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Mitigation of traffic-related noise – An overview of the focus research area within the BMDV Network of Experts

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Abstract

Increasing traffic flows and a densification of traffic networks lead to an increase in traffic-related noise. The consequences for people exposed to (traffic) noise can be concentration disorders, cardiovascular diseases and various other pathologies. In order to find interdepartmental solutions for problems that affect all modes of transport, the German Federal Ministry for Digital and Transport (BMDV) has set up the BMDV Network of Experts. In the subject area “Possibilities for reducing traffic-related sound emissions and noise”, different authorities have joined their expertise to develop new approaches for the mitigation of traffic-related noise. The present work gives an overview of the activities in this focus area. It summarises the promising results of the first research phase and presents the projects of the current second research phase, which started in 2020.

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Keywords: road noise; railway noise; ship noise; annoyance; innovative noise mitigation; psychoacoustics.

1. Introduction

In 2016, the German Federal Ministry for Digital and Transport (BMDV)[1] established the BMDV Network of Experts to tackle to the urgent mobility challenges of the 21st century. The key idea of this new research network was and is to promote the importance of cross-modal transport approaches and engage all subordinated authorities and institutes in the research planning process. Simply spoken, the main goal of the BMDV Network of Experts is to increase the reliability of the transport infrastructure and develop solutions which enable roads, railways and waterways to better resist the effects of extreme weather events while minimising the environmental impacts of the transport and mobility sector at the same time.

[1] Formerly called Federal Ministry of Transport and Digital Infrastructure (BMVI).

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Regarding the impact of transport on humans and the environment, traffic-related sound emissions and noise belong to the most urgent problems – directly after air pollution. The relevance of noise as one of today's biggest environmental challenges is also reflected in an increasing number of projects in the field of noise effect research. The study on noise-related annoyance, cognition and health, NORAH (2015), and the extensive studies of the World Health Organization, WHO (2011) and WHO (2018), are representatives of such activities - to mention but a few specific examples. Although technological improvements and the regular revision of legal standards and directives are working towards a reduction of noise pollution, the positive effects are partly offset by rising traffic numbers and denser traffic networks.

Here the subject area "Possibilities for reducing traffic-related sound emissions and noise" of the BMDV Network of Experts comes into play. Representatives of the German Federal Highway Research Institute (BASt), the German Centre for Rail Traffic Research (DZSF) and the German Federal Institute of Hydrology (BfG) have set up and compiled research concepts with the main goal being to open up new potentials for the reduction of traffic-related noise – in particular with regard to all modes of transport.

2. First research phase (2016 – 2019)

Starting point for the first research phase were two driving questions: *How can cross-modal approaches be used to improve noise protection? Can an extended modelling of sound propagation contribute to improve the level of noise protection?*

To answer these questions, on the one hand, possibilities for an assessment of complex noise scenarios involving more than one transport mode were investigated and the derivation of effective and efficient joint protection measures was analysed. The aim was to develop a practicable guideline for an overall noise assessment – i.e. for situations in which the consideration of more than one emission source is required.

On the other hand, a second focus was to evaluate the influence of meteorological factors on sound propagation. Across Europe, sound propagation models differ, in particular with regard to their physical level of detail. Traffic-independent influences are of special interest here, as these affect all modes of transport. The fact that weather can be favourable for the propagation of sound, leading to unexpected local level increases, is widely known. The primary objective of the study was to analyse in which cases simplified calculations (with generalised weather assumptions) are sufficient and under which conditions a more detailed physical model (considering meteorological parameters) should be used to reproduce and explain discrepancies between calculated and actual noise levels. Eventually, a meteorological correction is supposed to ensure a better assessment of the real noise exposure in specific scenarios.

2.1. Overall noise

According to UBA (2022), about half of the German population is feeling annoyed by more than one source of traffic noise. Yet, when carrying out the noise mapping in accordance with the EU Environmental Noise Directive 2002/49/EC, the different sources are calculated separately from each other. An overall assessment is not envisaged. On national level, there is also no harmonised procedure to evaluate areas affected by several modes of transport and to derive appropriate measures. At present, this is handled on a case-by-case basis.

In the frame of the research project, Eggers et al. (2021) investigated the overall noise problem, with particular focus on the assessment methods, the recognition of relevant influencing parameters and the finding of optimised mitigation measures. To do so, noise accumulation was systematically analysed based on various simple model calculations to first understand how the superposition depends on the position of the receiver, on the ratio between the emission levels and also on the spatial arrangement of the sources. Of course, buildings and topographical conditions play a major role. Shielding effects can easily lead to the dominance of one source. In a second step, a systematic analysis of realistic situations (e.g. taken from noise action plans) was carried out to determine useful approaches for noise mitigation measures. In addition to theoretical approaches, in-situ measurements were carried out at a road-railway crossing to obtain indications on special characteristics of noise accumulation for the case when the average noise level results from short periods with high noise levels.

