Interest Group on Traffic Noise Abatement

European Network of the Heads of Environment Protection Agencies (EPA Network)

Progress report on measures on rail traffic noise in the EU

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Colophon

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	This paper has been prepared by the Interest Group of Traffic Noise Abatement (IGNA) of the European Network of the Heads of Environment Protection Agencies (EPA Network) and presented at the 24th plenary meeting of the EPA Network on 23-24 April 2015 in Riga.
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Executive summary

With a total of about 15 million people that experience a level of 55 dB or more on the façade of their homes railway noise ranks second in the list of sources of noise exposure of the European population. This exposure is not evenly spread over the population but focusses on a limited number of hot spots along the major transport axes. Not only is the health and living quality of these people jeopardized by the railway noise, but also the high exposure of the population there hampers the modal shift from road to rail transport.

Most environmental rail noise issues are caused by freight transport. Not only because freight trains are running more frequent in the 10 dB more sensitive night period but also because freight trains are about 10 times noisier than modern passenger trains. One could say that a modern passenger train during the day is 100 times less annoying than a conventional freight train during the night.

The noisiness of freight trains can be traced back to the type of braking system. The conventional cast iron brake blocks spoil the smoothness of the wheel surface, thus causing vibration and noise in the environment, even when running on completely flat rail surfaces.

Chapter 2 tells how on the level of the European community, the noise emission is controlled by implementing acoustic requirements in the Technical Specifications for Interoperability (TSI). Compliance with TSI however is only required for new vehicles. Due to the long lifetime of rail vehicles and the resulting low renewal rate, real effects can only be expected in 25 years.

In chapter 3 it is shown that the technology to improve the acoustic performance of the block brakes is available through the introduction of K-blocks and LL-blocks. The application of K-blocks requires a modification of the braking system of the wagon; LL-blocks can replace cast iron blocks without any modification. The safety performance of LL-blocks was questioned, but the Europe train project proved that the wheel wear falls within the allowed range and as a result, two types of LL-blocks are now homologized. With LL-blocks a cost-effective measure is available.

In chapter 4 the possibility is discussed to stimulate application of such low noise technology through relating the track access charge to the noisiness of the train (NDTAC). Although quite simple as a principle, the application leads to several practical issues. How to define a low noise wagon, how is the wagon owner stimulated to modify, when the bonus is paid to the railway undertaker, how to prevent too high administrative costs, etc.. Only Switzerland, Germany and Netherlands have implemented a NDTAC. Although recently in force, it is expected that it will not lead to a sufficient high fraction of low noise wagons and thus Switzerland and Germany have indicated that a complete ban of c.i. blocks is considered in 2020.

Chapter 5 shows that the conventional way of mitigating noise by barriers exhibits an inferior benefit to cost relation. Source related measures, especially on the vehicle are much more efficient. This report addresses the ways national and international organizations are applying measures and stimulate technologies to reduce the noise emission of railway lines.

Chapter 7 treats vibration as a related topic. The effectiveness of noise mitigation is limited by the occurrence of vibration in the vicinity of railway lines. Vibration will add to the annoyance already experienced by the received noise. Secondly, the effect of barriers is limited when sound propagates through the soil as structure born sound and then excites structures in the house that consequently radiate air born sound. Mitigating measures for sound and for vibration are not independent.

In chapter 8 noise control is related to safety and sustainability aspects.

Content

1 Introduction

1.1 Background

The EPA Network is an informal grouping bringing together the directors of environment protection agencies and similar bodies across Europe. The network exchanges views and experiences on issues of common interest to organizations involved in the practical day-to-day implementation of environmental policy.

In the September 2010 EPA-Network meeting in Krakow an Interest Group on Traffic Noise Abatement (IGNA) was created. The IGNA will be forum to exchange information on current and future developments, an opportunity to learn from each other, particularly in relation to the development of the regulatory framework and scientific issues. The outcome shall be reports on the activities of the group, containing concrete and helpful recommendations to successfully protect the population from traffic noise.

The Swiss Federal Office for the Environment has contracted M+P -Consulting engineers in Netherlands to support the IGNA with relevant input for the work of the IGNA, with the preparation and reporting of the IGNA workshops, with summarizing the discussions within the workshops and with the composition of a final report.

M+P Consulting engineers is member of the international Müller-BBM group with offices in several countries throughout Europe. M+P is very active in the field of international standardization and regulation on noise properties of sources of transportation noise, such as road, rail and air transport.

1.2 Objective of this study

This study has the following objectives:

- to produce a concise insight in the technical and policy aspects of sources of rail traffic noise,
- to relate the state of noise abatement to the effect on the society
- to relate potential improvements with performances in the area of safety and sustainability
- to evaluate the costs of the measures with the benefits for society.

The study is performed on a European level, meaning that specific national rules and systems are taken into account on a lesser level. The situation in Europe, however is that the responsibility and policy on rail tracks is partly European, partly national organized.

The study is directed to policy makers and will therefore not be too extensive in technical details, although the general technical scheme, essential to understand the major interactions, is given. We will refer to background documents for necessary technical detailing.

The context of the report implies that most of the information presented in this report originates from existing studies. Only limited new work is presented.

The study focusses on the main topics that are on the table at the moment and are relevant for the IGNA group to be informed about and possibly addressed by them.

We have included vibrations in this report since it is closely linked to noise, both in the generation mechanisms (noise and vibration originates from the mechanical interaction between wheel and rail) and in the effectivity of annoyance reducing devices (barriers will shield noise, but will not prevent the propagation of ground vibration).

1.3 Valuable background information

Valuable background information can be found in several studies.

1. The DG for Internal Policies of the European parliament has issued a comprehensive study on railway noise in European countries [3]. It covers the following items:
   a. an overview of the impact of railway noise on human beings
   b. an overview of the national and European regulations and proposed action plans in European nations
   c. an overview of mitigation measures and findings of cost/benefit studies
   d. presentation of specific cases such as the German Rhine axis, some Alpine transits and some projects in the UK
   e. a listing of regulatory activities and financial schemes to facilitate the introduction of low noise technology.

2. The European Commission, DG MOVE, has issued two studies:
   a. a study about the effectivity of noise reducing measures on the existing fleet (ref. [4])
   b. a study about the implementation and harmonization of NDTAC (Noise-Differentiated track Access Charges) (ref. [16]).

3. A German study commissioned by the UBA investigating the technological level of the state-of-the-art technology and sound levels dedicated to the next revision of the TSI [5] and an English summary in [6]. It covers the following topics
   a. a description of TSI-noise regulations
   b. an introduction to noise generation and noise mitigation mechanisms and an overview of national and international research projects on that topic
   c. an analysis of the European type testing data base and evaluation of the short-term and mid-term state-of-the-art levels
   d. a comprehensive analysis of the specific values for all TSI-noise types and operating conditions
   e. some examples of state-of-the-art technology.

4. UIC 7th workshop on Railway noise, Paris November 2011, topic Railway Freight Noise reduction (see [8]). Comprises many national and international plans and policies for controlling railway noise and vibration.

5. UIC 8th workshop on Railway noise, Paris June 2013, the topics covered will include both regulation at European level (NDTAC, Noise TSI, Environmental Noise Directive revision, the Swiss ban of cast iron brake blocks) and the latest technical developments (EuropeTrain, RIVAS, AcouTrain, StarDamp) (See [9]).

6. RIVAS final symposium Brussels, November 21, 2013.

7. Stakeholder seminar on “Effective Reduction of Noise Generated by Rail Freight Wagons in the European Union”, Brussels, September 2013 [23].

1.4 Definition of the scope

To be able to focus on the relevant issues, we make the following limitations in the scope of the study

1. We are mainly interested in international traffic and traffic on the Trans European Network. (TEN). Traffic limited to national and local network can be regulated on a national level although these regulations have to comply with European law.

2. We are mainly interested in operations on the network. Any operations on shunting yards, parking areas etc. can be effectively regulated on a national level and are not that relevant based on % annoyed in the population.

3. Traffic in the night is more relevant than traffic during the day. This is corroborated by the 10 dB penalty for the night period and the separate definition of Lnight.

4. Freight traffic is the most relevant type. Freight operates on an international scale, is the most relevant contributor to night time levels and is also the main cause of hot spots along the European railway lines.

5. Next relevant is high speed stock. This also operates on an international scale and is also heavily regulated on an international level.

6. Vibrations are also important. Especially in the vicinity of freight lines, the effectivity of noise reducing devices and measures is significantly reduced by the simultaneously occurrence of ground borne vibrations.

1.5 Noise exposure of rail traffic in Europe

On base of the reporting of noise exposure in the framework of the European Noise Directive 2001/49 it is estimated that the exposure of the EU27 population to railway noise levels >55 dB Lden is about 15 million and to Lnight levels >50 dB about 13 million. These figures are far below those for road traffic (resp. 100 and 70 million) (ref figure 19). Additionally railway noise is regarded about 5 dB less annoying than road traffic noise (the railway bonus). Still railway noise imposes a real environmental issue in mid- and west European countries since especially in these regions, the freight lines between the harbours and industrial centres run through noise sensitive urbanized areas. It is also for these connections that the validity of the railway bonus is questioned, and is certainly not applicable for Lnight levels. Read more in par. 7.1.

1.6 International organizations relevant for railway noise

UIC
The railway companies and national infrastructure organizations worldwide cooperate in the UIC (Union Internationale des Chemins de Fer). It has 197 members from 5 continents and includes integrated railway companies, infrastructure managers, railway or combined transport operators, rolling stock and traction leasing companies service providers.

CER
The CER (Community of European Railway and Infrastructure Companies) is the leading European railway organisation. It brings together 79 railway undertakings and infrastructure companies – private and state-owned, large and small. Members come from the European Union, the candidate countries (Croatia, Macedonia and Turkey) as well as from the Western Balkan countries, Norway, and Switzerland. CER is based in Brussels and represents the interests of its members to the European Parliament, Commission and Council of Ministers as well as to other policymakers and transport actors.

UNIFE

(formerly Union des Industries Ferroviaires Européennes) – the Association of the European Rail Industry – represents Europe's leading rail supply companies active in the design, manufacturing, maintenance and refurbishment of rail transport systems, subsystems and related equipment"

EUROPEAN COMMISSION DG-ENV
DG Environment is responsible for the European Noise Directive and works on developing a common method for evaluating environmental noise levels in Europe. The European environmental Agency in Copenhagen gathers all results from the noise mapping of large agglomerations, roads, railway lines and airports each 5 year and make them available to the public. The EU does not impose noise limits in individual countries (such as is the case with air quality).

EUROPEAN COMMISSION DG-MOVE
DG Move focusses on the interests of railway transport and a level playing field. It is responsible for the rules of track access, especially the Trans European Network, and imposes Technical Specifications for Interoperability that includes also maximum sound levels.

ERA
The European Railway Agency (ERA) is one of the agencies of the European Union.
Its mandate is the creation of a competitive European railway area, by increasing cross-border compatibility of national systems, and in parallel ensuring the required level of safety. ERA prepares new and updated legislative acts for adoption by the Commission (e.g. the Technical Specifications for Interoperability), after a positive opinion from the Committee of Member States, and provides additional technical support to the Commission.

1.7 Relevant topics at the international level

At this moment there are four relevant topics on the international "table":

1. Revision of the Technical Specifications for Interoperability for Noise (TSI-noise).

2. Introduction and harmonization of Noise Differentiated Track Access Charge (NDTAC).

3. Homologation of the composite LL brake blocks.

4. Ban on Cast Iron (CI) brake blocks.

These four topics have separated discussion areas, but are closely connected in the following way.

1. The TSI applies for new or renewed vehicles only. The noise characteristics of the existing fleet are not affected. With a lifetime of about 40 years for freight wagons, it will take several decades before the effect of the TSI becomes noticeable at the level of an overall reduction of the sound emission.

2. The owner of the infrastructure can use the NDTAC to stimulate the application of lower noise wagons, by giving a bonus to silent types and charging a malus for noisy types. The financial amounts must be such that it is attractive for the operator to use silent wagons and for the owners to replace or renew them. At this moment refitting the brake blocks with K types implies redesigning the brake system. The LL blocks that can directly be exchanged with the CI blocks have only recently received a homologation.

3. Definitive homologation of the LL-blocks has lowered the costs of retrofitting since no redesign of the brake system is required; it is therefore more attractive for owners to silence their stock and thus it improves the effectivity of the NDTAC.

4 The logarithmic nature of sound levels implies that a small fraction of noisy trains can still jeopardize the total effect. In order to force the final users of CI blocks to improve their stock, a ban on CI blocks is decided in Switzerland and discussed in Germany.

2 Technical Specifications for Interoperability for Noise

2.1 Aspects of present TSI’s

2.1.1 European legislation

Unlike road vehicles and tyres, rolling stock is not regarded as an internationally traded commodity and thus the product itself is not subject to harmonized technical specifications within the EU. Every operator can specify and order according to its own requirements and every manufacturer can produce and deliver according to specifications.

