LIFE OPTIMUS

“Optimised Pavements Towards Innovative Mitigation of Urban noiSe”

Project 101214690 — LIFE24-ENV-IT-LIFE OPTIMUS

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1 Brief review of state of art in MCDA for noise abatement planning

Environmental noise—primarily generated by road traffic, railways, and airports—poses significant risks to human health and well-being. Despite growing awareness, noise pollution has often been underestimated in environmental policies, ranking behind air pollution in terms of priority (Bozkurt & Karakaş, 2022). However, increasing evidence links chronic noise exposure to adverse health effects such as cardiovascular diseases, sleep disturbance, and cognitive impairment. As urbanization and infrastructure development continue, the need for robust noise abatement strategies has become more pressing. Noise abatement planning is a complex process involving multiple, often conflicting, objectives: minimizing environmental and health impacts, controlling economic costs, ensuring social acceptance, and maintaining infrastructural functionality (D'Alessandro et al., 2022). In this context, Multicriteria Decision Analysis (MCDA) has emerged as a valuable tool, capable of integrating heterogeneous criteria to guide transparent, balanced, and scientifically informed decisions.

Historically, noise mitigation decisions were based predominantly on cost minimization or cost-effectiveness analysis (CEA). While useful, these approaches were limited by their focus on singular metrics—typically financial costs or noise reduction levels—neglecting broader health, environmental, and social consequences. The evolution toward MCDA reflects the growing recognition that noise abatement requires a multidimensional approach that incorporates diverse stakeholder values and complex trade-offs. Recent European policy frameworks, such as the Environmental Noise Directive (END) 2002/49/EC and its further amendments (Directive 2002/49/EC, 2002), have further emphasized the importance of holistic noise assessment. These directives encourage the integration of non-acoustic factors—such as health burden indicators and quality of life metrics—into action planning. This paradigm shift has paved the way for MCDA to become a cornerstone in strategic noise management across Europe (Guski et al., 2017).

Multiple decision support tools are employed in noise mitigation planning. These include:

1. Cost Minimisation Analysis (CMA) – Focuses solely on selecting the least costly alternative that meets a fixed noise reduction target (Hirst et al., 2016).
2. Cost-Effectiveness Analysis (CEA) – Identifies interventions that offer the best noise reduction per unit cost (Avanceña & Prosser, 2021).
3. Cost-Benefit Analysis (CBA) – Converts both costs and benefits into monetary terms to calculate net benefit (Dréze & Stern, 1987).
4. Cost-Utility Analysis (CUA) – Often used in health economics, it incorporates measures like Disability-Adjusted Life Years (DALYs) (Robinson, 1993).
5. Multicriteria Decision Analysis (MCDA) – Considers multiple qualitative and quantitative criteria without reducing all outcomes to monetary units (Ruiz-Padillo et al., 2016).

While CBA and CEA remain widespread due to their familiarity and simplicity, they often fail to incorporate qualitative or stakeholder-based aspects, such as public acceptance or urban aesthetics. In contrast, MCDA allows for flexible integration of a broader array of criteria, offering a more inclusive and participatory framework for decision-making.

The most commonly applied MCDA technique in noise abatement is the Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty. AHP structures complex decision problems into a hierarchy consisting of a goal, criteria, and alternatives. Pairwise comparisons are then used to assign relative weights to each element, allowing for the calculation of a final score for each alternative. The advantage of AHP lies in its ability to blend objective data (e.g., decibel reduction, cost, environmental impact, health consequence) with subjective judgments (e.g., visual impact, public preference) to deliver a comprehensive evaluation. AHP has been successfully used in various European contexts to assess and prioritize noise mitigation measures for road infrastructure projects. Researchers applied the AHP method to a road noise mitigation project, evaluating alternatives such as insulating windows, porous asphalts, and multiple types of noise barriers (Xu et al., 2023). They constructed hierarchical models and used expert input to weight sub-criteria like visual obstruction and CO_2 emissions. The results highlighted how different criteria favour different solutions. For example, porous asphalt scored highest for social acceptability, while aluminium noise barriers excelled in terms of health protection (Xie et al., 2022). This variability underscores the value of MCDA in capturing nuanced trade-offs and delivering balanced, context-sensitive decisions. Moreover, the model revealed that interventions that might seem less effective in isolation could be the most suitable when broader criteria are considered, such as public acceptance and sustainability.

Other MCDA methods found in the literature include:

- PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) – Offers partial and complete rankings based on outranking relations (Brans & De Smet, 2016).
- ELECTRE (ELimination Et Choix Traduisant la REalité) – Suitable for handling non-compensatory criteria (Govindan & Jepsen, 2016).
- TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) – Ranks alternatives based on their closeness to an ideal solution (Ai et al., 2022).

Despite methodological differences, the success of MCDA approaches depends heavily on the careful selection and weighting of criteria, stakeholder involvement, and the transparency of the process.

According to scientific literature, typical criteria included in MCDA models for noise abatement can be grouped into four categories:

1. Environmental Criteria: Noise reduction effectiveness, life cycle emissions (e.g., CO_2 equivalent), landscape and visual impact.
2. Economic Criteria: Construction, operational, and maintenance costs; impact on property values; cost-efficiency ratios.
3. Health Criteria: Reduction in relative risk for cardiovascular diseases, tinnitus, annoyance, and sleep disturbance. Calculations often rely on WHO guidelines or the DALY metric (WHO, 2011).
4. Social Criteria: Public acceptability, equity (e.g., protecting vulnerable populations), and alignment with urban development goals.

In practice, each intervention—such as porous asphalt, noise barriers, façade insulation, or traffic control measures—is evaluated against these criteria. Weightings are usually determined via expert panels or stakeholder surveys, allowing the model to reflect the priorities of both decision-makers and affected communities (Bawono et al., 2019).

Therefore, the potential of MCDA in noise abatement planning is substantial. It allows planners to:

- Move beyond cost-centric decisions and incorporate health, social, and environmental impacts.
- Transparently justify decisions to stakeholders and funding agencies.

- Adapt mitigation strategies to local contexts and priorities.
- Integrate community perspectives, enhancing legitimacy and compliance.

Going forward, more widespread adoption of MCDA methods could benefit from the development of standardized frameworks and digital decision-support tools (Bawono, 2022). Including dynamic weighting mechanisms and scenario analysis could further enhance the utility of these models. Finally, greater involvement of the public—not just experts—through participatory approaches and co-design of evaluation criteria would strengthen the democratic quality of noise abatement policies.

Multicriteria Decision Analysis represents a powerful and versatile framework for planning noise abatement interventions in complex and contested environments. By accommodating a diverse range of quantitative and qualitative factors, MCDA facilitates more holistic, transparent, and socially responsive decision-making. Its application to noise abatement planning—especially through methods like AHP—demonstrates that effective solutions must balance not only economic and technical feasibility but also environmental sustainability, human health, and social justice. Indeed, MCDA ensures a comprehensive evaluation of mitigation options, revealing optimal solutions that may be overlooked using conventional methods. Moreover, it provides a transparent and participatory framework that aligns technical assessments with community values, thereby enhancing the quality and legitimacy of decision-making.

2 Brief review of achievements of previous experiences

In the last years several projects, studies, review and analysis of low noise asphalts techniques have been performed. Results summarized in a 2017 report (CEDR Technical Report 2017-01) classified different types of low noise designed pavements and potential noise reduction for passenger cars into:

- thin layers pavements: 1-4.5 dB
- split mastic asphalt pavements (SMAP): 2.5 dB
- porous asphalt pavements (PAP): 2-5.5 dB
- optimized concrete pavements: 1-3 dB
- poroelastic pavements (PERS): 8-12 dB

More recent findings (Ling et al., 2021) attest that recycled asphalt pavements (RAP) can reduce 1-10 dB noise of passenger cars.

The same study carried out a comprehensive review of pavement characteristics and methods for attesting reductions: it derives that PAP and PERS seem to have poor durability due to pores clogging and low resistance with high temperatures respectively. The study also points out that scope of application of each typology is different and it concludes that:

- the noise reduction characteristics and in field acoustic performance of low noise pavements throughout the life cycle should be studied and well quantified;
- the accurate design of noise reduction effects of low noise pavements should be studied to meet the needs of different areas for noise reduction effects, and a low noise pavement design method based on noise reduction performance requirements should be established;
- the acoustic simulation research of low noise pavements should be strengthened.

All these issues are expected to be included in the OPTIMUS framework and the study will include findings of previous experiences and in particular of research projects, finished and ongoing, on the low noise asphalt topic.

