Advances in Noise and Vibration Reduction at DB
to comply with the EU Environmental Noise Directive

B. Schulte-Werning, B. Asmussen, K.G. Degen, J. Onnich, D. Stiebel

Deutsche Bahn AG, Technik/Beschaffung, DB Systemtechnik, Munich, Germany

Abstract

The Environmental Noise Directive of the European Union requires the member states to produce noise maps and to establish action plans for noise reduction. This directive has been put into a national law in Germany which directly affects Deutsche Bahn (DB) and its noise reduction policy. DB has set itself the goal of halving, by the year 2020, the level of rail traffic noise experienced by local residents in 2000.

As one of the major railway undertakings in Europe, DB performs continuous investigation to respond to public demand for railway traffic with low noise impact. The aspects of the reduction of the generation of noise are being tackled in several projects, mainly together with expert partners. Joint research projects provide a common knowledge base and strongly support the harmonisation of existing national rules and guidelines for train design and operation.

Thus, a research and development programme for a low-noise railway is under way at DB to treat the noise of the vehicles and infrastructure. The direct noise experienced by railway-lineside residents due to train movements on the track can be reduced by minimising the sound radiation directly at the source. This is the first-choice solution as it proves to be the most effective countermeasure regarding a cost-benefit relation.

This article describes three recent efforts of DB to develop a modern ruling for railway noise prediction, to reduce railway noise in urban traffic noise situations and to avoid excessive noise emission from bridges.

Introduction

The European Parliament and the Council have put in to force the Directive on the Assessment and Management of Environmental Noise (“Environmental Noise Directive (END)” [8]), aiming at avoiding, preventing or reducing harmful effects of environmental noise on human health. END requires member states to produce “strategic noise maps” by using noise indicators assessing the number of people affected by noise, to inform the public about noise exposure, and to draw up “action plans” to reduce noise where necessary. The directive was transposed into German legislation [10] in 2005 and has tightened the requirements governing traffic noise abatement. In future, local authorities will have to compile action plans to prevent and reduce environmental noise based on noise-mapping results. Cost-effectiveness will play a crucial role when assessing the proposed noise reduction strategies.

In the CALM network [2], basic studies and assessments were performed to support END. To follow the EU requirements and to strengthen the environmental friendliness of European railway traffic, the European Rail Research Advisory Council (ERRAC) has defined and now maintains the Strategic Rail Research Agenda (SRRA) also in the field of “environment” [9]. The most prominent keyword relating to the environmental friendliness of railway traffic is noise reduction.
DB responded positively with the self-obligation to decrease the environmental impact of railway traffic [4, 5, 6]. Among the seven central premises in the associated “Railway Agenda 21” of DB it is stated that for sustainable mobility
- the economically and ecologically successful railway creates the pre-conditions for the relocation of road and air traffic to rail,
- the quiet railway reduces the noise of rail traffic,
- the environmentally responsible railway protects nature and the countryside.

Deutsche Bahn takes its responsibilities seriously and has set itself the ambitious goal of halving, by the year 2020, the level of rail traffic noise experienced by local residents in 2000. If this target is to be achieved, all available noise abatement techniques will need to be used.

This stated self-obligation stimulates DB to lower the noise impact of the residents by consequent noise prevention measures to be applied to new lines and by a special noise abatement programme for those affected by noise from existing sections of the rail network. The German government has made € 51 million available annually for this programme. With the introduction of this scheme, it became financially feasible for the first time to realise noise protection measures along sections of railway track not undergoing significant modification. The implementation regulations are set out in the “Guidelines for promoting rail noise abatement measures” published by the Federal Ministry for Transport, Building and Urban Development [1].

Deutsche Bahn is aware of the effects that noise emissions from rail traffic can have. This is the reason why a noise reduction programme was initiated when railway privatisation took place. The greatest efforts are being made to reduce noise at the source, i.e. from the vehicle itself or from the wheel-rail interaction. Having optimised the acoustic characteristics of new vehicles used for local and long-distance passenger services, major reductions in noise emission levels from freight wagons are now feasible. The novel composite brake block (known as “K-block”), which has undergone years of extensive testing, was recently approved for international use [24, 27]. Up to now, wheel treads were roughened every time the cast-iron brake blocks were applied. With this new development, the treads remain smooth - a fact which will lead to a reduction of 8 to 10 dB(A) in rolling noise.

