CEDR Transnational Road Research Programme

Call 2012: Noise: Integrating strategic noise management into the operation and maintenance of national road networks	

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QUESTIM
Summary of Project Results
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CEDR Call2012: Noise: Integrating strategic noise management into the operation and maintenance of national road networks

QUESTIM: QUietness and Economics STimulate Infrastructure Management

QUESTIM: Summary of Project Results

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1. Why is controlling road traffic noise important?

Road traffic is the dominant source of environmental noise in the EU (ref. Fig. 1) and causes the loss of thousands of healthy life years each year in the European population.

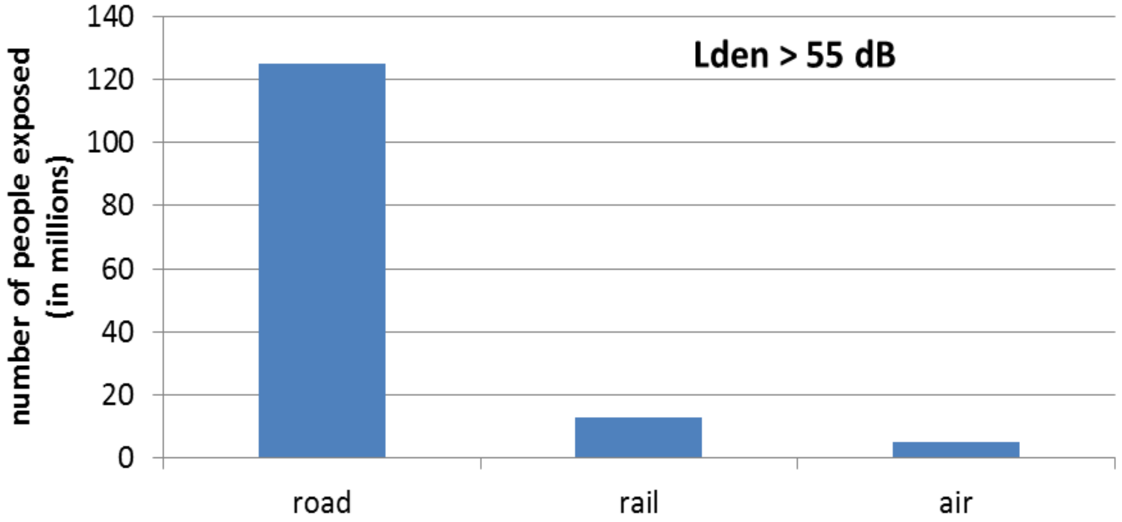


Fig. 1 Exposure in 2012 of EU-27 population to environmental noise levels above 55 dB L_{den} (extrapolated based on reported data in 2013)[1]

The negative impact of noise on society is reflected in the value that people attribute to an improved acoustic climate, referred to as the Willingness-To-Pay (WTP), or the lower property value in areas with higher environmental noise levels (Hedonic pricing). An average WTP over Europe is found to be € 25,-/dB/yr./household. The effect on property lies in the range of 0,2 to 1,0 % per dB over 55 dB (ref. [1] and [2]).

In addition negative effects are observed in the health of the population exposed to traffic noise because of sleep disturbance caused by night time noise and the more frequent occurrence of myocardial diseases that can be traced back to the higher arousal level of people that are exposed to higher noise levels (ref. [3]

2. What mitigation measure(s) to choose?

Traditionally mitigation is provided using façade insulation and noise barriers, but presently more and more emphasis is being placed on measures to control the noise at the source. The decision of what measure to choose will be steered by the balance of the costs and the benefits of the measure.

Benefits are found in the willingness-to-pay for the better acoustic climate and the improved property values. Additional benefits can be attributed to the improved health situation. The work package report on cost/benefit and life cycle costing (WP 5) presents some examples of such costs, although the information on health effects is still found to be inconclusive.

The possibilities for local administrations to reduce the sound production of the power train and the tyre of the vehicles are limited, since these properties are subjected to EU wide type approval regulations that do not allow additional tighter limits in member states. However, local administrations are able to influence the technical properties of the road infrastructure. Fortunately it is found that the type of road surface is decisive for the noise production of a traffic flow, more than vehicle or tyre property. Even speed and intensity are less important. This is clearly demonstrated in Fig. 2 where, for two road surface types the maximum levels of passing vehicles are plotted against the speed. The figure illustrates the spread due to vehicle and tyre properties against the effect of the surface. The effect of vehicle intensity comes from the logarithmic nature of sound. Halving the traffic flow results in only a 3 dB reduction.

