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CEDR Call 2012: Noise

Integrating strategic noise management into the operation and maintenance of national road networks

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CEDR Call 2012: Noise

Final Programme Report

QUESTIM, ON-AIR, DISTANCE AND FOREVER PROJECTS

by

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Executive Summary

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). Six CEDR member countries participated in the programme: Belgium/Flanders, Germany, Ireland, Norway, Sweden and the United Kingdom.

The research programme was developed to address the needs of National Road Administrations (NRAs) by providing appropriate guidance and tools to assist with integrating noise into the planning of new and the management of existing national roads, while considering planning legislation in EU member states. The overall aim of the Transnational Research Programme Call 2012: Noise is to integrate strategic noise management into the operation and maintenance of national road networks; taking a holistic approach.

Overall, four research projects were developed within the Call 2012: Noise as follows:

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

At the conclusion of the CEDR Transnational Road Research Programme Call 2012: Noise, a final CEDR Conference on Road Traffic Noise was held on 8th and 9th September 2015 in Hamburg, Germany; organised by LÄRMKONTOR GmbH. The aim of the conference was to present the findings and recommendations arising from the four projects, to discuss the synergies between them and possibilities for implementation of results across Europe.

Two separate workshop sessions were held on the second day of the conference, i.e. 9th September 2015. The sessions focused on obtaining participants' feedback in relation to the developed projects as well as possibilities for implementing the findings of the projects across European NRAs; potential future research activities were also discussed.

The conference indicated that the four projects of the CEDR Call 2012: Noise had taken a different approach on the topic. Nevertheless, all projects shared certain topics and displayed possible links between the various approaches. In summary, many views on the noise topic, regarding NRAs, resulted in a variety of approaches with multiple synergies. While some

projects divided their work into single (independent) work packages, the project size (e.g. in man hours or covered topics) could be limited to a feasible extent for future research projects.

The following points of contact and synergies were identified during the presentations and workshops at the final conference:

- Whilst FOREVER predicted future road traffic emissions in terms of changed propulsion (electric vehicles), DISTANCE investigated further changes in vehicle fleets and traffic parameters. These future predictions can be the basis for improved planning procedures of future road constructions and maintenance as presented in ON-AIR.
- QUESTIM focused on the degradation of noise barriers and noise reducing asphalts, whereas ON-AIR focused on the guidance of noise mitigation implementation in the planning of new roads and the maintenance and noise abatement along existing roads.
- DISTANCE presented the data requirements for future noise mapping and action planning, deriving from the Common Noise Assessment Methods in Europe (CNOSSOS-EU) calculations; ON-AIR provided guidance for the support of noise mapping by NRAs and the use of the outcomes in planning and maintenance.
- ON-AIR provided a list of proven and feasible “good examples”, and DISTANCE focused on novel “smart noise mitigation measures”.
- DISTANCE also presented a list of multi-function noise barriers and pavements with secondary uses (whether designed or “bonus”), and ON-AIR provided guidance on cost-benefit analysis that could take the non-acoustic uses with an assigned monetary value into account.

With the exception of FOREVER, the other projects did not perform their own research in terms of measurements, etc.; the variety of new knowledge indicates that many previous noise investigations have not yet been fully investigated. Further analysis of existing data and methods could lead to more elaborated and feasible solutions of noise consideration and abatement. In-depth research for individual topics could help to answer open questions.

One question discussed during the workshops was what basis the projects are offering for new meaningful research and demonstration projects. By referring to project presentations, and also from an open discussion, the following future activities were developed:

- Regarding road surfaces:

  Although research has been conducted on low-noise road surfaces for several years, the projects summarize that further research could be necessary. This research should mainly focus on the acoustical behaviour of quiet road surfaces. Acoustical deterioration of quiet surfaces could be the main scope of the future demonstration project (test lanes with various types of low-noise pavements).

- Regarding noise barriers:

As stated in the QUESTIM report on acoustic durability of noise barriers, only minimal data exists on the acoustic performance of noise barriers over their lifetime. To allow time-dependant relationships between barrier age and acoustic performance to be derived, more detailed measurements would be needed. Thereby the cause of performance loss and thus possible improvements for lower degeneration could be identified.

Outcomes of ON-AIR also indicated that some NRAs have insufficient inspection processes. The performance of the barrier as well as the structural condition should be investigated to ensure the desired effect of the barrier. Whilst technology exists for visual inspections for damages and obvious wear that needs to be implemented in NRA’s maintenance programmes, the workshop’s participants summarized that no methods currently exist to measure the performance without affecting road traffic, e.g. due to closing single lanes or the entire road.

Further projects can be recommended that could lead to performance improvements (as diffractors); advanced non-acoustic secondary uses (as improved photovoltaic elements and transparent absorbing barriers) could also be developed. This should lead to an enhanced benefit of noise barriers and, bearing higher costs, could lead to a higher cost-benefit ratio.

- Regarding communication on noise:

The participants of the final conference suggested improving the communication on various topics of noise, regarding the work of NRAs. In general, they expressed the need for more meetings and conferences on traffic noise.

A more elaborate idea was the implementation of an Internet database with proven technologies of noise reduction, innovative solutions and examples of efficient and inefficient noise mitigation measures. The database should be open to CEDR members for updating and editing. Therefore, NRAs could obtain all tools, information and research on traffic noise in one place.

Another idea was the foundation of an international centre for the innovative noise solution. This centre could also organize conferences or presentations on various noise topics.

Finally, communication between road planners of the NRAs, the decision makers and the public should also be addressed as political and public opinions can result in severe impacts on road planning.

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). Six CEDR member countries participated in the programme: Belgium/Flanders, Germany, Ireland, Norway, Sweden and the United Kingdom. The target budget for this call was € 950,000.

The research programme was developed to address the needs of National Road Administrations (NRAs) by providing appropriate guidance and tools to assist with integrating noise into the planning of new and the management of existing national roads, while considering planning legislation in EU member states. The overall aim of the Transnational Research Programme Call 2012: Noise is to integrate strategic noise management into the operation and maintenance of national road networks; taking a holistic approach. The project proposals were invited to address the following specific objectives in the first call in May 2012:

- Optimising current noise assessment and management strategies
- Integrating noise mitigation measures with national roads and how they perform over time
- Developing future visions for the management of noise on national road networks
- Strengthening/developing a holistic approach to pavement management systems (PMS)

From eight initial proposals, two projects were selected after an evaluation of the Programme Executive Board (PEB): FOREVER and QUESTIM.

As not all topics were covered by these two projects, a supplementary call was published in May 2013 with the following two topics:

- Optimisation of noise assessment and management strategies
- Development of future visions for noise management on national road networks

For the first topic, ON-AIR was initiated; the second topic was covered by DISTANCE.

Altogether, four research projects were developed within the Call 2012: Noise as follows:

- QUESTIM - QUietness and Economics STimulate Infrastructure Management
- ON-AIR - Optimised Noise Assessment and Management Guidance for National Roads
- DISTANCE - Developing Innovative Solutions for TrAffic Noise Control in Europe

- FOREVER - Future Operational Impacts of Electric Vehicles on national European Roads

At the conclusion of the CEDR Transnational Road Research Programme Call 2012: Noise, a final CEDR Conference on Road Traffic Noise was held on 8th and 9th September 2015 in Hamburg, Germany; organised by LÄRMKONTOR GmbH. The aim of the conference was to present the findings and recommendations arising from the four projects, as well as to discuss the synergies between them and possibilities for implementation of results across Europe. The conference results are presented in the Chapter 3 of this report (Final Conference).

The main purpose of this report is to provide a summary of the findings and recommendations from the four research projects, highlighting synergies and added value between the four projects, as well as to summarize recommendations for future activities which were developed within the workshops.

The FOREVER project produced a technical summary which provided a very brief overview of the objectives and their methodology, conclusions and recommendations. As the other projects covered multiple aspects in their work packages (WPs), a more extensive summary was required.

2 Project Description

2.1 QUESTIM – QUietness and Economics STimulate Infrastructure Management

2.1.1 Background and objectives

Low-noise road surfaces have been proven as an effective traffic noise mitigation tool. However, their broader use in noise mitigation on the NRAs network is still limited. The main reasons for the limited application of low-noise surfaces are uncertainties in the actual performance of low-noise surfaces, lack of knowledge on acoustical deterioration, need for more intense maintenance, possible higher building and maintenance costs, and potential negative effects on safety and sustainability.

Noise barriers have been widely used as a main traffic noise mitigation tool by NRAs. In the current maintenance practice, only structural changes on the barriers are considered during the replacement of existing structures. Possible changes in the acoustical performance are not taken into account. In addition, a lack of knowledge is evident surrounding the acoustical degradation of noise barriers in terms of sound transmission or absorption.

The objectives of the QUESTIM project have been summarised as follows in the project application:

- "*To identify mechanisms for the acoustic deterioration of pavement and barrier, develop prediction models for acoustic degradation, and methods for taking deterioration into account in noise modelling software*
- *To develop optimized procedures and technologies to survey the acoustic performance of pavements and noise barriers of large road networks*
- *To identify mechanisms for acoustic degradation and develop indicative procedures for predicting acoustic degradation of noise barriers*
- *To develop existing models to provide a state-of-the-art cost-benefit analysis methodology to assess mitigation measures at a scheme level and to anticipate on future tyre and vehicle developments*
- *To develop ways in which noise mitigation measures can be integrated into strategic models and pavement management systems (PMS) and asset management systems (AMS) to help inform long-term planning*" [1]

2.1.2 Methodology

The following methodology was adopted in the QUESTIM project:

1. Data gathering on the acoustical performance of low-noise surfaces from several European areas and development of an aging model with the hybrid approach.

   In the acoustic aging model, developed in the QUESTIM project, road surfaces have been categorised according to climatic zones, usage types and aging processes. A straight statistical analysis of the data sets has been implemented in order to identify relevant parameters and to define quantitative coefficients for these parameters, using the ANOVA (ANalysis Of VAriance) approach.

   An inventory of existing data on initial and lifetime performance of low-noise surfaces across Europe has been conducted. Three specific regions have been identified: Scandinavia, Mid-Europe and Southern-Europe. In terms of road types, the emphasis was on regional roads and highways. For the purpose of a more comprehensive understanding of surface aging, data related to the traffic intensity and traffic composition have been gathered and analysed.

   Collected data was studied in two ways. Firstly, the identification of the mechanisms underlying the loss of performance over the time through analysis of the spectral shifts in the sound recordings of traffic on these roads was carried out. Secondly, the straight statistical analysis of the performance data in relation to the traffic data was conducted in order to define relevant parameters, explaining the aging and the coefficients [2].

2. Monitoring of acoustical performance of road surfaces using the close proximity (CPX) method, development of a procedure for integration of obtained data into a PMS and a procedure which links this data to geographic and land-use planning information in order to assess the acoustic condition of road surfaces.

   For the purpose of rating of the acoustical condition of roads, reference CPX values for the various road surfaces were defined. *"The level difference between the CPX reference value for a particular type of road surface and the CPX reference value for the standard road pavement is called Zero Rating Niveau ZNR"* [3].

   In order to incorporate CPX data in to the PMS, they should be aggregated for easier handling. Several concepts for data aggregation such as smoothing methods, sensitivity analysis and aggregation of CPX data to Relevant Noise Segments (RNS) have been presented [3].

3. The QUESTIM noise barrier survey conducted a review of standardized and other test methods for characterizing the acoustic performances of noise barriers. In addition, an identification of mechanisms for the acoustical deterioration and recommendations for assessment, monitoring and use of noise data was performed.

   The QUESTIM noise barrier survey was undertaken using a specially designed questionnaire which was sent to both NRAs and industry [4].

   All CEDR member states received a questionnaire; 19 NRAs sent their completed questionnaire back to the project team. In total, 165 invitations were sent to noise barrier manufacturers, suppliers and installers; 18 companies participated in the questionnaire survey.