DB has established a special rail care programme called “Specially Monitored Track” in which noise radiation from the rail is regularly monitored by a custom-built sound measuring car [18, 19]. If the acoustic quality of the rail head surface is below a specified level, the roughness - i.e. short-pitch corrugations that occur on the rail head surface as a result of normal operations - is removed by grinding the rail head along these specially monitored track sections using a special technique.

The three further development activities reported here follow the above-mentioned guiding principle to improve the noise reduction at the source. To take all available modern low-noise technologies into account in the prediction of residents' noise reception and the dimensioning of noise abatement, an up-to-date prediction method is mandatory. Only by such a reliable and validated method all progress to reduce railway noise in urban traffic noise situations and to avoid excessive noise emission from bridges, which are often noise “hot spots” for the residents, can be made beneficial.
Recent developments in Germany in predicting the noise impact on railway line residents

The two DB regulations on computing noise immissions in the vicinity of railway track (“Schall 03”) and near shunting and freight handling yards (“Akustik 04”) are based on measurements and studies that were conducted in the 1980s. New research methods and modern measuring procedures on the one hand and innovative technologies in vehicle design, track construction and lineside installations on the other have raised new issues that need to be addressed when computing rail traffic noise.

The legal status of these regulations is governed by the Federal Immission Control Act. In section 43 of this act the regulatory authority is authorised to issue statutory instruments on certain subjects. A case in point is the so-called Traffic Noise Protection Ordinance (16th Ordinance on the Federal Immission Control Act) that was adopted and came into force in 1990. This ordinance specifies acceptable noise immission levels as part of the noise control measures for road and rail traffic areas. Specifically, the ordinance lays down noise limits and the conditions under which they are to be applied for different categories of location. Annexes 1 and 2 of the 16th Ordinance contain algorithms for computing the noise assessment level in road and rail environments. Furthermore, annex 2 (Computation of noise assessment levels near railway track) refers to the two administrative regulations issued by the former West-German Deutsche Bundesbahn. The regulation governing the calculation of noise immissions in the vicinity of railway track (“Schall 03”) from 1990 and that governing the acoustic studies to be carried out when planning shunting and freight handling stations (“Akustik 04”), also from 1990, are both rigid statutory orders and cannot as such be altered. As a result, any modification or revision of these regulations requires an amendment to the 16th Ordinance on the Federal Immission Control Act.

As our knowledge in these fields and the technology used have improved since these administrative regulations were drawn up, the computational algorithms they contain no longer always reflect the current state of the art in these areas. To avoid a situation in which the application of these regulations leads to results that might not withstand future court scrutiny, a review of the computational procedures used was urgently required. The highly simplified procedures and overly general assumptions used in some of the computational algorithms created problems when assessing the noise associated with, for instance, high-speed rail traffic. These difficulties generated a degree of uncertainty regarding the legal applicability of the Schall 03 regulation and the 16th Ordinance on the Federal Immission Control Act, which in turn led to growing criticism from environmental agencies and to problems with local residents, local councils and other groups when executing noise-protection-related planning approval procedures.

The following adjustments were therefore introduced to ensure compliance with the current state of the art [12, 16]:

- Emission characteristics
As in most other current noise emission regulations, the indicator parameter is the acoustic power level per unit length expressed in octave bands per vehicle unit and per individual noise source at three source heights (0 m, 4 m and 5 m above top of rail). The rolling noise emissions are split into a wheel component (wheel roughness) and a rail component (rail roughness). The situation is shown in Figure 1.
- Effect of vehicle type
Newly developed vehicles that have been designed to emit less noise can be incorporated into the new Schall 03 regulation. That is, the efforts made by Deutsche Bahn AG over the last few years to reduce noise emissions from modern rail vehicles will be taken into account when dimensioning necessary noise protection measures. Vehicles are classified into the following ten categories: Electric loco, diesel loco, high-speed multiple unit (ICE 3), high-speed power car (ICE1/2), high-speed tilting vehicle (ICE T), high-speed coach/trailer coach (ICE 1/2), DMU, EMU (local and suburban light rail services), freight wagons, passenger coaches.

- Effect of track type
The new regulation will also take into account the acoustic influence of different types of rail track. The new regulation incorporates, for example, the acoustic equivalence of a ballast bed with wooden sleepers and a ballast bed with concrete sleepers, and provides information on slab tracks with elastic absorber pads.