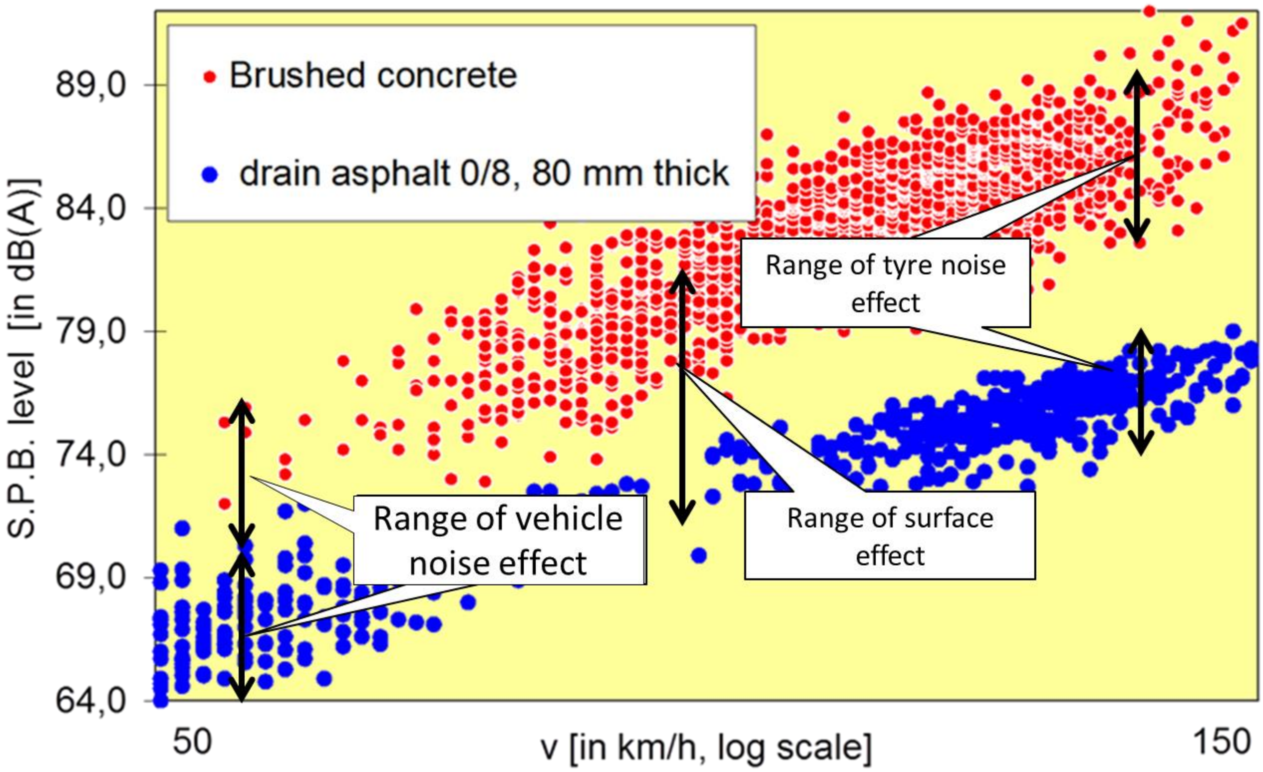


Fig. 2 The relevance of the road surface type to the overall vehicle noise level. Red and blue dots present pass-by levels of vehicles on two surface types. Arrows give the magnitude of the vehicle, the tyre and the road surface effect

Presented are the pass-by levels as a function of speed of individual vehicles in a traffic stream on two surface types, one a brushed concrete and the other a two-layer porous asphalt. Pass-by levels on a specific surface vary due to noisy/low noise power trains (low speed) or noisy/low noise tyres (high speed). The arrows on the left and right indicate the total ranges due to these effects. It can be seen that the magnitude of the tyre or vehicle effect is significantly smaller than the road surface effect (arrow in the middle). For nearly the total speed range the least noisy cars on the concrete surface are noisier than the loudest cars on a fine graded Porous Asphalt Concrete (PAC) surface.

An additional advantage of a low noise road surface is that it affects every passing vehicle, while the effects of low noise powertrains or tyres only become apparent when the majority of vehicles are equipped with them.

3. Why not apply noise reducing surfaces everywhere?

The application of low noise road surfaces has proven to be a very effective mitigation measure and has the potential to lower the level of road traffic noise by up to10 dB compared to a standard surfaces as is illustrated in Fig. 2. However, several national road authorities (NRAs) within the EU still regard low noise surfaces as experimental and only to be applied in situations where standard mitigation measures are not sufficient. They have concerns about the widespread application of such surfaces. Their concerns can be explained by:

- Uncertainties in the actual performance of low noise surfaces in both their new condition and over their (structural) lifetime.
- The reduced effective life time and the more intense maintenance regimes required for these surfaces, that do not fit into general pavement management schemes.
- Road builders lack of knowledge about the processes that cause deterioration of the pavement's acoustic quality and the material technology required to improve its durability.
- Uncertainty about the economic impact of these surfaces, both the cost of building and maintenance and the effect in terms of savings on other mitigation measures, economic benefits or health improvements.
- The possible negative effects of these types of surfaces on safety and sustainability.
- The uncertainty on the methods to survey the performance of a large network and to implement the effect of these surfaces in the noise mapping procedures.

It was the objective of the QUESTIM project to generate information on the aspects inhibiting wider application of low noise surfaces and innovative barrier designs in order to give these technologies a better position in the planning, managing, building and maintaining of roads.

The project objectives were as follows:

1. To supply NRAs with specific information and pavement management systems (PMS) type of instruments to integrate low noise surfaces and barriers in their task to manage the quality of their road network over longer periods and to manage the noise action plans emanating from the European Noise Directive.
2. To support NRAs with know-how to estimate the effects of future developments in vehicle and tyre technology and to prevent sub-optimal developments with respect to sustainability and safety.

3. To enable NRAs to assess the benefits and the costs of their noise control strategies and to weigh source and propagation related measures with urban planning and soundscaping initiatives.

4. How acoustically stable are noise barriers over time?

Noise barriers represent the conventional mitigation measure used for road traffic noise. Designs (i.e. appearance, shape/profile) and the materials used in the construction vary significantly across Europe, ranging from conventional vertical timber fences to more innovative solutions using pre-fabricated components. In some cases devices are added to improve performance whilst minimising any increase in height. Once installed, many of these barriers will only be replaced as a result of either structural failure or significant physical damage; loss of acoustic performance is not typically considered as a cause for replacement.

Noise barrier performance can be considered in terms of either the acoustic performance of the materials/components used to construct the barrier or the noise levels registered at noise sensitive receivers screened by the barriers. Much is known about the acoustic performance of noise barriers when new; many NRAs procurement specification procedures include some form of acoustic performance criteria under new condition.

Fig. 3 Examples of barrier constructions in Europe

Assuming that traffic conditions remain unchanged, noise levels over time at noise sensitive receivers will be largely unaffected unless a noise barrier is subject to significant physical damage resulting in the loss/removal of acoustic elements. However, less is known about the acoustic degradation of barriers in terms of the sound transmission or absorption performance of the constituent materials/components. In this context, many existing noise barrier products are not considered to degrade acoustically, although timber barriers are considered to be the most susceptible as shown in the WP 4 report (see chapter 13).