This has led to structured guidelines which provide a step-by-step instruction for determining overall noise levels across all modes of transport and identifying measures accordingly. These guidelines are flexible in the choice of input data and leave the user the possibility to adapt the calculation and evaluation methods to the specific application. As relevant tools, two visualisation types for the noise level distribution and the noise level changes were introduced.

In the first working phase of the guidelines, the occurrence of dominance is examined. If the investigated area is not dominated by aircraft or ship noise (or if this is ensured with according noise mitigation measures), the guidelines define an evaluation procedure for the case of two contributing traffic noise sources in the second phase. By analysing the noise level distribution, the extent of accumulation is identified and an identification and evaluation of noise mitigation measures is carried out, possibly with multiple iterations. Within the final assessment, the guidelines also give indications for an appropriate consideration of variations of noise mitigation measures, taking into account effectivity and efficiency aspects.

All in all, the developed procedure is mostly independent of legal standards and can offer relevant and practicable instructions for complex noise situations with more than one mode of transport involved.

2.2. Meteorological effects on noise

The atmospheric conditions (i.e. the weather) start to gain importance in the description of sound propagation for distances (between emission source and receiver) of about 50 to 100 m. If the noise level at a receiver point needs to be fully understood from a physical perspective, meteorology has to be included in the calculation model.

Meteorological effects on the sound propagation essentially are caused by the height dependence of the temperature, the wind field (strength and direction) and humidity. If those parameters vary with altitude, a vertical sound velocity gradient is created, so that the sound rays are refracted towards or away from the ground (see Fig. 1). Due to this effect, for inversion conditions at night – i.e. layers of air close to the ground are cooler than those above them – even distant noise sources that are barely audible during the day can suddenly be perceived as disturbing. Furthermore, the acoustic effectiveness of sound insulation measures can also be affected.

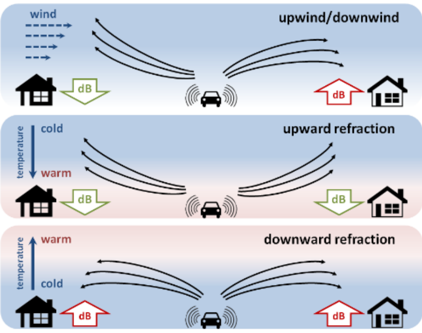

Fig. 1. Schematic representation of the influence of wind and temperature on sound propagation.

Meteorological influences therefore lead to favourable or unfavourable sound propagation situations by bending the sound rays and as a result the noise at a specific receiver can be greater or smaller than for so-called neutral or homogeneous propagation conditions. Such weather-induced noise level fluctuations are usually not reflected in the commonly used long-term average sound exposure levels.

The core of the project on meteorological effects on noise is the feasibility study by Liepert et al. (2021), the aim of which was to assess the applicability of complex meteorological sound propagation models and the resulting weather-corrected noise levels. Starting with an extensive literature review, it has been elaborated which calculation methods offer the possibility of modelling weather influences on sound propagation. Those methods were then categorised according to their level of detail. To determine the quantitative differences between the different meteorological models, test scenarios for simple traffic situations were constructed. Both standardised weather conditions (e.g. moderate wind conditions) and non-trivial meteorological boundary conditions were used here.

In a three-months measurement campaign, the previous theoretical considerations were examined in a real environment. The analysis pursued two goals: (a) a consistency check between the noise measurement and the calculation based on traffic and meteorology data and (b) the investigation of correlations between defined weather profiles and possible local level increases.

The overall results of the study led to a recommendation for the inclusion of meteorological parameters within the German standard calculation method (RLS-90, since March 2021 updated to RLS-19) – thereby providing a course of action for highly weather-affected noise situations. The proposal allows a supplementary correction of the noise exposure level (i.e. no changes in the method itself are required) and is based on a modification of the damping term for ground and meteorology, which is already part of the RLS-90. To compute the corrected noise levels, first the meteorological situation has to be classified using the respective stratification and wind speed classes as well as the desired wind direction. From this classification, an attenuation class can be determined which then defines the parameters required for the correction term.

In practice, the proposal allows an easy calculation of a weather-corrected noise level, which can function as a practicable supplement to the common long-term average level and provide assistance for efficient and optimised noise protection decisions.