   An overview of the standardized European and other test methods for characterizing the acoustic performances of noise barriers has been presented. Thereby, the extrinsic (noise barrier performance in correlation with the noise sensitive receiver) and intrinsic characteristics (performance of special materials and elements) have been explained. Intrinsic characteristics are most commonly used by manufacturers and/or suppliers to specify a product's performance.

   The most important elements influencing the acoustic durability of noise barriers have also been examined. Furthermore, two types of the monitoring/assessment are defined: acoustic assessment and visual assessment. Therefore, elements such as frequency and scale of monitoring were taken into account.

4. Integration of acoustic degradation data for low-noise surfaces and noise barriers into a PMS.

   The QUESTIM project had the initial intention of developing a concept for including acoustic degradation data for noise barriers and low-noise surfaces in the PMS, in order to provide important information for the maintenance practices and high-profile cost-benefit analysis. This approach applied the effects of acoustical degradation in broad terms.

5. Cost-benefit analysis of noise mitigation measures and development of methodologies for integrating noise into the PMS.

   The main focus was the development of an appropriate approach for the integration of noise impacts within the PMS, in order to acquire necessary information on the possible effects of chosen mitigation measures. Firstly, an introduction to the PMS and whole-life costing was performed, with emphasis on environmental factors such as noise. Secondly, an overview of the main methods for noise modeling, costing and mitigation was provided.

Finally, the process for integrating noise into the PMS was described and a case study demonstrated how this methodology can be implemented to one road on the Irish national network [5].

2.1.3 Outcomes

Lifetime performance of low-noise road surfaces

The acoustic aging research, conducted under the QUESTIM project, observed a significant variation of age effects among various surface types; from zero effect up to 5dB/yr [2]. The explanations for these variations are differences in climatic conditions (especially in Scandinavia), types of surface and vehicles. It is important to note that the wear of road surfaces in Scandinavia is non-typical for other European countries.

Furthermore, the initial noise reduction value was found to be a relevant factor; meaning that an initially quieter surface has a better performance over the lifetime.

The processes underlying the loss of acoustic performance is defined as follows in the Modelling of Acoustic Aging of Road Surfaces; Deliverable D2.2 8/2014 [2]:*"The processes underlying the loss of acoustic performance were identified by means of the spectral shifts that were recorded during service life. For Thin Surface Layer, clogging of the pores is the main cause. For porous surfaces the performance loss can be explained by assuming filling up of the porous layer while still remaining open on top. For the fine graded top layer with 2/6 grading additional texture deterioration was indicated from the spectral shifts. This could most probably caused by stone loss". Figure 2.1* illustrates the effects of different aging processes on the spectral composition of rolling noise of car tyres.

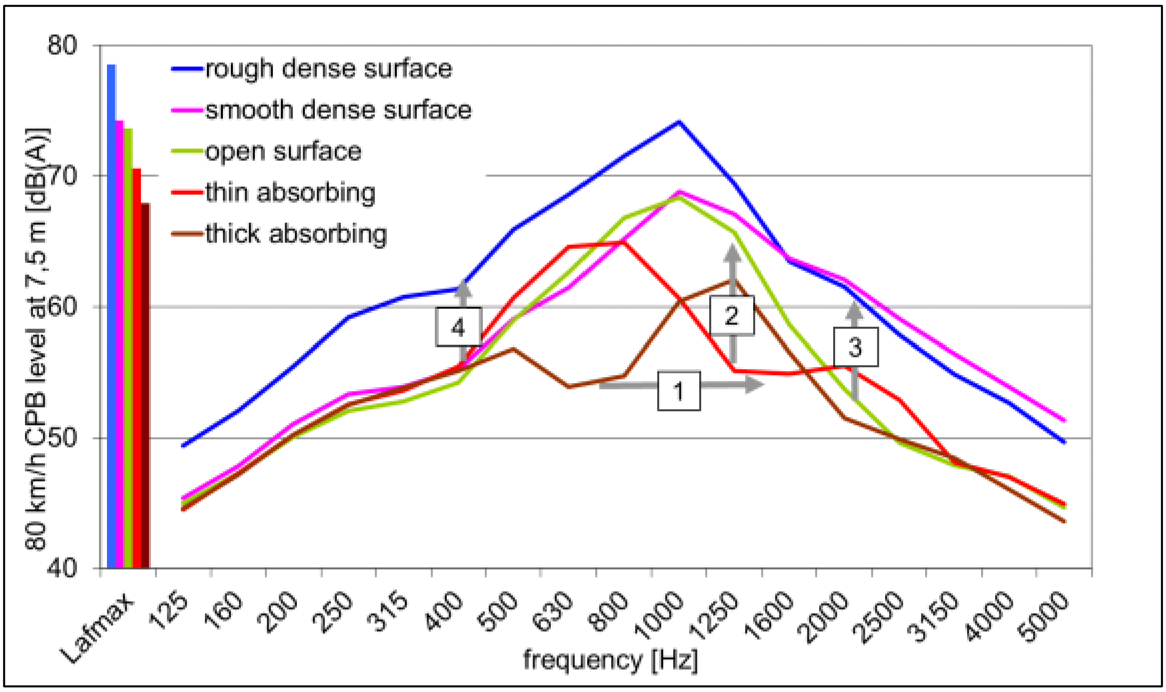

Figure 2.1: Spectral distribution of the different aging processes: (1) filling up of the lower layer, (2) further filling, (3) clogging of top-layer and (4) stone loss. Spectra are representative for light vehicle (LV) tyres and measured with the Statistical Pas-By (SPB) method [2]

The QUESTIM aging model managed to explain some of the observed variations between aging characteristics of different road surfaces. However, there are significant effects which are still unexplained, such as expertise of the road builder, climatic conditions, design of the road, etc. which are of major influence to the actual acoustical performance of the road.

In order to increase the accuracy of the acoustical lifetime performance prediction, additional information is necessary. Therefore, both the initial value and the value after 3–5 years are required. A lack of these values can significantly reduce accuracy of the performance prediction.

Procedures for monitoring acoustic quality of large infrastructures

WP 3 developed a procedure for evaluating the acoustical performance of road surfaces and addressed the following aspects of integrating noise into PMS:

1. *"The aggregation of raw CPX measurement segments up to longer segments which are meaningful with respect to the road maintenance and which homogenize the acoustic parameter without losing the relationship to the noise impact issue.*
2. *The introduction of a rating procedure which is strongly related to that what is needed in terms of noise protection issues without implementing a complex calculation procedure in order to take the relation between noise emission and noise impact resp. noise protection requirements into account"* [3].

"For pavement management purposes of large road networks raw CPX-data is too detailed regarding noise impact and should be aggregated for easier handling. Additionally to the categorization of levels, the length of continuous "noise segments" should not be interrupted by negligible fluctuations. The derived aggregation method is the median function of the levels of five consecutive 100 m CPX segments and subsequent rounding to 0.5 dB. Optionally, the aggregation of CPX data can be completed by using the distance between a road segment and the nearest receiver to determine so called Relevant Noise Segments (RNS) for each single CPX value. A concept for the derivation of RNS is introduced. This add-on procedure helps to align the length of aggregated CPX segments with the distance to sensitive housings next to the road" [3].

The desired acoustical quality is defined as Zero Rating Niveau (ZRN). By comparing the aggregated values with the ZRN, it is possible to determine the deviations (from expected aging). Such deviations can be included in the PMS and may lead to rescheduling of maintenance or road resurfacing [6].

The application of the ZRN is of great assistance when making a decision as to whether the current acoustical behaviour of a road section is relevant with respect to noise protection.

Due to safety concerns and the fact that most traffic concentrates on the right lane, CPX monitoring is conducted on this lane. However, contribution from passing lanes cannot be overlooked. It has been noted that the middle and the fast lane are usually in better condition and using just data from the slow lane for the entire road could be considered a worst-case scenario. *"One way to avoid measuring all lanes would be to incorporate an aging model into the PMS in order to track the acoustic deterioration of each lane"* [6].

Acoustic lifetime performance of noise barriers

The QUESTIM noise barrier study identified that only minimal acoustic data, related to changes in the acoustic performances of noise barriers, are considered. "*This is driven by the combination of acoustically robust products, a lack of long-term performance data for those barriers where performance does degrade and no mandatory requirement to specify acoustic performance over the working lifetime of noise reducing devices*"[6].

Furthermore, standardised tests are embedded in European Union (EU) standards and are used by manufacturers and suppliers in order to prove noise barrier performance is focused on the intrinsic characteristics. However, NRA expectations of the acoustic durability of noise barriers are more concerned with the extrinsic characteristics, i.e. whether or not they can maintain the required noise protection during their implementation lifetime.

The most common method for noise barrier monitoring used by NRAs is visual inspection, which should be considered a minimum requirement. Acoustical measurements are not a regular practice and obtained results are often only used in case of disputes or to prove the accuracy of predicted results.

Recommendations regarding the visual inspection and acoustical assessment for new barrier installations are as follows:

- Visual inspections of the new barriers should be undertaken during the installation or within 2 to 3 months. The whole length of a barrier should be inspected, preferably on both sides. During visual inspection, the following areas should be addressed: physical defects and damages, seals and fastenings, stability and alignment, alignment and fitment of doors, access gates, etc.

- Recommended methods for acoustical assessment are defined in EN 1793-6 [7] and the upcoming EN 1793-5 [8]. Nevertheless, these methods may not be suitable for use on every location due to certain practical issues. Methods such as ISO 10847 [9] should be used for the assessment of long-term performances in the far-field at sensitive receivers protected by the barriers. Measurements should ideally be taken during the installation of a barrier or within 1 to 2 months. As in the majority of cases acoustical measurements are used to supplement visual inspection, it is expected that one or two measurements on random locations along the barrier will be required. *"The use of the in-situ assessment techniques in the EN 1793 suite of standards is largely confined to research and is therefore not currently commonplace for post-installation checks at the roadside. Indicative cost information is therefore unavailable*" [6]

Recommendations regarding the visual inspection and acoustical assessment over the working lifetime of barriers are as follows:

- Visual inspection should be undertaken at least annually, whereby barriers from natural materials and those exposed to harsher climate conditions may require more frequent inspection. When it comes to the quantity of barriers to be inspected, recommendations are the same as for the new barriers. Visual inspection seeks to identify physical defects and changes that were not previously present. Therefore, it should focus on physical defects and damages, seals and fastenings, stability and alignment, alignment and fitment of doors, access gates, etc., gravel boards and/or ground level seals, damage due to vandalism, vegetation growth, etc.
- Recommended methods for acoustical assessment are the same as for newly installed barriers. Furthermore, the number of measurements will be similar to those for a barrier in new condition. The frequency of monitoring is determined by the material of which the barrier is made. For timber barriers, inspection is recommended 1, 3 and 5 years after installation and subsequently every 5 years. For other barrier types, inspection is recommended after 1 year from installation and then every 5 years [6]

In terms of integration of lifetime acoustic performances into PMS, it has been concluded that it is not feasible or beneficial for the purposes proposed with QUESTIM.

Cost-benefit analysis and life-cycle costs of barriers and low-noise road surfaces and the development of a PMS that includes noise

WP 5 of the QUESTIM project presented a methodology for integrating noise into a PMS and gave examples for developing necessary datasets.

Research indicated that current noise mapping data provides enough information and it can be used in the proposed methodology. Additional improvements are expected with further development of noise mapping. Noise datasets used in the methodology for integrating noise into the PMS are also suitable for updating and can be altered when a new noise data becomes available.

The QUESTIM methodology for integrating noise into the PMS can assist NRAs by the investigation of the following issues:

- *"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?" [5]*

The noise methodology developed in the QUESTIM project can help a road authority to develop a greater understanding of possible impacts which can integration of noise in to the PMS have on the maintenance programmes.