- Effect of bridges
Up to now, bridge noise is tackled by adding 3 dB(A) independent of bridge construction. In future, calculations of rail traffic noise will include a factor to account for the effects of bridges. The size of this corrective factor depends on the type of bridge, on whether the bridge has a continuous ballast bed and on whether the bridge was designed and built for reduced noise radiation. Measurements have shown that these factors range from 0 dB(A) in the case of composite bridges with a ballast bed and noise-reduction features to values of about 12 dB(A) for ballastless steel bridges. Bridge noise can be lowered by taking appropriate noise abatement measures.

- Effect of high-level noise sources
In the new version of the Schall 03 regulation, rail traffic noise incorporates rolling noise from high-speed rail vehicles and the aerodynamic noise from the pantograph. At speeds of more than 250 km/h, aerodynamic noise - such as the aeroacoustic noise generated by a pantograph - is also taken into account.
Effect of noise propagation and screening

In future, calculations of noise propagation and noise screening will require a more precise specification of the prevailing physical conditions. Improvements have been formulated in the areas: noise attenuation by buildings, influence of ground topography, meteorological effects and novel "soft diffraction" designs for the top edges of noise protection barriers. The calculation of noise propagation is essentially based on the specifications in the ISO 9613-2 standard though the special features of railway traffic have been taken into account. Air absorption effects are treated using a frequency-dependent approach. The attenuating effects of ground topography are treated as being frequency independent. Reflections are included up to the third order. The frequency-dependent screening calculations take into account all propagation-path obstacles. If an obstacle has several diffraction edges, a maximum of three diffraction edges will be included in the calculation. The effects of buildings are always included in the computational analysis.

The project is lead-managed by the Federal Ministry for Transport, Building and Urban Development (BMVBS). Project committee work is voluntary. The steering committee manages the project based on the results of the preliminary work carried out by the various working groups. Specifically, the steering committee analyses the revised drafts for the two regulations and assesses the effectiveness of the overall concept.

The steering committee comprises representatives from the Federal Ministry for Transport, Building and Urban Development (committee chair), the Federal Environmental Agency (UBA), the Federal Railway Office (EBA), the Federal Highways Agency, the Länder Technical Committee for Suburban Light Rail Systems, the Verkehrsclub Deutschland (a national advocacy group promoting environmentally compatible traffic systems), the Federation of German Transport Companies (VDV), the Federal Association against Railway Noise (BVS) and Deutsche Bahn AG. The implementation of the revised and updated version of the Schall 03 regulation is now a matter for the BMVBS.

Recent developments in reducing railway noise in urban traffic noise situations: SILENCE – an integrated approach

Substantial strategies and measures for noise reduction options will be developed within the SILENCE project [21], where Deutsche Bahn has been involved as a major partner since the project was launched in 2005.

SILENCE will run 2005-2008 as an integrated research project funded by the Sixth Framework Programme of the European Commission. It aims to develop an integrated methodology and technology for improved control of surface transport noise in urban areas. Issues that will be covered include noise control at the source, noise propagation, noise emission, and the human perception of noise. SILENCE aims at developing an integrated system of methodologies and technologies for an efficient control of urban traffic noise. “Integrated system” means the combined consideration of city authorities, individual traffic (on road) and mass transport (on rail and road) with a systemic treatment of all traffic noise facets: urban noise scenarios, individual noise sources (vehicles), traffic management, noise perception and annoyance.
The SILENCE approach starts with three steps: the assessment of urban noise situations based on data from European cities, the definition of two urban noise scenarios as reference bases for the whole project, the identification of the related noise abatement priorities and noise reduction potentials. On this basis, the activities are developed and integrated into a unique system of noise abatement technologies and tools and methodologies for noise reduction and policies. Thereby, the essential categories of urban traffic vehicles are considered such as cars, light duty trucks, buses, trams, trains etc. One key element of this approach is the global modelling for the prediction of noise effects on urban scenarios. Based on models for individual traffic elements developed in previous EU projects the global model predicts the overall noise emission of complex traffic situations and allows the prediction of noise perception by a source model coherent with the models used in the EU-funded project HARMONOISE [25]. This global model is used to apply the noise abatement technologies developed to the two reference noise scenarios, to predict their noise reduction effects and to validate the noise reduction potentials.

Thus, the key results and deliverables of SILENCE are first a noise abatement technology platform for road and rail vehicles, urban transport infrastructure and traffic flow aspects, and second tools, methodologies and input data for decision support systems, urban action plans and future noise scenarios. The SILENCE IP is a research project with the main objective to develop an integrated methodology and technology infrastructure for improved control of surface transport noise in urban areas. Thereby, the noise abatement technologies will be related not only to the noise emission (“control at source”), but will also consider also the noise propagation in urban situations and the noise immission aspects (i.e. noise exposure, human perception and annoyance aspects).

