurements campaigns will be carried out also in sites where standard statistical pass by are already available in order to compare data of the new identified procedure with the official one (data available from Leopoldo Project, see [**Error! Reference source not found.**]). In this second phase, the accuracy of the new methodology will be evaluated based upon the comparison with the official methodology in extra urban context with a known source. Several passages of the same vehicle used as a reference will be monitored and analysed.

The validation of the Urban Pass By is needed and will constitute a reference for the analysis of the new laid experimental surfaces. Validation will include also a monitoring campaign of some parameters (e.g. CPX values) that are going to be acquired for the experimental surfaces such that the data of the new methodology could be compared with other indicators.

3.1.2. On-site acoustical absorption measuring system

The aim is to develop during the first year of the project a new on-site acoustical absorption measuring system, built on a mobile laboratory set-up: a vehicle equipped with various instrumentation, able to perform both moving and standing measures and a first step of data analysis. The system will be used to monitor noise properties of new surfaces realized on demonstration sites. The instrument itself will be able to give real time results and a fine spatial acoustical characterization of the road surface, linkable to microscopic and macroscopic properties of the asphalt (parameters such as porosity and tortuosity but also an evaluation of macroscopic discontinuities or structural problems). In principle, it should be able to evaluate the current state of a whole pavement stretch and its goodness: it can be useful to infer indications for the manufacturer besides evaluating acoustic and mechanic ageing. This will allow to evaluate not only the goodness of the mixture but also if the laying has been carried out correctly, and if not to provide more technical guidance for the second laying stage. As for its implementation, it will be composed by four main parts, each to be tested and calibrated separately in controlled condition and on the actual mobile laboratory:

1) p-u probe: a sensor that measures the local values of pressure and fluid velocity, thus allowing a simple acoustic impedance evaluation as the ratio between the two values. They are also referred as “intensimetric probes”.

2) inertial damper: electro mechanic actuator driven by a laser distance measure between the car and the pavement surface that will grant constant distance between the probe and the asphalt, cancelling at the same time the vibrations from the moving vehicle

3) acoustic emitter: a simple amplified acoustic source whose pavement reflected field is measured by the probe

4) instrumentation control system: pc linked to a suitable acquisition board

All the above-mentioned parts will be finally assembled on a moving vehicle, the basic frame of the moving laboratory. Tests and data analysis to characterize the system will be performed on road: during this stage possible critical issues will be found and solved, while a correct measurement protocol will be established. Measures obtained by the probe system need to be compared to independent measurement devices, such as explained by ISO 13472-1, ISO 13472-2 and ISO 10534. Even if no direct theoretical link is established between the different measure systems a simple result comparison can clarify the actual sensitivity and limitations of the new device.

4. Conclusions

The monitoring activities will contribute to the two main results of the project:

- a holistic-approached analysis of pavements performances in terms of structural, acoustical and psychoacoustical parameters;

- the definition of guidelines for public and private bodies responsible for road managing on the definition of the tenders for the implementation of mitigation actions and to the definition of a replication and transfer strategy

The aim is to correlate the results of these analysis in order to identify common trends within indicators and to evaluate differences between experimental pavements. It will be verified if the lowering of noise levels acquired in noise monitoring will also correspond to a lowering of psychoacoustical indicators and if requirements in terms of structural properties are still met. The results will lead the guidelines for implementing the second step of the laying especially regarding homogeneity evaluations (CPX, absorption values and structural properties). In the second step, the comparison is carried out in order to identify a set of indicators able to assess the effectiveness of the new pavements and to rate them not basing on their physical properties in laboratory conditions, but on their true properties after the laying and in a specific situation. Finally, a comparison between the expected ranking of surfaces' performance and the real ones verified onsite will be carried out in order to assess possible gaps between theoretical considerations and on-site implementation. This holistic analysis will also allow an evaluation of the replicability of the implemented surfaces. In fact the monitoring analysis carried out in different sites will highlight difficulties and strategies to apply them in different places. A section of the final analysis report will describe in detail which are the strategies for implementing the developed surfaces and methods in different contexts in order to enhance transferability of the project actions.

The guidelines will include not only the lesson learnt during the implementation of demonstration sites but also the observations received through the technical disseminations events, the networking and by all stakeholders that have been reached within the project. The monitoring guideline will be useful for all the bodies responsible for drawing action plans and more generally to all the municipalities willing to improve sound quality. The drawing up of the deliverable will take into account the results of all the core actions in order to establish best monitoring protocols and minimum requirements in terms of acoustics and psychoacoustics indicators. It will highlight also pro and cons of actually standardized methods providing eventual modified procedures that could help in monitoring the efficacy of mitigating actions. Suggested monitoring methods will be described and new procedures clearly defined. Reports templates will be provided within the guideline. For each suggested indicator a threshold value will be identified in order to define a mitigation action efficient. Since the diffusion of common monitoring protocols and the diffusion of recycled materials for low noise pavements are the master objectives that could be achieved through a good and complete reference of what has been done and analysed, being that reference comprehensible and adaptable to other context, eventual limitations of the findings will be correctly highlighted to push further researches.

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