Retrieving a list of past/ongoing collaborative projects is not immediate since low noise asphalts have been studied from different points of view and both in research projects (FP, HORIZON funded) and in pilot demonstrative actions funded by other programs like LIFE and INTERREG. Only within framework programs (source CORDIS - EU research results), 7 projects were funded before the 2002/49/EC directive entry into force, 8 in the first 10 years of the directive and just one more recently. On the other side, the LIFE program (source LIFE Public database) funded about 15 projects guiding implementation of low noise asphalts after the END entry into force and 8 of them in the last decades, including the OPTIMUS project. These data support the findings that despite technologies being available, their implementation still needs to be explored, studied and guided for an effective use in cities.

A list of the projects funded by H2020 and LIFE programmes in the last 10 years is provided in Table 1.

Since, with the exception of LIFE 16 projects, they involved at least one partner or supporting partners of the OPTIMUS project, they can be a valuable source of data for the development of OPTIMUS project, together with other experiences detailed in the following (section 2.1). Then, further replications and experiences are detailed (section 2.2). Finally, major findings and an analysis of limitations of previous experiences is presented in order to present gaps addressed by the LIFE OPTIMUS project (section 2.3).

Table 1: List of Framework program and LIFE projects of last decade on “road traffic noise” and LNP

Programme	Acronym	Title	Start Date	End Date
LIFE15 ENV	LIFE NEREiDE	Noise Efficiently REduced by recycleD pavEments	01/09/2016	31/03/2021
LIFE15 ENV	LIFE MONZA	Methodologies fOr Noise low emission Zones introduction And management	01/09/2016	30/06/2020
LIFE16 ENV	LIFE C-LOW-N ASPHALT	LIFE COOL & LOW NOISE ASPHALT	01/07/2017	30/06/2023
LIFE16 CCA	LIFE HEATLAND	Innovative pavement solution for the mitigation of the urban heat island effect	02/10/2017	31/12/2021
LIFE18 ENV	LIFE E-VIA	Electric Vehicle noIse control by Assessment and optimisation of tyre/road interaction	01/07/2019	31/01/2023
H2020	NEMO	Noise and Emissions Monitoring and radical mitigation	01/05/2020	31/10/2023
LIFE20 ENV	LIFE SNEAK	LIFE SNEAK – optimized Surfaces against NoisE And vibrations produced by tramway tracK and road traffic	01/09/2021	28/02/2026
LIFE22-ENV	LIFE SILENT	Sustainable Innovations for Long-life Environmental Noise Technologies	01/09/2023	31/08/2028

2.1 Materials and results uptaken from previous research projects

As mentioned above, all the projects listed in Table 1 are valuable experiences, however the SILENT project is still ongoing and no asphalt implementations have been done at this time, neither planned mixture details are available. Regarding the two LIFE 16 projects, they were specifically oriented to reduce heat islands and increase luminance and only partially address noise with only 1-3 dB reduction achieved, thus no detailed results can be retrieved in this phase.

In addition to these projects, also a local experience is taken into account, the LEOPOLDO project, funded more than 15 years ago by the Tuscany Region in Italy. Being the prequel of many of the aforementioned projects, it is relevant to analyse its findings.

In the following subparagraphs aims, realized actions, their validations and limitations are detailed for each research project.

2.1.1 LEOPOLDO PROJECT

Aims

As part of the 2005 National Road Safety Plan, the Italian Ministry of Infrastructure and Transport, the Tuscany Region, and local Provinces funded the “Leopoldo” research project. The initiative aimed to develop guidelines for the design, construction, inspection, and maintenance of local roadways in Tuscany.

Following initial investigations, six test sites were selected for long-term monitoring to evaluate the performance of different pavement types. The project focused on testing innovative and environmentally sustainable asphalt mixtures, some of which included high percentages of recycled materials.

A key innovation of the project was the development of “closed-texture” pavements—more durable than traditional porous, noise-reducing surfaces. These new pavements are designed to reduce noise by minimizing its generation at the source, rather than relying on sound absorption.

Realizations

The Table 2 reports realized low noise pavements which have been studied for a long period (2008-2012).

Table 2: Realized pavements in Leopoldo project subjected to long term monitoring

Province	Type of low noise surface	Traffic volumes	Heavy vehicles volumes	Speed limit
AR	open graded	high	medium	90 km/h
FI	gap graded (optimized texture)	low	low	50 km/h
LU	dense graded (optimized texture)	medium	low	70 km/h
MS	open graded	low	medium	50 km/h
PI	Dense graded with expanded clay	high	medium	70 km/h
PT	gap graded asphalt rubber 3 cm	medium	high	90 km/h

Validations

In Table 3 the results of Close ProXimity Method (CPX) monitoring campaigns are summarized, where CPX was performed according to standard in draft ISO/CD 11819-2:2000, nowadays finally issued as ISO 11819-2:2017 (International Organization for Standardization, 2017). CPX values are provided as difference to a reference coeval surface (less influenced by measurement conditions) and in brackets as difference to the Ante Operam (AO) values.

Table 3: Outcomes of Leopoldo project (CPX measurements)

Province	CPX difference to reference (AO) beginning	CPX difference to reference (AO) ending	Years monitored
AR	3.7 (5.5)	3.7 (4.6)	5
FI	6.3 (7.3)	2.9 (6.0)	5
LU	4.5 (6.0)	4.9 (4.3)	5
MS	7.1 (1.8)	5.8 (2.5)	3
PI	6.4 (6.2)	3.6 (5.0)	3
PT	4.2 (4.1)	4.6 (2.3)	3

Limitations

The LEOPOLDO database offered long temporal series of CPX and also Statistical Pass-By (SPB) methodology (International Organization for Standardization, 2023) modified as in HARMONOISE project using SEL metric instead of LAmax as required by the standard (Jonasson; 2004). Both techniques revealed reductions for the different pavements. Within LEOPOLDO also vibrations were assessed in order to estimate durability of pavements. However, SPB results varied a lot with seasons and provided less stable results.

The LEOPOLDO project might be considered outdated somehow because it was developed before the entry into force of approved CPX standard and absolute values are not comparable to to-date data. SPB data collected in the project were strongly influenced by local conditions and cannot provide reliable data due to grass, terrain slope influence. LEOPOLDO low noise pavements were made according to experimental mixtures, thus not all of them are still on the market as diffuse solutions. However, some of them have been replicated across the Tuscany region to mitigate regional roads.

2.1.2 LIFE NEREIDE PROJECT

Aims

The LIFE NEREiDE project wanted to demonstrate the use of new porous asphalt pavements and low noise surfaces composed of recycled asphalt pavements and crumb rubber from scrap tires. These materials will be mixed to produce warm mixture asphalt pavements with specific benefits, among them to reduce the disposal of waste materials and to achieve better acoustic performance than ones on the market.

The effectiveness of the new pavements was evaluated by measurements of surface characteristics, acoustic properties and by surveys submitted to the exposed population. The effectiveness evaluation is based on a before-after criterion 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 to rate them also in urban context.

Realizations

Two experimental sites in Tuscany, Italy, and a test track in Ghent, Belgium, were used to evaluate innovative asphalt pavement solutions. In Italy, test sections were built on two regional roads—SR 439 and SR 71 (all stretches having 50 km/h as speed limit)—featuring 12 types of asphalt mixtures. These included traditional hot mix asphalts and new low-noise pavements made with crumb rubber (CRM) and reclaimed asphalt pavement, using warm mix technology.

In Belgium, a prefab poro-elastic (PERS) test track demonstrated excellent noise reduction but had to be removed after 1.5 years due to durability issues caused by surface roughness and manufacturing flaws. Despite its early failure, valuable data were collected, and recommendations were developed for future improvements. The cautious decision not to construct a long PERS section in Italy was validated by the Belgian results.

The typologies of compounds used are described in Table 4.

Table 4: Realized pavements within LIFE NEREIDE

Site	Type of low noise surface	Reference	CRM	Reclaimed
I	0-12 porous compound	X		
	0-12 SMA	X		
	open graded grain sizes (dry process)		X	
	open graded grain sizes (wet process)		X	
	gap graded grain sizes (dry process)		X	
	gap graded grain sizes (wet process)		X	
II	open graded grain sizes (dry process);		X	X
	open graded grain sizes (wet process);		X	X
	gap graded grain sizes (dry process);		X	X
	gap graded grain sizes (wet process);		X	X
	dense graded grain sizes (dry process);		X	X
	dense graded grain sizes (wet process);		X	X

Validations

A Life Cycle Assessment (LCA) was conducted to quantify material and energy consumption, as well as environmental emissions, of experimental asphalt surfaces compared to traditional hot mix asphalt. The LCA showed that using warm mix technology combined with recycled materials, such as asphalt millings and rubber powder, significantly reduces environmental impacts related to road surfacing and maintenance.

This approach not only lowers the consumption of raw materials like bitumen and aggregates but also reduces production and laying temperatures, leading to decreased emissions. Overall, it represents an eco-friendly and effective alternative to traditional asphalt technologies.