It was concluded that such regional or national requirements could jeopardize interoperability of rolling stock, which is seen as essential for increasing the rail share in the model split by improvement of the competitiveness of rail versus other transport modes.

All new or renewed rolling stock to be used on European railway lines must therefore comply with the technical specifications defined in the TSI. Exceptions are railway lines that are separated from the main network, stock that is only used regional and locally and stock for touristic and historical use.

In 2002 noise limits were formulated for Trans European high speed rail systems (2002/735/EC). In 2006 noise limits were set for conventional stock by a decision of the Commission (C (2005) 5666). The regulation implies the following types of noise:

- Stand-still noise
- Starting noise
- Pass-by noise
- Noise in the drivers cabin

Depending on the type of rolling stock two, three or four of the listed items are limited. For freight stock only pass-by noise and stand still noise is defined, for passenger coaches also the noise in the drivers cabin (if applicable) is regulated, while for electric and diesel locomotives and electric and diesel multiple units additionally a starting noise limit is set.

The values of the limits and the driving conditions of the vehicle during the testing depend on the type of vehicle, and specific characteristics as e.g. power output or number of axles per meter. An overview of this system is given in figure 1.

2.1.2 Rolling stock

- TSI-noise refers to rolling stock, both for freight and passenger usage and is limited to approval of the stock at an acceptance level. Stock in use, both entered before and after the introduction of the TSI-noise, is not subjected to the limit values.
- The noise requirements are defined on that level that practically all wagons with brake systems that not use cast iron blocks, will comply with the limit values. Also the limit values for the towing vehicles are such that practically all locomotives comply.
- Distinction is made between new and renewed wagons. The latter have 1 to 2 dB higher limit values.
- Application of cast-iron brakes on passenger stock was already obsolete before the introduction of the TSI. The TSI-noise is mainly intended to prevent influx of new freight wagons with cast-iron blocks. In the 2006 version compliance of a renewed freight wagon or passenger coach can be proved just by the absence of cast-iron blocks without the need of actual testing.
- The limit values were defined such that conventional cast iron block braking systems would not comply which at that time was the interpretation of the state-of-the-art technology.

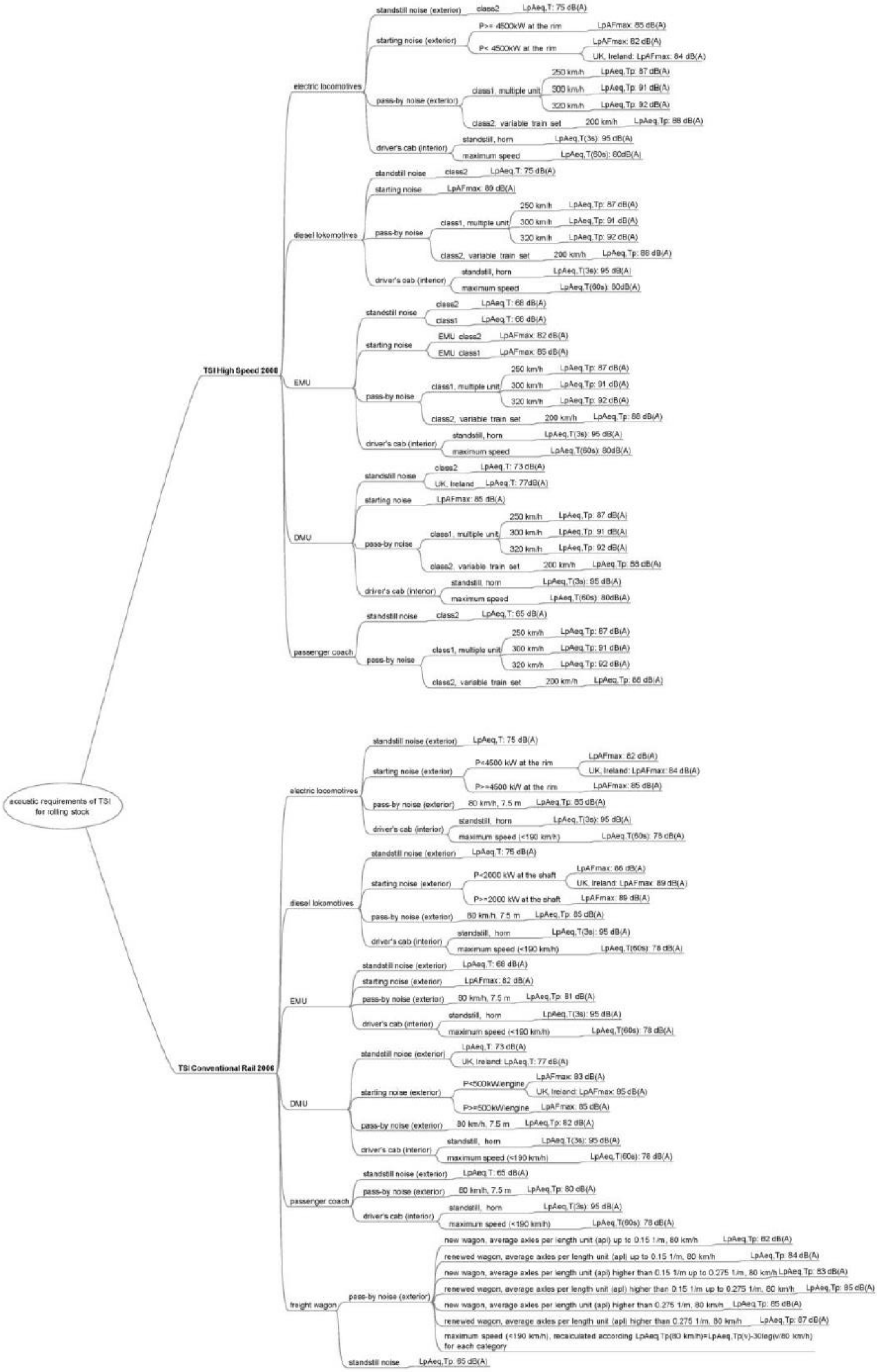


figure 1 *Overview of the acoustic requirements in the TSI for conventional rail (2006) and for high speed rail (2008)*

2.1.3 Testing conditions

The 2002 version did not fully specify the track conditions on which compliance with the set levels were to be determined. The 2006 version for conventional stock and the revision of 2008 for high speed stock formulate specific requirements for the track, in terms of roughness and decay rate. The 2011 revision for conventional stock confirmed mandatory testing for all new stock, but in order that all parties are able to perform that task, it removed partly the requirements such that compliance with the TSI can also be checked on non-standardized test tracks.

The specifications for the test track are formulated in terms of maximizing the noise effect of the track. This implies a maximum value for the rail roughness and a minimum value for the track decay rate. There exists no lower limit to the noise effect of the track. Consequently it is possible to achieve relative low pass-by levels on optimized TSI tracks (see also discussion on tightening of TSI limits in §2.2). A similar standard on test tracks for road vehicles (ISO 10844:2011) does comprise both higher and lower limits for the relevant surface parameters.

2.2 Planning of TSI revision in 2014

2.2.1 Topics

After the revision of the TSI for HS rolling stock in 2008 and the limited revision for Conventional rolling Stock NOI in 2011, a major revision is currently under progress and planned to be voted in 2014.

The major issues covered in the revision are:

- Merging of the CR TSI 2011 and the noise requirements set out in the HS RST 2008 in a single TSI
- Revision of the limit values
- Creation of a continuous curve of limiting values
- Extension of scope (from TEN network to the complete EU network)
- Infrastructure measures
- Maintenance measures (catalogue of wheel defects)

Next issues are taken into account in the revision process:

- Define new limit values on baser of the 2nd step of tightening, already formulated in the 2011 TSI-noise
- Extending the TSI to infrastructure requirements as this came out as one of the solutions to quieting railway noise in the public consultation process.

Underlying the planned modification shall be a clear cost/benefit analysis of the measures involved in implementing the new limit value system.

2.2.2 The TSI revision process

TSI revision is organized by the European Railway Agency. Several stakeholders are included in the drafting process (see figure 2) that eventually results in a recommendation to the European Commission.

The TSI serves interoperability. The TSI must not exhaustively cover all Essential Requirements defined in the Directive 200/57/EC, but only those requirements critical for interoperability. Nevertheless, the applicant has the responsibility to fulfil all essential requirements whether they are harmonized in the TSI or not.

The TSI must not mandate technical solutions. Only functional requirements are allowed.

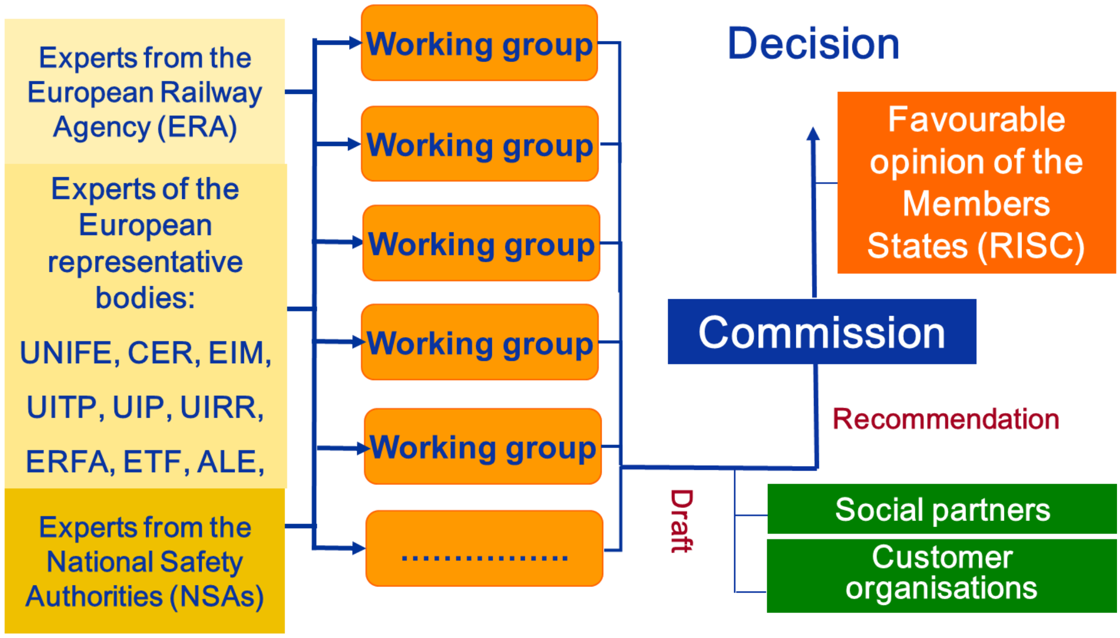


figure 2 *Scheme of stakeholders included in the drafting process of the revised TSI.*

With respect to the issues mentioned in clause 2.2.1, the outcome was:

1 Merging of the CR TSI 2011 and the noise requirements set out in the HS RST 2008 in a single TSI was achieved
2 Revision of the limit values resulted in a slight decrease of the limit values
3 Creation of a continuous curve of limiting values was achieved for all types of Rolling Stock
4 Extension of scope (from TEN network to the complete EU network) was achieved without major problems, as the requirement of testing in a reference track already makes the assessed rolling stock independent of the track
5 Infrastructure requirements were finally not included in the TSI
6 Maintenance measures (catalogue of wheel defects) were not defined as they are already required by other EU legislation (Railway Safety Directive)

ad 1: In the 2011 TSI for conventional rail in clause 7.3 a second step pass-by noise limits for future stock (ordered after June 2016 and in use after June 2018) was recommended of 2dB for EMU's and DMU's and 5 dB for all other stock in the context of the TSI revision process. Some members fear unpredictable costs and the 2nd step was refused. An additional argument was that further tightening of pass-by values would lead to the extended usage of very silent tracks to comply with lower limits. Such results would in their opinion not lead to real world noise reduction.

ad 4: Including infrastructure requirements in the TSI is rejected. Infrastructure Managers in many Member States already deploy noise abatement measures as part of their tasks and responsibilities. Requirements should be customised to be fit for purpose in every location. Otherwise, the cost/benefit ratio of generic solutions would be either too high for remote areas or too low for densely populated areas. The TSI is not the right legal instrument to manage this. Infrastructure requirements are not needed to achieve interoperability

2.3 Study by the German Environmental Agency (UBA)

The German Environmental Agency (*Umweltbundesamt* or UBA) has commissioned Müller-BBM GmbH to investigate the state-of-the-art of noise control for new and renewed rolling stock. The study is reported in [5] with an English summary in [6]. The findings of the study are presented in Annex 1.