It would be incorrect to expect the PMS to provide one concrete answer. Instead, it provides NRAs with the possibility to investigate a range of scenarios which provide them with a series of probable outcomes.

"The modelled maintenance programmes use national schemes and therefore detailed consultations with engineers will be required to translate the PMS data into a more complete maintenance programme. And although the principles of whole-life costing attempt to assess the scheme benefits and costs over a longer period (e.g. 30-60 years), the immediate programme period (i.e. 1-4 years) is the period of most importance to a road authority and they would be expected to undertake revised analyses each year and adapt the programme accordingly as more recent condition data, costs, deterioration relationships etc. become available to the model" [5].

2.2 ON-AIR – Optimised Noise Assessment and Management Guidance for National Roads

2.2.1 Background and objectives

Road traffic is the major source of human noise annoyance and adverse environmental health effects in Europe. Whereas many environmental effects have been reduced over time, no similar reduction in noise-related effects has been achieved. The population is increasingly demanding good living conditions in residential areas along roads and highways and expecting the infrastructure owner to have the responsibility and bear the cost for handling the noise issues. Due to limited funds and unsuitable policies, NRAs are faced with difficulties when it comes to effective noise mitigation [10].

Therefore, ON-AIR aims to develop tools and guidelines, presented in a guidance book, which can facilitate the integration of noise abatement into the three most common planning and management situations of NRAs as follows:

- Planning of new roads and highways
- Planning of reconstruction and enlargement of existing roads and highways
- Maintenance and management of existing roads and highways

2.2.2 Methodology

The following methodology was adopted in the ON-AIR project:

1. Investigation of noise planning procedures and tools

   In the first stage of the project, an in depth interview guide, containing 34 questions, was developed. The objective of the interview was to obtain a series of beneficial and interesting planning procedures, tools and practical implementation. The following issues were included:

   Planning of new roads and Environmental Impact Assessment (EIA) of alternative solutions; road enlargement/redevelopment projects; in detailed planning of the road construction; day to day maintenance of road infrastructure; planning and handling of noise in the construction phase; cooperation and efficient handling of noise issues between NRAs and regional as well as local authorities; communication with the public and public participation in the planning and decision making.

Experts in noise planning and management from Flanders/Belgium, Sweden, Ireland, Norway, Germany and Switzerland took part in an interview and workshop event in Hamburg, Germany. Additional interviews from Denmark, Hungary and the United Kingdom have been taken into account.

With the aim of development of new ideas for noise abatement and management, a “Future Workshop” was organized as part of the Hamburg event.

Based on the literature review, a short analysis of noise action plans developed in relation to the Environmental Noise Directive (END) has been performed in the report “Investigation of noise planning procedures and tools“ [11].

2. Assessment of traffic noise in complex situations

   The ON-AIR consortium focused on situations representing complex noise source conditions and complex sound propagation. Based on typical cases selected in cooperation with the PEB for which noise maps had already been made in connection with strategic or other noise mapping, the consortium showed examples for noise measurements to assist in validating a noise map, defining appropriate input data for noise prediction or documenting the effect of a measure taken to mitigate traffic noise.

   A literature review and interviews were performed. Three examples of complex noise calculations given by PEB members were investigated: a Norwegian tunnel case, a Danish fly-under case and a Norwegian flyover case [12].

3. Guidance book

   The information from the “status report” was the background for the development of a guidance book on the integration of noise in road planning and management in the second part of the project. Based on the methods in use in various NRAs mentioned by the experts in the workshops, results of literature surveys and the teams experience, a wide range of topics regarding noise at NRAs was covered [13].

4. Suitable examples

   The guidelines presented in the ON-AIR guidance book are complemented with a series of illustrative examples of various measures of noise abatement. It is developed on the background of existing experiences and best practices used in various CEDR member countries, identified through interviews with CEDR experts and literature studies [13].

5. Interactive examples

In addition to the static content of the guidance book, several aspects were integrated in interactive examples. By these examples, various methods shall be comprehensible and provide a feeling for a possible consideration of noise in different planning stages.

2.2.3 Outcomes

Investigation of noise planning procedures and tools

An early output of ON-AIR was the report on the existing practices of selected European countries, based on the result of the questionnaire and the "Future Workshop".

The "status report" provides an overview on how noise is handled today in the planning procedures of selected NRAs in Europe. A comprehensive European investigation was performed on the variety of noise planning procedures and tools currently in use in various CEDR countries. The interviews of experts in noise planning and management from selected European countries provides an overview on how noise is integrated in the following areas:

- Planning of new roads and EIA of alternative solutions
- Road extension/redevelopment projects
- Detailed planning of the road construction
- Day to day maintenance of road infrastructure
- Planning and handling of noise in the construction phase
- Cooperation and efficient handling of noise issues between NRAs and regional as well as local authorities
- Communication with the public and public participation in the planning and decision making

An inventory of measures of noise abatement and their estimated effect based on literature is included. Different methods to evaluate and quantify noise and noise abatement are presented, together with methods on how to include noise in Cost Benefit and Cost Effectiveness methods. A number of illustrative examples are included [11].

Assessment of traffic noise in complex situations

After examining literature and performing a number of interviews, the consortium reached the following conclusion:

- "*Planning and mitigation should predominantly be based on calculations made by means of high quality software based on high quality prediction models and operated by skilled personnel*
- *The process denoted reverse engineering was found less versatile for noise mapping than anticipated during drafting the project proposal, but might in some cases provide a practical way of improving noise source models and thereby increasing the accuracy of noise maps. Measurements should then be made in positions near to important noise sources*
- *Only in exceptional cases, however, should measurements be applied, and it should be realised that measurement uncertainty is substantial. Such an exceptional case could by that there is reason to suspect that a noise limit is clearly exceeded at a complainant's home, but even then a review of a noise calculation would be preferred instead of carrying out a noise measurement*
- *If a measure like traffic speed regulation or laying a noise reducing pavement is taken, then its effect may be reliably estimated based on noise measurements made at the same position close to the road before and after taking the measure*
- *In case* where it is indicated *that calculation results do not yield true and fair assessment of traffic noise exposure, resources should be allocated in improving models and their implementation rather than in measuring noise exposure of individual dwellings"* [12]

Guidance book

The ON-AIR guidance book presents tools and guidelines which can facilitate the integration of noise abatement into the following three most common planning and management situations of NRAs:

1. Planning of new roads and motorways
2. Planning of reconstruction and extension of existing roads and motorways
3. Maintenance and management of existing roads and motorways

As a technical background, the guidance book presents a toolbox for the road planner working with noise issues. The toolbox provides a rough overview and background knowledge on the topic of noise assessment and gives practical tools that can be used in the integration of noise as an active factor in road planning. Methods for assessing noise and establishing priorities, noise impact on recreational activities as well as overall noise impact and noise from various sources are included. For example, aspects of noise effects regarding annoyance, disturbance and health are considered with references to possible impacts. In addition to general guidance on noise predictions, indications are provided for simplified noise predictions in early planning stages. 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. Furthermore, spatial aspects of hotspot identification, as summarisation by grids, assignment to line sources, etc. are considered.

Lastly, common tools of noise abatement are presented, including noise reduction at the source, noise reduction under propagation as well as by the receiver. For each measure, a short summary is provided, including basic advice, e.g. for planning and maintenance.

The key focus of the guidance book is on planning of new roads and improvement or extension of existing roads. The guidance book presents how noise can be described, analysed and taken into consideration in various stages of a road project; from the early planning where the knowledge about the project is low, over the EIA stage where different road alignments and solutions are evaluated, until the more detailed planning of the project where the physical framework of the project is finalized.

Figure 2.2 provides an overview of stages of a road infrastructure project in which noise can be taken into consideration.

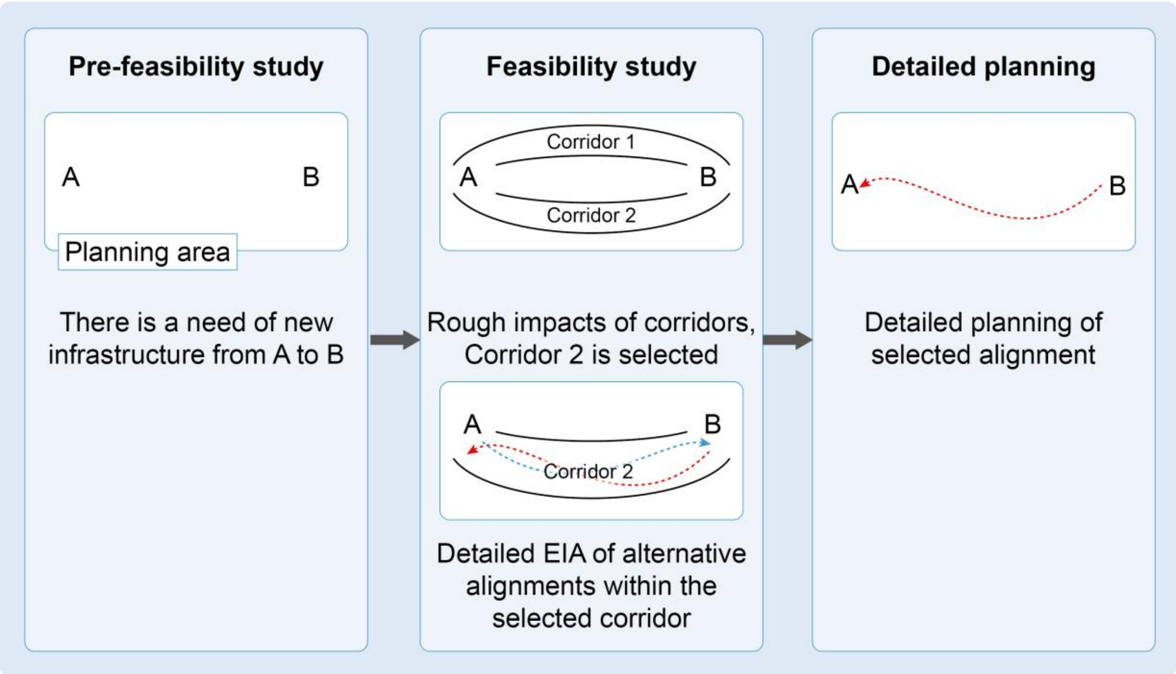

Figure 2.2: An example of different steps of the feasibility study and the EIA [13]

The guidance book presents noise in connection with maintenance procedures. This focuses on noise considerations in the ongoing process of maintaining pavements as well as on maintenance of noise abatement structures such as noise barriers and earth berms, etc. Planning and prioritization of active noise abatement along existing roads with noise barriers and façade insulation is included, together with a section on how to avoid an increase of existing noise problems that can be caused by urban development along roads and highways as well as by increased traffic.

Methods for managing construction noise are also presented in the guidance book. This includes tools for mitigation of construction noise such as smart design of construction sites, definition of contract specifications and special provisions, sequencing of construction operation, use of alternative construction methods and standard noise mitigation such as noise barriers and building insulation. Also, an insight into construction noise criteria as well as modelling and monitoring of construction noise is provided.

Furthermore, the guidance book includes a short presentation on how the noise mapping and noise action planning performed according to the END [14] can be used to support work on integrating noise in the processes of planning and maintaining of roads and highways.

Public participation in the planning process is considered through the entire guidance book. Methods and strategies for public participation are presented in a separate chapter with a focus on positive possibilities for road administrations to establish contact and dialogue with the neighbours near the roads. Examples of various ways to engage the public in road projects are public meetings, exhibitions, presentation of noise levels, listening examples, noise walks and bicycle tours, brochures, social and local media.

Good examples

The guidance book is complemented by more than 30 “good examples” of tools of noise abatement and noise management. The main aim of the examples is to inspire road administrations in Europe as well as consultants working on road projects to seek innovative solutions in the noise abatement. The illustrative examples not only include noise mitigation measures as barriers or noise reducing surfaces but also examples for planning and examples showing secondary uses or improvements in maintenance. Examples may not always be directly copied; it can be necessary to take local conditions and practices into consideration.