In parallel, a holistic evaluation of acoustic properties was carried out including CPX, U-SPB pass by measurements (Ascari et al., 2022) according to innovative protocol, psychoacoustic evaluation and other indicators that didn't reveal as stable. The evaluations were carried out just a few months after the laying. In the first site with CRM gap dry mixture and open wet mixtures performed at best with reduction (compared to Ante Operam results) of more than 5 dB both in terms of CPX and U-SPB roadside levels. In the second site where reclaimed asphalt was used, similar achievements were obtained again for open wet surface and for dense wet. Thus, Tuscany Region and ANAS decide to replicate open surfaces with reclaimed asphalt also in other sites (see section 2.2).

Limitations

The LIFE NEREIDE project developed protocols for measuring roadside noise and tested various pavement technologies, comparing different mixtures under similar traffic conditions. However, more repetitions across diverse contexts would have better demonstrated performance.

Acoustic tests were only conducted after laying, with no long-term monitoring due not only to project timing but also to underground utility works that hindered tracking pavement performance over time during after LIFE. Comparisons were made with pre-installation values, but seasonal variations and the COVID-19 pandemic may have influenced results, especially at site 2.

2.1.3 LIFE MONZA PROJECT

Aims

The project is aimed at the development and validation of a technically sound and easily replicable methodology for the identification, planning, and operational management of Noise Low Emission Zones (Noise LEZs), using the Libertà District in the city of Monza (Italy) as a pilot site. The intervention strategy combines top-down measures—defined based on municipal planning and regulatory needs, such as traffic flow optimization and the replacement of existing road pavements with low-noise surfacing materials in critical road sections—with bottom-up actions, derived from stakeholder engagement processes and end-user input, including behavioural change incentives to encourage modal shifts towards low-noise mobility solutions (e.g. cycling). The core objective is to achieve quantifiable reductions in environmental noise levels, with ancillary benefits in terms of air quality improvement and positive effects on public health indicators. In parallel, the project integrates citizen involvement in a participatory monitoring and co-decision framework, aimed at fostering awareness and proactive behavioural changes in relation to urban noise management and health-related environmental quality.

Realizations

The laying of a new low-noise asphalt, carried out in September 2018, has affected about 1 km of Viale Libertà. A “dense-graded” pavement with an optimized texture has been used as a wear layer. This type of road surface has been designed and tested by the Tuscany Region on provincial roads with smooth traffic characteristics within the "Progetto Leopoldo", namely the same mixture used in Lucca has been realized in an urban context with 50 km /h as speed limit.

Validations

The validations have been carried out through low-cost monitoring systems compared to traditional monitoring with long lasting campaigns. Noise levels during day-evening-night periods were reduced by 4-5 dB after the laying.

Limitations

No specific measurements addressing road-tire nor single vehicle noise were performed.

2.1.4 LIFE E-VIA PROJECT

Aims

The project aimed to address urban road traffic noise pollution with a future-oriented approach, considering the growing presence of electric and hybrid vehicles. Its main goals were to:

- Investigate tire/road interaction specific to the characteristics of electric vehicles.
- Fill the regulatory gap by providing the missing coefficients needed to apply the CNOSSOS model (Directive 996/2015/EC) to new vehicle types and traffic patterns.

- Develop and test an optimized solution combining road design and tire technology to reduce urban noise and Life Cycle Costs, improving upon existing best practices.

Realizations

A mitigation measure aimed at optimizing road surfaces and tires of EVs to reduce noise for roads inside very populated urban areas has been developed.

Two road surfaces, 5 different EV types, one reference ICEV and 6 tire versions per vehicle type (including tires specifically designed for EVs) have been tested. Specifically, in Nantes two versions (with and without crumb rubber) of the prototype were tested.

Finally, the final prototype with crumb rubber has been laid in the pilot case in Florence (Via Paisiello).

The Table 5 reports realized low noise pavements which have been implemented:

Table 5: Realized pavements within LIFE E-VIA

Site	**Type of low noise surface**	**Traffic volumes**	**Heavy vehicles volumes**	**Speed limit**
Nantes (FR)	Very Thin Asphalt Concrete 0/6 (Initial prototype with CR, named PCR)	controlled access (prototype on a test track)	N.A.	N.A.
Nantes (FR)	Very Thin Asphalt Concrete 0/6 (Initial prototype without CR, named P)	controlled access (prototype on a test track)	N.A.	N.A.
Florence (IT)	Dense graded (optimized texture) Final prototype named E-VIA PCR with crumb rubber	medium	low	50 km/h

Validations

By referring to the final prototype laid in the pilot case in Florence, the main validation results are summarized below in terms of:

- CPX levels difference at the reference speed of 50 km/h between E-VIA PCR pavement and a coeval reference P pavement (a traditional road surface) (Table 6)
- Absolute CPX levels at the reference speed of 50 km/h. Both the Reference P and the E-VIA PCR pavements, respectively with LCPX values of 89.8 dB(A) and 87.6 dB(A) after 3 months, were compliant with the conformity limit value (90 dB(A) at 50 km/h) provided by the EU Green Public Procurement criteria for road design, construction and maintenance (referring to the "core" criteria).
- Significative noise reduction (4.4 dB(A)) at a façade level in terms of Lnight (in the night period from 10 p.m. to 6 a.m.) immediately after the laying of the optimized E-VIA PCR pavement (Table 7)
- Noise perception: 70% of interviewees inside an electric taxi identified the optimized pavement as the one with the best acoustic comfort, compared to new standard asphalt and the worn one.
- Resident feedback: 77% evaluated the intervention as acoustically positive.
- Tyre development: The noise optimized tire for EV showed a 0.8 dB(A) reduction of rolling noise.

- LCA/LCC: The E-VIA solution demonstrated a 33% reduction of the DALY (Disability-adjusted life years) in terms of human health impacts. The comparison between the E-VIA and Reference scenarios showed that E-VIA solution leads to an increase of 4% in GWP.
- Estimation of specific CNOSSOS rolling noise coefficients and road surface correction factor obtained also through Controlled Pass By measurement method (Moreno at al., 2023).

Table 6: Δ LCPX (LCPX @ 50 km/h) for the realized pavement within LIFE E-VIA at different age

Pavement	**Reference P**	**Age of E-VIA PCR (months)**
E-VIA PCR	–2.2 dB(A)	3
E-VIA PCR	–0.9 dB(A)	7
E-VIA PCR	–0.7 dB(A)	12
E-VIA PCR	–1.1 dB(A)	15

Table 7: Noise reduction at a façade level in LIFE E-VIA

	E-VIA PCR	**Reference (New standard asphalt)**
Lnight Leq (Ante-Post)	4.4	1.5

Limitations

The demonstration sections covered quite a limited street length (150 m each) and monitoring was limited in time. Additional measurements are needed to assess the durability over time of the properties of the new optimized mixture.

2.1.5 NEMO PROJECT

Aims

The NEMO (Noise and Emissions MOnitoring and radical mitigation) project was financed by the Horizon 2020 programme to improve air quality and to reduce noise impact by implementing innovative solutions across different European contexts, such as remote-sensing technologies and low noise and pollutant-reducing asphalt mixtures.

Within the project, two different kinds of low-noise and pollutant-reducing pavement mixtures have been developed for an urban road and a peri-urban road pavement and tested in a controlled laboratory full scale test (not open to public traffic).

Three real-life pilots (in Madrid, Valencia and Florence) were aimed to demonstrate NEMO solutions and to establish a standardized methodology for the use of remote-sensing systems.

The urban mixture, developed inside the project, was implemented in the city of Florence (Foggini street) and validated by performing Ante Operam and Post Operam evaluations and comparison with a traditional road surface with the same age.

Realizations

Table 8 reports details of the real-world implementations. The experimental pavement did not include recycled rubber.

Table 8: Realized pavements within cities in NEMO project

Site	Type of low noise surface	Traffic volumes	Heavy vehicles volumes	Speed limit
Florence (IT)	Very Thin Asphalt Concrete (VTAC) surface with discontinuous particle size distribution	medium	low	50 km/h

Validations

The NEMO's experimental pavement showed excellent acoustic performance with an important reduction in measured noise levels.

In table 9 the results of CPX monitoring campaigns are summarized in terms of CPX levels difference (at the reference speed of 50 km/h) between the NEMO's experimental pavement (named PS) and the Ante Operam pavement (named AO) and the traditional road surface (named RIF) with the same age of PS.

Table 9: ΔLCPX (LCPX @ 50 km/h) for NEMO pavement at different age

Pavement	Difference to AO	Difference to Reference pavement	Age of PS (months)
PS	-10.5 dB(A)	–3.3 dB(A)	3
PS	-9.9 dB(A)	–3.6 dB(A)	7

In absolute terms, the experimental pavement PS showed excellent acoustic performance: after 7 months, CPX levels, at 50 km/h, were of about 8 dB(A) lower than limit values provided by the GPP. Also, the experimental mixture showed good mechanical performance in terms of resistance to plastic deformation and water damage.