The study is based on an extensive data base with acoustic type testing for homologation under the TSI-noise. The state-of-the-art levels were defined at the 25% and 10% cumulative level. Results are presented in table I.

table I *Overview of the present TSI limit values and the proposals formulated in the UBA study. Short term refers to the 25% lowest values found in the study, midterm refers to the 10% lowest values found in the study. Both are increased with 2 dB for measurement uncertainty.*

Train category	**Stationary level [$L_{pAeq,T}$ in dB]**			**Starting level [L_{pAFmax} in dB]**			**Pass-by [$L_{pAeq,Tp}$ in dB]**		
Limit value	**present**	**short term**	**mid term**	**present**	**short term**	**mid term**	**present**	**short term**	**mid term**
Diesel-electric locomotive	75	68	67	86/89*	80	80	85	85	83
Diesel-hydraulic locomotive					84	84			
Electric locomotive (P < 4500 KW)	75	63	59	82	81	81	85	85	83
Electric locomotive (P ≥4500 KW)				85	83	81			
Diesel multiple unit	73	65	63	83/85*	79	79	82	80	77
Electric multiple unit	68	57	53	82	73	73	81	77	77
Passenger coach	65	57	53	--	--	--	80	77	76
Freight wagon	65	--	--	--	--	--	82/83/85 **	80***	78***

** depending on the power*

***depending on the axle per length*

****pass-by level normalized to APL = 0.225 axle/m*

2.4 First proposal of ERA for TSI 2014 revision compared to UBA proposal

A proposal for the TSI 2014 revision is presented by the ERA at the 8th Worksop on noise at the UIC in Paris, June 2013. Comparing this proposal to the present limits and to the UBA proposal learns that a modest improvement may be expected. In table II and figure 3 a comparison is made for pass-by levels at 80 km/h. The main improvement of the ERA proposal is the equivalence of new and renewed stock.

table II *Overview of the present TSI limit values and the proposed limits for the 2014 revision.*

Train category	**Pass-by [$L_{pAeq,Tp}$ in dB] at 80 km/h**				
Limit value	**present**	**UBA short term**	**UBA mid term**	**ERA proposal**	**difference present-ERA**
Diesel-electric locomotive Diesel-hydraulic locomotive	**85**	85	83	**85**	**0**
Electric locomotive (P < 4500 KW) Electric locomotive (P ≥4500 KW)	**85**	85	83	**84**	**1**
Diesel multiple unit	**82**	80	77	**81**	**1**
electric multiple unit	**81**	77	77	**80**	**1**
Passenger coach	**80**	77	76	**79**	**1**
Freight wagon	**82/83/85****	80***	78***	**83*****	**0*****

*** depending on the axle per length*

****pass-by level normalized to APL = 0.225 axle/m*

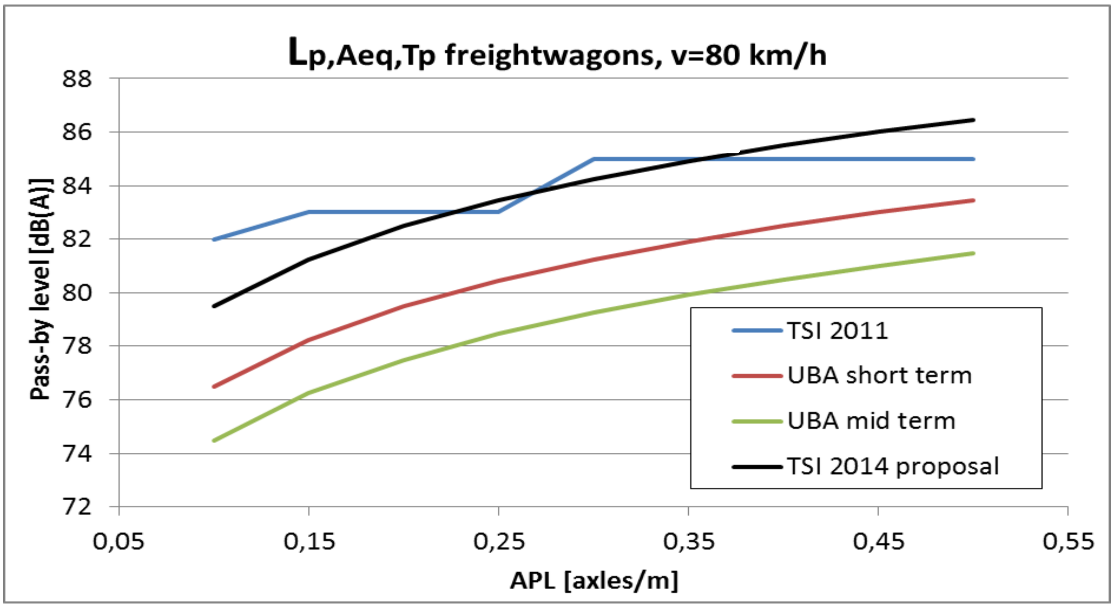


figure 3 *Current limit value and 2014 ERA proposal for the TSI revision for the pass-by noise of freight wagons. TSI 2011 refers to new wagons. For upgraded and renewed wagons an allowance of 2 dB is applied.*

3 Composite brake blocks

3.1 Relevance of the braking system

Although apparently, mainly a safety issue, it is found that the type of braking system is decisively for the noise production of a train. The reason for that can be understood from the listing of most relevant noise sources of a train and the mechanism behind the excitation of the main noise sources.
The graph in figure 4 illustrates the relevance of different noise sources of a train as function of speed. Her it can be seen that in the relevant speed range between 30 and 250 km/h rolling is the dominating noise source of passing trains.

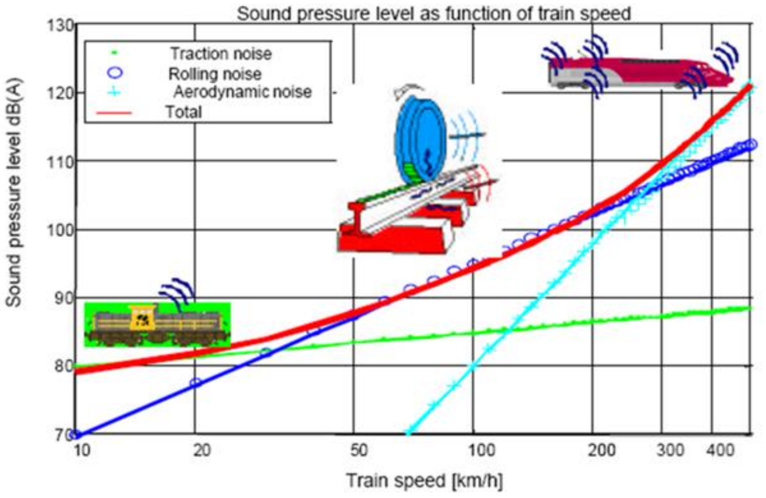


figure 4 *Schematic view of the level of rolling noise, propulsion noise and aerodynamic noise as a function of speed. The red curve presents the total sound level. The actual values and the speeds at which transition takes place depend strongly on the technology of the vehicle and the track.*

The mechanical processes responsible for the rolling noise are treated in §7.3. The scheme in figure 22 explains the mechanism. The basic input to the total noise generation system is the sum of the wheel and rail roughness.

The level of the wheel roughness is defined by the type of braking system. In most conventional freight wagons braking is obtained by pressing brake blocks to the surface of the wheel. If Cast Iron (CI) material is used for the blocks, the thermal processes in the block/wheel interface result in large irregularities of the wheel surface. In the case of braking on other surfaces as the running surface of the wheel, the roughness values of the wheel will be significantly lower. This is for instance the case with disc brakes that are nowadays standard on passenger coaches.

In the case of freight wagons equipped with CI block brakes, the wheel roughness is much larger than that of the rail roughness and the summed roughness value of wheel and rail together is dominated by the wheel roughness. If the brake system is changed to disc brakes, the wheel roughness is lowered and consequently, the summed roughness is significantly lower resulting in lower rolling noise values.

A significant improvement of the wheel/rail roughness value in the case of block brakes is found by modifying the block material where CI is replaced by a composite material. Roughness data of the different types are displayed in figure 5 as a function of the wavelength. For a speed of around 100 km/h. it is the 2-4 cm area that is decisive for the frequencies around 1 kHz that are dominating the total A-weighted spectrum.

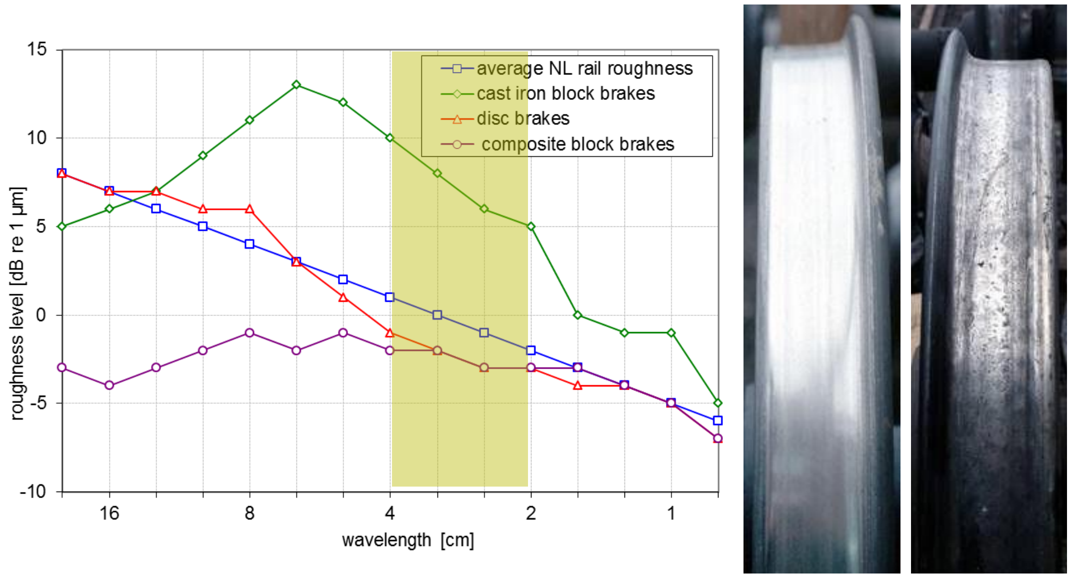


figure 5 *Left: wheel roughness spectrum of a wheel with a disc brake, a cast iron block and a composite block compared to the average Dutch rail roughness spectrum. Most relevant for the total A-weighted level is the spectral energy around 4 cm (M+P). Right: picture of a smooth and a rough wheel surface (DB AG).*

3.2 Noise reduction with composite blocks

The essential difference between the composite K and LL blocks at one hand and the CI blocks at the other is that composite blocks maintain a much better wheel surface in the sensitive wavelength range of 10 to 1 cm (see figure 5). The figure demonstrates that around this wavelength the total roughness for CI block braked wheels will be dominated by the wheel roughness. Replacing CI with composite will result in a significant reduction of rolling noise. Depending on the rail roughness it can be up to 12 dB. The figure below (see figure 6) presents measurement data of CI, K and LL blocks on three roughness classes of rail (ref. [14]).

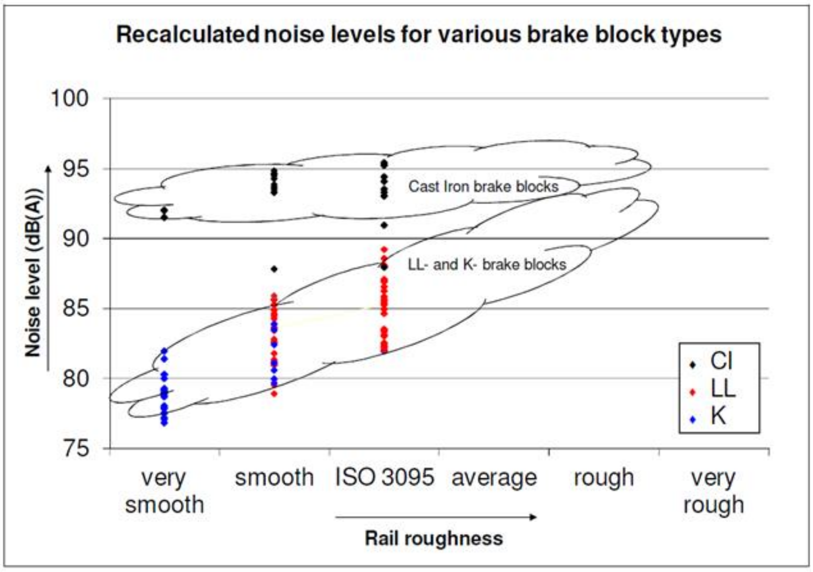


figure 6 *Measurement data of Freight wagons with LL, K and CI blocks presented as function of the smoothness of the rail surface. It illustrates that there exists only a very small difference between LL*

and K blocks. The largest effects are caused by the rail roughness level. Data refers to a normalized level of 0,2 axles/m and a speed of 80 km/h (ref. [14]).