Interactive examples

A series of interactive examples has been developed (refer to *Figure 2.3*) and can be found on the ON-AIR homepage (www.on-air.no).

The first part aims to provide an overview of the various methods that can be used for noise impact analysis. An example for a “constructed” but not real national road project is presented, starting with three variants for comparison.

The second part of the interactive examples is a tool for comparison of noise mitigation measures. It quickly predicts the results from various noise abatement strategies and displays results as both noise maps and statistics on noise exposure. The user can change traffic, speed, pavement, etc. and also chose several variants of noise barriers.

The interactive examples show planners how they can evaluate various strategies for noise abatement and select the most suitable measures for noise abatement in given situations. Similar tools can also be used to facilitate political and public involvement in the actual planning and decision making process.

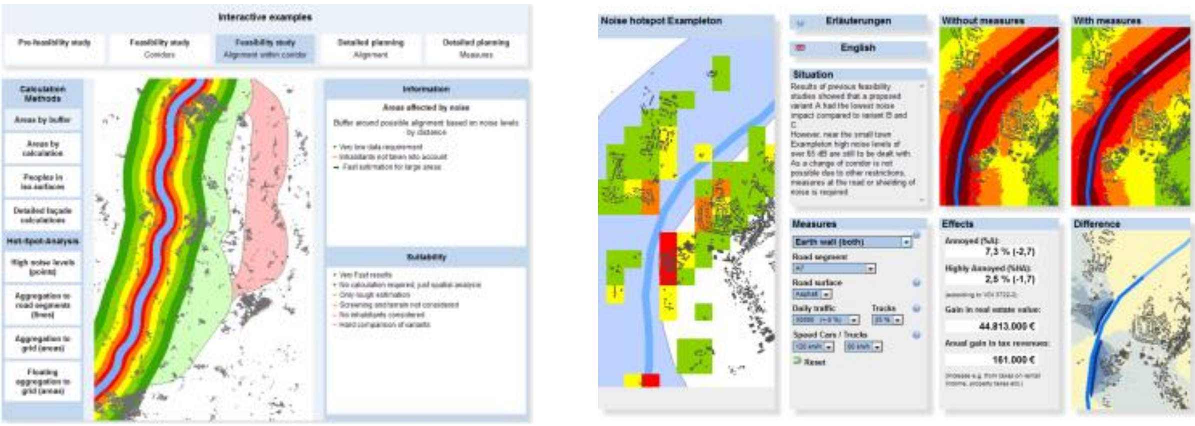

Figure 2.3: Interactive examples for different planning stages (left) and detailed planning (right) [15]

2.3 DISTANCE – Developing Innovative Solutions for TrAffic Noise Control in Europe

2.3.1 Background and objectives

Traffic noise has been identified as one of the major environmental public health issues in Europe. Future traffic growth will bring additional stress to the noise sensitive receivers and increase existing traffic noise problems. NRAs are facing an increased pressure to reduce noise exposure but at the same time have restricted budgets at their disposal.

The main challenge for NRAs is to find effective measures for a reduction of noise exposure and/or nuisance. In order to facilitate NRAs in planning future noise abatement, the DISTANCE project aims to provide comprehensive information and guidance on the following issues:

1. Data requirements for future noise mapping and action plans (WP 2)
2. Multi-function noise barriers and pavements (WP 3)
3. Future potential traffic scenarios (WP 4)
4. Smart mitigation measures (WP 5)
5. Perception and awareness of noise mitigation measures (WP 6) [16]

2.3.2 Methodology

The methodology for the project included a combination of a literature review, questionnaire survey and traffic noise modelling. In WP 2, for the analysis of the issues and data requirement for Common Noise Assessment Methods in Europe (CNOSSOS-EU), the following methodology was implemented:

A study of the requirements provided by CNOSSOS-EU, together with an overview of the present guidance on strategic noise mapping and road traffic management among NRAs, was conducted. A questionnaire was then developed with the objective to gather updated information on how individual countries plan to adopt changes introduced by CNOSSOS-EU. The questionnaire has been sent to 15 countries; primarily to those funding the CEDR Call 2012: Noise. Finally, an evaluation and analysis of the questionnaires was made [17].

1. In WP 3, the DISTANCE project sought to investigate how noise mitigation tools such as noise barriers and road surfaces can be enhanced to provide additional benefits; referred to as “secondary functions” in the project. The secondary functions were categorised as:

- “Designed” secondary functions: imply a physical modification of a conventional noise barrier or surface by integration of additional elements within structure or mounting onto the structure.
- “Bonus” secondary functions: are non-acoustic benefits which can be categorised as environmental, economic and social functions.

Furthermore, secondary functions are classified as “demonstrated” (documented evidence of the implementation has been identified) and “concept” (no documented evidence, possibly completely new concepts). *Table 1* summarizes all secondary functions considered in the DISTANCE project.

Potential benefits and drawbacks of the presented secondary functions were also considered. An Indicative Cost Band has been developed as follows in order to present likely costs of implementation of additional elements, in comparison with the cost for conventional noise barriers and road surfaces:

- Cost band **'-'**: The noise barrier/road surfaces with the secondary function is expected to be less expensive than a conventional noise barrier/road surfaces
- Cost band **'='**: The noise barrier/road surface with the secondary function is expected to be comparable in cost to a conventional noise barrier/road surfaces
- Cost band **'+'**: The noise barrier/road surface with the secondary function is expected to be more expensive than a conventional noise barrier/ road surfaces
- Cost band **'++'**: The noise barrier with the secondary function is expected to be considerably more expensive than an average noise barrier

Table 1: Summary of secondary functions considered in the DISTANCE project [1][18]

Noise barriers		Road surfaces	
Designed (Demonstrated)	**Bonus (Demonstrated)**	**Designed (Demonstrated)**	**Bonus (Demonstrated)**
Integrated noise/safety barriers	Green (vegetative) barriers	Dynamic road markings	Use of recycled materials
Solar energy collection via PV cells	Transparent noise barriers	Inductive charging	
Air pollutant capture using TiO_2 coatings	Use of recycled materials for noise barrier elements	Heat generation/storage	
Fine dust capture using electrostatic concepts	Enhanced visual aesthetics	Modular pavements	
	Added devices to enhance acoustic performance	Self-healing road surfaces	
		Air pollutant capture using TiO_2 coatings	
		Energy generation via vibration	
Designed (Concept)	**Bonus (Concept)**	**Designed (Concept)**	**Bonus (Concept)**
Integrated lighting			
Advertising displays			
Information displays			
Rainwater harvesting			

[1] Photovoltaic (PV)

2. In WP 4 of the DISTANCE project, potential influences of future traffic scenarios on traffic noise were analysed.

   Firstly, a brief overview of the latest changes in the European vehicle fleet was conducted. Thereby, changes in traffic composition, fleet size, vehicle developments, vehicle noise type approval regulations, future direction of vehicle technology and tyre technology and an increased use of electric vehicles (EVs) and hybrid electric vehicles (HEVs) were considered and discussed.

   Furthermore, a summary of network infrastructure changes which could influence traffic noise at the source has been completed. Including road surfaces and Intelligent Transport Systems (ITS), which are expected to have a major impact on the future transport. Generally, the biggest impact on traffic noise from implementation of ITS lies in the reduction of traffic speed, density and promotion of the smooth driving.

   The information on vehicles and road infrastructure was used in the next stage of the work for the development of a baseline model which widely reflects current road infrastructure and vehicle technology. The modelling was undertaken using CNOSSOS-EU methodologies and correction factors for EVs developed in the FOREVER project [23]. Following the development of the baseline model, a potential future scenario was develop and used as an example of what could happen in the next 20 years [19].

3. WP 5 of the DISTANCE project aimed to develop a schematic procedure for the selection of smart noise mitigation measures.

   This procedure was developed on the basis of a critical literature review and information obtained from NRAs though questionnaires, focused on innovative smart mitigation measures. The data review covered information on effectiveness, applicability cost and benefits of smart measures. The literature review outlined four categories of smart mitigation solutions: traffic control and management, urban planning and road design measures, socio-economic actions and innovative technological solutions [20].

4. The last stage of the DISTANCE project focused on non-acoustical mitigation measures and their potential for noise annoyance reduction, using a literature review and a workshop.

   The literature review concentrated on the most relevant publication and projects on this subject while the workshop helped to reveal new ideas. All DISTANCE project partners, PEB and psycho-acoustic experts from the Foundation for Scientific and Industrial Research (SINTEF) participated in the workshop. The work was divided into four areas: communication, participation, compensation and other non-acoustical mitigation [21].

2.3.3 Outcomes

Data requirements for future noise mapping and action plans

From 15 countries which received the questionnaire, 12 sent their completed questionnaire back to the project team (Finland, Sweden, Norway, Germany, the Netherlands, Belgium/Flanders, France, Scotland, Ireland, Switzerland, Italy and Spain). As a result, the conducted research covered representative geographical regions of Europe.

When it comes to CNOSSOS-EU requirements, limited to the themes of the present study, NRAs appear to be well prepared. However, some issues such as pavement degradation, ground surfaces and population assignment to building façades require an additional effort from the majority of NRAs. Furthermore, some of these issues, in particular ground surface, population assignment to façades, pavement degradation and speed distribution over vehicle categories, should be addressed internationally across several NRAs. In addition, single issues need to be addressed by individual NRAs. Since the challenges related to the CNOSSOS-EU requirements are similar for the majority of the interviewed countries, NRAs could significantly benefit from a mutual cooperation, including experience and knowledge transfer.

Multi-function noise barriers and pavements

Table 2 and *Table 3* present the main features of noise barriers and road surfaces with secondary functions. The technical feasibility is a parameter which indicates a readiness of the analysed functions for conventional implementations by NRAs. Potential use by the NRAs is presented with green, yellow and red colours, whereby green and yellow features are suitable for widespread/restricted use on the NRAs' networks. All features which are not suitable for implementation are marked with red.