An environmental and economic assessment (LCA and LCCA) of the NEMO pavements compared to conventional pavements have been carried out (including the effect of noise reduction). The results indicate a huge environmental and economic benefit when high traffic and population density is affected. However, the aging rate of pavements might highly influence the estimates.

Limitations

Only CPX measurements were performed and covered a limited time (7 months after the installation). Additional measurements are needed to assess the durability over time of acoustic properties of the new mixture.

2.1.6 LIFE SNEAK PROJECT

Aims

The LIFE SNEAK project aimed to reduce road traffic noise and vibrations in densely populated urban areas, with Florence as the pilot case. The project focused on developing and testing low-noise/vibration road surfaces and retrofitting solutions that maintain life cycle costs similar to traditional surfaces. Specific goals concerning road traffic noise included:

- Mitigating combined noise sources, such as airborne and ground-borne noise from road traffic.
- Applying "quiet pavements" to reduce air-borne noise and minimize pavement-tyre interaction and its propagation.
- Reducing overall annoyance caused by noise and vibrations generated by road traffic.

An experimental asphalt mixture, designed inside the project and implemented in the city of Florence, was evaluated by carrying out Ante Operam and Post Operam measurements and through comparison with newly paved traditional road surfaces.

Realizations

A dense-graded asphalt mixture (optimized texture), specifically designed to mitigate the transmission of noise and vibrations generated by vehicular and tram traffic, was engineered and laid over an approximately 150-meter section of Via La Marmora in Florence. Adjacent to this section, additional segments of newly paved but conventional asphalt were applied, serving as reference areas for performance comparison.

Table 10: Realized pavement within LIFE SNEAK

Site	**Type of low noise surface**	**Traffic volumes**	**Heavy vehicles volumes**	**Speed limit**
Florence (IT)	dense-graded asphalt mixture (optimized texture) with crumb rubber	medium	low	30 km/h

Validations

Noise impact has been measured through roadside measurement of noise levels and with CPX method. Campaigns have been performed in the Ante Operam condition and 3 months after the laying.

The following table summarizes the results of CPX monitoring campaigns in terms of CPX levels difference between the SNEAK's experimental pavement and two Ante Operam pavements (named AO1 and AO2).

Table 11: ΔLCPX (LCPX @ 50 km/h) for SNEAK pavement after the laying

Pavement	**AO1**	**AO2**	**Age of PS (months)**
SNEAK	-5.6 dB(A)	–4.4 dB(A)	3

In absolute terms, the experimental pavement SNEAK, with LCPX values of 86.8 dB(A) after 3 months, was compliant with the conformity limit value (90 dB(A) at 50 km/h) provided by the GPP (referring to the "core" criteria).

Referring to another comparison between the Ante e Post-Operam (PO) scenarios (considering both the experimental SNEAK pavement and a coeval traditional reference pavement), table 12 shows the obtained reduction in noise levels expressed in terms of Lden and Lnight indicators. In terms of CPB measurements determined considering a light vehicle at 40-50 km/h, reductions of 3 to 4 dB were found compared to new traditional asphalt.

Table 12: Roadside levels differences between AO and PO scenarios depending on different pavements

SNEAK		New traditional asphalt	
Lden (dBA)	**Lnight (dBA)**	**Lden (dBA)**	**Lnight (dBA)**
8,1	8	4	3,8

In terms of mechanical impedance, the experimental pavement SNEAK showed significantly lower dynamic stiffness values (80.5 and 89.5 MN/m) than Ante Operam condition (127.1 MN/m).

LIFE SNEAK performs also a comparison of results of ante and post-operam measurements of vibrations both outdoors at the roadside and indoors for the different considered scenarios (for the SNEAK and traditional pavements).

Limitations

Demonstration sections covered a limited street length (150 m each). Nowadays, monitoring is limited in time because the project is not yet concluded and more measurement sessions are foreseen within the entire project.

2.2 Material and results uptaken from the replications in other contexts and further experiences

It is relevant to consider replications in order to extend performances of mixtures to other contexts. LIFE MONZA is already a replication of the Leopoldo project to a slower speed and more urbanized context.

Other replications of Leopoldo (Lucca site) include several stretches on Tuscany regional roads as for example in following locations: SR439 (Capannori-loc. San Leonardo in Treponzio, Lucca province, 2015), SR142 (Castelfocognano - loc. Rassina, and Bibbiena loc. Soci, Arezzo province, 2015), SR302 (Marradi, Firenze province, 2017), SR71 (Vitiano, Arezzo province, 2018), SR 439 (Camaiore, loc. Capezzano Pianore, Lucca Province, 2017), SR439 (Buti, Pisa province, 2018), SR74 (Manciano, Grosseto Province, 2019), SR66 (Campi Bisenzio, Firenze province, 2023 and 2024) SR429 (Poggibonsi, Siena province, 2024). All the roads were monitored with CPX technique by ARPAT (Tuscany region environmental protection agency) proving at least 3 dB reduction.

Replications of LIFE NEREiDE open graded grain sizes (wet process) with CRM and reclaimed asphalt were performed on regional road SR 2 in Tavarnelle Val di Pesa (Firenze-Toscana, Italy, jan 2021) and regional road SR 436 in San Pierino-Fucecchio (Firenze-Toscana, Italy, nov 2020) and validated by ARPAT with CPX measurements.

All these replications were performed inside urban centres, with a speed limit of 50 km/h. Validations were performed normally only once a few months after the laying.

A further developed experimental surface of 1.25 km of porous asphalt derived from experience of Leopoldo Project was realized in 2025 in Scandicci on FI-PI-LI road (motorway, 90 km/h speed limit with very high traffic flow) which will allow insights at higher speed.

Other experimental surfaces have been developed after the experience of Leopoldo and Nereide by ANAS (national company for road management) on SR 73 in San Sepolcro with 4 difference mixtures, a standard dense graded hot mixture, an optimized texture from Leopoldo and two warm mixtures wet and dry from Nereide. All of them complied with CPX requirements of Green Public Procurement (LCPX below 90 dB(A)) and with best performances achieved by the warm dry mixture (average LCPX of 88 dB(A)).

Further experiences by ANAS and Autostrade per l'Italia (national company for highway management) might be collected during the project. In particular, Autostrade per l'Italia has shared previous studies (Cuciniello et al., 2023a; Cuciniello et al., 2023b) concerning designing of low noise paving for high speed road scenarios owned by Autostrade per l'Italia.

2.3 Findings from prior MCDA analyses, what is missing

The *MCDA* (Multicriteria Decision Analysis) of experimental asphalt mixtures is a comprehensive approach based on environmental results derived from a life cycle assessment (*LCA*). It aims to provide a holistic evaluation of both environmental impacts (emissions and resource consumption) and human health effects, with particular focus on noise and its evolution throughout the service life of the pavement. Unlike previous projects, which have only partially or separately addressed specific aspects of these impacts, this study presents an integrated analysis that considers both environmental and acoustic factors in a unified framework. The input data for the predictive environmental and acoustic analyses will be derived from existing experimental projects, allowing the development of a model that will be periodically updated throughout the project as results from scheduled analyses are incorporated.

Previous experiences in validating the performance of LNP mixtures have highlighted that various parameters have been analysed to define their efficiency. However, these studies typically focused on individual factors, such as thermal or noise performance, without considering their interplay or providing a complete lifecycle analysis. Table 13 presents the parameters addressed in each experience, demonstrating that, in many cases, the environmental and acoustic evaluations were either isolated or incomplete. Moreover, Table 14 reports on which kinds of noise evaluations were carried out.