3.3 Composite brake blocks, technical issues

At present two types of low noise brake blocks are homologated for application on rolling stock, K blocks and LL blocks, the latter only very recent.

- CI blocks are the standard for several decades and they can be applied practical all standard freight stock. They are the main cause for roughness in the noise sensitive 10 to 1 cm range.
- K blocks are made of synthetic material. K blocks differ with CI blocks on the friction coefficient and in their speed dependency as is illustrated in figure 7 . That means that when replacing CI blocks by K blocks to obtain the same braking force, the pressure in the contact area must be much smaller and steered different to account for speed changes. This is accomplished by modifying the total braking system of the vehicle. K blocks and CI blocks, thus cannot be freely interchanged. The modification of the braking system is marked on the vehicle (see figure 8).
- LL blocks are also made from synthetic material, but designed such that they exhibit nearly the same friction effect as CI. They can be interchanged freely with CI blocks. The problem encountered with LL blocks is that they work more aggressive on the wheel surface thereby destroying the cross profile. This implies more frequent re-profiling of the wheel surface.

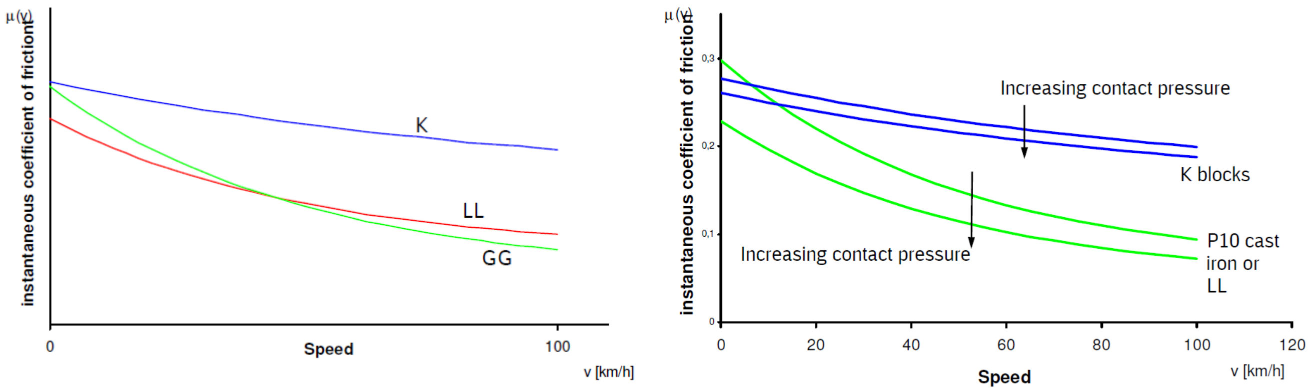


figure 7 *Left: friction coefficient of K-blocks vs. LL/CI(GG) blocks as a function of speed. Right: Speed and pressure dependency. The graphs demonstrate the difference between K and CI blocks and the equality of CI(GG) and LL blocks (ref*

3.4 Status of homologation of K blocks

Several types of K-blocks (Cosid C810, Becorit 929-1 and Jurid 816M, FR 513) are homologated by the ERA in accordance to the regulations in UIC leaflet 541-4 for general application on rolling stock.

figure 8 *Picture of a block brake with K blocks. Since K blocks imply modification of the braking system, (K) at the side of the train warns against wrong replacements (source SBB)*

3.5 Status of LL blocks

3.5.1 EuropeTrain test for LL blocks

Test results with LL blocks demonstrated the significant noise reduction potential, but showed some issues on the wear of the wheel surface. The EuropeTrain project is performed in order to speed up the solution process of the points yet to be finalized in homologation and to further improve the LL brake block. This project is coordinated by UIC and Deutsche Bahn and is supported by 29 railway companies, 7 partners from the industry sector, the Community of European Railway and Infrastructure Companies (CER) and the European Rail Infrastructure Managers (EIM). The test train with about 30 representative freight wagons with CI and LL blocks has managed about 16 trips across Europe. All operational, topographical and climatic conditions relevant for Europe are covered in a balanced way, e.g. running on different gradients with different operational modes, arctic winter areas and high temperature zones.

figure 9 *Sketch of the coverage of European rail conditions by the Europe Train Project*

At this moment the 200.000 km are accomplished and the LL blocks have performed successfully, both technically and economically.

7 It was found that the wear of the blocks is about 2 times less than CI blocks, wheel wear is about 1½ times higher. Results from the individual trips varied significantly though;

8 The development of equivalent conicity 1/40 was investigated by measuring the wheel geometry after every trip. Over the total length of 200.000 km it was found that equivalent conicity degrades with an average rate of 1,0.10-6 which is about three times faster than CI, but remains clearly below the intervention value of 0,40. It is recommended to check conicity after the first 100.000 km and then after every 50.000 km

9 Noise reduction, determined on an ISO 3095 compliant track, was found to be around 10 dB relative to the CI blocks after the 200.000 km usage.

3.5.2 Homologation of LL blocks

Based on these results IB116* and C952-1 have been homologated by the UIC according to leaflet 514-4.

3.6 Costs of applying composite block brakes

The cost benefit ratio of noise reduction with composite brake blocks depends strongly on the type of block and if it is a new or retrofit:

- retrofitting of existing stock with K-blocks requires also retrofitting of the brake system, this because of the deviating friction performances of these blocks in relation to the conventional cast iron blocks
- the brake system for new wagons can already be adopted for the K-block performance and in principle does not involve extra costs
- retrofitting of existing stock with LL-blocks can be done without modifying the brake system. These blocks do require more frequent re-profiling of the wheels in order to maintain conicity.

Unfortunately there exists no common understanding on the definition and the magnitude of the costs of retrofitting existing stock with LL or K blocks. This is one of the factors that affects the smooth introduction of Noise Differentiated Track Access Charge on the European Network (see more in chapter 4 and in §6.1).

3.7 Next steps

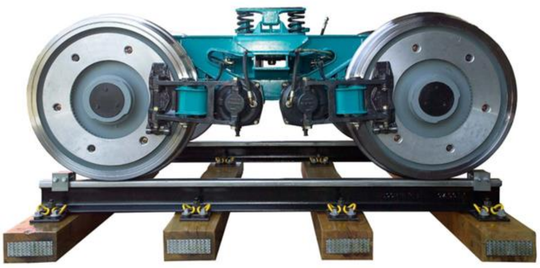
The process of homologation of K blocks and, even more, LL blocks learns that it is a very laborious and time consuming process that hampers the introduction of new block brake technologies. Therefore the European Railway Agency has established a brake blocks Working Party to work out the specifications covering brake blocks (all types, all materials) and the assessment method associated to the approval of composite brake blocks. This would feed into a revised TSI WAG, closing the open point on brake blocks and allowing to quicker develop and authorise new products.

3.8 Future developments

The application of K blocks and LL blocks represents a significant reduction of the noise emission of freight wagons compared to cast iron blocks. The table below presents the combined effect of smoothening of the wheel and the rail surface. This shows an additional 6 to 8 dB can be gained by applying extra smooth wheels. Such low roughness levels can be obtained by not using the wheel surface as braking material as is the case with drum or disc brakes. Studies performed in Switzerland demonstrated the feasibility of such technologies. At the moment four bogie types are equipped with disc brakes. Two examples are given in figure 10.
Besides further noise reduction, disc braked systems also allow higher train speeds (up to 140 km/h) end thus enabling the scheduling of freight trains between passenger trains that will allow more day time operations of the freight transport through Switzerland.

table III *Combined effect of three types of brake systems (actually three levels of wheel surface smoothness) with two levels of rail surface smoothness. Levels refer to LpAeqT at 80 km/h at a distance of 7.50 m (ref. [7]).*

	Rail		Δ
	smooth	bad	
CI-blocks	91	92	1
K-blocks	82	86	4
Disc	76	85	9
Δ	15	7	



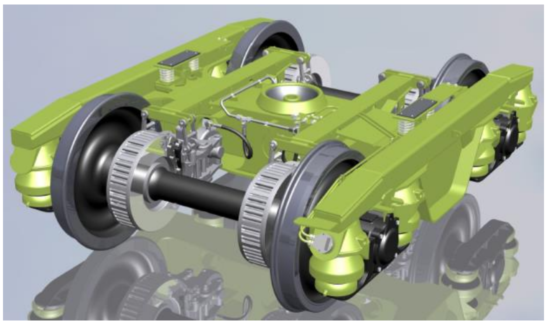


figure 10 *Two examples of future technology of bogies with disc brakes for freight trains. Left: Leila (JMR), right: DRRS 25 NT from DB Wagonbau Niesky.*

To stimulate the application of such technology a financing program is started. The subsidy depends on several requirements of which 70% is related to noise and 30% is based on other items such as the application of derailment detectors, automatic vehicle couplers etc. The noise limit for this subsidy is given below by the drawn black line as a function of axles per lengths.

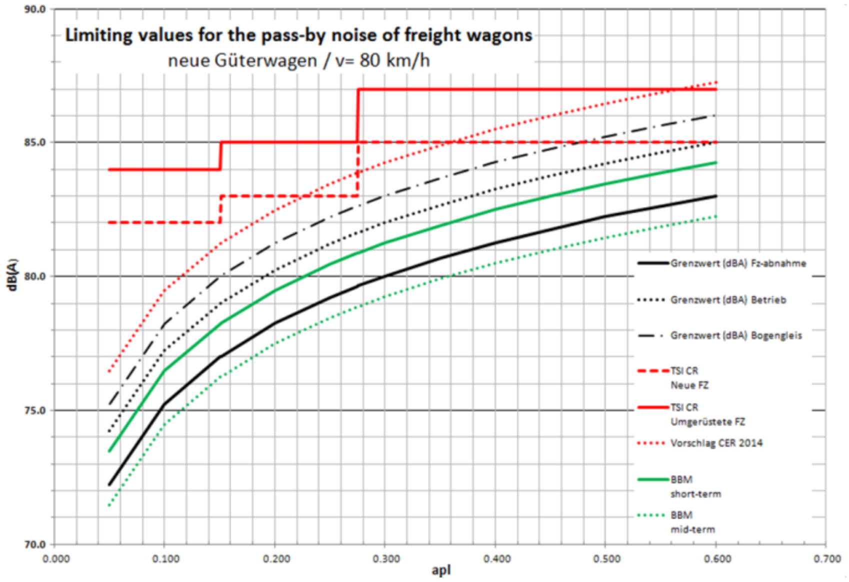


figure 11 *Pass-by levels as a function of axis per length. The red curves present the present TSI and the TSI proposal. The green curves present the UBA short term and mid-term proposals and the black drawn line the Swiss requirement for the extra quiet freight wagon subsidies.*

3.9 Rail grinding

The data from table III learns that with decreasing roughness of the wheel, as can be achieved by moving towards composite block brakes and then towards disc brakes, the effect of controlling the rail roughness increase from 1 dB to 4 and, with disc brakes, to about 9 dB. In some countries the effect of reduced rail roughness can be implemented as a measure to reduce noise. Examples of this are the “besonderes überwachtes Gleiß” in Germany and the rail roughness monitoring procedure implemented in the Dutch High speed line.

Lowering rail roughness is done through mechanical grinding of the rail surface to remove variations in the noise sensitive wavelength ranges. At the moment such grinding is laborious and time consuming due to the low grinding speed. Presently tests are conducted in Switzerland, Germany and Netherlands to overcome the low speed limitation and grind with higher speeds, so line closure can be shorter or is not necessary at all. Results of these tests learn that high speed grinding has a potential for acoustic smoothing of the rail, but results can also be disappointing due to unknown reasons. More experience is obviously needed to achieve stable results.

An example of a severely corrugated rail is presented in figure 12.

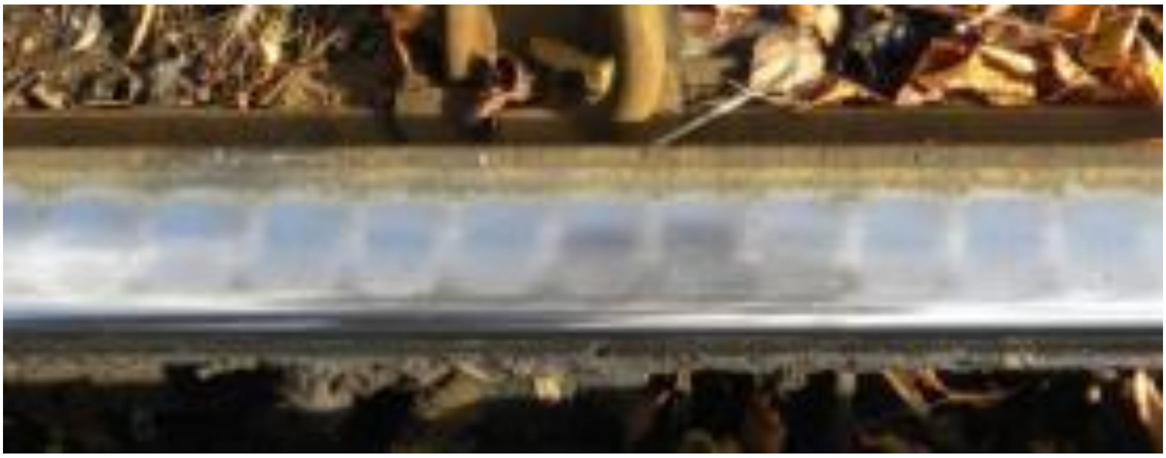


figure 12 *Clear example of severely corrugated rail with the waviness at the most sensitive area around 4 cm (source RIVAS).*

4 Noise Differentiated Track Access Charge

4.1 Relevance of existing, non TSI compliant, rail vehicle fleet

The noise limits of the TSI are defined at such level that existence of CI blocks on TSI compliant wagons are de facto not possible so all new or renewed stock will be equipped with the low noise composite brake blocks or similar low noise brake systems. The TSI however does not affect the existing fleet and due to the relatively low renewal rate it will take a long time before any noticeable effect can be observed from the inflow of low noise equipment.