With regards to the "secondary functions" which have been evaluated according to their advantages, disadvantages, likely costs and the state of the technological readiness (refer to *Table 2* and *Table 3*), the following functions have been recommended as the most useful solutions for 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

- Green barriers

Road surfaces:

- Use of recycled materials (recycled asphalts)

Table 2: Main features of noise barriers with secondary functions[2,3] [18]

Description of enhancement	Technical feasibility	Financial impact	Sustainability impact			Why	Why not	Potential for use by NRA
			Ecological ('planet')	Financial ('profit')	Social ('people')			
PVNB	*Now*	*= to +*	✓	✓		*Renewable energy generation*	*Maintenance and overall cost*	
Safety barriers	*Now*	*+*			✓	*2 functions in 1*	*Safety issues*	
Added devices	*Now to Near*	*= to +*			✓	*Additional reducing noise*	*Difficult to predict noise benefit*	
Enhanced visual characteristics	*Now*	*= to +*			✓	*Urban aesthetics*	*Cost?*	
Transparency	*Now*	*+*			✓	*Urban aesthetics*	*Cost, safety*	
Recycled materials	*Now to Future*	*= to +*	✓	✓		*Cost and ecology*	*None*	
Green barriers	*Now*	*= to +*			✓	*Urban aesthetics*	*Maintenance*	
TiO2 capture	*Near*	*++*	✓		✓	*Health issues*	*Efficiency*	
Electrostatic capture	*Future*	*++*	✓		✓	*Health issues*	*Efficiency*	
Lighting	*Future*	*Unknown*			✓	*2 functions in 1*	*Cost*	
Adverts/information	*Now-Future*	*Unknown*	✓		✓		*Distraction of drivers*	
Rainwater harvesting	*Future*	*Unknown*	✓				*Negative CBA*	

Table 3: Main features of road surfaces with secondary functions[2,3] [18]

Description of enhancement	Technical feasibility	Financial impact	Sustainability impact			Why	Why not	Potential for use by NRA
			Ecological ('planet')	Financial ('profit')	Social ('people')			
Dynamic markings (lane delineation)	*Future*	*=*			✓	*Improve safety*	*Insufficient light energy storage*	
Dynamic markings (lane control)	*Future*	*Unknown*			✓	*Improve traffic movement*	*Cost and technology*	
Inductive charging	*Near-Future*	*++*	✓			*Increased electric vehicle use?*	*Cost and technology*	
Heat capture/storage	*Near-Future*	****	✓	✓		*Renewable energy generation*	*Cost and technology*	
Modular pavements	*Near*	*++*			✓	*Less disruption to road users. Faster installation and maintenance*	*Cost*	
Self-healing surfaces	*Near*	*=*	✓			*Less maintenance*	*Limited surface types*	
Air pollutant capture	*Future*	*=*	✓		✓	*Health issues*	*Efficiency*	
Energy generation	*Near*							
Recycled materials (asphalt & concrete)	*Now - Near*	*- to =*	✓	✓		*Ecology*	*Durability concern*	
Recycled materials (tyres, etc.)	*Near*	*++*	✓			*Ecology*	*Durability concern*	

[2] Colour used for "Potential for use by NRA":

Readily implemented and suitable for widespread use on an NRA road network

Readily implemented and suitable for restricted use on an NRA road network

Not ready for implementation or suitable only for very restricted use on an NRA road network

[3] Photovoltaic noise barriers (PVNB); Cost Benefit Analyses (CBA)

Future potential traffic scenarios

Regarding changes to traffic noise levels induced by potential changes in road infrastructure, vehicle and tyre technology, it was concluded that the following changes are likely to occur in the next 10 to 20 years:

- *"An increase in motorways as a fraction of the road network*
- *An increase in the use of Intelligent Transport Systems, designed to smooth traffic flow*
- *An increase in light goods vehicles as a fraction of the fleet*
- *An increase in the use of durable low-noise road surfaces*
- *Minimal impact on overall traffic noise from improvements in vehicle and tyre technology*
- *An increase in the use of electric and hybrid electric cars"* [19]

None of these factors in isolation are expected to drastically reduce traffic noise but modelling results of the potential future scenario with some important limitations, presented in the *Table 4*, indicate that a notable reduction of traffic noise could be achieved with a smart design of ITS and road surfaces which will take advantage of advancements in vehicle and tyre technology and an increasing role of EVs.

Table 4: Modelling results of the potential future scenario [22]

Scenarios	Difference in $L_{Aeq,1h}$ relative to baseline
Increase in traffic volume	+ 1.8dB
Changes in % heavy goods vehicles (HGVs) (exc. congested motorways)	-0.4dB to +0.4dB
Changes in % HGV (congested motorways only)	-2.2dB to +1.5dB
Increased motorway speed limits (free-flowing motorways only)	+1.1dB
ITS systems (congested motorways only)	-3.1dB
Road surfaces (exc. congested motorways)	-5.9dB to +1.2dB
Studded tyres (exc. congested motorways)	1.2dB to 3.0dB
EVs	-0.8dB to -0.3dB
Vehicle regulations	-1.6dB to -0.2dB

Future scenario (low-noise thin surface, some ITS, quieter cars with quieter tyres, 25% EVs)	-4.6dB to +2.4dB

Smart mitigation measures

The main outcome of research on smart mitigation measures is the development of a simple decision support tool for the implementation of smart mitigation measures in the form of an algorithm (Figure 2.4). The selection of measures is based on road age, cross section and possible noise reduction.

A mitigation measure with high performance can also be used to achieve a low insertion loss (IL). In the algorithm, three subsets have been used: low noise reduction (IL≤ 3dB(A)), medium noise reduction (3<IL≤ 7dB(A)) and high noise reduction (IL≥ 7dB(A)). Based on the modelling results, the following conclusions have been drawn:

- Higher levels of noise reduction (IL≥ 7dB(A)) could be achieved with two specific innovative technologies: Poroelastic Road Surfacing (PERS) and sonic crystals (cannot be used in deep cuttings). Among the technical solutions, PERS is recognized for its unequalled noise reducing potential
- Medium noise reduction, next to PERS and sonic crystals, could be achieved with diffractors (noise reduction up to 4dB(A), suitable for shallow sections and use along highways only), replacement of hard ground (possible noise reduction between 2 and 9dB(A), implementation is limited to rural areas), roundabouts and Helmholtz resonator pavements
- In order to achieve lower levels of noise mitigation, traffic management measures such as smoothing of traffic or speed reductions are required. In addition, certain socio-economic actions such as new EU tyres and vehicle noise limits are listed [20]

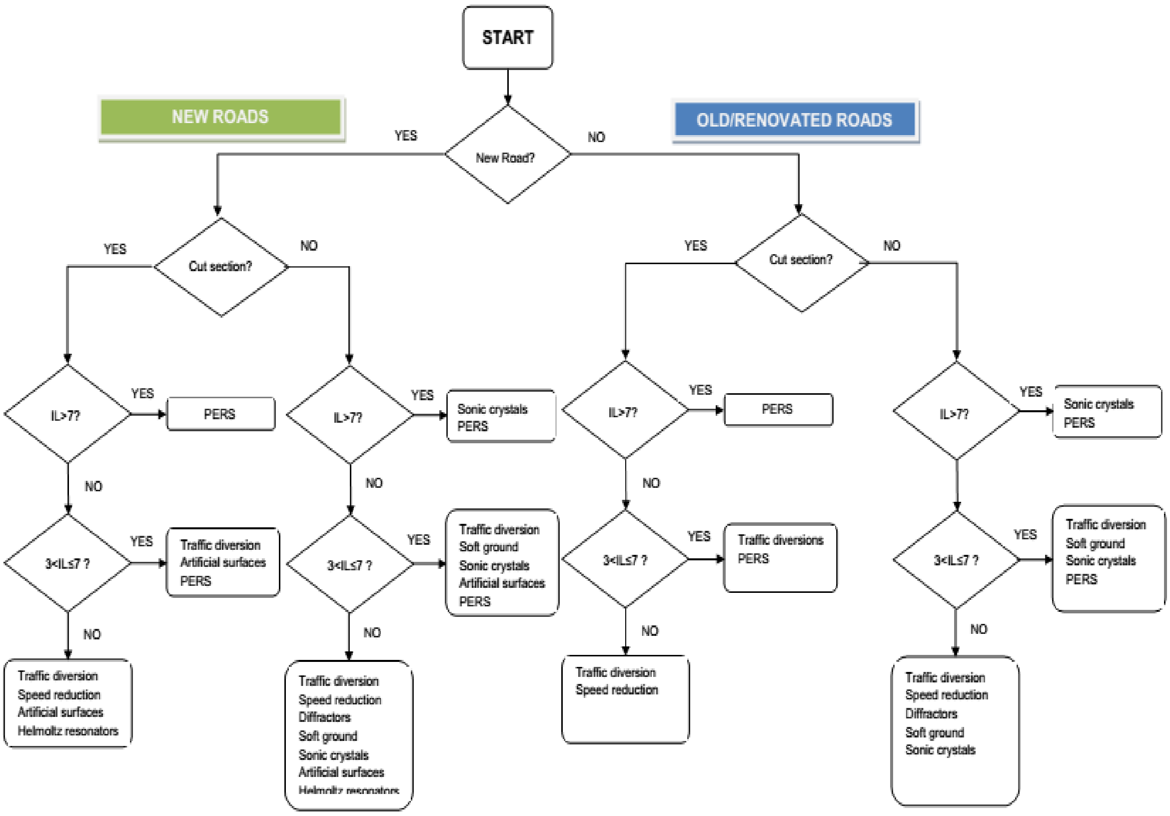

Figure 2.4: Decision algorithm for the implementation of smart mitigation measures [20]

Perception and awareness of noise mitigation measures

The DISTANCE research on perception and non-acoustical mitigation measures produced the following conclusions:

- Communication and participation: It has been noted that annoyance is strongly connected to the personal feeling of being in control. If people are informed, involved and have a feeling of being treated fairly, they tend to feel less annoyed. The use of organized events such as public meetings, workshops and social media can be of great help. Thereby, it is strongly recommended to use descriptors (next to the standard parameters such as L_{den} and L_{night}) which are easily interpreted by the general public
- Compensation: Economical compensation for noise exposure can lower annoyance. The compensation can be in a form of single or several payments or annual property tax reductions

- Other non-acoustical mitigation: This can be implemented at the source that influences drivers’ behaviour (ITS; eco-driving, dialog displays, etc.), on the propagation path (e.g. façade design) or at the receiver (quiet areas, quiet façade and soundscaping)

2.4 FOREVER – Future Operational Impacts of Electric Vehicles on national European Roads

2.4.1 Background and objectives

One of the aims of the END [14] is the prevention and reduction of noise, originating from road traffic, in order to achieve or preserve life quality of sensitive receivers. Next to the use of the low-noise surfaces, noise barriers and innovative “smart” mitigation measures, an increased use of quieter vehicles is one of the main mechanisms for achieving this. A possible solution for quieter vehicles is an enhanced use of EVs or HEVs.

Previous research in this area concentrated on the potential influences of EVs on road users at lower speeds. However, relatively little research has considered potential noise influences on roads under NRAs. Since it is expected that the number of EVs will increase in the future, it is important to understand the noise levels generated by EVs at higher speeds which are characteristic for NRAs’ roads.

The main objectives of the FOREVER project are as follows:

- Identification of noise emission levels for EVs and HEVs for use in noise prediction models
- Identification of noise emission levels from low-noise tyres on EVs and HEVs
- Assessment of potential future noise impacts of HEVs and EVs under a range of scenarios

2.4.2 Methodology

In order to achieve the proposed objectives, the following methodology was developed:

1. For the identification of noise emission levels from EVs and HEVs, practical measurements of both electrical and hybrid vehicles (cars, vans and trucks) have been carried out. Research also sought to develop correctional factors for EVs and HEVs in order to take these types of vehicles into consideration for noise prediction models. Additionally, perception studies were conducted to investigate subjective responses on noise originating from EVs and HEVs, operating at higher speeds
2. The next phase of the research related to EVs’ noise emission levels and concentrated on rolling noise produced by the interaction between road surfaces and tyres. Initially, a market study was been conducted, focusing on both tyres for EVs and HEVs and low-noise

tyres. Based on the market study, a set of tyres was selected. This was followed by controlled pass-by measurements of the chosen samples. The results obtained were analysed and their relation with CNOSSOS-EU was defined

3. In order to assess future noise influences of EVs and HEVs, a fleet composition review was carried out. In addition, information gathered in the previous project steps was used for the modelling of various scenarios, aiming to prove the influence of the increase in EVs on the NRAs' roads. Thereby, CNOSSOS-EU algorithms have been used, together with correctional factors developed in the project

2.4.3 Outcomes

The research undertaken in the FOREVER project on the identification of noise emission levels from EVs and HEVs was carried out on a limited sample of vehicles. Measurement results for LVs in electric mode indicated that "*the global noise emitted by all vehicles followed a linear trend with log (speed)".*

At a speed greater than 40km/h, HEVs work in hybrid mode, whereas the real differences in the noise emissions between electrical and hybrid mode occur in the lower speeds. *Figure 2.5* displays noise maps of a hybrid car in electric and hybrid mode.