Table 13: Summary of issues addressed within previous experiences

Project	**Comforts addressed**				**Long term noise monitoring**	**LCA**
	Noise	**Thermal**	**Luminance**	**Vibration**		
Leopoldo	X				X	
LIFE NEREIDE	X					X
LIFE MONZA	X				X	
LIFE C-LOW-N ASPHALT	X	X			X	
LIFE HEATLAND	X	X	X			
LIFE E-VIA	X				X	X
LIFE NEMO	X					X
LIFE SNEAK	X			X		

Table 14: Summary of acoustics issues addressed within each project

Project	**Road-tyre Noise**	**Vehicle Noisiness**	**Citizens' exposure**	**Pavement Absorption**
Leopoldo	CPX ISO/CD	SPB Imagine		Extended Surface method (ES), ISO13472-1
LIFE NEREIDE	CPX ISO/CD CPX ISO 11819-2	U-SPB	Regulatory and Lden/Lnight verification roadside	
LIFE MONZA			Regulatory and Lden/Lnight verification at façade	
LIFE C-LOW-N ASPHALT	CPX ISO 11819-2		Regulatory and Lden/Lnight verification at façade	
LIFE HEATLAND			verifications roadside	
LIFE E-VIA	CPX ISO 11819-2	CPB	Regulatory and Lden/Lnight verification at façade	Impedance Tube method (IT), ISO 13472-2, Extended Surface method (ES), ISO13472-1
LIFE NEMO	CPX ISO 11819-2			
LIFE SNEAK	CPX ISO 11819-2	CPB	Regulatory and Lden/Lnight verification roadside	

In these projects, characteristics such as noise, thermal performance, and vibration were generally evaluated in isolation, with limited integration of environmental and acoustic impacts. Additionally, few projects incorporated *LCA* evaluations at the design stage of the mixture or after its installation. Moreover, *LCA* analyses rarely included *LCCA* (Life Cycle Cost Analysis), where noise exposure is treated as a cost in terms of health impacts. The *NEMO* project (Indacoechea-Vega et al., 2024) is an exception, as it performed post-laying evaluations, integrating noise as a cost factor. This approach, which treats noise as a cost, is also examined by Piao (Piao et al., 2022), who tested the different impacts of *SMA* and semi-dense asphalt pavements using *CPX* results from the first 4 years, modeling their durability up to 15 years of service. This study thus takes a step towards predicting future scenarios, but, as with traditional *LCA*, predicting the acoustic impact is still a challenge. Piao used the Swiss noise model and *CPX* values.

In contrast to these prior studies, the *OPTIMUS* project aims to estimate the optimal LNP mixtures for demonstration sites through a comprehensive approach that applies *MCDA* both at the planning stage and after the pavement has been laid. This methodology will predict and verify performance at real receivers, considering all environmental and acoustic factors in an integrated model. To ensure accurate predictions, a reliable pavement model will be developed, using precise surface correction coefficients, taking into account durability of performances. The details of how this can be achieved are discussed in the following paragraph.

In order to achieve a more reliable and standardized assessment of noise impacts, the *OPTIMUS* project will integrate the *CNOSSOS* (Common Noise Assessment Method) approach into its methodology. The *CNOSSOS* method, widely recognized in noise studies, will provide an advanced and consistent framework for noise prediction, allowing the integration of acoustic modeling with environmental life cycle data. This will enhance the overall accuracy of performance predictions and ensure that noise is effectively considered as a significant factor within the broader context of pavement life cycle assessment.

3 Brief review of modeling methods within CNOSSOS for planning criteria

In the event of an LNP proving to be the optimal solution in a given area, the subsequent planning and evaluation of its efficiency is a complex process. This is due to the presence of various mixtures, each exhibiting distinct performance characteristics in response to variations in traffic flow conditions, geographical context and meteorological conditions. The CNOSSOS method has been designed with the intention of predicting potential benefits. However, in order to make accurate calculations, it is necessary to use a specific mixture, or at least a reference surface typology. The calculation of scenarios both before and after the implementation of the mitigation measure is undertaken, with the calculation of benefits based on the reduction of noise achieved by the exposed population. It is imperative that a precise representation of each LNP is incorporated into noise models during both the planning and evaluation phases, in order to assess the reduction in noise exposure for citizens. The implementation of the European CNOSSOS-EU common methodology (Commission Directive 2015/996/EC, 2015) for noise mapping has enabled this type of estimation by providing a set of reference surfaces.

Nevertheless, the inventory of available surfaces is by no means exhaustive. As indicated by the findings of Odeh et al. (2025), there is a high probability that the selected surface in the model is not representative of the efficiency of the real surface, as evidenced by the not-negligible differences reported in the studies. This has the potential to result in erroneous estimation of citizens' exposure and mitigation benefits. Moreover, this has the capacity to modify the evaluation of various mitigations during comparisons and to influence the assessment of priority indexes during the development of action plans. The aforementioned factors may collectively contribute to the ineffective implementation of LNPs in situ. Ascari et al. (2024) demonstrated that monetary costs saved for health estimated according to the DALY metric (Kantor et al., 2021) can lead to variations greater than five times the effect of a standard porous asphalt only by modelling the correct/incorrect surface.

Aware of this limitation, the EU has allowed the user to define new surfaces in CNOSSOS-EU by introducing specific corrections parameters for each vehicle category and frequency.

The CNOSSOS-EU model was developed as an updatable source model, with the capacity to adapt to new surfaces. A paucity of studies has hitherto been dedicated to the customisation of surface parameters. Some authors incorporate adjustments based on national methods previously employed, especially if local databases are accessible (Mikhailenko et al., 2022; Larsson, 2021; Heutschi et al., 2018; Peeters & van Blokland, 2018). As demonstrated in the study by Anfosso-Ledee and Goubert (2019), other researchers have utilised the CPX to assess the properties of road surfaces. In order to undertake measurements, CPX necessitates the utilisation of particular equipment and the adherence to stringent safety conditions. The technology under discussion enables consideration of noise related to the surface, while simultaneously minimising the effects from the surroundings. However, it should be noted that the measurement of rolling noise alone does not allow for the complete calibration of CNOSSOS-EU parameters, which account for both rolling and propulsion noise. This issue will be addressed in more detail in the following section. Consequently, the CPX approach alone is inadequate for complete characterisation. As opposed to this, other authors (Borchi et al., 2023) expressed a preference for the SPB methodology, a technique that evaluates the noise produced by individual vehicles passing by. Whilst certain authors lend their support to the CPX approach, others undertake a comparative analysis of the two methods and draw attention to potential issues with categories beyond passenger cars (Anfosso-Lédée et al., 2016). These techniques facilitate the incorporation of all traffic noise components. However, the conventional CPX and SPB methods necessitate specific measurement sessions and specialised equipment, which are not widely accessible. A further approach to establishing individual surface parameters for LNPs to be used in CNOSSOS-EU has been published more recently (Ascari et al., 2024), based on an adapted procedure, called U-SPB, capable of simplifying SPB requirements and achieving comparable outcomes even in urban settings (Ascari et al., 2022). In order to facilitate a more profound comprehension of the manner in which the CNOSSOS model can be utilised to evaluate LNP, a concise overview of the source model and corrections will be presented. This will be accompanied by a concise description of the surfaces that have been previously defined within the 2002/49/EC in force version.

3.1 CNOSSOS source model

The CNOSSOS-EU road source model is derived from the Harmonoise/IMAGINE project (Peeters, & Van Blokland, 2007), while the propagation model was derived from NMPB-2008 (Dutilleux et al., 2010). In terms of the source model, sound power coefficients were generated through a regression analysis based on Harmonoise/ IMAGINE datasets. The source model itself consists of two separate noise sources - rolling and propulsion noise (Faulkner & Murphy, 2022).

Rolling and Propulsion noise are defined for different vehicles categories, indexed with m as defined in CNOSSOS-EU (1 - light vehicle, 2 - medium truck, 3 - heavy truck, 4 - two-wheelers), and for each frequency octave band from 63 to 8 kHz, referenced as i.

According to the model description, the equivalent linear power of the road source can be represented as in Equation 1.

$$L_{W',eq,line,i,m} = L_{W,i,m} + 10\left(\frac{Q_m}{v_m*\frac{1000}{3600}}\right) - 10(3600) \quad == L_{W,i,m} + 10\left(\frac{Q_m}{v_m*1000}\right) \tag{1}$$

Where*:*

- $L_{W,i,m}$ is the power of m^{th} category at i^{th} frequency band;
- Q_m is the flow of m^{th} category.

The sound power level of the vehicle is defined as the energy sum of rolling (R) and propulsion (P) components as function of speed as in Equation 2.

$$L_{W,i,m}(v_m) = 10\left(10^{\frac{L_{WR,i,m}(v_m)}{10}} + 10^{\frac{L_{WP,i,m}(v_m)}{10}}\right) \tag{2}$$

If *m=4* rolling noise (L_{WR}) is assumed null.

According to the model, the sound power due to rolling and propulsion noise defined for *m=1,2,3* ,4 can be written as in Equation 3 and 4, where corrections for surface are highlighted from other contributions.

$$L_{WR,i,m} = A_{R,i,m} + B_{R,i,m}\left(\frac{v_m}{v_{ref}}\right) + \Delta L_{WR,road,i,m} + \Delta L_{WR,others} \tag{3}$$

$$L_{WP,i,m} = A_{P,i,m} + B_{P,i,m}\left(\frac{v_m - v_{ref}}{v_{ref}}\right) + \Delta L_{WP,road,i,m} + \Delta L_{WP,others} \tag{4}$$

Where:

- $\Delta L_{WR,road,i,m}$ is the correction due to rolling noise to the reference surface as determined from Equation 7;
- $\Delta L_{WR,others}$ accounts the effects due to studded tires, accelerations and deceleration, temperature on rolling noise;
- $\Delta L_{WP,road,i,m}$ is the correction due to propulsion noise to the reference surface as determined from Equation 8;
- $\Delta L_{WP,others}$ accounts the effects due to road gradients, accelerations and decelerations on propulsion noise.