5. How acoustically stable are low noise road surfaces over time?

Low noise road surfaces obtain their properties from optimized texture and porosity properties. Deterioration due to passing traffic will change these properties and consequently affect the noise suppressing performance. Within the QUESTIM project an inventory was made of available aging data for regional roads and motorways throughout Europe. Preferably such data referred to repeated measurements over a series of years on the same location. Eventually data sets were received from Norway, Sweden, Germany, Spain, France, United kingdom, Netherlands, Belgium. Extended data sets were also available for Switzerland but could not be included in time.

The development of the acoustic performance over time is categorized in pavement categories, such as one layer or two-layer porous pavements, semi open thin surface layers (TSL) and stone mastic types. Also is taken into account is the maximum grain size of 6, 8, 11 or 16 mm.

A few examples of results of repeated measurements over time are given below. Shown are pass-by levels of passing vehicles as a function of age. Increasing levels indicate a lower noise suppressing effect.

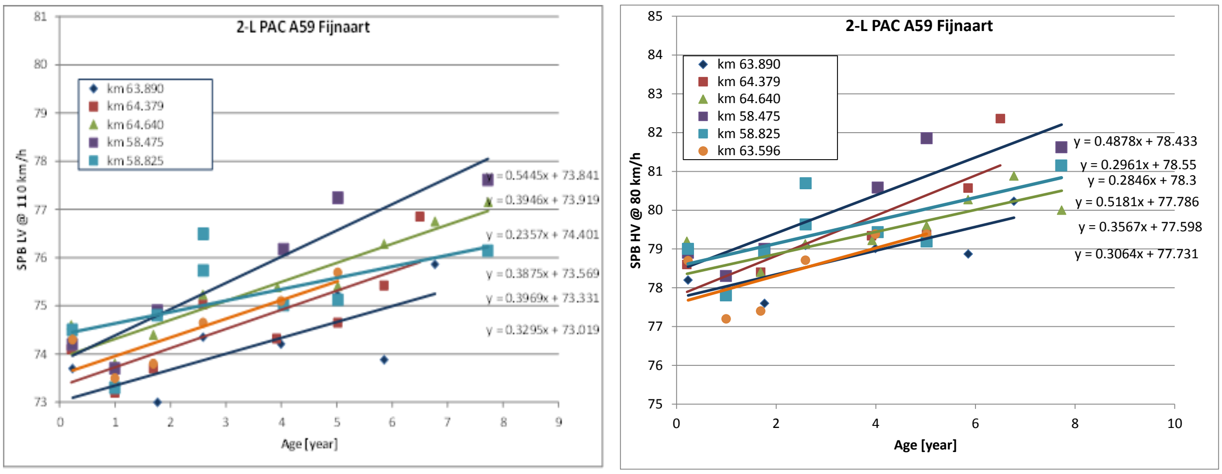


Fig. 4 Repeated pass-by measurements on 8 test sections of 2L-PAC on a test location on a Dutch highway . Left cars, right trucks. The slopes in dB/yr. are given in the regression formula

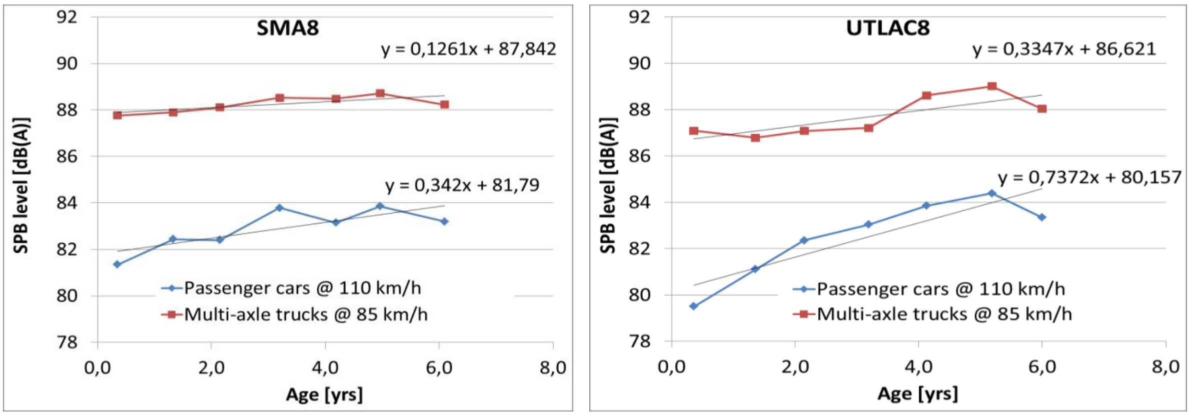


Fig. 5 Repeated pass-by measurements for cars and trucks on a test location on a Danish highway . Left SMA 8, right TSL 8. The slopes in dB/yr. are given in the regression formula

The general trend, presented by the data set is that dense surface types age less than porous surface types and semi dense surfaces age the fastest. The effect for trucks is in general lower than for cars. The table I presents an average over all available data for mid and south European countries.

table I   ranking of road surface types with respect to amount of yearly loss of acoustic performance. Rank #1 is lowest performance loss; values of yearly loss are estimated on base of mid and south-European data. Assumed are highway conditions

rank	Road surface type	loss of acoustic performance dB/yr.	
		LV's	**HV's**
1	Brushed and exposed aggregate concrete surfaces	0,1	0,1
2	SMA 11 and SMA16 surfaces	0,15	0,1
3	ACSURF11 and ACSURF16	0,2	0,1
4	ACSURF8, SMA8 and SMA6	0,2	0,1
5	2L-PAC8	0,4	0,3
6	1L-PAC8 to 1L-PAC16	0,5	0,3
7	TSL6	0,7	0,5

For Nordic countries a totally different speed of aging is observed. A few examples are given below (Fig. 6). The graphs present degradations of several dB's in the first years.