The graph below (figure 13) illustrates the time line of effective reduction of average noise level considering a renewal of about 3% per year. It will take 15 years to achieve an effective 2,5 dB reduction.

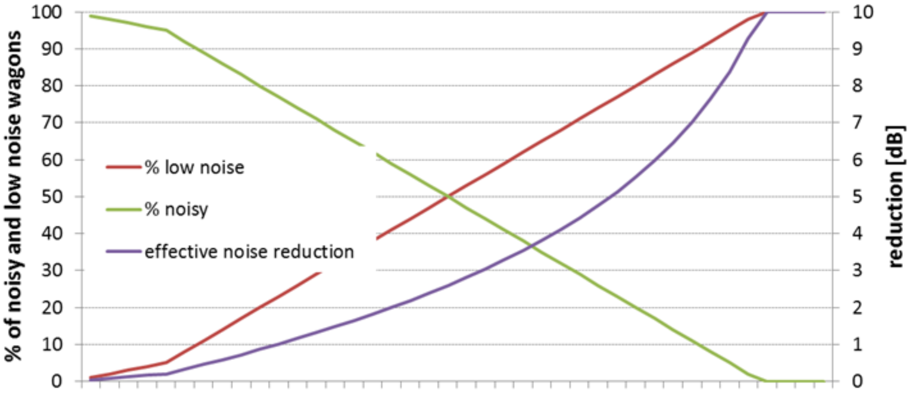


figure 13 *Effect of a 3% fleet renewal rate on average noise emission of vehicle fleet. Clearly illustrated is the low effectiveness in the beginning (23% new for 1 dB effect) and the high ratio in the final phase (6% new for 1 dB).*

Active retrofitting of existing stock is therefore essential for the achievement of noticeable effects.

4.2 Financial stimulation through Noise Differentiated Track Access Charge

The key to effective lowering of the emission of the total fleet lies in the retrofitting of existing stock (almost exclusively freight wagons).

Between 2005 and 2012 Switzerland has performed an ambitious program that lead to the retrofitting of the fleet of 6.000 freight wagons and 1.200 coaches, operated by the SBB, with K-blocks. The retrofitting of the around 3 000 wagons operated by other parties will be finished in 2015 (ref [19]).

Although society benefits strongly (also financially) from retrofit (see par. 6.2), the possibilities for direct subsidies of wagon owners in the EU are limited. The mechanism chosen by several countries is to relate the costs of usage of the (state owned) infrastructure to the noise characteristics of the stock operated on it. Low noise vehicles pay less, noisy ones pay more. This principle is then included in the general cost coverage of infrastructure by the user as defined in EU Directive 2001/14/EC.

This simple principle does however exhibit several practical constraints since there are three and sometimes four parties involved, namely

A. The infrastructure Manager (IM) or administrators
B. The railway undertaker (RU)
C. The wagon keeper (WK)
And when the wagon keeper does not also own the wagon:
D. The wagon owner (WO)

The charging process takes place between A. and B. The actual target of the financial operations however is C. To transfer the incentives from B. to C. is complicated. In about 20% of the cases C. is different from B and in a growing number of situations wagons are financed by third parties and in some kind of lease construction made available to B. or C.

In order to get a NDTAC systems working the following series of issues have to be solved:

- The noise characteristic of individual wagons in a train must be identifiable in order to calculate the bonus/malus for that train
- The charge is imposed on whole trains and not on individual wagons, how to distribute the total bonus/malus to individual wagon owners, that in worst case may be different for every single wagon in the train.
- The administrative costs of the system must be balanced by the profits for individual wagon owners
- The incentive must be defined at an optimal level. Two cases can be distinguished:
    - Level is too low: no effect since the extra income will not outweigh the extra costs (mind: the costs precede the income)
    - Level is too high: cost efficiency is lowered since also non-frequent used wagons will be retrofitted

From a technical point of view the following options are available for determination of the low noise wagons in a passing train

- Classification of the wagons according to the RU's definition of LN (low-noise) or non-LN. IM has to verify all vehicles in the train when passing a cordon
- Application of TSI-compliance to all LN wagons and administrating these wagons in the train. TSI compliance is automatically awarded to disc or composite blocked brakes
- Direct measurement of the emission of a passing train and through that identification of the LN wagons. This requires a measurement system accepted by all stake holders and traceable wagons in the train

4.3 Present status

No European harmonized system exists at the moment. Switzerland, the Netherlands, Germany and Austria have a system operational.

4.3.1 The Swiss system

In 2000 Switzerland introduced a bonus in the track access charge to reward the usage of silent wagons. The bonus is based on the number of silent axles per kilometre. Silent refers to drum, disc or composite-block braked axles. The bonus is paid to the RU and Wagon oners can benefit from:

- The NDTAC bonus passed on from the RU
- The willingness of the RU's to pay a higher price for silent wagons.

The basis for granting the bonus is the self declaration of RU's (with added control by the government) and forwarding the bonus to the WO/WK's

The current bonus is 0,02 CHF/axle.km for K and LL blocks and 0,03 CHF/axle.km for disc brakes which roughly represents 5 to 8% of the total TAC. For wheels a diameter less than 50 cm, the bonus is limited to 0,01 CHF/axle. With a bonus per silent wagon of in total € 24 for a 300 km transit through Switzerland, about 20 transits per year suffice to cover the extra operating costs of composite block brakes.
In addition the Swiss government is performing a program to retrofit all existing Swiss freight stock with K blocks that will be finished within a few years. In 2012 100% of all 6 270 SBB freight wagons were retrofitted and 15% of the 3 360 private cars. In 2015 also all private cars shall be retrofitted.

Nevertheless the NDTAC and retrofit program at this moment still about 50% of the transit freight stock is fitted with CI blocks. In figure 13 it is shown that 50% retrofit only gives 2,5 dB reduction, frustrating the 1,8 billion CHF investment in railway noise abatement by the Swiss government. This led to the decision to implement a complete ban on CI blocks, possibly in the year 2020 but 2022 at the latest.

4.3.2 The Netherlands system

Netherlands introduced a NDTAC system in 2008 to stimulate retrofitting of freight stock. Eligible to a bonus of € 0,04/wagon.km are wagons that came into service before 2008 and are retrofitted with K or LL blocks after 1/1/2008. Newly build wagons which are already silent (since they have to comply with the TSI) are not eligible for the bonus. The bonus per freight wagon are maximized to € 4.800

The application for a bonus is based on self-declaration of the RU, but the limit per wagon forces the IM to keep an administration of all wagons included in the program. In a later stage RFID devices and measuring stations along the track give input to the awarding system.

At this moment only bonus is paid, but it is planned that after homologation of LL blocks the current system will be replaced by a bonus/malus system.

The bonus is paid to the RU and the RU can pass it to the WO/WK but this is not mandatory.

Until now the NDTAC has not been successful, probably due to the low incentives and limitations.

Pilot Silent Freight Train
In order to overcome the limitations in the NL NDTAC system regarding pre 1/1/2008 retrofitted trains or new low noise trains, a pilot is started with three major RU's to grant the bonus of € 0,04/wagen.km also in case of a total low noise train that may include pre 1/1/2008 retrofitted stock or TSI approved stock. Again this system is based on self declaration, although the agency may take samples to check the compliance with the rules. Incidentally up to 1 of every 20 wagons may be of a not low noise version.

4.3.3 Germany

In Germany the NDTAC was set into force in December 2012.Only wagons retrofitted after the introduction are eligible. The bonus of 0,5 ct/axle/km is paid not to the RU but directly to the owner. Although referred to as bonus, it actually must be considered a bonus/malus system since in advance of the introduction an increase of the overall level is proposed that has to cover 50% of the bonus budget.

The funding of the bonus comes from an increase of the TAC with 1%. This 1% extra can be saved for trains that consist of minimal 80% silent wagons. Over a period of 8 years starting at 2013, this minimal fraction will be increased to 100%.

It is expressed by the traffic ministry that after 2020, noisy stock will not be accepted on the German rail net anymore.

4.3.4 Austria

Austria is faced with similar noise problems for Alpine transit traffic as Switzerland but addresses it with a different system. To remove noisy freight traffic from the densely populated valley of the river Inn, it offers reduced prices for freight wagons for an alternative less populated route (ref [20]).

4.4 Conclusions

- At this moment there exists no EU harmonized NDTAC system
- There exists no common approach to a NDTAC
- There exists no common definition of costs, both initial coats, operational costs and transaction costs
- There exists no common methodology to define low noise vehicles. The current TSI can be used for that.
- There exists no common understanding of the way wagon owners can get access to the bonus payments and will be stimulated to retrofit their wagons.
- There exists a common preference to focus on freight wagons
- The recent homologation of LL blocks improves the speed of retrofit
- There exists a general concern by RU's and EU DG-MOVE that extra costs involved in the implementation of a NDTAC malus system would jeopardize the competiveness of rail transport.

5 View of European commission

5.1 Relevance of noise

The noise emission from rail freight traffic is regarded by the Commission (DG-MOVE) as a negative factor in the modal shift from road to rail.

- The Commission seeks to address the following problems:
  - Freight wagons not conforming with TSI-Noise limits are the most important source of rail noise
  - Existing measures are not sufficient to quickly reduce the level of rail noise
  - Risk of unilateral measures leading to barriers to railway interoperability and internal market
  - Different regimes in place lead to legal uncertainty and over-utilisation of old rolling stock
- Objective of the Commission is to effectively reduce, by 2020-23, the level of noise of freight wagons in the European Union, while maintaining the competitiveness of rail sector vis-à-vis other modes

5.2 Commission actions

The following measures concerning railway noise have been recently adopted or are currently in the pipeline:

- The recast of the first railway package (Directive 2012/34/EU), adopted in November 2012, foresees an optional introduction of noise-differentiated track access charges (NDTAC) as is described in Noise provisions – article 31(5):
  - at the moment NDTAC is non-mandatory but the COM reactivated the NDTAC Noise Expert Group to investigate feasibility of a harmonized NDTAC system
  - COM must adopt implementing measures setting out the modalities to be followed for the application of the charging for the cost of noise effects (examination procedure) "based on the experience gained by infrastructure managers, railway undertakings, regulatory bodies and competent authorities, and recognising existing schemes on noise differentiation"
  - Those implementing acts shall not result in an undue distortion of competition between railway undertakings and affect the overall competitiveness of the rail sector
  - Modification of charges to take account of the cost of noise effects shall support the retrofitting of wagons with the most economically viable low-noise braking technology available.
- Commission adopted on 19 October 2011 a proposal for a Regulation of the EP and Council establishing the Connecting Europe Facility (COM (2011)665/3) with substantial budget earmarked for transport projects. It allows the EU to co-fund retrofitting of existing freight wagons with silent brake blocks (max 20% of eligible costs). The proposal is now in discussion between the Parliament and the Council.

The NDTAC is seen as a step towards internalisation of the cost of noise. The Commission adopted on 17 September 2010 a proposal with legal requirements for implementation of noise-differentiation of track access charges (NDTAC), within a recast of Directive 2001/14/EC (included in the recast of the first railway package. However, the commission is aware of limited success of NDTAC in Netherlands, as a result of insufficient financial incentives, complicated procedure to receive the "quiet wagons/train" bonus and unwillingness to retrofit due to increased (and not refunded) operating costs on the side of operators. Even the more generous Swiss system which includes coverage of retrofit costs is not sufficient to make all operators retrofit their wagons.

