Evaluation of Noise Mitigation Measures: Summary of four research projects - CEDR „Call 2012: Noise"

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ABSTRACT

A variety of different possibilities for the evaluation of the noise mitigation was investigated in four research projects (QUESTIM, ON-AIR, DISTANCE and FOREVER) developed for the Conference of European Directors of Roads (CEDR) within the „Call 2012: Noise". Following topics were researched more detailed, the identification of mechanisms for the acoustic deterioration of pavement and noise barriers, the development of procedures for acoustical evaluation and monitoring of this structures, the presentation of methods and indicators for identification of so called "hotspots", the evaluation of smart mitigation measures and future potential scenarios. In summary, many views on this topic resulted in a variety of approaches with multiple synergies and broad possibilities for further implementation in the evaluation of noise mitigation measures. The projects also indicated that further analysis of existing data and methods could lead to more elaborate and feasible solutions of noise consideration and abatement. In-depth research of individual topics could help to answer open questions.

Keywords: CEDR, Evaluation, Mitigation Measures, Barriers. I-INCE Classification of Subjects Number(s): 31.1, 52, 68

1. INTRODUCTION

The Transnational Research Programme Call 2012: Noise "Integrating strategic noise management into the operation and maintenance of national road networks" was launched by the Conference of European Directors of Roads (CEDR). The overall aim of the programme was to provide National Road Administrations (NRAs) with the appropriate guidance and tool for integration of strategic noise management into the operation and maintenance of national road networks, while considering planning legislation in European member states and taking a holistic approach. In the framework of the programme four research projects were developed:

- QUESTIM QUietness and Economics STimulate Infrastructure Management
- FOREVER Future Operational Impacts of Electric Vehicles on national European Roads
- ON-AIR Optimised Noise Assessment and Management Guidance for National Roads
- DISTANCE Developing Innovative Solutions for TrAffic Noise Control in Europe

The four projects have taken a different approach on the noise topic considering different aspects of traffic road management, resulting in numerus recommendations, guidance and tools for integration of noise into road planning, everyday operation and maintenance. Many views on the noise topic resulted in a variety of approaches for the evaluation of the noise mitigation measures. In this paper will be considers the mechanisms and approaches for the identification and evaluation of the noise mitigation measures develop within the framework of the CEDR "Call 2012 Noise".

QUESTIM conducted research on the acoustical lifetime performances of low-noise surfaces and noise barriers. DISTANCE considered possible benefits of multi-functional noise barriers and pavements, smart and non-acoustical mitigation measures. FOREVER presented potential future noise impact of increased us of Electrical Vehicles and Hybrid Electrical Vehicles at higher speeds. ON-AIR considers methods for establishing priorities and common noise tools for noise abetment.

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2. QUESTIM

The QUESTIM project conducted research on the acoustical lifetime performances of low-noise surfaces and noise barriers, considering mechanisms for the acoustic deterioration, available recommendations and practice in assessment and monitoring of acoustical performances of noise barriers and developing an aging model for the acoustical performances of road surfaces.

Development of an acoustic aging model required collection and analysis of available data (preferably spectral data) on initial and lifetime performance of road surfaces across Europe (NL, DK, DE, FR, Flanders/BE, GB, ES). Three interesting regions have been identified: Scandinavia, Mid Europe and South-Europe.

In the acoustic aging model road surfaces have been categorized according to usage types (the emphasis was on regional roads and highways), aging processes and climate zones. For identification of relevant parameters and their quantification, a straight statistical analysis has been implemented, using ANOVA (ANalysis Of VAriance) approach. Some of the road surfaces, which have been examined: brushed and exposed aggregates concreate surfaces, SMA6, SMA8, SMA11, SMA16, ACSURF8, ACSURF11, ACSURF16, 2L-PAC8, 2L-PAC16 und TSL6.

Obtained data was studied in two ways. First, through analysis of spectral shifts in the sound recordings of roads it was possible to identify mechanisms underlying the loss of performances. Second, straight statistical analysis of the performance data was conducted in order to define and explain relevant aging parameter and coefficients (1).

A comprehensive survey on acoustical performances of noise barriers was undertaken using a specially designed questionnaire made for NRAs and industry. In the QUESTIM study on noise barriers standardized test methods for characterizing the acoustic performances of noise barriers and the most important parameters influencing acoustic performances were considered. Further, two types of monitoring methods were analyzed (2).