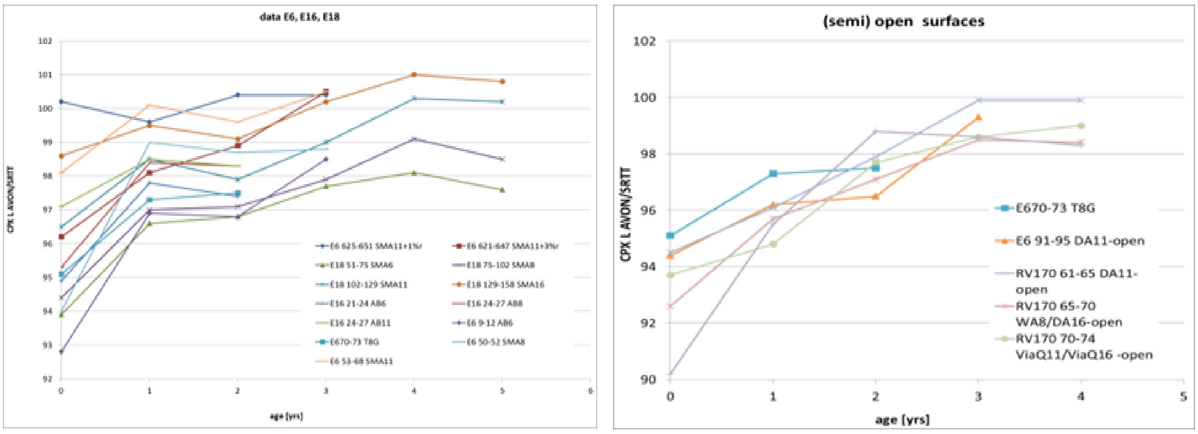


Fig. 6   Repeated noise measurements on Norwegian test sections. Data present the average of the sound levels close to two types of test tyres, the SRTT (supposed to represent car tyres) and the AVON AV4 (represents truck tyres). The presented value is the close proximity index (CPX-I) that is supposed to represent the performance of the road surface for a mixed fleet

6. Understanding the mechanisms of acoustic aging of road surfaces

The type of deterioration of the surface characteristics can be identified in the changes in the frequency spectrum of the tyre/road noise. Coarsening texture creates more low frequency sound, clogging of pores is recognized by increased high frequency components. Filling up of porous road material is recognizable in the disappearing absorption dip.

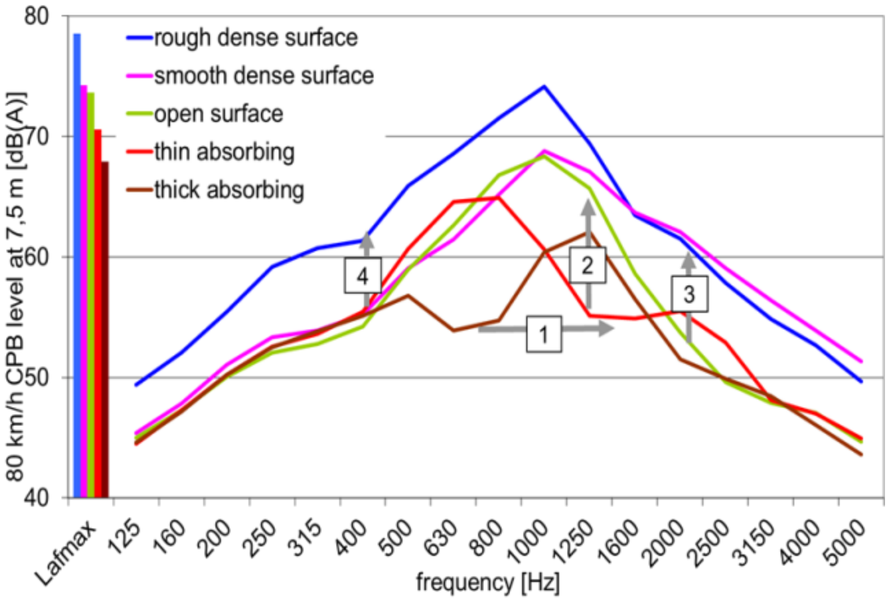
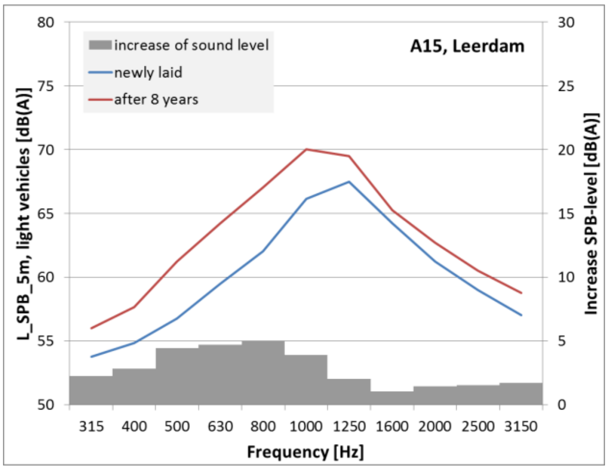
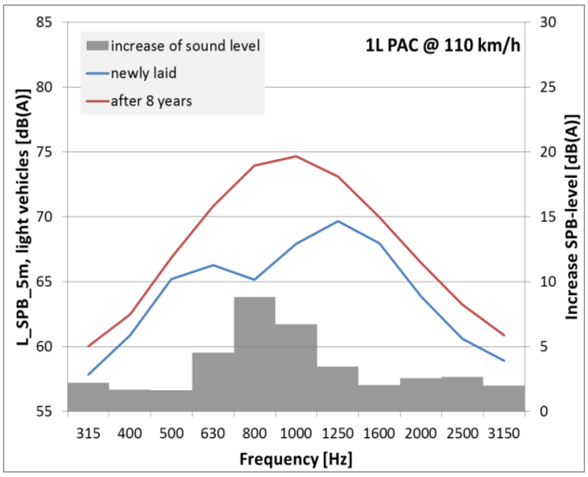


Fig. 7 Spectral composition of rolling noise on different surfaces reflect the effect of specific surface properties. [1] filling up of open layer causes shift in acoustic absorption dip, [2] further filling remove absorption, [3]: clogging increases flow resistance and [4] stone loss leads to roughening texture. Data for car tyres at 80 km/h

When comparing the spectra in new condition and in aged condition the changes can be recognized. Some typical examples of spectral changes are given in the graphs in Fig. 8. On the left is a clear example of roughening of the surface, while on the right is an example of loss of acoustic absorption.