Modeling scheme is summarized in Figure 1.

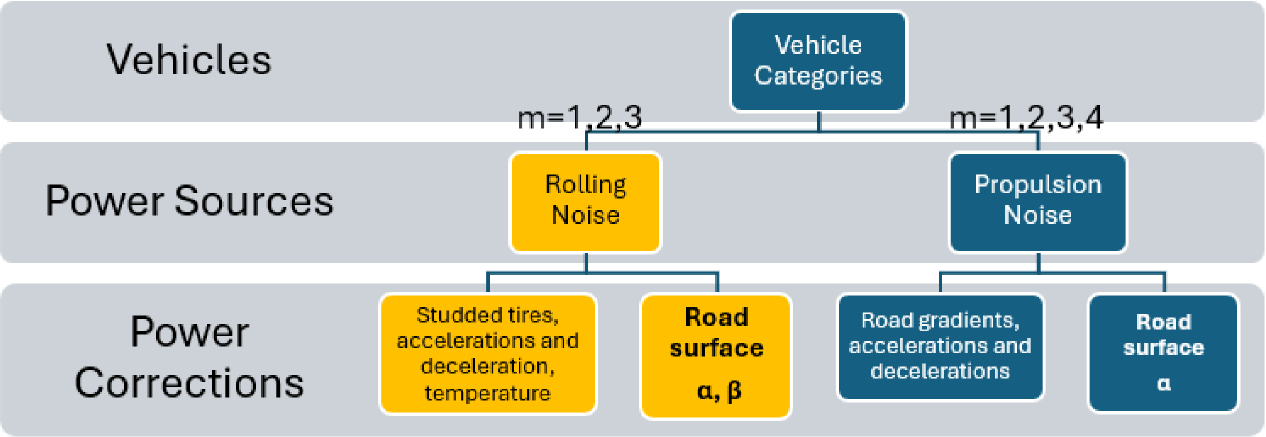

Figure 1: summarized source model in CNOSSOS for roads

If the road surface is different from the reference one, road contributions are defined as in Equation 5 and 6, changing respectively rolling and propulsion contribution.

$$1 \leq m \leq 3 \qquad (5)$$

$$\Delta L_{WP,road,i,m} = \{\alpha_{i.m} \; if \; \alpha_{i,m} < 0 \; 0 \; if \; \alpha_{i,m} \geq 0 \qquad (6)$$

Where $\alpha_{i,m}$ is frequency-dependent and β_m is the same for all bands.

Note that the change in propulsion contribution is not zero only for absorbing pavements and does not vary with speed. These parameters are the ones already defined for a set of standard surfaces and to be set in the model (i.e. in software) to include user-defined surfaces.

To conclude, it must be considered that:

- β does not affect 4th vehicle category at all;
- α might affect 4th category only if negative;
- generally, contributions of road correction to rolling and propulsion noise vary in a different way with speed, eventually leading to counterbalancing effects.

3.2 Brief description of standard surfaces included in CNOSSOS

In the following, standard surfaces included in the model are presented considering their technical characteristics and the corresponding surfaces as defined in the previous interim model (Extrium report, 2014). This is useful to understand the similarities to the pavements analysed in the OPTIMUS framework.

Table 15: Description of standard CNOSSOS surfaces and comparison with those of previous modeling method NMPB 96

Description of the road surface type	**Road surface included in CNOSSOS database**		**NMPB 96 EU Interim method**
	Code	**Description**	
Dense asphalt concrete 0/11 - 0/16, Stone mastic asphalt 0/11	0	Reference	
porous asphalt	NL01	1-layer ZOAB	
dual-layer porous asphalt	NL02	2-layer ZOAB	
dual-layer porous asphalt with fine top layer	NL03	2-layer ZOAB (fine)	
Stone mastic asphalt with stones of maximum 5 mm	NL04	SMA-0/5	
Stone mastic asphalt with stones of maximum 8 mm	NL05	SMA-0/8	Smooth asphalt (0dB)
Brushed concrete	NL06	Brushed concrete	
Optimized brushed concrete	NL07	Optimized brushed down concrete	
Fine broomed concrete surface	NL08	Fine broomed concrete	Cement concrete and corrugated asphalt (+2)
Road surface with extra treatment on the surface	NL09	Worked surface	
Hard clinker elements in herring-bone	NL10	Hard elements in herring-bone	Smooth texture paving stones (+3)
Hard clinker elements not in herring-bone	NL11	Hard elements not in herring-bone	Rough texture paving stones (+6)
Silent elements (clinker stones)	NL12	Quiet hard elements	
Thin layer low noise asphalt Type A	NL13	Thin layer A	Porous surface (-1 to -3 dependent upon speed)
Thin layer low noise asphalt Type B	NL14	Thin layer B	

To these surfaces NLx are associated alpha_i,m and beta_m coefficients for each vehicles' category m, as correction to the reference surface. It is important to note that NL07-NL12 does not apply to OPTIMUS framework at all since no concrete surfaces nor paving stones will be taken into account as possible low noise surfaces.

4 Description of intervention logic

OPTIMUS wants to fill the gap identified in 2.3 on the efficiency evaluation for LNP concerning particularly durability, noise and LCA performances depending on the implementation scenario. It will develop a MCDA procedure, define optimal LNP for the different demonstration sites and contribute to an enriched database of CNOSSOS correction coefficients to obtain reliable emissions of LNP. The workflow for optimization of LNP is here detailed and sketched in Figure 2:

1. Data Collection from Previous LNP Installations

The process begins with the collection of data from past LNP installations. This includes construction details, material specifications, and previously conducted acoustic measurements. The data will be structured according to the database schema outlined in Annex 1 and will serve as a foundational input for the MCDA analysis performed in WP2.

2. Database Enrichment with New Acoustic Measurements

To enhance the robustness of the dataset, new acoustic measurements will be added. These measurements will be carried out on the same or similar pavement types to ensure consistency and to expand the reliability of the data pool. This step is also part of WP2.

3. Derivation of CNOSSOS-EU Coefficients for Previous Installations

Using the consolidated dataset, CNOSSOS-EU acoustic emission coefficients will be calculated for each previously implemented pavement type. This step will enable standardization and comparability of results in subsequent simulations. It is carried out under WP6.

4. Multicriteria Decision Analysis (MCDA) of the Enhanced Database

An MCDA will be conducted to rank the performance of different pavement types under various environmental and traffic conditions. This analysis will identify the most promising solutions and is part of WP4.

5. Definition of Demonstration Sites

Based on the results of the MCDA and the database analysis in WP2, suitable demonstration sites will be selected. The choice of sites will be driven by two primary criteria: the number of people exposed to road noise in each area and the lack of experimental data currently available for those specific conditions.

6. Selection and Definition of Optimal Pavement Mixtures

Taking into account the MCDA outcomes, the most promising pavement mixtures will be selected and defined for implementation in the identified demonstration sites. This activity is shared between WP4 and WP5.

7. Acoustic Simulations Using Updated CNOSSOS Coefficients

Acoustic simulations will be performed for the selected demonstration scenarios using the newly derived CNOSSOS coefficients. This will help validate the expected noise reduction performance of the optimal mixtures. This task is managed in WP6.

8. Construction of Optimized Low-Noise Pavements (LNP)

The selected optimal pavement designs will be implemented under real-world conditions at the chosen demonstration sites. This step is part of WP5.

9. Acoustic Measurements of the New Installations

Once the optimized LNPs are constructed, standardized acoustic measurements will be conducted to assess their actual noise reduction performance. This is carried out under WP3.

10. Recalculation of the MCDA with New Data

Finally, the MCDA will be updated using the new acoustic measurements and recalculated CNOSSOS coefficients. This final step aims to refine the selection criteria for future mixtures and improve the predictive models for LNP performance. It involves both WP4 and WP6.