2.1 Outcomes

QUESTIM study on low-noise surfaces show significant variations between overall loss of acoustic performances of road surfaces. Differences for individual surfaces for light vehicles were between 0 dB/yr and 5 dB/yr.

The explanation for these variations can be found in climatic conditions, type of road and road surface, traffic intensity, heavy vehicle intensity, age and initial reduction value. It has been noted that climatic conditions have significant influence on aging process especially, in the regions with harsher winter condition such as Scandinavia, DK and UK (1).

The ranking of main parameters influencing the acoustic aging of road surfaces is presented in Table 1.

Table 1 – Ranking of parameter influencing the acoustic aging of road surfaces (1)

Parameters	Light vehicles	Heavy vehicles
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

Spectral shifts recorded during service life of the road surfaces were used to identify processes underlying the loss of acoustic performances. It has been established that for Thin Surface Layer pores clogging is the main cause, with assumption of filling up of the porous layer whiles still remaining open on top layer performance loss of porous surfaces can be explained. Additional texture deterioration indicated from the spectral shifts by the fine graded top layer with 2/6 grading could be explained with the stone loss. The aging effects of heavy vehicles follow the same trend and are not that different from light vehicles. Figure 1 illustrates spectral distribution of different aging processes. Spectra are representative for light vehicle (LV) tyres and measured with the Statistical Pas-By (SPB) method (1).

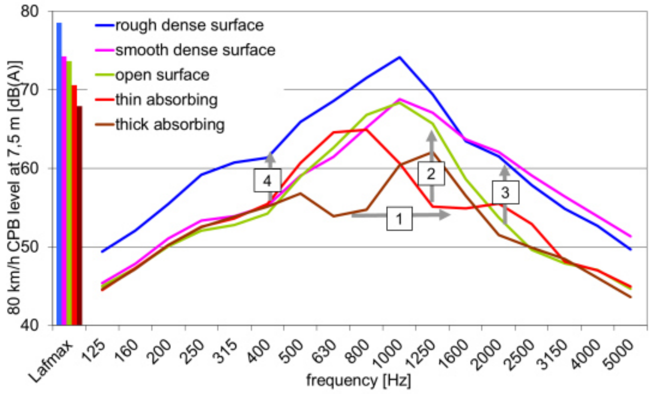

Figure 1 – Spectral distribution of the different aging processes:

(1) filling up of the lower layer, (2) further filling, (3) clogging of top-layer and (4) stone loss (1)

QUESTIM aging model explained some of the variations influencing acoustical deterioration of road surfaces. However, there is still significant number of parameters which need further clarification. In order to increase model accuracy both initial reduction value and value after several years (3-5 years) is required (1).

QUESTIM study on noise barriers show that only minimal acoustic data related to the changes in acoustic durability are considered. Standardized tests develop for characterization of acoustic performances of noise barriers, which are embedded in European standards, are used by manufactures and suppliers for declarations of noise barriers performance. These tests focus on intrinsic characteristic i.e. the performance of individual materials and elements. Here is important to note that NRAs expectations of acoustic durability of noise barriers are more aligned with extrinsic characteristic i.e. capacity of noise barriers to provide the required noise protection over operation life.

Visual inspection was identified as the most common monitoring method and it is recommended as minimum requirement, which should be undertaken after the installation of noise barrier and over the working lifetime of barrier. Recommendations for visual inspection and acoustical assessment of noise barriers are presented in the Tables 2 and 3 (2).

Table 2 – Monitoring scheme of visual inspection of new barriers (2)

Visual Inspection		Acoustic Assessment	
Timing	Preferably during installation otherwise within 1-2 months strong	**Method**	EN 1793 Part 6/Part 5 or ISO 10847 as appropriate
Scale	Whole length is preferable, ideally on both sides	**Timing**	Preferably during installation otherwise within 1-2 months
Look out for	Physical defects and damage; Seals and fastenings; Stability/alignment of posts; Gravel boards and/or ground level seals; Doors, access gates, etc	**Scale of tests (Low)**	1-2 positions randomly located along the barrier (& at locations of defects found by visual inspection)
Use manufacturer's installation instructions as a guideline for defect detection.		**Scale of tests (Low)**	At regular intervals, e.g. every 100m, on sections between 2 or 3 posts