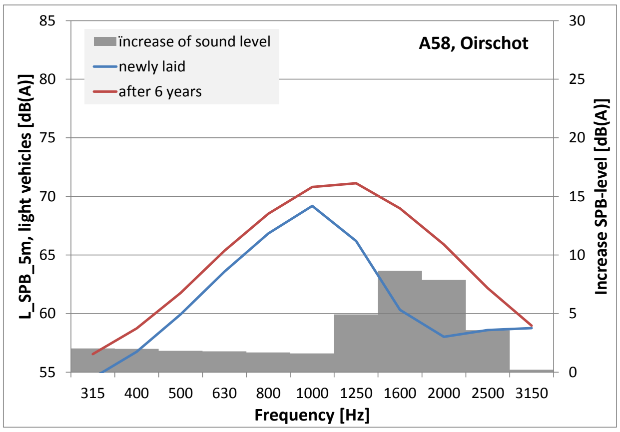


Fig. 8 :Spectral changes in pass-by noise of cars at 110 km/h over a six to eight year period. Top-left 2L-PAC, top-right 1L-PAC. Bottom-left: TSL6. Data for cars @110 km/h

For trucks similar effects are found but less pronounced.

In several cases though, the aging is due to more than one process and the resulting spectral changes show less clear examples.

7. Can we predict aging of road surfaces?

The figures in table I present average values but large variations around these averages are found in practice. With the database compiled in the QUESTIM project, we have tried to identify the relevant parameters that affect the aging and have tried to quantify these effects. Most relevant is the age of the surface. In many cases a more or less linear relation is found between the age and the acoustic quality, expressed by loss of the noise reduction capacity. Second is the intensity of heavy vehicles (HVs). Roads or lanes with high HV intensity such as slow lanes on motorways, or regional roads in industrial areas, age quicker than the fast lanes on motorways, or the more rural regional roads. The intensity of cars was not found to be decisive. An example of the influence of HV intensity is given in Fig. 9

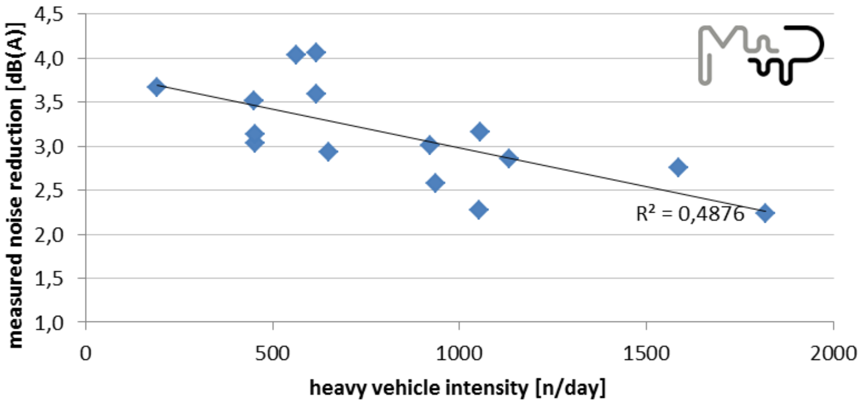


Fig. 9 Observed reduction of TSL8 after 2 years as a function of HV intensity (regional roads NL)

What is surprising is that the performance in new condition is found to be a relevant factor. If a surface is extra low noise in new condition, often it remained low noise during its service life.

In total we come to the following ranking of parameters influencing the acoustic aging of road surfaces (see table II).

table II List of parameters that are found to be of influence to the magnitude of deterioration of the acoustic effect for light vehicles and for heavy vehicles. Weak/medium/strong indicates the relevance of the parameter

influencing parameter	**for vehicle type**	
	LV's	**HV's**
Type of surface	strong	strong
Age	strong	weak to medium
Climatic zone	medium	weak
Type of road	medium	medium
Initial value	strong	medium
Traffic intensity	weak	weak
HV intensity	strong	weak

Unfortunately only about half of the observed variance could be explained with the parameters. The unexplainable part comprises experience of the road building company, weather conditions during laying, construction of the sublayers and the shoulders, etc..

When noise reducing surfaces are implemented in a Pavement Management system, additional monitoring of the development of the quality is therefore essential.

8. *How can you monitor acoustical quality of road surfaces*

National Road Administrations (NRAs) monitor the quality of road surfaces with Pavement Management Systems (PMS). These mainly involve structural attributes such as skid resistance and evenness, that have to meet fixed defined criteria in order for the road to be safe for its users. In contrast, acoustical quality attributes and required limits are not consistent along roadways because they depend on land-use, population density and traffic. Thus in order to incorporate the acoustical quality of road surfaces into PMS, the attribute is defined by the environmental noise control requirements at the receiver and how noise is transferred from the road to the receiver. In cases of a few houses, houses away from the road or behind a shielding construction the road surface may be noisier than when the road runs through densely populated areas or with houses directly next to the road.