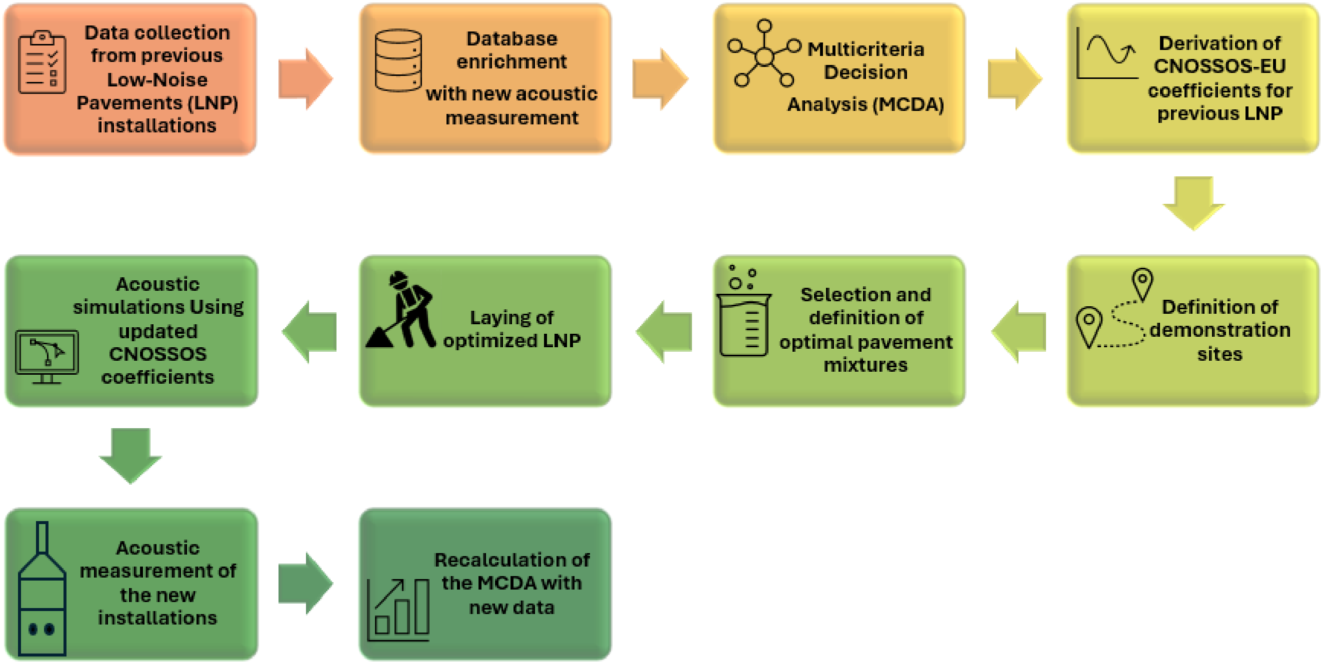

Figure 2: Workflow summary

All the analysis will be dedicated to different implementation contexts in terms of urbanization level and speed. In the following paragraph details of demonstration sites characteristics are detailed.

4.1 Description of selected sites

According to the first analysis of the current dataset, the relevant scenarios that need to be detailed investigated have been defined. The selection has been driven by the following main reasons:

a) high number of people interested;
b) poor experimental data into the current dataset.

With reference to point a) (high number of people interested), urban scenarios with high traffic level and relatively low speed (<= 50 km/h) are considered very important to be analysed in depth and three demonstration sites in Florence, Forlì and Bozen have been selected:

- Florence: 400 m with 2 stretches of optimised asphalts (2 different mixtures) + 200 m of standard asphalt.
- Forlì: 1 stretch of optimised asphalt (1 mixture) + 200 m of standard asphalt.
- Bozen: 1 stretch of optimised asphalt (1 mixture) + 200 m of standard asphalt.

In particular, the city of Florence confirms the experimentation on a site with “U” section (tall buildings present on both sides), high traffic flow, presence of buses, low speed (<= 50 km/h) i.e. “Via del Ponte alle Mosse”, from Puccini square to the intersection with Via Paisiello (see Figure 3) hypothesized in the original proposal.

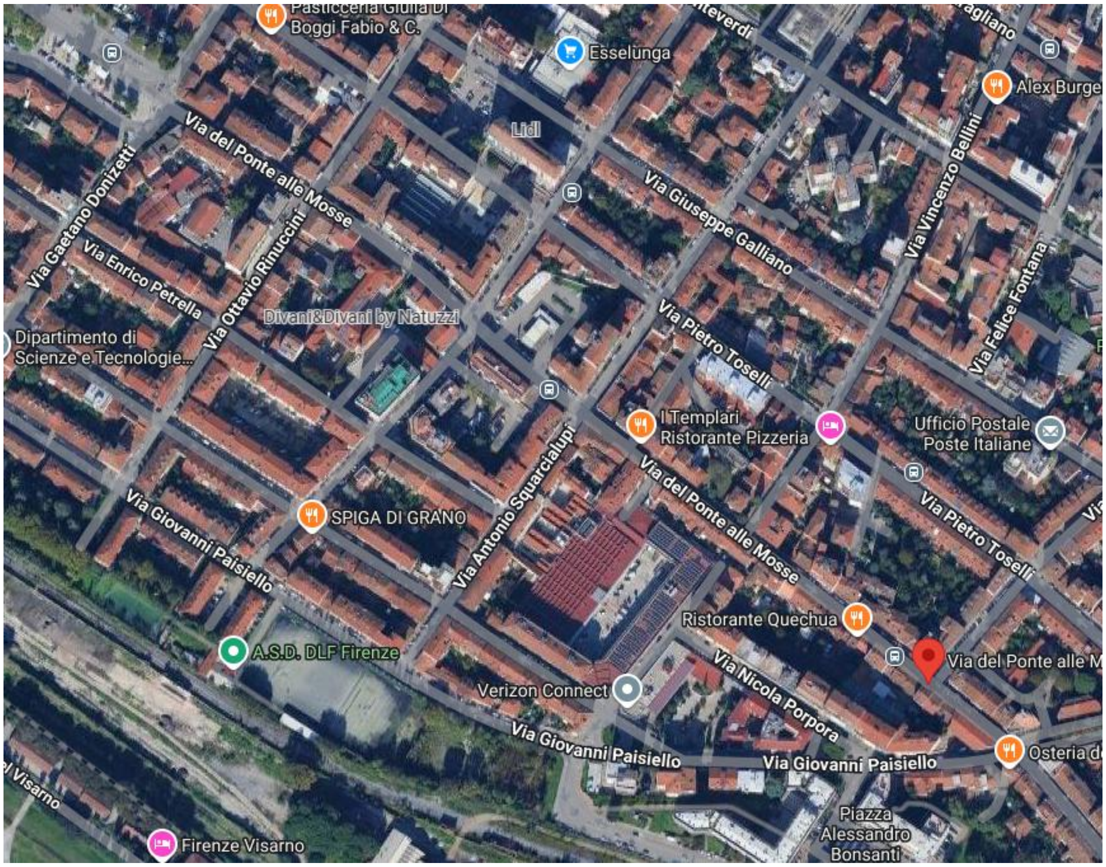

Figure 3: Demonstration site in Florence

The city of Forlì confirms the experimentation on a 500 m stretch of “Via Ravegnana” street (from street number 506 to 538, see the stretch between the two roundabouts), a site with relatively open section (with few low buildings present on both sides), high flow traffic, and low speed (<= 50 km/h) (see Figure 4).