Table 3 – Ranking of parameter influencing the acoustic aging of road surfaces (2)

Visual Inspection		Acoustic Assessment	
Timing	Annually unless location suggests otherwise	**Method**	EN 1793 Part 6/Part 5 or ISO 10847 as appropriate
Scale	Whole length is preferable, ideally on both sides	**Timing (years)**	Timber: After 1, 3 & 5 years then every 5 years Other: 1 year then every 5 years
Look out for	Physical defects and damage; Seals and fastenings; Stability/alignment of posts; Gravel boards and/or ground level seals; Doors, access gates, etc; Damage due to vandalism, vegetation growth, etc.	**Scale of tests (Low)**	1-2 positions randomly located along the barrier (& at locations of defects found by visual inspection)
Use manufacturer's installation instructions as a guideline for defect detection.		**Scale of tests (Low)**	At regular intervals, e.g. every 100m, on sections between 2 or 3 posts

3. DISTANCE

DISTANCE considered possible benefits of multi-functional noise barriers and pavements, smart mitigation measures and non-acoustical mitigation measures.

Project investigated how mitigations tools such as noise barriers and road surfaces can be further enhanced in order to provide additional value in project referred as “secondary functions”. Suitable solutions have been examined and assessed according to the possible advantages/disadvantages, cots, suitability for commercial implementation and technical readiness.

Secondary functions have been categorized as “designed” (physical change by integration of additional elements within or onto the structure of noise barriers or road surfaces), “bonus” (social, environmental and economic non-acoustic benefits) “demonstrated” and “concept” (documented evidence of implementation exist i.e. no documented evidence). Project also developed an Indicative Cost Band for presentation of likely cost of measures (3).

The main objective of researcher on smart mitigation measures was development of a schematic procedure for selection of smart mitigation measures. The smart mitigation measures are defined as number of technological solutions, strategies and elements which can be used for innovative mitigation of traffic noise. The schematic procedure was developed on the basic of a questionary received from NRAs and a literature review which covered information on effectiveness, applicability and benefits of a certain innovative measures. Four categories of inovatieve measures have been identified: traffic control and management, urban planning and road design, socio-economic measurs and inovativ solutions (4).

Further, DISTANCE south to investigate how non-acoustic mitigation measures can contribute to low-cost reduction of annoyance. The research was based on the literature review and a workshop on new ideas and the study concentrated on four main areas: communication, compensation, participation and other non-acoustical measures (5).

3.1 Outcomes

The DISTANCE study on “secondary functions” recommended the following solutions as most suitable for implementation on the road networks of NRAs:

- Noise Barriers: Noise barriers with photovoltaic elements, integrated noise and safety barriers, enhanced visual aesthetics (including the use of transparency) to suitably match the noise barrier to its installation environment and green barriers
- Road surfaces: Use of recycled materials (3)

DISTANCE research on the smart mitigation measures developed a decision making support schem/algoritam (Firure 2). Mitigation measures have been selected according to the road age, cross section, noise reduction and rated using the inseration loss index (IL): low noise reduction (IL≥ 3 dB(A)), medium (3<IL≤ 7 dB(A) and high noise reduction (IL> 7 dB(A)).

Two specific noise mitigation measures, Poroelastic Road Surfaces (PERS) and sonic crystals are promising solutions for achievement of a higher noise reduction (IL> 7 dB(A)). PERS have been recognized for its unequalled noise reduction potential. Medium noise reduction can be achieved, beside PERS and sonic crystals, with diffractors (up to 4 dB(A) noise reduction) which are suitable for shallow sections and can be installed for the safety reason on highways only, replacement of hard ground (between 2 dB(A) and 9 dB(A) noise reduction) suitable for rural areas, artificial surfaces, roundabouts and Helmholtz resonator pavements. In order to achieve lower noise reduction measures such as traffic management, socio-economic actions (new EU tyre and vehicle noise limit) can be implemented (4).