The necessity to encompass all the main sources and aspects of noise in SILENCE leads to a total of 11 sub-projects which are numbered from A to K and indicated by SP. The whole IP structure is illustrated in Figure 2.

Figure 2: Organisation and structure of the SILENCE project.
Within SILENCE 16 partners from railway undertakings (FS Trenitalia, STIB, SNCF, DB, RATP), railway industry (ALSTOM, Ansaldobreda, Bombardier, CRF, LS, Corus, D2S) as well as engineering and academic institutions (ISVR, KTH, VTC, AEAT) form a railway related sub-consortium.

The railway related activities are concentrated in two subprojects (SP). SP E, led by SNCF, deals with rail vehicle noise on of highly efficient systems and used in urban applications. SP G, led by DB, tackles the railway infrastructure, especially with the development and implementation of efficient infrastructure based noise reduction technologies for considerably reducing the noise emission from railway lines in typical urban scenarios. Details of the work-packages within SP E and G are shown in Figure 3. These work-packages are not only closely linked with each other but also with the annoyance studies carried out in SP A and the global modelling, which is the subject of SP B.

Key work-packages for both SP E and SP G are the validation platforms for trams and conventional rail. Their objectives are to clarify the state of the art by running assembled prototypes of state of the art low noise trains on low noise tracks thus building a consensual prototype validation platform at the beginning of the project, to identify the needs for further acoustical improvement and to run upgraded prototypes at the end of the project. First measurements for the validation platforms have been carried out in Belgium (tram), France, Italy, and Germany (heavy rail). Vehicle related noise abatement techniques to be developed or to be further improved within SILENCE focus on diesel engines, cooling and auxiliary systems and the noise from traction equipment and running gear. Particularly challenging is the goal to considerably further reduce the rolling noise of freight wagons equipped with K-blocks (which is considered to be state of the art within SILENCE) by adding dampers to the wheels. Unlike in the case of disk braked wheels, where dampers are known to be an efficient way to reduce noise emission by about 4 dB, wheel dampers for tread-braked wheels are not available due to the high temperatures the wheel is subjected to during braking. DB will perform extensive measurement campaigns with freight wagons equipped with K-blocks on the TSI track near the town Solpke on the high-speed line Hanover-Berlin within the framework of the “state of the art” validation platform in the first half of 2006 and, at a later stage of the project, with freight wagons equipped with the newly developed dampers.

Infrastructure-based work is the content of SP G because efficient noise reduction for rail traffic requires an integrated approach including both railway vehicles and railway infrastructure. The work packages focus on tracks for trams, tracks for conventional rail and noise from depots. From thorough analyses of real existing “hot-spots” in urban areas with known existing noise problems, typical situations were identified and characterized in terms of noise sources, noise level and annoyance. Critical structures and components of railway infrastructure (e.g. noisy track types, high roughness growth rate) have been characterised and analysed in terms of their noise reduction potential.

It is well-known that increasing the track decay rate by dedicated “rail dampers” attached to the rail web can considerably reduce rolling noise emission. A novel approach followed within SILENCE is that existing solutions for rail damping shall be optimized not only for noise reduction but also for reducing roughness growth. Over a long period of time, the noise level is dependent both on the noise for a given roughness and also the growing roughness level. Therefore parameters which influence the rate of degradation of the track as well as the noise emission are treated in an integrated fashion, not in isolation from one another. This approach has never previously been taken. The development of the rail dampers is being carried out by Corus Rail and is supplemented by extensive modelling performed by the Institute of Sound and Vibration Research at the University of Southampton. A first field test devoted to
measurements of the state of the art of rail damping was performed in 2005 on DB’s network on a test section near Augsburg. From this test, the needs for further development, in particular to improve the acoustic coupling of the damper to the rail were defined. Further field tests will be carried out at the end of the project both on DB’s and SNCF’s tracks. Of particular interest is the combination of the above-mentioned damped freight wheel and a damped rail, where a noise reduction higher than 5 dB(A) can be expected. This combination will also be tested on DB’s test track near Augsburg at the end of the project.