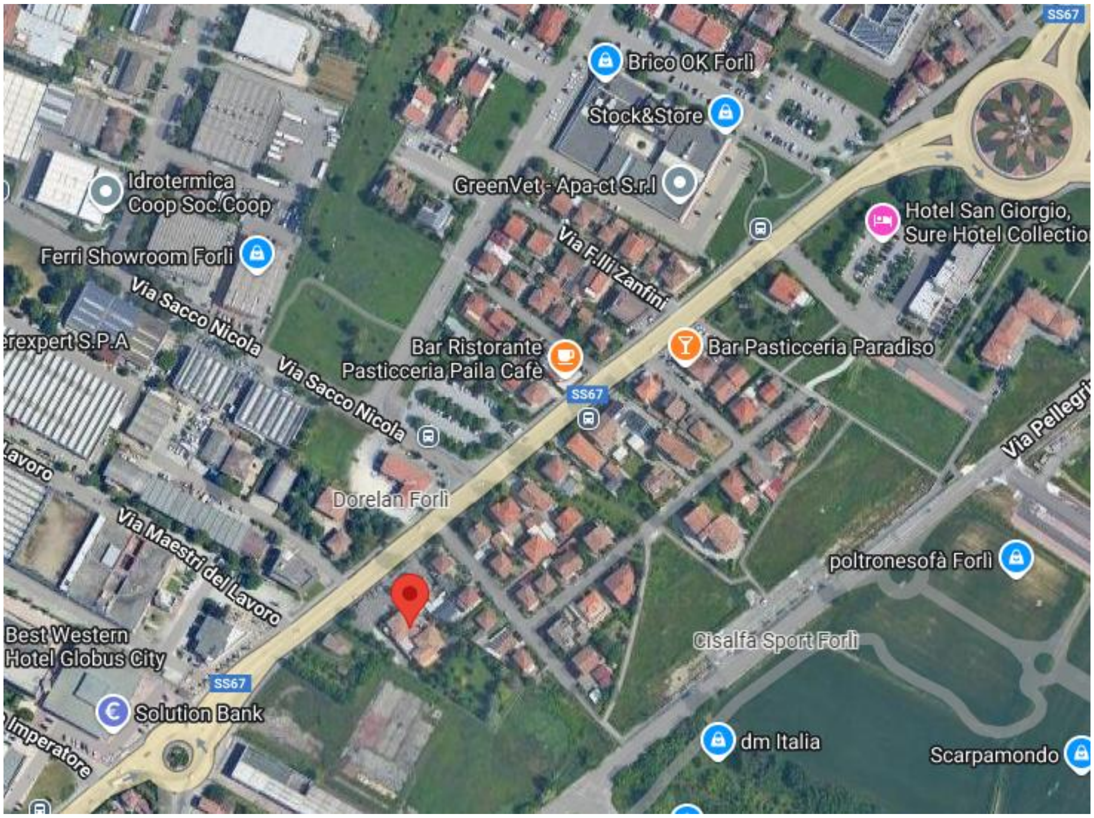

Figure 4: Demonstration site in Forlì

Finally, the Province of Bozen identified the Abetone and Brennero state road, SS12, between km 408,500 – 409,000, as a low average speed (50 km/h) scenario (see Figure 5). SS12 is a state road that connects Pisa to the Austrian border at the Brenner Pass. The current route was built between the 19th and 20th centuries. The first real stretch of the road was already passable in 1860 between Trento and Bolzano, then more and more stretches followed until 1956 when the entire route was completed. The stretch of road intended for testing is located between km 408,200 – 410,800 (probably between km 408+500 and km 409,000), and passes through the town of Laghetti, a hamlet of Egna, with 1,400 inhabitants at an altitude of 213 m above sea level. The travel speed between km 408,200 – 409,800 is 50 km/h between km 409,800 and 410,800: 60 km/h. The TGM in Laghetti is about 10,000 vehicles of which 9.0% is heavy traffic (estimated numbers - interpolation of data from the traffic detection stations of Salorno and Ora).

Currently the wearing course of the section is made of a bituminous conglomerate with AR 12 rubber asphalt, installed in 2018, badly damaged, which has cracks, crumbling and in some places potholes. The wearing course has reached its useful life and must be replaced. It is included in the maintenance program of the Bolzano Bassa Atesina Road Service. The number of people who will benefit from the intervention is 1,400 people.

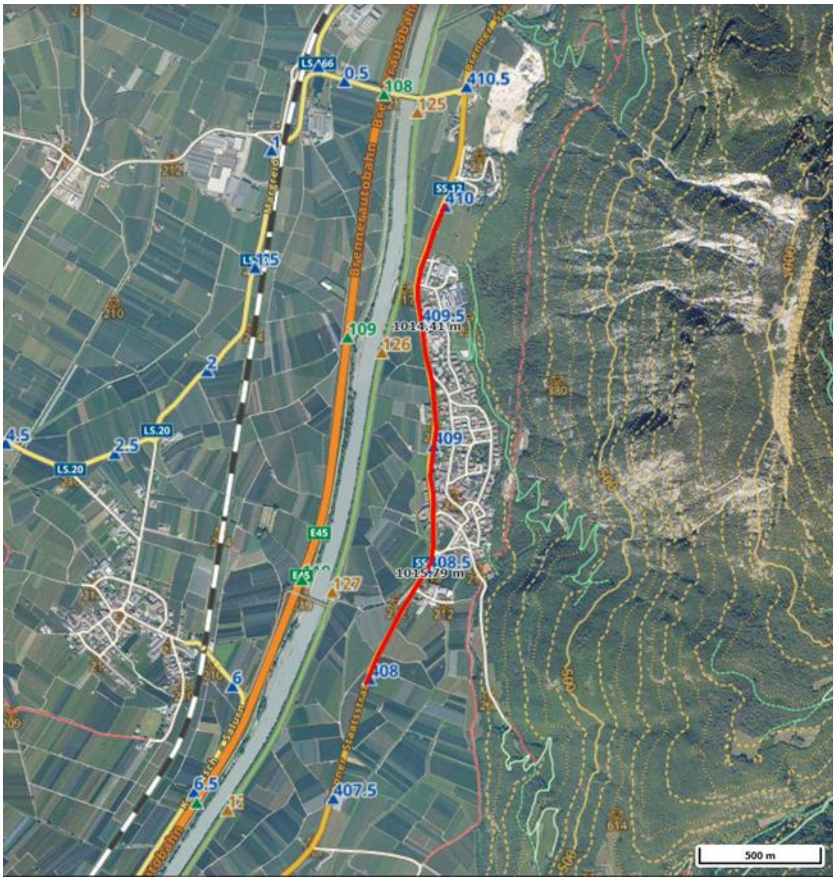

Figure 5: Demonstration site in Bolzano – SS12

With reference to the point b) (poor experimental data into the current dataset), a peri urban scenario with high average speed (110 km/h) are defined in the Province of Bolzano on Superstrada Bolzano Merano SS 38 (MEBO) (see Figure 6).

Here 3 stretches of optimised asphalts (3 different mixtures) + 200 m of standard asphalt are expected to lay and test between km 199.500 – 202.100, stretched in adjacent to the town of Marlengo, on the southern carriageway of MEBO.

The MEBO, a 37.1 km long main extra-urban road, was opened to traffic on 2 August 1997 and runs through the Adige valley to Bolzano.

The road section that will host the pilot project is located between km 199.500 – 202.100 on the southern carriageway of the MEBO and is adjacent to the town of Marlengo. Marlengo is a municipality with just under 3,000 inhabitants in the Burgraviato district, between the cities of Merano and Bolzano. It is located at an altitude of 363 m above sea level. To the east it is bordered by the Adige river. The affected road section stays on the right bank of the river. The speed limit is set at 110 km/h. The TGM in Marlengo is 32,619 vehicles of which 4.5% are heavy traffic.

Currently the wearing course of the section is made of a bituminous conglomerate type AR 12, in operation since 2016 and badly damaged with branched cracks and potholes. The section is included in the maintenance program of the Burgraviato Roads service.

The number of people who will benefit from the intervention is estimated at 2,500 as the settlement is located on a slope orthogonal to the road so the propagation of noise covers a large part of the town centre.

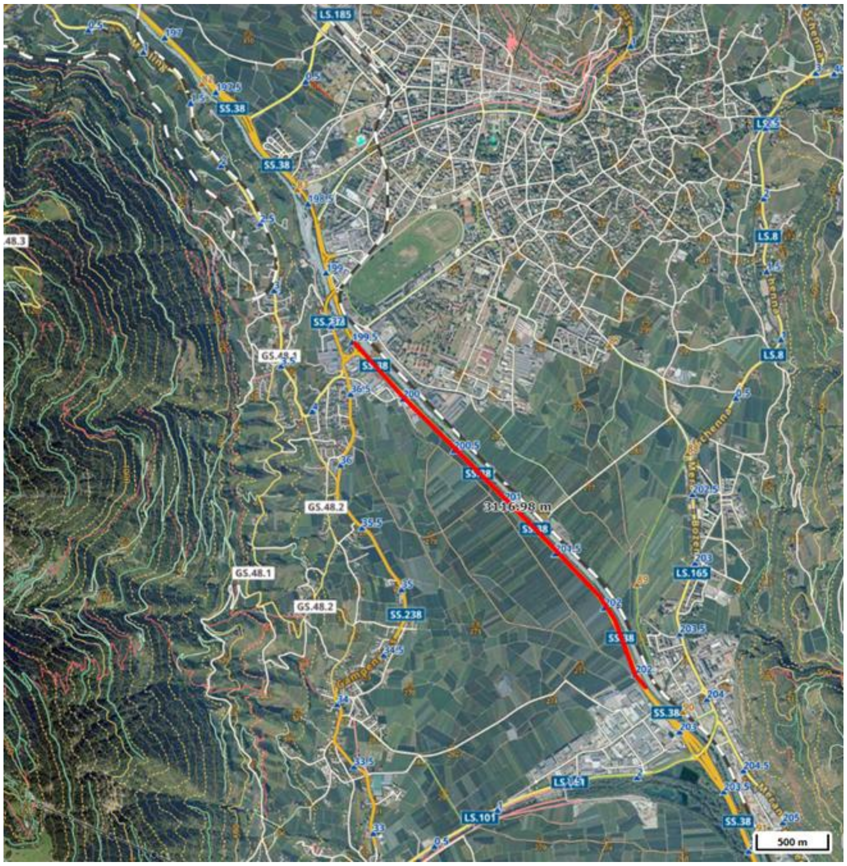

Figure 6: Demonstration site in Bolzano - MEBO

Annex

ANNEX 1 Structure of low noise pavement Database

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