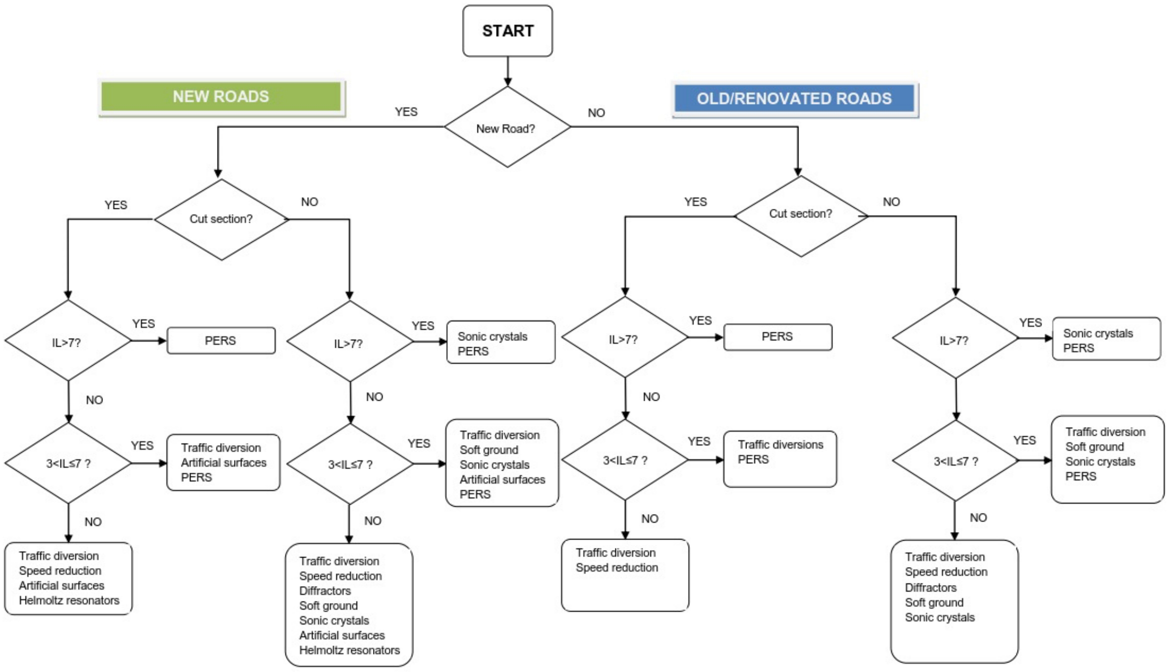

Figure 2 – Decision making supporting schem/algoritam (4)

Personal feeling of being in control and treated fairly has strong influence on the traffic noise annoyance. If people are informed and involved in a decision making process they tend to feel less annoyed. It has been noted that use of organized events such as public meetings and workshops can be good tool for public information and participation. Modern means of communication such as social media and web presentations can also be of a great help. The use of descriptors is highly recommended since they are easier for understanding to general public.

Economical compensation is often used as a tool for increased acceptance of loud noisy environment. There are several mechanisms which are used in practice: economic settlement in form of a single or several payments to residents, property tax reduction or “compensation to the community” where a new motorway has better chance to be accepted if pedestrian and bicycle roads are also build or if the local public spaces such as parks or playground are renewed as part of the compensation program.

Other non-acoustical mitigation can be implemented on the noise source by, by influencing drivers behavior (eco-driving, ITS, dialogue-display, etc), on the propagation path (façade design, ground treatment) or on the receiver (quiet façade, quiet areas). It has been noted that annoyance reduce when residence have access to quiet areas such as parks and backyards (5).

4. FOREVER

FOREVER consider potential noise impacts of electric vehicles (EVs) and hybrid-electric vehicles (HEVs) at the higher speed which are characteristic for the roads under jurisdiction of NRAs. At the first stage the project sought to determine noise level emission from electric and hybrid vehicles under different operation conditions (noise measurement of both EVs and HEVs), to define correction factors for EVs and HEVs in order to incorporate them into the noise prediction models and to explore subjective response to EVs and HEVs.

Further, project considered the rolling noise originating from the interaction between tyres and road surface with the focus on the tyers for EVs and HEVs and low-noise tayers. Based on the market research, a set of tyers was selected. Chosen samples were used in controlled pass-by measurements. Furthermore, the obtained results have been analyzed and their relation with the harmonized EU road traffic noise model CNOSSOS was established (6).