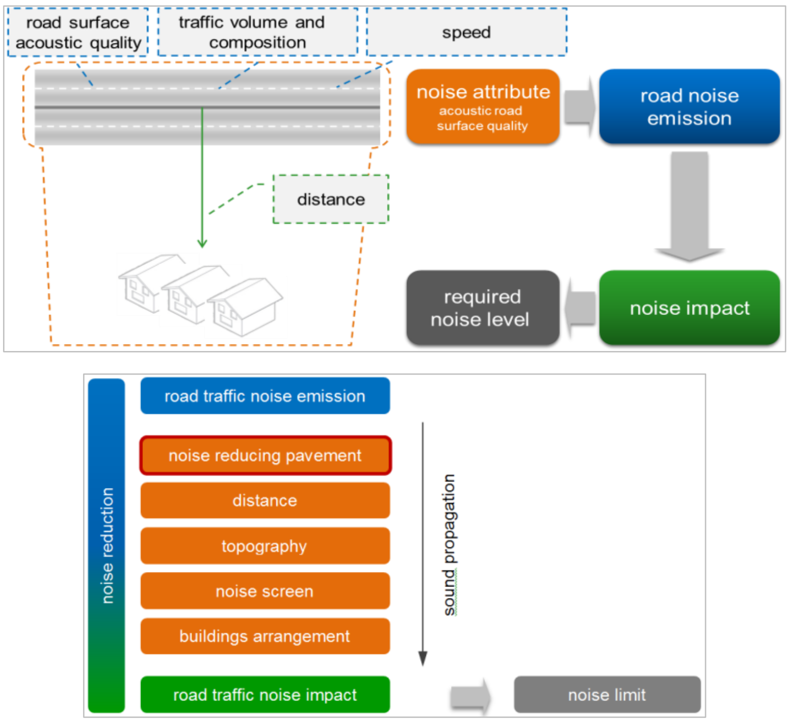


Fig. 10 Schematic depiction of interdependent attributes and contributing parameters concerning the reduction of the road noise impact

In WP 3 several methods were evaluated, such as direct measurement of the vehicle noise, or assessing the noise relevant surface properties such as texture and absorption. It was concluded that the Close Proximity (CPX) method (ISO 11819-2) fits the requirements best. An example of a common measurement system is shown in Fig. 11.

Fig. 11 : Picture of a Close proximity measurement system (source M+P)

In order to establish a rating system, reference values for different surface types are derived from collected data.

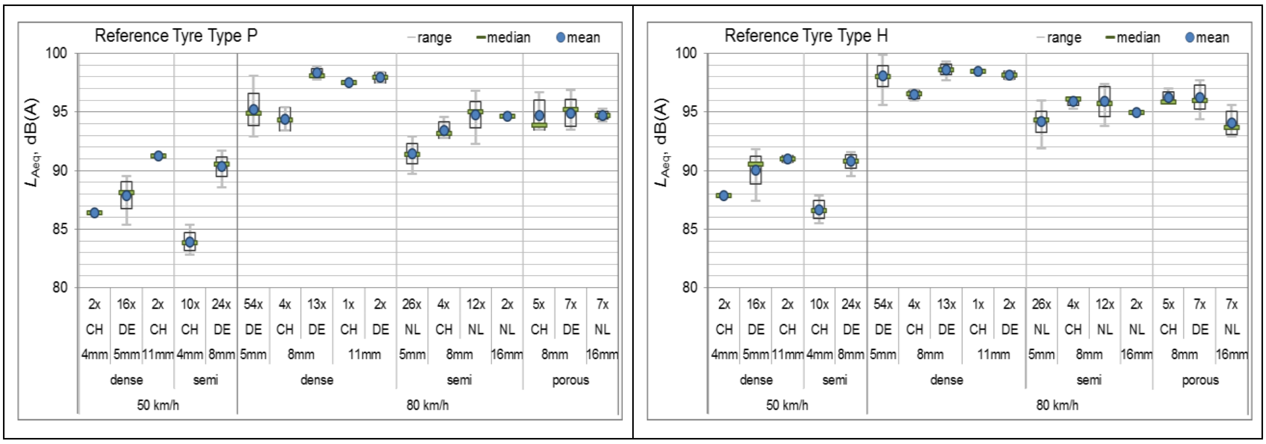


Fig. 12 Average CPX levels, right: tyre type P, left: tyre type H, at 50 and 80 km/h). The average standard deviations are represented by the black boxes. The range equals the difference of the extreme values (maximum minus minimum)

Due to an unpractically high resolution, an aggregation of CPX data is necessary, without losing its relevance towards sound impact.

A methodology for the inclusion of environmental noise control requirements is shown:

- composition of Relevant Noise Segments (RNS) which incorporate the distances to the nearest residencies
- comparison with a Zero Rating Niveau (ZRN) which represents an expected acoustical performance

As a result an aggregation and comparison procedure is recommended in order to derive an acoustical quality attribute from CPX data for the inclusion in a PMS.

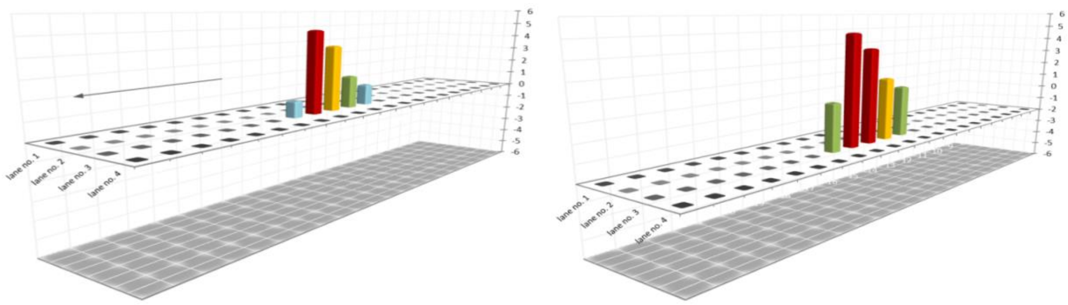


Fig. 13 Effect of the zero rating niveau (ZRN) on the acoustic condition values.
Left: ZRN = 0 dB(A), right: ZRN = -2 dB(A)

Additionally a strategy for multi lane highways is discussed when measurements on passing lanes are not recommended due to safety issues: Generally the deterioration of the right lane is higher because of heavy traffic. With an appropriate aging model the different aging can be estimated. The aging effect of low noise road surfaces is investigated, quantified and modelled in WP2.