5.3 EU study into the practical and financial aspects of NDTAC systems

The commission expresses a concern that a too quick introduction of NDTAC may harm the competitiveness of railway transport in comparison with other transport modes and that national varying schemes may harm international interoperability. DG-MOVE has contracted a study analyse the preconditions for the implementation and harmonisation of NDTAC's in Europe (ref. [16]). The study rated different systems to implement NDTAC (see table below).

table IV *Overview of options to apply NDTAC systems and their rating with respect to practical and economic effects. [16]. IT refers to a software administrative system, RFID to tags mounted on each wagon.*

KCW's Evaluation of the incentive models

	ND Bonus model	NDTAC -IT Bonus	NDTAC -IT Bonus-malus	NTDAC-IT TAC-rise	NDTAC -RFID Bonus	NDTAC -RFID Bonus-malus	NDTAC-RFID TAC-rise	Direct funding
Incentive effect	Very good	Medium	Medium	Medium	Good	Medium	Good	Very good
Feasibility practicability	Very good	Medium	Very poor	Poor	Poor	Very poor	Very poor	Very good
Negative impact on rail freight market	Very poor	Medium	Very high	Very high	Medium	Very high	Very high	Very poor
Employment of transaction costs	Effective	In part effective	Ineffec-tive	In part effective	Very in-effective	Very in-effective	Very in-effective	Very effective

It came to the following recommendations for an optimal NDTAC system;

- a pure bonus system proposed: operators running "silent" wagons would pay less track access charges
- the bonus would be an incentive to retrofit wagons in new, silent composite brake blocks
- the bonus should be calculated on basis of costs of retrofitting plus additional operational and administrative costs on the side of the RU and WK
- the bonus should be based on number of brake blocks per axle.

A bonus scheme was proposed (see table V).

The study also determined the administrative costs involved in implementing and executing a NDTAC system. Although estimates do widely differ (and estimates by parties opposing the NDTAC are generally much higher than those in favour) a fair estimate was found in 10 to 20% of the bonus actually paid. Transaction costs however can be very high if advanced systems such as RFID and IT are used for identifying the wagon classes.

table V *Funding scheme proposed in EU study by KCW [16].*

Type of wagon	Type of cost [unit]	K- block			LL- block		
		min	recommended	max	min	recommended	max
4 axle-wagon	***6 yr funding*** [€/km]	0.024	**0.032**	0.040	0.009	**0.012**	0.015
	12 yr funding [€/km]	0.015	**0.019**	0.023	0.007	**0.009**	0.011
2 axle-wagon	***6 yr funding*** [€/km]	0.012	**0.016**	0.023	0.004	**0.005**	0.007
	12 yr funding [€/km]	0.007	**0.009**	0.013	0.004	**0.004**	0.005
Average per axle	***6 yr funding*** [€/axle km]	0.0060	**0.0079**	0.0111	0.0021	**0.0027**	0.0034
	12 yr funding [€/axlekm]	0.0036	**0.0046**	0.0063	0.0019	**0.0021**	0.0026

The study also recommended to add an extra bonus for trains entirely fitted with low-noise wagons. The logarithmic nature of sound implies that a few noisy wagons can jeopardize the total effect of the Low-noise wagons in a similar way as is shown in figure 13.

5.4 Study on effective reduction of noise generated by railway freight wagons in use in the European Union

5.4.1 Topics

The Commission performs a Study on "Effective reduction of noise generated by railway freight wagons in use in the European Union ". The following options were considered:

1 Status quo (baseline scenario)
2 Increased financial support for retrofitting of existing wagons with low-noise brake blocks ["incentives approach"]
3 Noise-differentiated track access charges ["NDTAC approach"]
4 Mandatory application of TSI-Noise limits to all existing railway wagons ["TSI Noise approach"]
5 Introduction of a noise limit along the TEN-T railway Network ["TEN-T approach"]
6 Introduction of noise limits in relation to density of population ["Density approach"]
7 Track management in relation to noise ["Maintenance approach"]

5.4.2 Public consultation

Part of the study is a public and stakeholder consultation on reduction of rail freight traffic noise. This consultation was clear about the relevance of noise reduction although it should be taken into account that the majority of the responses originates from German citizens (90%) and professional organizations (60%).

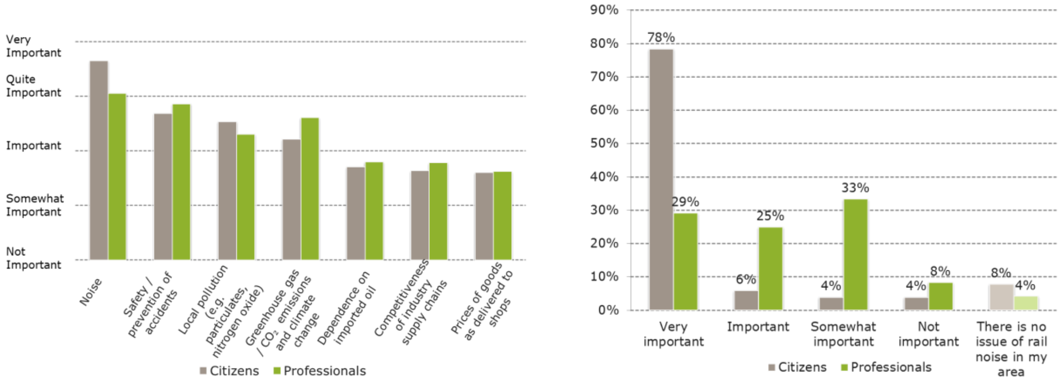


figure 14 *Relative importance of freight transport policy challenges (left) and importance of rail noise in residential area (right) as expressed in the public consultation (ref [23]).*

The public opinion favoured maintenance, NDTAC, TSI Noise and END options while the Organizations preferred subsidies instead of NDTAC. It did however show rather negative opinions on the progress of quietening of freight wagons.

5.4.3 Next steps

- The study is to finish in April 2014;
- Commission should adopt a relevant Communication by the end of 2014
- The Communication could be accompanied by legislative measures, depending on the outcome of the impact assessment process

Uncertainty about the next steps is introduced by the election of the new Commission. The views presented here refers to the present Commission.

6 Cost/benefit

6.1 Costs of retrofit

Since retrofitting of freight waggons is by nearly everybody seen as the most promising and most cost effective way of reducing rail traffic noise, it is essential to have a clear indication of the costs involved. The table below gives an overview of initial and operating costs of different sources.

table VI *Overview of cost estimates for retrofitting with K blocks and LL blocks, for 2 and 4 axle freight wagon. The values between brackets are the reported range. [10].*

Year	Source	Retrofitting costs K-blocks (€/wagon)		Retrofitting costs LL-blocks (€/wagon)		Additional LCC using K-blocks (€/ wagonkm)	Additional LCC using LL-blocks (€/ wagonkm)
		2-axled wagons	4-axled wagons	2-axled wagons	4-axled wagons		
2001	UIC Steering group noise reduction freight	3756 – 5961	5471 – 9981	418 – 2623	836 – 5246		
2004	ERRI report					0.007 – 0.025	Not investigated
2004	AEAT assessment	3812 – 6678	5471 – 11,110	418 – 2623	836 – 5246	Not quantified in €/wkm	Not quantified in €/wkm
2007	PWC DG TREN assessment	7022 (average value used in the study)		1360 (average value used in the study)		0.004	0.0041
2008 / 2009	UIC NRTAC report	3000 – 10'000		1000 – 5000		only dealt in qualitative matter due to lack of data	
2009	KWC DG TREN Study	3000 – 6000	6000 – 10,000	250 – 4800	500 – 6600	0.0053	0.0054
2010	German Rail sector data (Leiser Rhein)	Not investigated	5650 – 7450	Not investigated	1250 – 2280 No ss-wagons	0.020 – 0.026	0.017 – 0.020
2008 / 2010	Whispering Train Programme NL	Not investigated	7110 (30 wagons type Tapps)	0 (costs included in €/wagonkm – no ss wagons)		0.002 – 0.007	0.003 – 0.030

The table exhibits widely varying data on cost estimates for both initial and operating costs. For LL blocks for instance, initial; costs ranged from € 0 (LL blocks do not require modification of the vehicle) to € 5 000 (LL block initial costs are only half from initial costs of K blocks). Operating costs also vary with a factor of 10.
It is obvious that such uncertainties will cause variation in the cost/benefit ratios. However it will be shown later that even with such uncertainties, retrofit of rolling stock is economically superior to track related measures and barriers.

6.2 STAIRRS project (1999 and 2013 update)

The STAIRRS project (1996 -1999) gave an extensive cost/benefit analysis of different types of measures to mitigate railway noise, both at the source, in the propagation and at the receiver. It calculated costs of measures and benefits in terms of reduction of people exposed to Lden levels > 60 dB over a series of railway lines in Europe (see figure 15). The undisputed result was that source measures such as acoustic grinding and composite block brakes gave superior benefit/cost ratios than propagation and receiver measures such as barriers and façade insulation.

figure 15 *Overview of railway lines that served as a basis for the calculation of costs and benefits in the STAIRRS project*

In a recent study (ref. [15]) the study was updated and included the latest costs and durability data from composite blocks, the implementation of wheel and rail dampers and the existing information on the number of freight wagons and the status of retrofitting. The results presented a larger total amount of costs due to the more recent insight in the real costs, including maintenance and depreciation of existing stock. The ranking of measures however was not changed as can be seen in figure 16. Retrofitting is by far the best option. LL blocks are less costly than K-blocks even if heavier wear of the wheels is included.
As was already clearly indicated in the STAIRRS project, this update corroborates again that barriers are the worst option from a cost and benefit point of view.

The most effective combination in terms of reduction of exposed people is the application of composite blocks, together with tuned absorbers and a 2 m high barrier. Source measures alone cannot solve all hot spots.

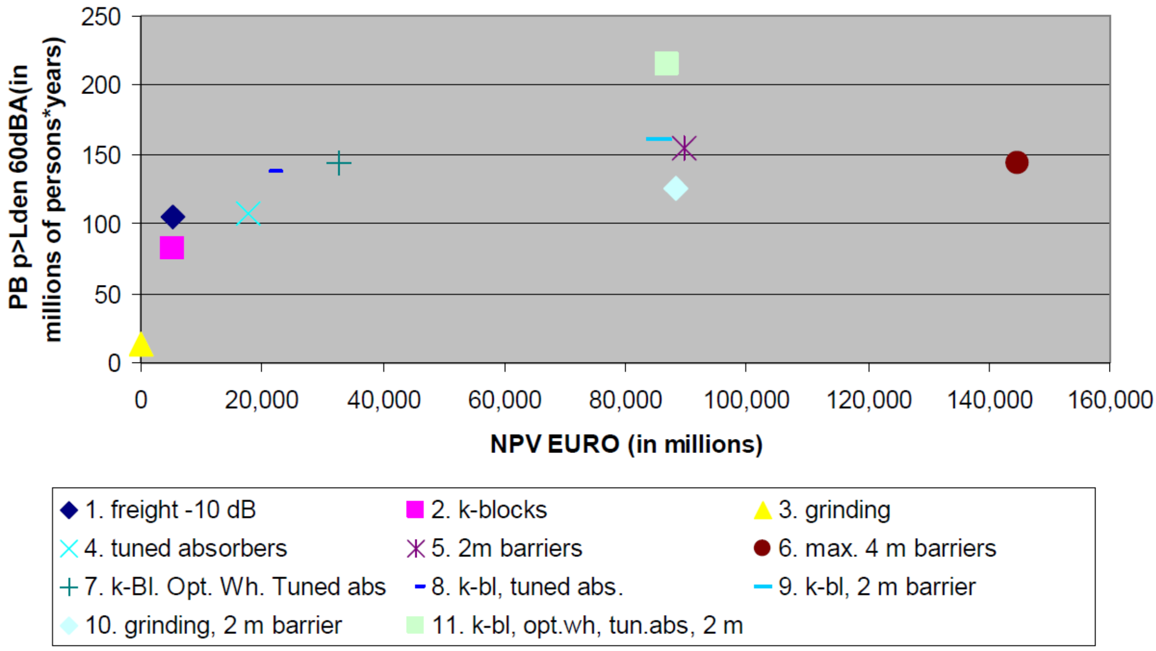


figure 16 *Costs of the abatement measures and benefits in terms of reduction of people exposed to Lden >60 dBA in EU27+CH+N*

6.3 Austrian study

An Austrian study (ref [8]) demonstrated that about 50 of the infrastructure costs for noise mitigation, such as barriers and façade insulation might be saved when all freight wagons are equipped with low noise braking systems, and 65% when all stock were equipped with disc brakes or K/LL blocks.