4.1 Outcomes

FOREVER study on noise emission form electric vehicles show that overall emission of light vehicles (LVs) in electric mode follow linear trend with the speed. It was found that CNOSSOS-EU tends to overestimates the propulsion noise for LVs and that a correction was required. Therefore, the indicative correctional terms were developed in order to integrate electric vehicles into the CNOSSOS-EU traffic model. Here is important to note that the number of tested electrical vehicles used for development of CNOSSOS-EU correctional factors was limited. Therefore, result presented in the FOREVER project should be taken as indicative and a first step towards specification of electric vehicles into CNOSSES-EU.

At the hybrid passenger car difference between electric and hybrid mode occurs up to 40 km/h, at the higher speeds there is no difference (Figure 3).

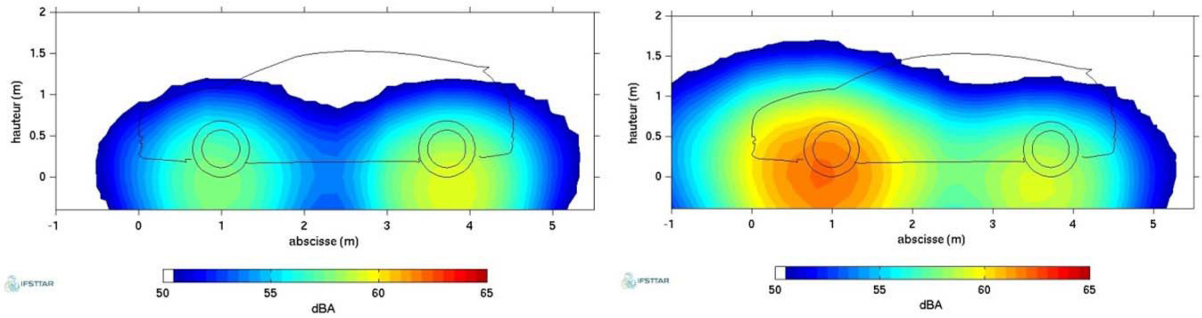

Figure 3 – Noise maps of HEVs at hte stady speed 23 km/h in electrical (left) and hybrid mode (right) – Global sound pressure level in dB (A) at hte ref. Distance 2.7 m from the vehicle side (6)

Pass-by mesurment was condacted on tayers presented in the Table 4, where the EU labele is the format ROLLING Resistenc / Wet Grip / Noise Emission (6).

Table 4 – Set of tyers chosen for the measurements (6).

Short Form	Brand	Model	Dimensions		EU label
A	Dunlop	Sport BluResponse	205/55	R16 91H	B/A/68
B	Goodyear	Efficient Grip	205/55	R16 91H	C/C/68
C	Kumho	Ecowing ES 01 KH27	205/55	R16 91V	B/B/67
D	Pirelli	Cinturato P1 Verde	205/55	R16 91H	B/B/70
E	Toyo	NANOENERGY 2	205/55	R16 91V	A/C/70
F	Bridgestone	Ecopia EP150	205/55	R16 91H	B/B/69
G	Michelin	ENERGY SAVER	205/55	R16 91W	B/A/70
H	Hankook	Kinergy Eco K425	205/55	R16 91H	B/B/70
I	Michelin	ENERGY E-V	195/55	R16 91Q	A/A/70

Mesurment results from the selected set of tyers indicated that tyers for EVs and HEVs and low-noise tayers do not have effect on the roiling noise compared with conventional tyers. Therefore, there is no need for correctional factors for the CNOSSOS-EU model. Figure4 illustrates maximal pass by levels (L_{AFmax}) of all examined tyres.