9. *Do noise barriers age and how to monitor the acoustic quality?*

Noise barriers are generally designed to required minimal maintenance over their working lifetime. Degradation of a noise barrier most commonly manifests itself in terms of changes in the structural integrity of the barrier and its physical condition/aesthetics. Any change in actual acoustic performance will, for the most part, be restricted to changes in the acoustic performance of the materials from which the barrier is constructed.

Good design, the use of good quality materials, the used of acoustic elements prefabricated under controlled factory conditions and ensuring installation in accordance with manufacturer instructions can go some way towards mitigating causes of physical degradation such as shrinking/warping of timber planking, slumping/compression of acoustic absorbers and protection against UV radiation.

However, there remains a need for robust monitoring processes and methods to ensure barriers remain fit for purpose and that appropriate remedial action is taken where necessary.

For *new barrier installations*, it is recommended that some form of assessment be undertaken soon after installation to indicate if the system is installed (and performing) as intended. Visual inspections are recommended as the minimum requirement, using manufacturers' installation instructions as a guideline for defect detection. Acoustic assessments using standardised test methods (e.g. *in situ* methods as described in the EN 1793 suite of European standards for noise reducing devices) can be used to verify that the barrier meets declared performance specifications or contract requirements, but the need for these may be dependent upon the needs/requirements of individual NRAs.

Monitoring of noise barriers *over their working lifetime* is necessary if NRAs are to ensure that barriers on their networks remain robust, intact and fit-for-purpose. Visual inspections are recommended on at least an annual basis and are recommended as the minimum requirement. Such inspections may indirectly inform of possible changes in acoustic performance, however it is expected that the need for and frequency of any direct measurements of acoustic performance (either in terms of the performance of the materials or noise levels at receivers screened by the barrier) will be driven by a combination of costs, logistics (access to the barrier, traffic management requirements, etc) and barrier maintenance/replacement strategies implemented by individual NRAs.

10. How to implement acoustics in an asset management system?

A Pavement Management System (PMS) is commonly used to store data about a road network (e.g. inventory, condition, traffic) and apply rules to that data to identify sections that need maintenance and prioritise the maintenance sections against any given time or budget constraints. However there is no one overall assessment approach that can be universally applied to a pavement network.

Among other things, data are required to enable engineers to:

- Identify when and where maintenance is needed.
- Make decisions on the type of maintenance that will provide the best return on investment.
- Plan the maintenance at times that cause the least inconvenience to road users.
- Better understand the impacts (positive and negative) of the road pavement networks.

Noise is one of the key transport parameters currently considered for inclusion within appraisals but there is still a lack of recognised approaches at either a scheme or a network level, especially where a quantitative (or costed) methodology is desired.

By integrating noise into a PMS many of the issues still faced by a road authority in assessing noise implications against direct costs can be addressed.

The noise data for use in a PMS needs to reflect the network and analysis being undertaken. For example, if a scheme level analysis is being undertaken, detailed localised noise data is most appropriate if it is available. However, if a network level, strategic analysis is being undertaken then coarser level noise data will allow adequate modelling of policy scenarios at a network level, especially considering that the detailed localised noise data is unlikely to be available for a whole network.

A methodology for integrating noise into a PMS was developed, in addition to describing how to generate the required datasets, although it is expected that datasets should be localised where possible.

The developed methodology aimed to take account of the competing factors with the different noise surfaces, such as shorter expected lives associated with low-noise surfaces. This ability was incorporated into the methodology and means that a greater range of realistic options can be investigated when this methodology is included within a PMS.

The types of questions that can be investigated using this methodology are:

- What are the implications on a road maintenance programme between the different choices of noise surface available?
- If low-noise surfaces are selected at times of maintenance what are the implications on developing a maintenance programme?
- What are the longer-term effects (e.g. the timing and number of future interventions) when choosing low-noise surfaces for maintenance?

The noise methodology developed can help a road authority develop a greater understanding of the impacts from these types of questions, especially when compared to a more traditional approach that doesn't include noise alongside the direct works costs when developing a maintenance programme.

11. Conclusions from QUESTIM

As an alternative to noise reducing road surfaces, noise barriers are generally designed to require minimal maintenance. Degradation of a noise barrier over the course of its working life most commonly manifests in terms of changes to the structural integrity of the barrier and its physical condition/aesthetics. Acoustic degradation most readily affects the acoustic properties of the component materials but not necessarily its performance at noise sensitive receivers.

Regular visual surveys are therefore recommended with the need for any acoustic testing generally depending upon the requirements of the road authority. Where significant damage or vandalism to noise barriers occurs, resulting in major damage to or removal of acoustic elements, this may affect noise levels at receivers screened by the barrier and may affect the perceived effectiveness of the barrier. It is important that prompt remedial action is taken to correct these physical defects.

Planning with a reliable cost-benefit tool together with an understanding of the time related acoustic performance of road surfaces enables a road authority to select the optimal surface type, that gives the best balance between the profits for the environment and the costs of the road owner

The benefits of the project can be summarised as follows:

1. Improved knowledge on the performance over lifetime of low-noise road surfaces and noise barriers.
2. Improved cost-benefit analysis methodologies at strategic and scheme level, including proposals for integrating noise mitigation measures into PMS and AMS and integrate it with safety and sustainability aspects.
3. Improved measuring standards to survey pavement and barrier performances of road networks.

Although the QUESTIM project can be understood as a series of separate research topics, there exists a clear relation between them as the scheme in Fig. 14 below reveals.