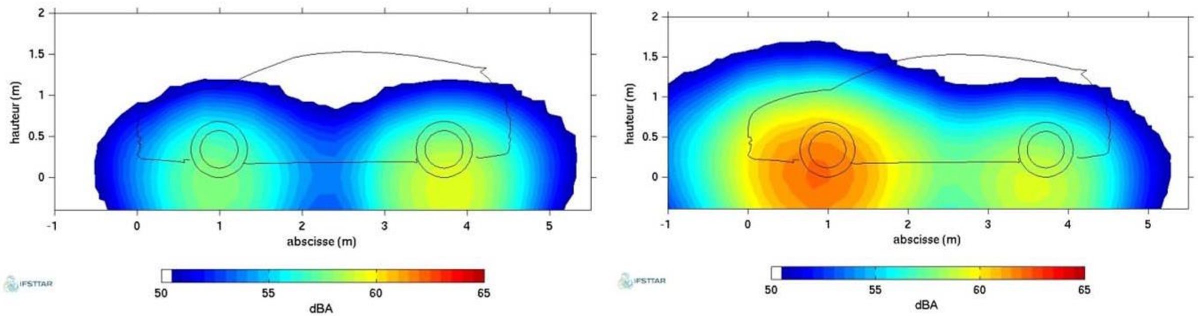

Figure 2.5: Noise maps of HEVs in electrical and hybrid mode [23]

It was found that CNOSSOS-EU overestimates the propulsion noise from EVs. Therefore, a correction was required in order to include EVs in the traffic flow. For this purpose, indicative correction factors have been developed.

The practical measurement results with selected tyres (both low-noise and ones selected by EV manufactures) identified that they do not have an effect on the roiling noise emission compared with standard tyres (refer to *Figure 2.6*). Accordingly, there is no need for correctional factors for the CNOSSOS-EU model.

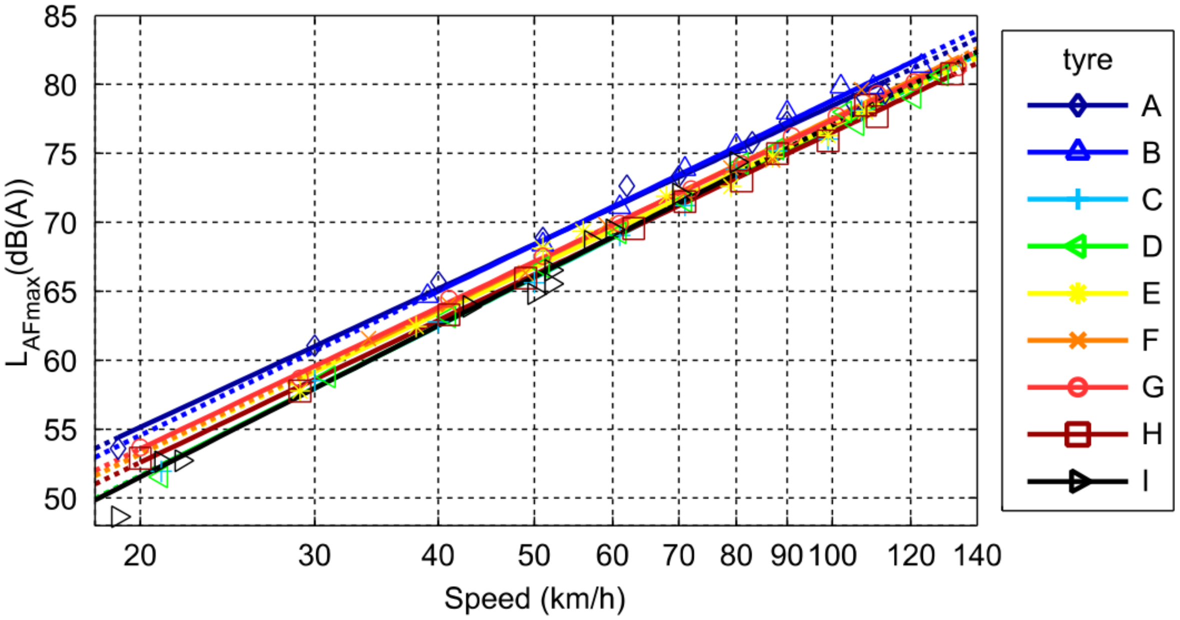

Figure 2.7: Maximum pass-by level for different tyres [23]

Furthermore, perception studies found that 100% of EVs were perceived as less disturbing than 100% of conventional vehicles. The positive subject response is induced by changes in the frequency band (elimination of engine tones). Even though modeling results indicate only minor changes in overall noise level with an increased use of EVs and HEVs on the NRAs' roads, they are perceived as more favorable when compared to conventional vehicles.

The FOREVER project provided the following key recommendations:

- *"Existing noise annoyance metrics, such as EPNL (Effective Perceived Noise Level), could be utilized to quantify differences in electric and non-electric vehicle noise which are not reflected in the overall noise level"*
- *"Since the number of vehicles available in the development of the CNOSSOS-EU corrections for electrical vehicles were limited, the results given in the report should be taken as indicative, proving only a first step towards the specifications of electric vehicles in CNOSSOS-EU. Confirmation on the correction terms by complementary studies on a wider range of vehicles are strongly recommended if there is a strong desire by NRAs and traffic noise modelers to be able to robustly model vehicle fleets on public roads"* [23]

3 Final Conference

At the conclusion of CEDR Transnational Road Research Programme Call 2012: Noise, a final CEDR Conference on Road Traffic Noise was held on 8th and 9th September 2015 in Hamburg, Germany. The aim of the conference was to present the findings and recommendations arising from the four projects and discuss the possibilities for implementation of results across Europe. The conference was organised by LÄRMKONTOR GmbH and was attended by 40 participants.

3.1 Opening session

The opening session on both conference days comprised the following programme:

Vincent O'Malley and Albert Daly, Transport Infrastructure Ireland (TII), Ireland: **Welcome and introduction**

Steve Phillips, Conference of European Directors of Roads (CEDR), Belgium: **Transnational research and the future for road traffic noise**

Phil Morgan, Transport Research Laboratory (TRL), the United Kingdom: **Project presentation – FOREVER**

Jean-Pierre Clairbois, A-tech Acoustic Technologies, Belgium: **Noise barriers and standards for mitigating noise**

Gijsjan van Blokland, M+P, the Netherlands: **Project presentation – QUESTIM**

Jakob Fryd, Danish Road Directorate (DRD), Denmark, and Sebastian Eggers, LÄRMKONTOR GmbH, Germany: **Project presentation – ON-AIR**

Dr. Luc Goubert, Belgian Road Research Centre (BRRC), Belgium; Truls Berge, SINTEF, Norway; Johan Maeck, BRRC, Belgium; Phil Morgan, TRL, the United Kingdom; Massimo Losa, Road Research Laboratory, University of Pisa, Italy: **Project presentation – DISTANCE**

Ian Holmes, Highways England, the United Kingdom: **An NRA approach to utilizing outputs from the 2012 Noise Research Call**

Vincent O'Malley, TII, Ireland: **Introduction to the workshop session**

Vincent O'Malley and Stephen Byrne, TII: **Workshop results**

Vincent O'Malley, TII: **Closing remarks**

Albert Daly provided an introduction on the research strategy of the CEDR Transnational Road Research Programme. He also explained the background of the programme and special roles of the Programme Manager, Executive Board and CEDR Research Coordinator. Also, he gave further insight into the process of selection of the research topics, projects' financing, and the fair and competitive selection process. The CEDR research programme focuses on the implementation and requirements of road administrations. An overview of previous and current CEDR programme calls was presented.

Vincent O'Malley presented the Call 2012 with his four programmes: Recycling, Traffic Noise, Safety and Climate Change. The overall objective of "Traffic Noise: Integrating strategic noise management into the operation and maintenance of national road networks" is a holistic approach to the management of environmental noise issues by developing a range of technical and economical solutions to minimise vehicle noise emissions by examining four sub-themes: noise assessment and management strategies; noise mitigation measures integrated with national roads; future visions for the management of noise on national road networks and strengthening/developing holistic pavement management. He also provided an introduction to the four projects: FOREVER, QUESTIM, ON-AIR and DISTANCE.

Steve Phillips described the mission, work and structure of CEDR and the main challenges of European road directories. He also presented key CEDR recommendations regarding traffic noise:

- a simplified approach by noise mapping in order to minimise costs;
- the introduction of noise bands lower than 55dB L_{den} and 45dB L_{night} will only add additional uncertainty and inaccuracy;
- cooperation with other noise mapping bodies and vehicle and tyre manufacturers;
- integration of noise action plans into planning processes or asset management programmes
- by the noise mitigation close to major roads low-noise pavements should be exploited as the first option.

With regards to the road noise research recommendation, CEDR has identified five thematic domains meeting member states' interest: rolling noise, advanced noise reduction technologies, improved regulations related to noise emission (including test methods) and noise control management, traffic management, improved or new socio-economic instruments to promote efficient noise abatement.

Phil Morgan presented the outcomes of the FOREVER project which will help NRAs to understand the potential impact of EVs/HEVs on their road networks. Results confirm the dominant role of tyre noise in medium and high speed traffic; hence overall noise levels will only change slightly with an increased share of EVs. Furthermore, there is measured and theoretical evidence for EVs being considered less annoying and more pleasant than standard cars. Existing annoyance metrics could be utilized to quantify differences between electric and non-electric vehicle noise, not reflected in overall levels. The outcomes of the FOREVER project for NRAs are largely informative rather than implementable.

Jean-Pierre Clairbois explained the work of the CEN/TC226/WG6 working group, which drafts a comprehensive set of standards, allowing fair comparison of various road Noise Reducing Devices (NRD) available on the EU market since 1990. He also provided an insight into the major characteristics which NRD should have in order to achieve optimized noise reduction for many years: acoustic performances, non-acoustic performances, long-term performances and sustainability.

Gijsjan van Blokland presented the main results of QUESTIM. The project demonstrated that the magnitude of acoustic aging exhibits large variation and recommended the CPX method (ISO 11819-2) for pavement monitoring. There is a need to develop alternative noise barrier monitoring methods that can preferably be carried out without the need for staff and static equipment on the roadside. A cost-benefit analysis and PMS were presented.

Jakob Fryd and **Sebastian Eggers** presented the outcomes of the ON-AIR project which developed a guidance book, supported by best practice and interactive examples. The ON-AIR guidance book includes recommendations regarding noise abatement in the three most common management situations of NRAs: planning of new motorways, reconstruction and extension of existing roads and daily maintenance. The current status on noise handling by NRAs, noise action planning according to the END, noise abatement measures, and noise exposure evaluation methods were also provided. In addition, methods and suitable examples on noise impact assessment, planning procedures, maintenance and monitoring as well as economical assessment of noise were presented. Interactive examples available at http://on-air.no/ demonstrate implementations of noise indicator methods and advantages/disadvantages of specific mitigation measures.

The DISTANCE team, led by project coordinator **Luc Goubert**, presented the outcomes of the project which researched a variety of topics: data requirements for future noise mapping and action planning, multi-function noise barriers and pavements, future potential traffic scenarios, smart mitigation measures and perception and awareness of noise mitigation measures. NRAs appear to be well prepared for CNOSSOS-EU requirements, limited to the themes of the conducted study. However, for some issues more work is required by many NRAs. In relation to secondary functions, noise barriers with photovoltaic elements, integrated noise and safety barriers, enhanced visual aesthetics, green barriers and use of recycled materials (recycled asphalts) may offer the most useful benefits to NRAs.

However, not all identified secondary functions are suitable for widespread and routine use by NRAs. This is specially the case with photovoltaic elements. Furthermore, a notable reduction of traffic noise could be achieved with a smart design of ITS and road surfaces which will take advantage of advancements in vehicle and tyre technology and an increasing role of EVs.

Ian Holmes presented Highways England and his role as Noise Advisor. Furthermore, he provided an interesting insight into the possible use of project findings into the everyday noise practice of Highways England, covering areas such as: revision of the policies and noise assessment methods, stakeholder management, delivery of Key Performance Indicators (KPIs), etc.