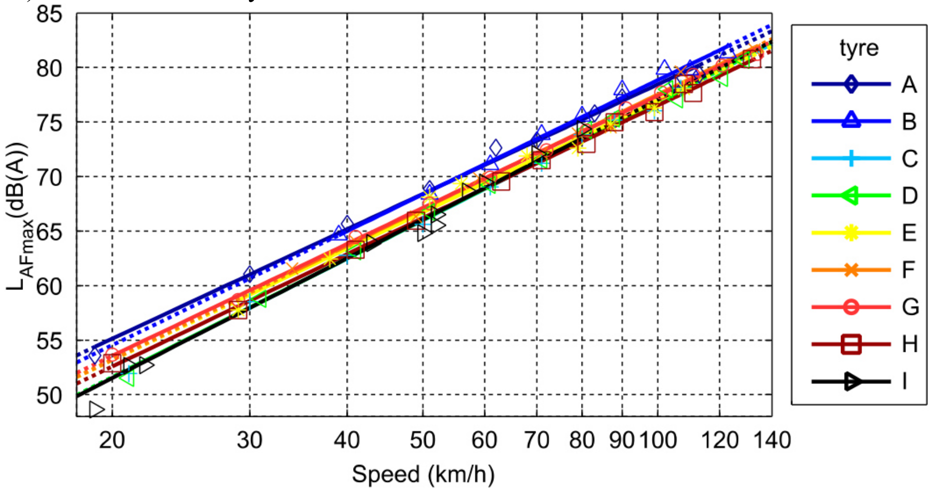

Figure 4 – Maximum pass-by level for different tyers, the symbols mark the individual measuremnts used for the regression, dotted lines are extrapolated (6)

Modeling work on overall noise reduction potential from increased use of EVs and HEVs found this vehicles no more than 1-1.5 dB quieter compared with the standard vehicles at speed over 40 km/h. Traffic noise on the national roads is not expected to decrease significantly with the increased use of EVs and HEVs since not all vehicles in the fleet will be electrically powered. However, perception study pointed out that 100% of electrical vehicles are perceived less disturbing than 100% of conventional vehicles. Improved subject response can be explained with the change in frequency band (elimination of engine tones) (6).

5. ON-AIR

ON-AIR project developed a guidance book with a range of tools and guidelines for integration of noise abatement in to the planning of new roads, enlargement and reconstruction of existing roads and everyday maintenance and management of existing roads. In this paper recommendation regarding methods for establishing priorities in noise mitigation and common tools for noise abatement will be presented.

For establishing priorities, different aspects of common methods are characterized. A number of indicator methods, summarizing the noise loads for a better comparison and weighting the noise levels by different aspects as noise annoyance, are compared.

Common tools for noise abatement are presented, including noise reduction at the source, noise reduction under propagation as well as by the receiver. A general rule is that the most cost-effective noise abatement can be performed at the source. However, in practice priority is often given to noise barriers (7).

5.1 Outcomes

For identification of the so-called noise 'hotspots', it can be helpful to blend the number of people with the magnitude of the noise load. This can be done individually for the calculated façade levels, for example, according to the END noise mapping. However, a large number of calculated spots make the identification of hotspots more difficult.

Identification of methods and indicators which can summarize and quantify the noise exposure along examined road or highway or in a given urban residential area can be an advantage in the planning process. Based on different approaches, they can take noise annoyance or costs of noise into account; some methods use freely selectable limits to allow different 'steps' of assessment.

For evaluation of noise exposure a wide variety of methods is used in European countries. A main distinction between different methods is the requirement for a 'limit value' or the use of dose–response relations based, for example, on noise annoyance. Some of the methods which are currently used in European countries are German LKZ ('LärmKennZiffer', 'noise index') and

VDI 3722-2, the Danish noise exposure factor (NEF), the disability-adjusted life-year (DALY) method, provided by WHO, the Norwegian Noise Annoyance Index.

When considering noise mitigation at the source noise-reducing pavement and restrictions of traffic were considered. The most commonly used low-noise surfaces are so-called-thin-layer pavement (a lifetime noise reduction of 2 to 3 dB) and one- or two-layers porous asphalt (average noise reduction of 2 to 4 dB or more). For more detailed information on lifetime performance of noise-reducing pavement the handbook pointed out to two other source: QUESTIM project and the report "Noise reducing pavements – What is known!" of CEDR working group on noise which will be published in 2017.

Further, restriction of traffic implies introduction of following measures: reduction of traffic volume, volume of heavy vehicles, general reduction of speed, reduction of speed during night (and weekend), reduction of traffic volume at night (and weekends), reduction of heavy vehicles volume at night (and weekend). However, implementation of road restriction measures on the roads under NRAs jurisdiction is limited. Since the main function of major state roads is to relive the municipal and regional roads and to ensure fast and effective function of traffic, introduction of restriction such as speed reduction or limitation for heavy vehicles will push traffic back to the municipal and regional roads (7).