3. Topics of the current research phase (2020 – 2025)

Both research topics are being continued in the current second research phase: Since comprehensive practical experiences for the application of the proposed methods are still missing, one focus is the practical testing, both for the overall noise guidelines and the meteorological correction. Applying the new procedures to concrete cases will also help to further specify and improve the methods and promote the transfer of knowledge into relevant areas.

As a further major goal, additional research addresses the expansion of the range of available mitigation measures. Namely, this comprises the development of an automatic measurement system to study inland ship noise, the investigation of psychoacoustic potentials to reduce annoyance reactions and, more general, the identification and evaluation of innovative noise reduction principles.

3.1. Overall noise

In the follow-up research on overall noise (BASt project number FE 69.0004), the developed guidelines for complex noise scenarios with more than one mode of transport will be tested in practice. The primary aim here is not to realise a fundamental revision of the method but rather a thorough testing of the guidelines with regard to their practical suitability.

The planned workflow includes an update of the guidelines (especially regarding accompanying training material), the investigation and conception of realistic test scenarios and a practical testing phase in a dedicated workshop.

Dissemination and cooperation partners will be of major importance here. Within the project, relevant players from the field of noise protection – e.g. members of ministries, agencies, other institutions – as well as potential users – i.e. persons who carry out an assessment and identify measures in situations with noise accumulations – will be involved.

The evaluation of the guidelines is based on various test criteria, addressing the aspects significance, comprehensibility, transparency and practicality. The reproducibility of measures must also be evaluated, considering different approaches for the protection goals. The practical tests and applications will result in a revised version of the guidelines, facilitating their use in practice. As another important outcome, user-friendly materials will be produced to accompany the dissemination process of the guidelines and ensure smooth training and a successful learning procedure.

3.2. Meteorological effects on noise

The proposed method for a simple consideration of a meteorological correction based on empirical models within the framework of RLS-90 or RLS-19 (see section 2.2) is also being further developed in a follow-up research project (BASt project number FE 02.0438). For a secured application of the correction method in practice, an extensive validation of the method by measurements in a further study area and an extension of the data set with extreme wind situations must take place. In addition, due to the introduction of the RLS-19 in the meantime, an adaptation of the procedure to the model of the RLS-19 has to be carried out. As for overall noise, in this research, too, the assessment and revision of the methodology are focussing on the aspects of validity, reproducibility, applicability and comprehensibility.

The validation of the meteorological correction will address (a) already measured meteorological situations using new measurements at equivalent measurement sites, considering also varying amounts of heavy traffic and different road pavements; (b) the extension of the application range using new representative measurement sites to include situations with extreme wind conditions and situations with shielding close to the emission source; and (c) the transferability to deviating meteorological conditions.

The sighting and final choice of measurement sites have been completed and the measurement campaigns are currently in progress. The subsequent analysis will on the one hand determine the attenuation class for the extended meteorological situations (and thus the parameters required for the corresponding correction term). On the other hand, from the validation measurements it will be possible to check the correct classification of the measured meteorological conditions and assess the discrepancies between measurement and model.

3.3. Ship-induced noise

Inland waterway noise is not a main contributor to traffic noise, especially in situations with another traffic noise source, such as road or railway traffic. Hence, noise induced by inland vessels is usually only taken into account if it is the only emission source. To asses waterway noise (continuous sound level L_{Aeq}) in construction planning procedures, the calculation is based on the "Instructions for the Calculation of Airborne Sound Propagation along Waterways", ABSAW (2003), which was developed by the German Federal Institute of Hydrology. Since then, technological development in motor and propulsion technology have taken place and noise emissions from inland vessels may have changed considerably.

Thus, an automatic measurement system has been developed to study inland ship noise (Sommer (2021) and Sommer and Wagner (2021)), significantly reducing personnel deployment. The measurement system is controlled via AIS (Automatic Identification System). The AIS signals from a passing ship are used to control the approach-based activation of sound level recording. Furthermore, it is used to gain information about the passing ship, such as distance to the microphone, speed over ground, ship size and type. The recorded sound data is checked for disturbing noise and valid weather conditions and then automatically analysed by considering single event levels and sound power levels. The latter are calculated under the assumption that a passing ship can be described as a moving point source along a line.

A first measurement campaign was carried out next to the Rhine near the Dutch-German border. This part of the Rhine is the busiest inland waterway segment in Germany, allowing the acquisition of data from various ship sizes. The measurement campaign took place mainly during winter. A preliminary data set with measurements from September to beginning of December 2021 has been analysed.