3.2 Workshop session

Two separate workshop sessions were held on the second day of the conference, on 9th September 2015. The sessions focused on obtaining participants' feedback in relation to the developed projects as well as possibilities for implementing the findings of the projects across European NRAs around Europe. Therefore, conference participants were invited to discuss following questions:

1. How do the findings of the presented projects reflect the current best practice in the field of road traffic noise?
2. What is the potential for the implementation of the findings of the four projects across member states?
3. What are the synergies between the findings of the projects?
4. Are the projects offering a basis for new meaningful research and demonstration projects?

According to their interests, the participants were divided into two groups. The first group focused on the projects ON-AIR and QUESTIM, and the second group focused on FOREVER and DISTANCE.

3.2.1 Workshop 1

The first workshop featured a discussion involving the projects ON-AIR and QUESTIM and was moderated by Albert Daly. Prior to the discussion, the project coordinators gave a small introduction to each project (refer to Chapter 2 of this report).

In addition, a discussion was instigated by Jean-Pierre Clairbois, regarding testing and certification of NRD and long-term performances. Regarding the questions provided for the workshop, some points relating to sustainability, testing and aspects of procurement were derived from these contributions.

<u>How do the findings of the presented projects reflect the current best practice in the field of road traffic noise</u>?

- It was noted that results of measurements on low-noise pavements from Switzerland and Sweden were not considered in QUESTIM. It is proposed that the project team should investigate those outcomes
- The cause of reducing performance was not determined. Further research could be required in this area
- The performance of noise barriers should be measured on installation as it can depend on the environment and the installation itself
- Considering ON-AIR, it was questioned whether "bad examples" should be part of the report. As the project team decided not to "point fingers", they are not included. In some cases, mistakes should be avoided and could be a useful "bad example"; however, some solutions that appear to be a bad example in a single application could be an alternative in another situation

<u>What is the potential for the implementation of the findings of the four projects across member states?</u>

On the outcomes of QUESTIM, the following issues were addressed:

- How could the performance, especially of noise barriers, be measured?
- How could the performance be monitored?
- How could a "Guarantee" of performance be implemented?
- Could a "Bonus" be implemented for good performance over 1, 2, 5 years?

Regarding the measurements and particularly the monitoring, some concerns were raised on the work close to traffic. As closing national roads on a regular basis for monitoring is not feasible, novel methods for monitoring would be required. This was also mentioned later by Ian Holmes in his presentation.

Concerning the outcomes of ON-AIR, the project provides guidance that can be implemented to improve noise considerations of national roads in the following areas:

- In various planning stages
- In the preliminary design

- In the detailed design
- During the construction phase
- In the general operation
- In the maintenance

In addition, the following aspects were mentioned:

- A “product standard” could be prepared, characterising the performance of noise mitigation products (such as road surfaces, barriers, etc.)
- A checklist for the implementation of measures could be developed. This should take various installation conditions into account. Also a list of “Dos” and “Don’ts” could help national road authorities to improve the implementation of noise mitigation measures
- A guidance could also be developed on procurement. The tendering procedure could be developed to implement (for example, a lean procurement) “bonuses” after years of fulfilled specifications, etc. The procurement should also consider environmental aspects, such as sustainability and climate aspects, in the sense of a green procurement
- Regarding the life cycle performance guidelines, information should also be deduced. The timescale should be considered when comparing low-noise pavements to noise barriers as they both present a different type and extent of degradation

What are the synergies between the findings of the projects?

With the projects QUESTIM and ON-AIR, the issue of aging was found as a synergy that can be beneficial.

The ON-AIR guidance book states that the degradation of the performance of noise mitigation measures should be taken into account. It is mainly focusing on the performance loss of noise reducing road surfaces but problems arising from a lack of maintenance of noise barriers are also mentioned.

QUESTIM provides methods to predict the degradation and thus the future performance of noise mitigation measures. These methods can be used to plan ahead to fulfill (legal) future requirements but can also be part of a cost-benefit analysis.

Regarding the four projects together, the following synergies were identified:

- Outcomes of the FOREVER project provide a prediction of future traffic scenarios
- Methods to improve the performance of noise barriers should be considered, e.g. using diffractors (the participants mentioned current research undertaken in the Netherlands)

- The work in association with the END should be used by NRAs in planning and maintaining a road network (ON-AIR). The NRAs also have a task to implement national parameters for CNOSSOS-EU (DISTANCE)
- When implementing noise mitigation measures, secondary uses (as photovoltaic elements on noise barriers, aesthetic and design aspects of barriers, additional uses on earth walls, etc.) should be considered
- Soundproofing solutions could be included
- Methods developed (for example, in QUESTIM) could be included in NRA processes with support from the guidelines developed by ON-AIR

Are the projects offering a basis for new meaningful research and demonstration projects?

During the workshop, various future research requirements were identified as follows:

- Noise barrier additions that improve the performance (as diffractors) as well as offer secondary uses (as photovoltaic elements and transparent absorbing barriers)
- The physics of aging of low-noise pavements could be investigated in detail to determine the cause of performance loss and thus improve the mitigation measures for lower degeneration
- Large-scale demonstration projects could show the effects of different barriers and road surfaces
- The interaction between different tyres and surfaces should be investigated further
- Communication with decision makers and the public should also be addressed
- Sustainability
- Full life cycle, from planning through to operation

3.2.2 Workshop 2

The second workshop, moderated by Ian Holmes, involved a discussion related to the other two projects: FOREVER and DISTANCE. Prior to the discussion, the project coordinators gave a small introduction to each project.

In the brief overview of the FOREVER project, it was highlighted that even though use of EVs will result in a positive influence on the environment from the traffic noise perspective, they won’t significantly influence noise reduction on NRAs’ networks in the future. However, EVs can still prove attractive since they are perceived as less disturbing than standard vehicles.

DISTANCE demonstrated that NRAs are relatively well prepared for the third round of noise mapping with CNOSSOS-EU but some additional work is still required. Modelling work has indicated that infrastructure changes such as low-noise surfaces and ITS systems offer the best options for mitigating noise but some further work is required in relation to understanding noise from congested traffic. Research related to smart noise measures suggested that there are some innovative options such as PERS and sonic crystals that may be worthy of further investigation. Public involvement in planning processes should be more exploited in order to increase awareness and understanding of the traffic noise.

<u>How do the findings of the presented projects reflect the current best practice in the field of road traffic noise</u>?

- The findings of four projects reflect the current best practice in some member states. At the same time, it has been pointed out that there are other member states which only take noise into the consideration to some extent in the planning process.
  The guidance and tools developed in the four research projects could strengthen the NRAs in establishing effective mechanisms for traffic noise management, especially in the countries where traffic noise mitigation was not one of the priorities in environmental management of the roads
- Findings from FOREVER indicate that traffic noise won't be significantly reduced with a simple increase of EVs in national fleets

After conclusions, the following comments and recommendations were also identified during a discussion on the first question:

- There is a potential conflict between policies and their implementation in practice. A need for noise policies which will support the implementation of noise mitigation measures was pointed out
- Urban planning has to be further improved in order to incorporate noise protection in all aspects of future urban development. This could be an effective way to break the link between bringing noise to people and bringing people to noise
- There is a need for the development of a business case for noise protection; establishing clear correlation between noise levels, health risks, property value and other social-economic impacts. Mitigation costs could be presented through possible increases of property value and/or reduction of healthcare costs with every reduced dB
- It is difficult to identify a clear benefit from noise mitigation measures. Worthy arguments are required for new mitigation measures to be accepted. Quite often, noise mitigation is seen as one more financial demand on already stressed project budgets. Further education and information of public and stakeholders is needed

- Mitigation of existing noise can be an issue, particularly on sites where conventional solutions may not be suitable for implementation

What is the potential for the implementation of the findings of the four projects across member states?

- Findings of four research projects, especially ON-AIR and DISTANCE, can be implemented in the third round of noise action planning in accordance with the END. The projects should be used to improve the action plans across member states
- With regards to noise mitigation measures, silent surfaces have the biggest implementation potential. It has been noted that one of the main obstacles in a broader use of the low-noise pavements is a tendency for NRAs to stick with the standard practice of predominant use of noise barriers in traffic noise mitigation. Therefore, the findings of both the DISTANCE and QUESTIM projects can provide new information, resulting in some changes to the NRAs' practice
- The projects also revealed a requirement for an improvement of data through long-term monitoring of low-noise surfaces and noise barriers. Therefore, recommendations arising from the QUESTIM project present valuable guidelines for everyday maintenance and monitoring of noise protection installations on NRAs' networks
- Applying proven noise mitigation technologies on the road networks of the CEDR member states which are just starting with noise mitigation, could produce beneficial results. The research projects provided an overview of standard and innovative noise mitigation measures
- Participants suggested that the effectiveness of certain innovative mitigation techniques (such as sonic crystals, diffractors and PERS) needs further practical investigation in the form of demonstrative projects

The discussion on the second question led to several additional questions such as:

- What drives technological development?
  The first step in promoting further development of innovative noise mitigation technologies is their incorporation into noise prediction software and regulations; this is particularly the case for diffractors on noise barriers. Currently, there is no scope for innovative solutions in the new CNOSSOS-EU model.
  A joint approach at European level could drive further innovation, development and improvement of noise mitigation solutions. The private sector could also be encouraged to conduct such research.

What are the synergies between the findings of the projects?

The four projects developed within CEDR Call 2012: Noise addressed various aspects of traffic noise management and mitigation. The project findings and outcomes provide the road authorities with an extensive set of tools and guidance for integration of noise into planning of new and management of existing national roads.

Initially, in may be difficult to establish direct synergies and overlapping between FOREVER and QUESTIM.

Outcomes from FOREVER indicate that traffic noise won't be significantly reduced by a simple change in fleet. Since the rolling noise was proven to be the predominant source of noise at EVs/HEVs, and standard cars at higher speeds, a possible solution to this problem could be low-noise surfaces. Therefore, the findings of FOREVER point NRAs in the direction of QUESTIM and its results.

Are the projects offering a basis for new meaningful research and demonstration projects?

- Participants pointed out that the projects gave a sound basis for further research, especially on the acoustical behaviour of quiet road surfaces. Acoustical deterioration of quiet surfaces could be the main scope of future demonstration projects (test lanes with the different types of low-noise pavements)
- Further investigation into possible uses of diffractors and low-noise barriers is required
- A comprehensive noise database of proven noise reduction technologies, innovative solutions, examples of efficient and inefficient noise mitigation, interactive and audio examples could be of great benefit to NRAs. The database could be developed as an Internet portal on traffic noise which would be available to all CEDR members for updating and editing. Therefore, NRAs would have access to all tools, information and research on traffic noise in the one location

* Development of living laboratories for noise abatement which would enable investigation, testing and development of innovative solutions for traffic noise mitigation. Living laboratories could be created with the joint effort of NRAs, municipalities, companies, research institutes and citizens
* Foundation of an international centre for innovative noise solutions
* Participants expressed the need for more meetings and conferences on traffic noise

4 Conclusion and Recommendations

4.1 Experience from the four projects

Experience from QUESTIM suggests the following:

- The magnitude of acoustic aging exhibits large variations due to the differences in climatic conditions, types of surfaces and vehicles. The initial noise reduction value is also a relevant factor. Further investigation of early acoustical degradation is necessary
- Recommended methodology for pavement monitoring is the CPX method (ISO 11819-2)
- The noise barrier study identified that only minimal acoustic data, related to the changes in the acoustic performances of noise barriers, are considered in the monitoring. The most common method for the monitoring of noise barriers used by the NRAs is visual inspection
- The noise barrier study provides the following recommendations regarding the visual inspection for new barrier installations: the visual inspections should be undertaken during the installation or within 2 or 3 months and the whole length of barrier should be inspected, preferably on both sides; areas such as physical defects and damages, seals and fastenings, stability and alignment, alignment and fitment of doors, access gates, etc. should be addressed
- Recommended methods for acoustical assessment of new barriers are defined in EN 1793-6 [7] and the upcoming EN 1793-5 [8]. Methods such as ISO 10847 [9] should be used for the assessment of long-term performances in the far-field at sensitive receivers protected by the barriers. Measurements should ideally be taken during the installation of the barrier or within 1 or 2 months; it is expected that 1 or 2 measurements on random locations along the barrier will be required
- Visual inspection over the working lifetime of barriers should be undertaken at least annually and the whole length of barrier should be inspected, preferably on both sides. Barriers from natural materials and those exposed to harsher climate conditions may require more frequent inspection. Visual inspection should focus on physical defects and damages, seals and fastenings, stability and alignment, alignment and fitment of doors, access gates, etc., gravel boards and/or ground level seals, damage due to vandalism, vegetation growth, etc.
- Recommended methods for acoustical assessment over the working lifetime of barriers are the same as for newly installed barriers. Furthermore, the number of measurements

will be similar to those for a barrier in new condition. The frequency of monitoring is determined by the material of which the barrier is made. For timber barriers, inspection is recommended 1, 3 and 5 years after installation and subsequently every 5 years; for other barrier types, inspection is recommended after 1 year from installation and then every 5 years

- The most suitable way for an integration of noise aspects into PMS is to base it on the implementation of the CPX method
- A database system that allows the CPX data to be related to geospatial information and to be synchronized with official roadway points in a systematic and consistent way should be pursued in order to make acoustic data readily available for NRAs
- The QUESTIM methodology for integrating of noise into PMS can assist NRAs by the investigation of the following issues: 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 when choosing low-noise surfaces for maintenance?