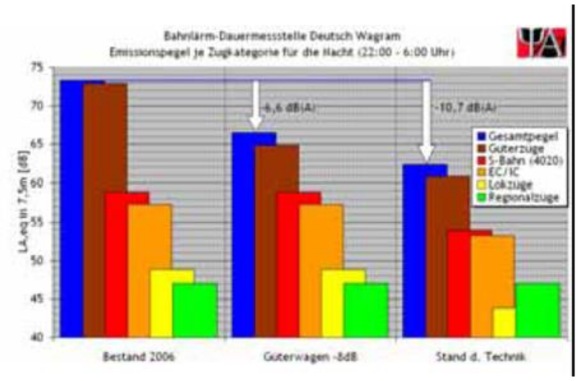


figure 17 *Effect of low noise freight wagons and application of Stand der Technik for all stock on Austrian railway noise levels. Data from Deutsch Wagram monitoring station.*

6.4 Swiss study

Since the Cost Benefit Index (CBI) Cost/benefit ratio is an important factor in the application of noise mitigation measures in Switzerland, the CB ratio was studied for the Swiss territory. For the total network about 70 scenarios were calculated. Results are in line with the already mentioned studies. Retrofitting gave better benefits per costs ratio's than only barriers. An important issue in the Swiss study was that retrofitting only Swiss stock was only slightly better than application of noise barriers only below a certain CBI. This is explained by the vast number of non-Swiss stock on the transit corridors. Including all stock gave a major improvement for the Cost Benefit ratio. The addition of barriers with a maximal CBI resulted in only a slightly lower benefit/cost ratio (see figure 18).

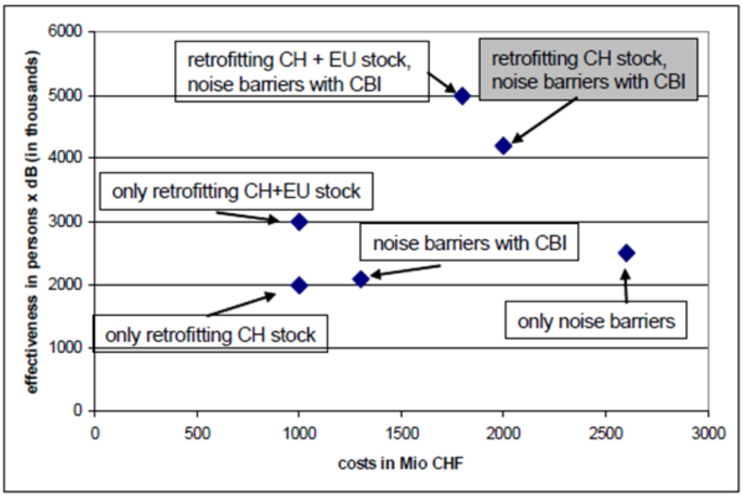


figure 18 *Costs and benefits of retrofitting freight wagons compared to application of barriers (source J.Örtli [8]).*

7 Background information

7.1 Relevance of railway noise and its sub contributions

The exposure of the European population to railway noise is much less than the exposure to road traffic noise as is indicated by the figure below. The distinction between road and railway is increased by the fact that the annoyance due to a certain level of railway noise is lower than the annoyance experienced by the same level of road traffic noise. Despite the lower impact of railway noise on society, the relevance of suppressing railway noise is still very high.

- It causes large public demonstrations in case of the new high speed trains such as between Paris and Marseille, Amsterdam-Brussels, London-Manchester, the freight corridor through Rhine Valley and the Betuwe, the rail freight transit through the alpine countries Austria and Switzerland and several other cases.
- It hampers the environmental friendly modal shift from road and air to rail traffic
- It is a subject of significant yearly spending on abatement measures. In Europe in the order of 150–200 M€ per year (UIC 2007).
- It is the origin for specific annoying activities and noises such as curve squeal, the impact of wagons during shunting and the stationary noise of trains while being serviced, cleaned and parked during the night.

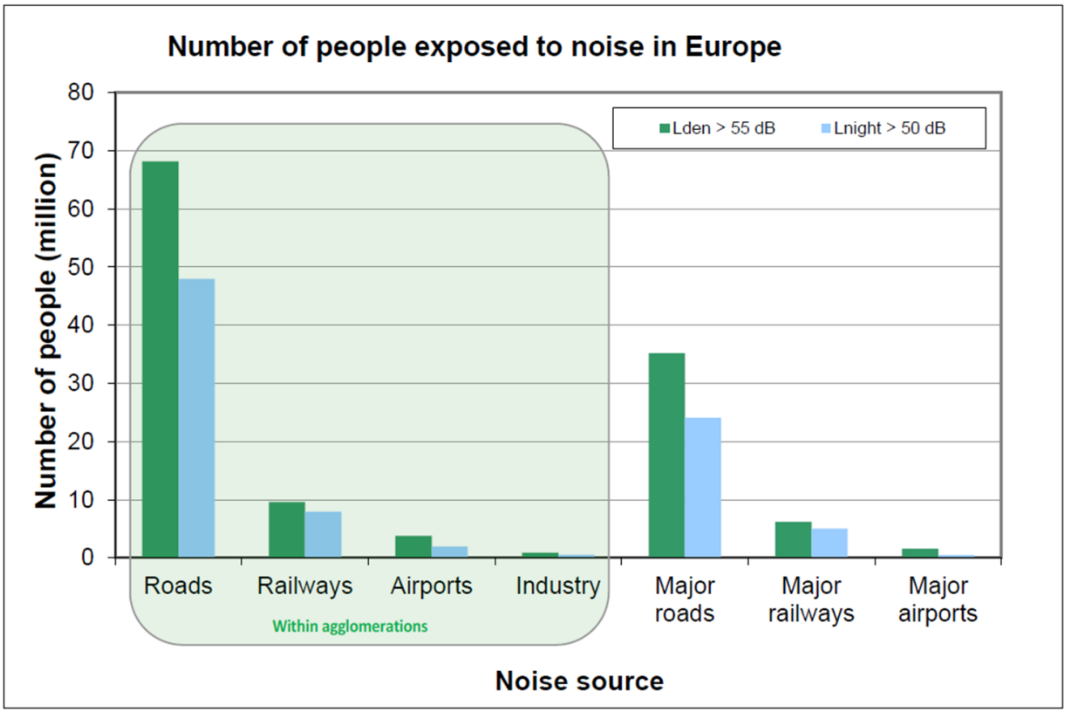


figure 19 *Exposure of the EU 25 population to different sources of noise. About 15 million people are exposed to railway noise levels over 55 dB and slightly less to Lnight levels over 50 dB. (EEA).*

In the majority of the situation where railway noise is an issue, its main source can be identified as freight trains. This can be explained by:

- freight trains running more frequent at night when the capacity of the line is not needed for the regular person traffic. In the night, the sensitivity to noise is 10 times larger as during the day as is expressed in the penalty of 10 dB applied in the Lden calculation.
- conventional freight train that produces 5 to 10 times more sound energy than a passenger train with the same speed and axle configuration.

The combined effect is illustrated in the figure below, that presents the outcome of a noise monitoring station in Austria.

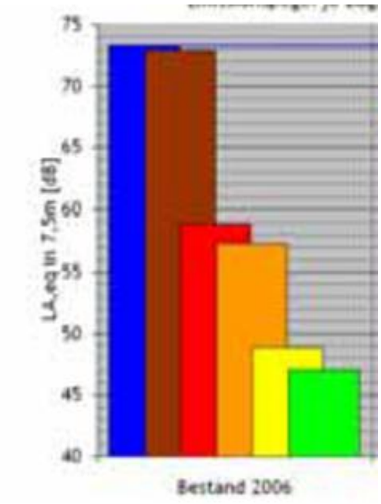


figure 20 Result of a noise monitoring station at Deutsch Wagram, operated by the Austrian OBB. Presented are the LAeq during the night. The dominance of freight traffic (brown) in the overall noise level (blue) is clearly visible.

7.2 Origin of railway noise

In general railway noise is composed of three sources, traction noise, rolling noise and aerodynamic noise. The relevance of each of these sources to the overall level differs quite strong as a relation of speed as is illustrated in the graph below. In the majority of cases however it is rolling noise that dominates the overall level. Aerodynamic noise is mainly an issue because it lowers barrier efficiency due to the high location of the sources.

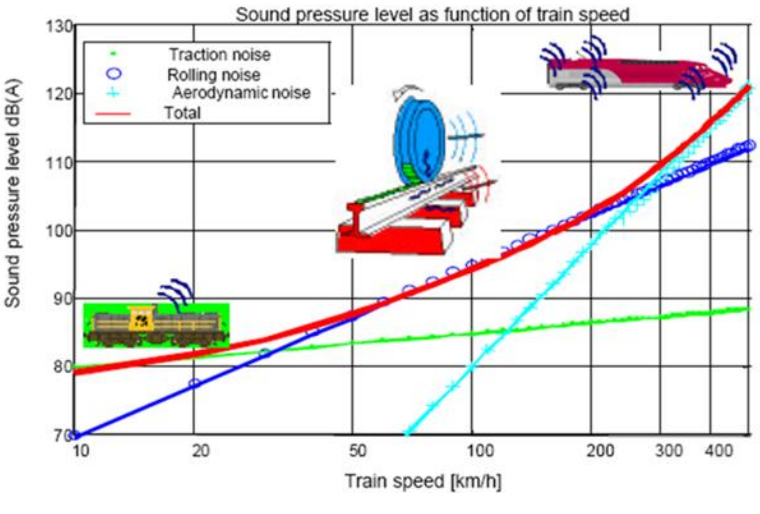


figure 21 Schematic view of the level of rolling noise, propulsion noise and aerodynamic noise as a function of speed. The red curve presents the total sound level. The actual values and the speeds at which transition takes place depend strongly on the technology of the vehicle and the track.

7.3 Rolling noise mechanisms

7.3.1 Mechanisms and modelling

To identify mitigation measures for rolling noise, one must understand its cause and nature. This can be done by a proven sequence of distinguishing in the process the relevant interactions and transfer mechanisms. Since it is a mechanical process (unlike aerodynamic noise and part of the traction noise), it can be explained by 4 stages:

1 excitation due to irregularities in the wheel/rail contact
2 vibrational respond of the wheel, rail and sleeper construction due to this forces
3 transmission of the vibration into radiated sound
4 propagation of the sound into the environment

A model explaining this process and able to predict the levels in specific situations is the TWINS model (Track-Wheels Interaction Noise Software).

1 The basics are that combined roughness of the rail and rolling wheel leads to a excitation on the wheel and the rail
2 This results in vibration of wheel and rail.
3 The vibrating rail transmits part of its energy into the sleeper
4 The vibrating wheel, rail and sleeper causes sound waves that propagate into the environment.

The TWINS scheme points to the mechanisms where noise reduction can be found:

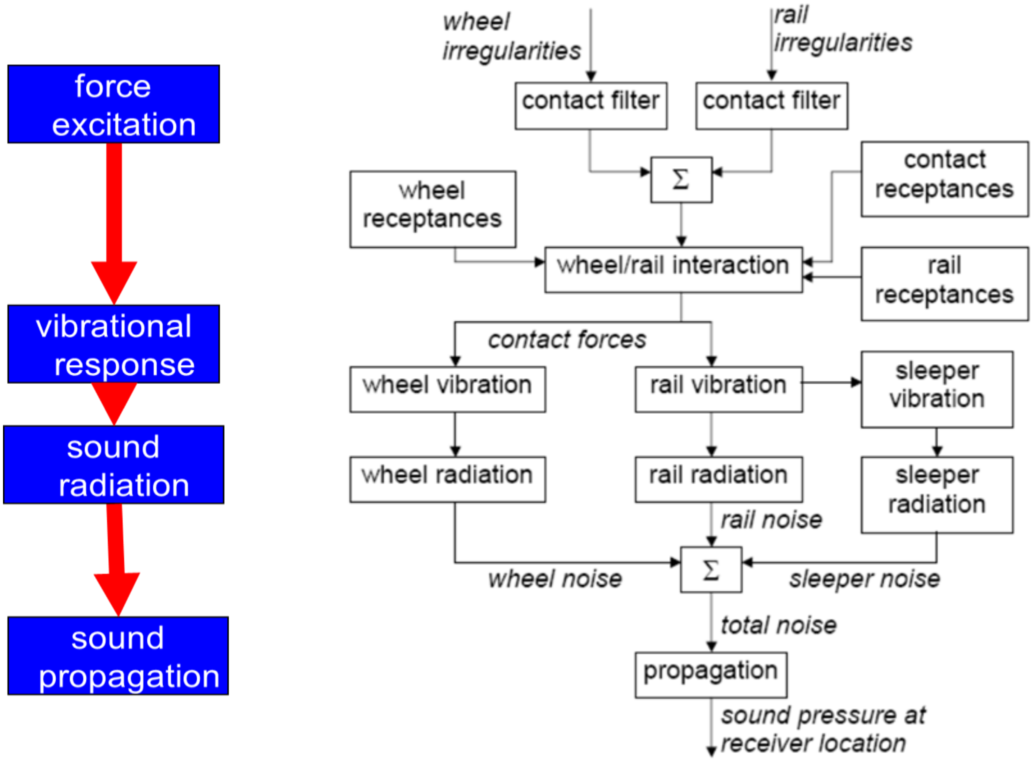


figure 22 *Schematic overview of the mechanisms that cause rolling noise. At low speeds traction noise adds to the overall level and at high speed aero-dynamic noise contributes although never as the dominating source. It may become dominating only when due to barriers the rolling noise contribution is limited.*

7.3.2 Effect of measures

The sequence of excitation, response, radiation and propagation helps explaining the effectivity of measures.