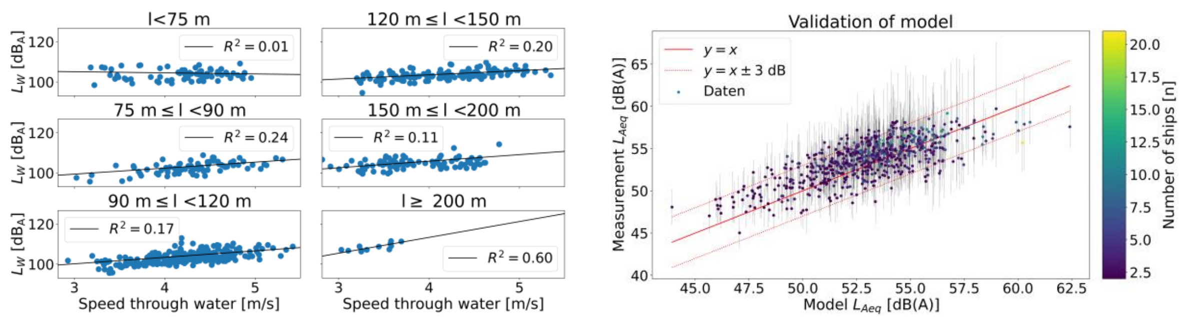

Fig. 2. (left) Sound power level depending on speed through water and ship length; (right) Comparison of measured and continuous sound levels in situations with several ships passing.

In flowing waters, such as the Rhine, the speed over ground (SOG) is not equal to the speed trough water (STW). As the STW depends mainly on the engine output of a ship, the sound power level (SWL) is depending on the STW. Using the STW, the sailing direction (up- or downstream) of a ship is no longer considered. Hence, the flow velocity has to determined. Here, the one-dimensional hydrodynamic-numerical model SOBEK is used. Fig. 2 (left) shows the derived SWL depending on the STW for different ship length classes. For larger ship lengths (l > 75 m), the SWL increases with STW. The smallest length class probably contains a too large variety of ship types in order to show an increase in SWL with STW. The data shown in Fig. 2 (left) includes only situations, in which a single ship determines the SWL and therefore can be used to derive a SWL model. The dependency of the SWL is modelled with a linear fit, indicated by black solid lines. The L_{Aeq} of events with more than one ship in the vicinity of the measurement site can be used to validate the model, as this data has not been previously used to derive the SWL model. For each multiple ship event, the modelled L_{Aeq} is compared to the measured L_{Aeq} as shown in Fig. 2 (right), yielding a good fit. Most modelled data do not deviate by more than 3 dB from the measured data. This shows, that measurements from an automatic measurement site can be used to derive waterway noise emissions.

3.4. Psychoacoustics

The field of psychoacoustics has been implemented as an own subtopic in the second phase of the BMDV Network of Experts, as it is becoming increasingly important and enables new "out-of-the-box" intervention strategies.

A research project has been initiated to investigate the applicability of psychoacoustic parameters to road traffic noise and to extend the current range of noise mitigation measures. Especially in heavily polluted areas, where conventional noise protection is hardly possible, a reduction of noise exposure via psychoacoustically effective measures might open up new opportunities. The research project addresses the following central questions:

- Which dimensions of perception describe the effect of road traffic noise on humans?
- What is the relation between spectral noise levels on the one hand and psychoacoustic parameters on the other?
- How do psychoacoustic parameters correlate with the noise annoyance perceived by humans – in dependence on personal and situational characteristics?
- Can psychoacoustic parameters be used to assess noise situations and to predict the effectiveness of noise protection measures?

The expected results might help to evaluate the reduction potential of noise protection measures more comprehensively, by going beyond the common long-term average level. More details on this project can be found in the dedicated article of Chudalla et al. (2022), which is also part of the TRA 2022 Proceedings.

3.5. Innovative noise mitigation

New technological approaches and the consideration of environmental-friendly criteria lead to innovative ideas in the field of noise protection. However, for innovative noise reduction measures (especially in the early development stages), reliable studies on the acoustic effectiveness are often missing and it is not straightforward to consider them in the corresponding calculation methods. The mandatory proof of safety is also often a problematic issue. The German government is continuously funding research to support the development of new mitigation solutions.

Within the BMDV Network of Experts, innovative approaches – that are still in the testing/development stage or have only been implemented on a pilot basis so far – are identified and classified. The term "innovative" here refers to an improved reduction effect, new operating principles, an optimised design and/or an expected greater acceptance by residents.