Experience from ON-AIR suggests the following:

- The “status report” provides NRAs with state of the art information on how noise is handled today in the planning procedures of selected NRAs in Europe
- ON-AIR assessment of traffic noise in complex situations provides the following conclusions: planning and mitigation should predominantly be based on calculations made by means of high-quality software, based on detailed prediction models and operated by skilled personnel; the process denoted reverse engineering was found less versatile for noise mapping than anticipated during drafting the project proposal; only in exceptional cases should measurements be applied and it should be realised that measurement uncertainty is substantial; if indications are found that calculation results do not yield true and fair assessment of traffic noise exposure, resources should be allocated to improving models and their implementation
- The ON-AIR guidance book presents tools and guidelines which can facilitate NRAs in the integration of noise abatement into the planning of new roads and motorways, planning of reconstruction and enlargement of existing roads and motorways, and maintenance and management of existing roads and motorways
- A toolbox for handling noise was developed as a technical background for the road planner working with noise issues. The toolbox provides a rough overview and background knowledge on the topic of methods for assessing noise and establishing

priorities, noise impact on recreational activities as well as the overall noise impact and noise from various sources

- The ON-AIR guidance book presents how noise can be analysed and taken into consideration in various stages of a road project, from the early planning, over the EIA stage, to the more detailed planning of the project where the physical framework of the project is finalized
- Considering road maintenance, the focus was on the ongoing process for maintaining pavements as well as on maintenance of noise abatement structures such as noise barriers and earth berms. Furthermore, planning and prioritization of active noise abatement along existing roads with noise barriers and façade insulation was considered
- During the road construction phase, the following noise mitigation measures should be considered: smart design of construction sites, definition of contract specifications and special provisions, sequencing of construction operation, use of alternative construction methods and standard noise mitigation such as noise barriers and building insulation
- The public could be engaged in the road construction process by the organisation of public meetings, exhibitions, listening examples, noise walks and bicycle tours, brochures, use of social and local media
- Interactive examples which can be found the ON-AIR homepage (www.on-air.no) demonstrate how NRAs can carry out evaluations of various strategies for noise abatement and how the right measures for noise abatement in given situations can be selected. Similar interactive tools can also be used to facilitate political and public involvement in the actual planning and decision making process, since it allows quick prediction of different noise abatement strategies and presents results as both noise maps and statistics on noise exposure
- “Good examples” have been used as an illustration of not only standard noise mitigation measures as barriers or noise reducing surfaces but also examples for planning and examples demonstrating secondary uses or improvements in maintenance
- The ON-AIR guidance book is a comprehensive assessment of existing planning procedures, practices, legislation, guidelines and prediction methods used in a number of MS in Europe. The guidance book can be directly implemented by professionals as inspiration and a tool box supplemental to local national procedures, practices, etc.

Experience from DISTANCE suggests the following:

- When it comes to CNOSSOS-EU requirements limited to the themes of the present study, NRAs appear to be well prepared. However, some issues such as pavement degradation, ground surfaces and population assignment to building façades require an additional effort from the majority of the NRAs
- Since the challenges related to CNOSSOS-EU requirements are similar for the majority of the interviewed countries, NRAs could significantly benefit from mutual cooperation, experience and knowledge transfer
- The following secondary functions may offer the most useful benefits to 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
- Modelling results of potential future scenarios indicate that notable reduction of traffic noise could be achieved with a smart design of ITS and road surfaces which will take advantage of improvements in vehicle and tyre technology and an increasing role of EVs
- The main outcome of research on smart mitigation measures is the development of a simple decision support tool for the implementation of smart mitigation measures in the form of an algorithm. The selection of measures is based on the road age and possible noise reduction
- DISTANCE research on communication, perception and non-acoustical mitigation measures suggested that people tend to feel less annoyed if they are informed, involved and have a feeling of being treated fairly. The use of organized events such as public meetings, workshops and social media can be of great assistance
- Economical compensation for noise exposure can lower annoyance. The compensation can be in a form of single or several payments or annual property tax reductions
- Recommended non-acoustical mitigation measures are as follows: on source - influencing drivers' behaviour (ITS; eco-driving, dialog displays, etc.), on the propagation path (façade design) or at the receiver (quiet areas, quiet façade and soundscaping)

Experience from FOREVER suggests the following:

- Measurement results for LVs in electric mode indicate that total noise emitted by all vehicles followed a linear trend with the logarithm of the vehicles' speed

- Real differences in noise emissions between electrical and hybrid mode of HEVs and EVs occur at speeds lower than 40km/h
- It was found that CNOSSOS-EU overestimates the propulsion noise from EVs. Therefore, a correction was required in order to include EVs into the traffic flow. For that purpose, indicative correction factors have been developed
- Measurements with selected tyres (both low-noise and ones selected by EV manufactures) identified that they do not effect the roiling noise emission compared with standard tyres
- Perception studies found that 100% of EVs were perceived as less disturbing than 100% of conventional vehicles. The positive subject response is induced by changes in the frequency band
- Existing noise annoyance metrics, such as EPNL, could be utilized to quantify differences in electric and non-electric vehicle noise which are not reflected in the overall noise level
- Since the number of vehicles available in the development of the CNOSSOS-EU corrections for EVs was limited, the results presented in the FOREVER project should be taken as indicative, providing only a first step towards the specifications of EVs in CNOSSOS-EU

4.2 Conclusions

The final presentations indicated that all four projects of the CEDR Call 2012: Noise took a different approach to the topic. Nevertheless, all projects shared certain topics and displayed possible links between the different approaches. In summary, many views on the noise topic, regarding NRAs, resulted in a variety of approaches with multiple synergies. While some projects divided their work into single (independent) work packages, the project size (e.g. in man hours or covered topics) could be limited to a feasible extent for future research projects.

The following points of contact and synergies were identified during the presentations and workshops at the final conference:

- Whilst FOREVER predicted future road traffic emissions in terms of changed propulsion (EVs), DISTANCE investigated further changes in vehicle fleets and traffic parameters. These future predictions can provide the basis for improved planning procedures of future road constructions and maintenance as presented in ON-AIR

- QUESTIM focused on the degradation of noise barriers and noise reducing asphalts, whereas ON-AIR focused on the guidance of noise mitigation implementation in the planning of new roads and the maintenance and noise abatement along existing roads
- DISTANCE presented the data requirements for future noise mapping and action planning deriving from the CNOSSOS-EU calculations; ON-AIR provided guidance for the support of noise mapping by NRAs and the use of the outcomes in planning and maintenance
- ON-AIR provided a list of proven and feasible “good examples”, and DISTANCE focused on novel “smart noise mitigation measures”
- DISTANCE also presented a list of multi-function noise barriers and pavements with secondary uses (whether designed or “bonus”), and ON-AIR provided guidance on cost-benefit analysis that could take the non-acoustic uses with an assigned monetary value into account

With the exception of FOREVER, the other projects did not undertake new research in terms of measurements, etc. The variety of new knowledge obtained, indicates that a lot of previous noise investigations have not yet been fully investigated. Further analysis of existing data and methods could lead to more elaborate and feasible solutions of noise consideration and abatement. In-depth research for individual topics could help to answer open questions.

4.3 Recommendations for future activities

Based on the outcomes of the projects and the workshop, the following activities can be recommended:

Regarding road surfaces

The results of FOREVER indicate that noise emissions of tyres do not necessarily correspond to their EU labelling: *“the tyre labels range over 4 label values from 67 to 70 dB(A) while the measured noise levels are contained within an interval width of approx. 2 dB(A)”* [23].

As the rolling noise emission of vehicles is not only affected by the tyre itself but by the combination of tyre and road surface, further investigation in this area could help to improve the overall rolling noise emissions.

Although research has been conducted on low-noise road surfaces for several years, the projects summarize that further research could be necessary. This research should mainly focus on the acoustical behaviour of quiet road surfaces. Acoustical deterioration of quiet surfaces could be the main scope of the future demonstration project (test lanes with various types of low-noise pavements).

Regarding noise barriers

As stated in the QUESTIM report on acoustic durability of noise barriers, only minimal data exists on the acoustic performance of noise barriers over their lifetime. To allow time-dependant relationships between barrier age and acoustic performance to be derived, more detailed measurements would be needed. Thereby, the cause of performance loss and thus possible improvements for lower degeneration could be identified.

Outcomes of ON-AIR also indicated that some NRAs have insufficient inspection processes. The performance of the barrier as well as the structural condition should be investigated to ensure the desired effect of the barrier. Whilst technology exists for visual inspections for damages and obvious wear that needs to be implemented in NRA’s maintenance programmes, the workshop’s participants summarized that no methods currently exist to measure the acoustic performance without affecting road traffic, e.g. due to closing single lanes or the entire road.

Further projects can be recommended that could lead to performance improvements (as diffractors); advanced non-acoustic secondary uses (as improved photovoltaic elements and transparent absorbing barriers) could also be developed. This should lead to an enhanced benefit of noise barriers and, bearing higher costs, could lead to a higher cost-benefit-ratio.

Regarding communication on noise

As three of the projects of the Noise Call: 2012 did not perform measurements or develop novel methods for managing noise issues but instead analysed existing data and summarized methods and processes common among different CEDR member states, a clear lack of communication can be identified. ON AIR conducted a workshop with experts of different CEDR member states. In this workshop for most participants previously unknown aspects and methods of handling noise issues, e.g. from other countries, became aware.

The participants of the final conference suggested improving the communication on various topics of noise regarding the work of NRAs. In general, they expressed the need for more meetings and conferences on traffic noise.

A more elaborate idea was the implementation of an Internet database with proven technologies of noise reduction, innovative solutions and examples of efficient and inefficient noise mitigation measures. The database should be open to CEDR members for updating and editing. Therefore, NRAs could obtain all tools, information and research on traffic noise in one place.

Another idea was the foundation of an international centre for the innovative noise solution. This centre could also organize conferences or presentations on various noise topics.

Finally, communication between road planners of the NRAs, the decision makers and the public should also be addressed as political and public opinions can result in severe impacts on road planning.

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Call 2012: Noise

QUESTIM, ON-AIR, DISTANCE, FOREVER

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