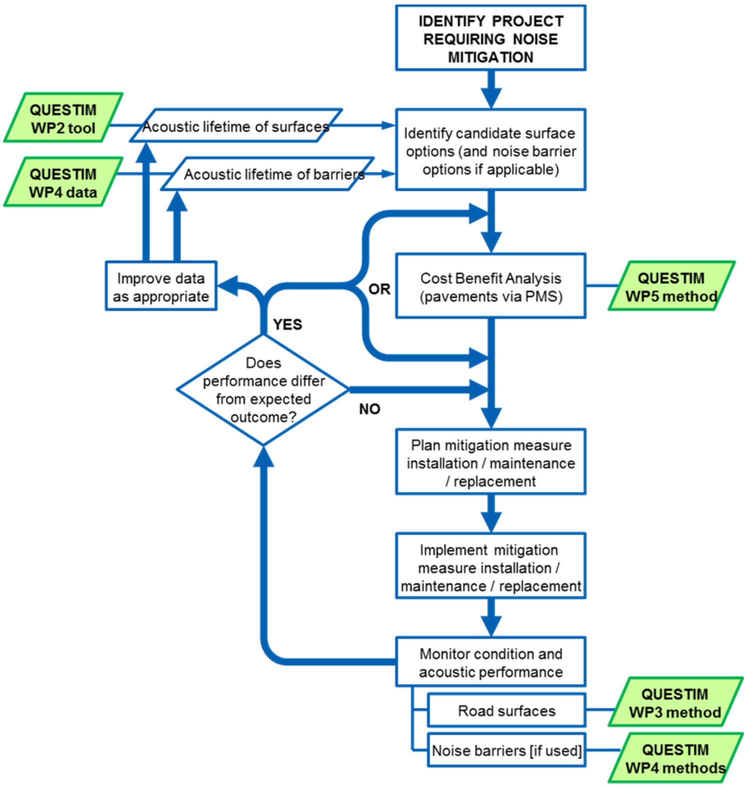


Fig. 14 How the selection of noise mitigation measures at project level and their installation/ maintenance/ replacement align with the activities of the QUESTIM project

The scheme in Fig. 14 presents the activities and information requirements of a road authority that has decided to apply a noise reducing road surface in order to reduce environmental noise exposure of the population in the vicinity of the road.

It incorporates:

1. The planning of the surface including service life expectancy and resurfacing scheduling. It covers the costs and benefits of alternatives. It enables the balancing of source related measures against measures in the propagation such as barriers.
2. After laying, a fit-for-purpose monitoring scheme has to be installed in order to follow the development of the surface over time, the calibration against the expected age related performance and to enable more accurate planning of repair or resurfacing.
3. When barriers are applied in combination with or as an alternative for noise reducing surfaces, tools are presented that can be used to assess the performance of the barrier during its life time. Possible sources of degradation are described.

The wish to apply the described procedure may come from legal obligations within the framework of environmental impact studies for new roads or the obligation to meet maximum allowed noise exposure limits in national or local noise acts. It may also originate from policies to improve the environmental noise situation based in local, national or European noise action plans.

12. Recommendations by QUESTIM to NRAs

1. Further research to understand the causes and nature of acoustic aging of road surfaces is essential in order to improve its durability
2. The evaluation of acoustic road surface effects shall include the spectral composition in 1/3rd octave bands. The limited availability of spectral data from other areas of Europe hampers the identification of aging mechanisms.
3. The CPX method (ISO 11819-2) is the preferred method for monitoring the acoustic performance of a road network. The method have to be completed with standardization of the reference test tyres and of the temperature correction coefficient.
4. In order to safeguard the environmental quality around the road network, the acoustic performance shall become an attribute of Pavement Management Systems. After averaging over a suitable distance (500 m by default) the negative deviation from the reference level can be interpreted as an indication of failing acoustic performance. A positive deviation refers to a longer than expected remaining service life.
5. The acoustic road surface effect is an essential part of the common European noise calculation procedure (CNOSSOS). It is therefore important to integrate the aging performance into the standard procedure. Proposed is to use a time invariant figure, the life time averaged effect .

6. A quicker and more practical evaluation method for noise barriers is required. The present CEN based measurement standards are too cumbersome.
7. The evaluation of the time related performance of noise barriers is hampered by the limited availability of empirical data. It is recommended to extend the test programs to barriers and make the data available for further study.
8. The practicalities of applying existing standardised *in situ* acoustic test methods (such as those from the EN 1793 suite of European standards for road traffic noise reducing devices) at the roadside are constrained by cost and logistics such as access to the barrier, any traffic management requirements, health and safety considerations for the assessors, etc, As such, there is potentially a need for alternative, simpler test methods to be identified or developed that do not require operators or equipment to be statically sited on or close to the carriageway; such methods might not be required to produce the same results as standardised test methods but may be sufficient to determine whether more in-depth assessments are required.
9. Further data on the long-term acoustic performance of noise barriers in terms of the component materials is required; the majority of data currently available as a result of research studies, etc, is focussed on the performance of noise barrier materials in new conditions.
10. NRAs should, using the framework provided within QUESTIM, attempt to fully integrate noise into their Pavement Management Systems such that it is considered in a quantitative manner when planning network maintenance.

13. Where can I read more

The QUESTIM project has resulted in 4 scientific reports and an overall report explaining the interactions between the studied topics and formulating the main conclusions and recommendations.

1. QUESTIM D2.1, “Performance, Maintenance and Materials of Low Noise Surfaces under Winter Conditions”, Antti Kuosmanen, Aalto University, SF,
2. QUESTIM D2.2, “Modelling of Acoustic Aging of Road Surfaces”, Gijsjan van Blokland, Ronald van Loon and Christiaan Tollenaar, M+P, NL.
3. QUESTIM D3.1, “CPX monitoring”, Thomas Beckenbauer, Müller-BBM, D,
4. QUESTIM D4.1, “Assessing the acoustic durability of noise barriers on NRA road networks”, Phil Morgan, June 2014, TRL, UK,
5. QUESTIM D6.2, “ Final project report”, July 2015,

All reports are available at the project website www.questim.org

General information on the exposure of the European population to traffic noise and the impact on the well-being and health can be found in:

[1] EEA report 10/2014, “Noise in Europe 2014”, ISSN 1977-8449

[2] EEA Technical report 11/2010, « Good practice guide on noise exposure and potential health effects”, ISSN 1725-2237

[3] World Health Organization and JRC-European Commission, “Burden of disease from environmental noise”, ISBN: 978 92 890 0229 5

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