Figure 3: Details of the railway related sub-projects within SILENCE.
Recent developments in reducing noise generation of bridges

Bridge noise is a well-known phenomenon that has been investigated theoretically and experimentally in the past [11, 14, 15, 26]. In the following, the effect of bridge noise and the results of the DB-internal project “Leise Brücke” (“Low-Noise Bridge”) will be described.

When a train passes over a bridge, vibrations are generated at the wheel-rail contact point leading to rolling noise that may be different compared to the plain track. In addition, vibrations are transmitted to the bridge structure. The vibrating bridge parts radiate sound that is particularly distinct in the range of low frequencies. Both components - the rolling noise on the bridge and the noise radiated by the bridge structure - contribute to the bridge noise. Especially steel bridges without ballast bed are known to be rather noisy but also steel bridges with ballast bed and even concrete bridges can be problematical [14].

The effect of bridge noise has been subject of investigation at DB for more than 30 years. Based on a large amount of measurements, efficient resilient elements in the track structure as resilient rail fixations and ballast mats have been optimised from the acoustical point of view [13, 17]. Considering the bridge construction, it has been found that small changes in the construction details can lead to large differences in bridge noise. The conclusion has been drawn that bridge noise is higher when the first natural frequency of the noise radiating bridge parts (e.g. deck or web plate) equals the main excitation frequency that corresponds in most cases with the sleeper passing frequency [23].

In 2003, the DB-internal project “Leise Brücke” was started to improve measures for the reduction of bridge noise by a combination of experimental investigations and simulations. Besides measurements of the vibration and sound radiation of two steel bridges with and without ballast, simulations have been performed using different commercial simulation tools. To model the rolling noise and the transmission of vibrations into the bridge structure, the impedance track model RIM is used [7]. In the low-frequency region up to some hundred Hz, the vibration of bridge parts and the sound radiation is calculated by using the finite elements method (FEM) [3]. For the simulations of the vibrations and the sound radiation of the bridge at high frequencies, the statistical energy analysis (SEA) is used [13].

Within the project, simulations have been performed to investigate the influence of the bridge on the efficiency of resilient elements in the track [20]. The comparison of measurement and simulation results for a steel trough bridge with ballast bed shows very good agreement [22]. In further investigations, the modelling concept will be used to compare different bridge constructions.

As an example, two steel box-girder bridges with the same dimensions related to the total length and the cross-section but different structuring of the web plate are considered (see Figure 4 (a)). The web plate is built of single side plates with stiffeners located at the contact line between two plates. Having the same total bridge length, bridge 1 consists of half as many side plates as bridge 2. Because of its different dimensions, the first natural frequency of the side plates is different for the two bridges. In the example, the first natural frequency of the smaller side plates is 53 Hz and corresponds to the sleeper passing frequency of a train running at 120 km/h. The natural frequency of the larger side plates of bridge 2 is 21 Hz and therefore much smaller than the main excitation frequency of the train running at 120 km/h. According to the theoretical considerations, bridge 2 should be louder than bridge 1. The simulation results for the pass-by of a train at 120 km/h are shown in Figure 4 (b). Averaging over the pass-by time of the train and different points of the side plates, the first and second natural frequencies of the side plate
dominate the third-octave spectra of the vibration level for both bridges. Because the vertical velocity level at the dominating frequency at 50 Hz is significantly higher, the noise radiated by the bridge structure is also higher for bridge 2. This result supports the theory mentioned above. Beyond the theoretical considerations, the simulations give more detailed information about the bridge behaviour and can be used for a further optimisation of the construction.

In future, the modelling concept will be used to investigate the influence of different constructions details on the noise radiated by the bridge. As a result, an optimised steel bridge construction will be developed. The project will be completed in the end of 2006.

![Cross section and side/top views of bridges](image)

Figure 4: The cross-section and the side/top view of the two steel box-girder bridges used for the simulation are shown in figure 4 (a). As illustrated, the web plate is built of 14 / 28 single side plates. In figure 4 (b) summarizes the results of the simulations during the pass-by of a train running at 120 km/h. Averaged over the pass-by time of the train and different points on the side plates, the simulated third-octave spectra of the vertical velocity levels of the two bridges show significant differences.

**Conclusions**

This article describes three recent efforts of DB to develop a modern ruling for railway noise prediction, to reduce railway noise in urban traffic noise situations and to avoid excessive noise emission from bridges. These projects will support DB’s self-obligation of halving, by the year 2020, the level of rail traffic noise experienced by local residents in 2000. To achieve this ambitious target, all available noise abatement techniques will need to be used.
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References