3.5.1. Road

Low-noise road surfaces are among the most effective and preferred measures for reducing road traffic noise, as they act directly at the source. The greatest challenge in the production of low-noise pavements is, on the one hand, the reproducibility of the construction and, on the other hand, the acoustic durability. Possibilities for optimising the sound emission e.g. are the grinding method (see e.g. Villaret et al. (2020)), modifications of the surface structure, the use of poroelastic materials or porous concrete.

In the case of noise barriers, current research is also always dealing with possible modifications to increase airborne sound insulation and/or sound absorption. These can address the shape, the use of innovative materials, the combination of different working principles or can be achieved via noise barrier tops or extensions. Examples are given here by: bended/curved noise barriers; diffractors, see e.g. Strigari et al. (2022); so-called sonic crystals or other metamaterial technologies (see e.g. Fredianelli et al. (2019)).

The innovative character of a noise protection measures can also involve a non-acoustic additional benefit.

A promising approach is a recently started research project on the technical and ecological suitability of noise barriers made of loam (see Chudalla et al. (2022)). Such a noise barrier made of natural and locally occurring materials requires less energy in the manufacturing process and, thus, can contribute to reducing greenhouse gas emissions. At the end of its lifetime, the building material can be recycled or reused as soil material, and there is a possibility that a loam barrier will provide new habitat, e.g. for cavity-nesting insects.

Embedding photovoltaics (PV) systems in existing infrastructure such as noise barriers offers new potential for generating electricity from PV and minimising land consumption. In the research project PVwins (2022) specialised photovoltaic (PV) elements are being developed for integration into noise barriers. For the use on reflective noise barriers, photoelectrically active (bifacial) PV modules with increased efficiency are being investigated. In the absorbing case, the PV structures must predominantly transmit the incoming sound (so that deeper absorbing layers are reached), absorb themselves or be part of an absorbing layer. The acoustic evaluation of the module prototypes within the framework of PVwins is carried out by BASt.

3.5.2. Railway

In the past years, several initiatives examined the acoustic effectiveness of innovative rail noise mitigation measures under regular operating conditions, see BMDV (2022). The tested solutions comprise amongst others rail dampers, rail screens, rail coating, new rail profiles, rail grinding techniques, different noise barriers and top pieces, bridge dampers, under sleeper pads, new sleeper types and mobile barriers to reduce noise from track construction sites. The so-called “LärmLab 21” (NoiseLab 21) of the German Centre for Rail Traffic Research (DZSF) will continue the testing of innovative mitigation measures to increase the number of applicable solutions.

The concept of LärmLab 21 envisages the implementation of a two-step approach, described by Böhm et al. (2022). First, the acoustic effectiveness of an innovative mitigation measure will be examined in preliminary tests. These tests can include simulations, laboratory measurements or measurements at an unused track. During this phase, it should be possible to make design changes to improve the acoustic effectiveness and the suitability for railway use.

Promising prototypes will be tested during regular railway operation in a second step. For these tests, the level of development of the products needs to be high to fulfil the safety requirements. The acoustic test sites will be situated in the Open Digital Test Field of the DZSF. The Open Digital Test Field is a part of the regular German railway network situated in the East between the cities of Halle (Saale), Cottbus and Niesky. This research infrastructure was opened in 2021 in order to provide a facility for testing new technologies and railway innovations, see ODT (2022) for more information.

In addition to the acoustic testing, the LärmLab 21 includes complementary research to support achieving the requirements for regular implementation of mitigation measures and to investigate the acceptance of mitigation measures.

3.5.3. Waterway

Noise abatement measures on the propagation path are not effective on waterways, as the efficiency of noise barriers decreases with increasing distance from the source. Therefore, innovative noise abatement measures along waterways must affect the source to reduce noise emissions. This can be achieved through the use and promotion of electric motors (see support programme by the MULNV NRW (2022)). Other proposed reduction measures are improved bearings of the driving shaft or an optimized flow around the ship’s propeller (see Friedhoff et al. (2018)). At berth, the use of shoreside power supply can reduce noise emissions completely, as no on-board generators have to be in use. An increased number of berthing areas offer shore power, sometimes even mandatory, leading to zero noise emission during docking time.

4. Conclusions

With the investigations in the focus area on noise of the BMDV Network of Experts, two important approaches for a more comprehensive and cross-modal noise protection have been established. A practical tool for the handling and assessment of overall noise situations was developed and meteorological influences on sound propagation can be considered to resolve discrepancies between calculation models and actual noise exposure.

The ongoing research will refine those methods and make them ready for an actual application. In combination with the expansion of the set of mitigation measures – including innovative technical solutions and psychoacoustic concepts – the BMDV Network of Experts contributes significantly to a more effective noise abatement strategy.

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