Furthermore, noise barriers and earth walls have been considered as most effective mitigation measures on the propagation path. In the planning of noise barriers following elements should be considered: the noise barriers should be placed either close to the road or area which needs to be protected, increasing the height of a barrier increases the noise-reduction, the barriers should be extend two to four times in each direction as the distance from the receiver to the barrier. Furthermore, the noise is reduced by 2 dB every time the height of barrier is increased by 1 m up to the total height of 4 m i.e. 1 dB over a total height of 4 m.

Noise reduction measures at the receiver are usually costly measures which are implemented in the cases of high noise levels and/or when other noise reduction measures are not an option. Some of the measures which can be implemented at the receiver are: noise-reduction windows and doors, better insulation of walls and roofs, class covering of balconies and windows.

Table 5 gives a short overview of noise reduction effects of different mitigation measures with the description of perceived changes (7).

Table 5 – Example of how and how much noise can be lowered by different tools, compared to how the changes in noise level are experienced (7)

Noise reduction	Can be achieved by:	Changes are experienced as:
1 dB	Removing 25% of traffic or reducing traffic speed by 5–10 km/h	Very small change
2 dB	Using noise-reducing asphalt or reducing traffic speed by 10–20 km/h	A barely audible change
3 dB	Removing 50% of traffic, increasing distance to the road by 100% or reducing speed by 15–20 km/h	An audible but small change
5 dB	Removing 65% of the traffic or using a noise berm, noise barrier or noise insulation	A considerable and clear change
10 dB	Removing 90% of the traffic or using a high noise berm, noise barrier or noise insulation	A halving of noise
20 dB	Removing 99% of traffic or building a block of flats with closed courtyard areas	A very significant change

6. CONCLUSIONS

Recommendations and guidelines arising from the four research projects develop within the CEDR "Call 2012 Noise" provide NRAs whit comprehensive set of tools for integrations of noise mitigation in to the all phases of national road management. Mechanisms for identifications and evaluation of noise mitigations measures presented in this paper will assist NRAs in their important role in the development and implementation of the noise action plans on national roads in accordance with Environmental Noise Directive (END).

Considering the identification and evaluation of noise mitigations measures research project gave following conclusions:

- QUESTIM research on the acoustical lifetime performances of road surfaces pointed out that the magnitude of acoustic aging exhibits large variations due to the differences in climatic conditions, type of vehicles and surfaces. The initial noise reduction value was found to be a relevant factor. Additional investigation of early acoustic detrition is required (8).
- The QUESTIM report on acoustic durability of noise barriers noted that only minimal data exist on the acoustic performances of noise barriers during their lifetime. In order to establish time-dependant relationships between barrier age and acoustic performance, further more detailed measurements are needed (8).
- DISTANCE identify following "secondary function as most suitable for implementation by NRAs: noise barriers with photovoltaic elements, integrated noise and safety barriers, enhanced visual aesthetics (including the use of transparency) to more suitably match the noise barrier to its installation environment, green barriers and use of recycled materials (recycled asphalts). However, not all identified secondary functions are suitable for widespread and routine use by NRAs; this is especially case with photovoltaic.
- A simple decision support tool in a form of an algorithm is the main outcome of DISTANCE research on smart mitigation measures.
- DISTANCE research on perception and non-acoustic mitigation measures suggested that people tend to feel less annoyed if they are informed and involved in decision making process. Economic compensations are often used as a mean for lowering annoyance
- FOREVER pointed out that traffic noise on the national roads is not going to decrease significantly with the increased use of EVs and HEVs. Further, CNOSSOS-EU overestimates the propulsion noise from EVs. Therefore, indicative correction factors have been developed. Since the number of tested electrical vehicles used for development of CNOSSOS-EU correctional factors was limited, developed correctional factors should be taken as indicative.
- Research on the selected set of tyers demonstrated that they do not have effect on roiling noise emission compared with standard vehicles. In addition, perception study found that 100% of EVs are perceived less disturbing as 100% of conventional vehicles.
- ON-AIR gave an overview of methodologies for identification of so called "hot spots" and methods for evaluation of noise exposure. Some of the identified methods are German LKZ ('LärmKennZiffer', 'noise index') and VDI 3722-2, the Danish noise exposure factor (NEF), the disability-adjusted life-year (DALY) method, provided by WHO, the Norwegian Noise Annoyance Index.
- ON-AIR study on common tools for noise abatement suggested that implementation of the road restriction measures may interfere with the main function of major state roads. Therefore, implementation of road restriction measures on the NRAs roads is limited.

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