1 Optimizing brake systems with K or LL blocks or with disc brakes and grinding of the rail surfaces reduces the roughness and therefore the magnitude of the force excitation of both the wheel and the rail.

2 The total vibrational response can be controlled by application of damping structures that for wheels reduce the time that the wheel remains vibrating and for rail the length over which the

vibration can travel. Both lead to reduction of amplitude and area. As both, the rail and the wheel radiate noise, a high reduction can only be archived if both are damped.

3 Radiation efficiency is strongly coupled to material and geometry parameters that do not differ that much over the wheel and rail systems used in Europe. Only old fashioned spoke wheels will show a major advantage in this.

4 The radiated sound energy is then propagated into the environment. Reduction is found by shielding due to barriers and absorption in the ballast track.

The figure below expresses these mechanisms in the TWINS modelling scheme.

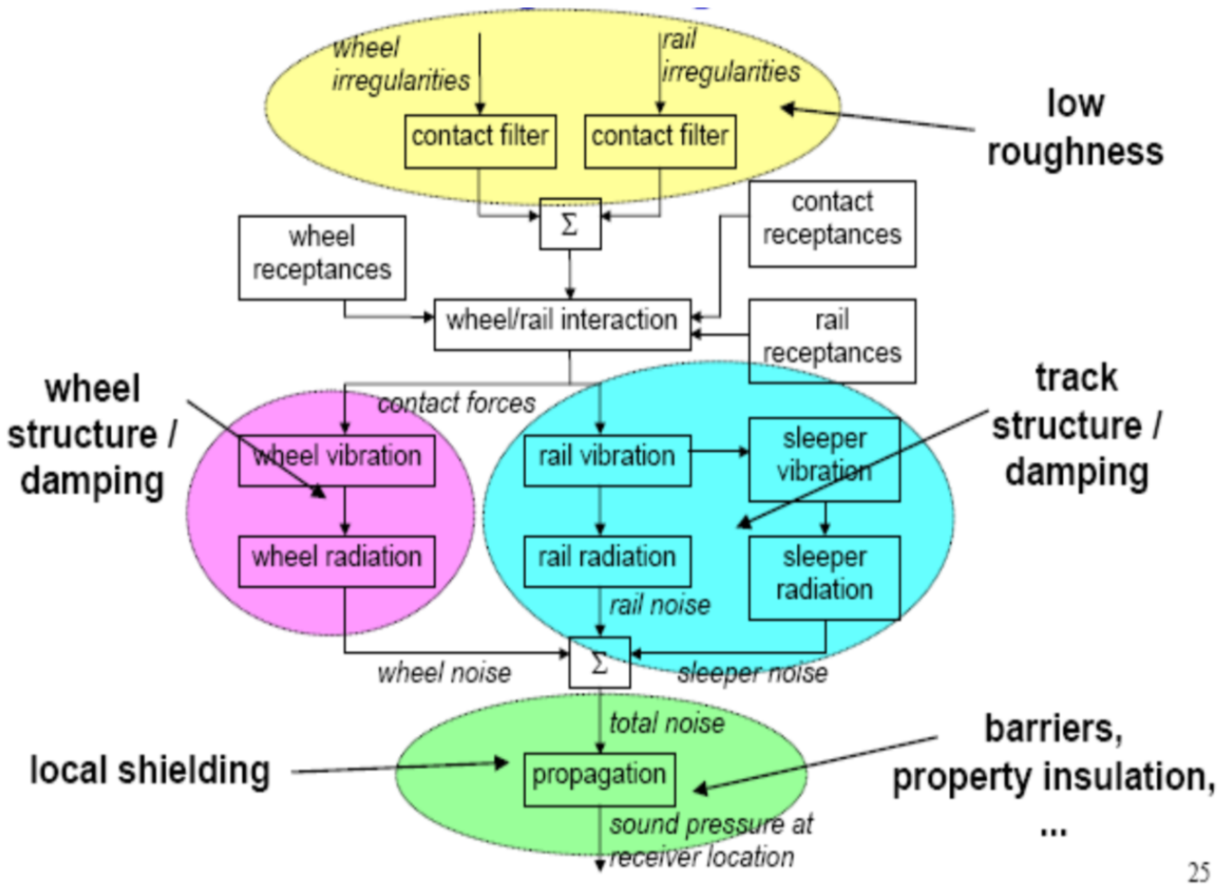


figure 23 *The effect of mitigation measures explained by the TWINS rolling noise model (Source D.Thompson)*

7.4 Noise mitigation at EU, national and local level

table VII *The coloured cadres indicate the reducing mechanisms of the measures given at the left [6]. Matrix indicating the supra national / national / local level on which policies are formulated and measures are taken. The report focuses on the light orange elements.*

	Source	Propagation path	Point of impact
EU level	▪ TSI ▪ NDTAC ▪ Retrofit program	▪ Barrier standardization (ISO/CEN)	▪ EU harmonized calculation scheme (CNOSSOS) ▪ European Noise Directive
National level	▪ Retrofit program ▪ NDTAC ▪ Ban on CI blocks ▪ Acoustic grinding ▪ Rail dampers (homologation) ▪ no noisy stock in the night	▪ House planning policies ▪ Planning infrastructure and controlling environmental noise in the vicinity	▪ National legislation on noise exposure of houses and other noise sensitive objects ▪ National policy on health and annoyance effects of rail traffic noise
Local level	▪ Rail dampers ▪ Acoustic grinding	▪ Actual planning and building of barriers ▪ Separation of noise producing infrastructure and noise sensitive objects/houses	▪ Noise policy plans (for instance. indicated by the END)

8 Vibration

8.1 Relevance of vibration control

Annoyance due to vibration is frequently reported in the vicinity of railway lines. Although the annoyance by noise exceeds the annoyance caused by vibration it is relevant to address the vibration topic since there exists strong links with railway noise, both at the level of exciting mechanisms, combined effect of mitigation measures and sensitivity of the humans exposed to only noise or noise and vibration. Moreover, the efficiency of noise barriers or sound-proof windows is limited by the ground born noise effect.

Vibration at relevant annoyance levels is most frequently encountered in the vicinity of freight lines, but also in situations with passenger trains with boogie mounted electric motors or high speed trains on soft soil vibration annoyance is reported.

The relevance of vibrations lie in the frequency range between 4 and 100 Hz. Vibrations at frequencies >100 Hz are rapidly damped out in the ground and humans have reduced sensitivity for these frequencies. They do have relevance when the vibrating foundation excites resonant vibrations in the floors that then radiate as sound. Then the passing train will be noticed as a rumbling noise. This type of noise can be observed in buildings above tunnels or when the direct noise is shielded by barriers or sound-proof windows.

8.2 Excitation of vibration

The main causes of vibration are:

1 longitudinal variation in the rail support stiffness (parametric excitation)
2 geometrical unevenness in the wheel/rail contact
3 Eigenfrequency of the unsprung mass on the track superstructure.

8.2.1 Variation in the rail support stiffness

Even in case of a perfect wheel and rail surface, excitation occurs through periodic stiffness of the rail support. A wheel running over irregularity rail will cause a varying force on the foundation of the track that propagates into the environment. The common variation is that one caused by the discrete support of the rail by sleepers.

8.2.2 Unevenness

This mechanism is similar to the excitation of noise but at a much longer wavelength and much higher amplitude. In case of a train moving at 100 km/h, an unevenness of 1 m wavelength will excite a vibration of 30 Hz and relevant vibrational levels can be expected for amplitudes close to 0,5 mm. For comparison, in case of noise wavelength in the mm/cm range and amplitudes down to less than 1 µm have to be considered.
The irregularities occur in the wheel surface or in the rail surface
Wheel irregularities have several causes and appearances. It can be localized such as flats from blocked braking, spalling and localized spreading, or periodic such as eccentricities, ovalities and polygonization. A typical example of a periodic and a local irregularity is given below.

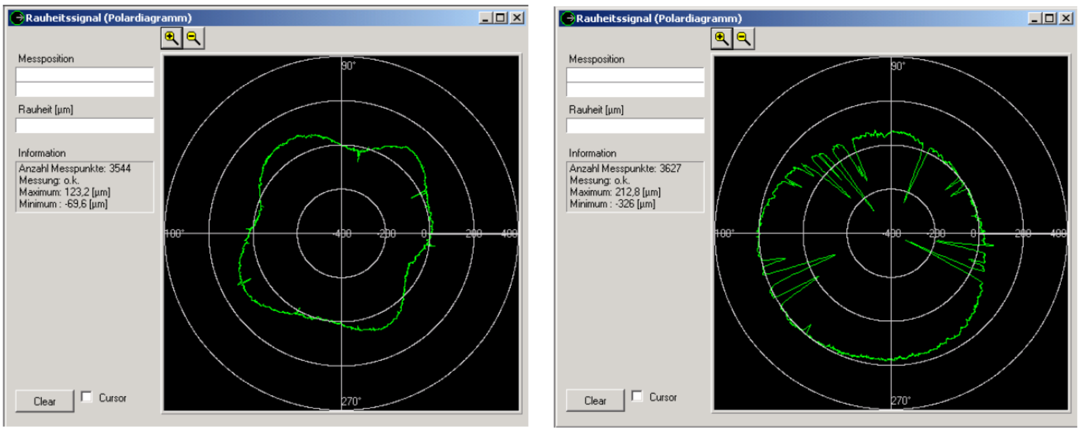


figure 24 *Wheels measured within the framework of the Europe train project. Left: periodic irregularity: polar diagram of wagon 29, right: local irregularity(ies) including flats, polar diagram of wagon 19 (ref [28]).*

Rail irregularities with respect to vibration emission can be

- Unevenness of the rail with a long wavelength
- Local impacts as worn out joints, local rail head defects, worn out frogs. Such local defects cause a broad band increase of the vibration level but however act as a point source and are therefore mainly noticeable in the near field.

The example below shows missing ballast in the support in the middle and thus the area is softer. The movement of the rail under load shows that failing support.

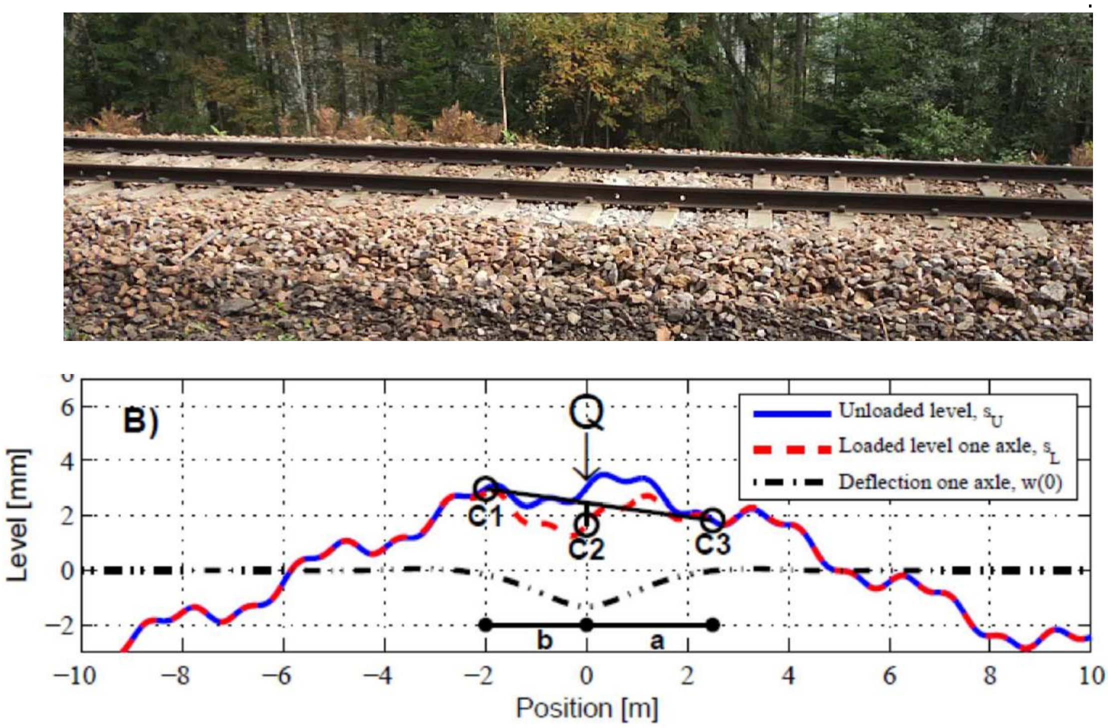


figure 25 *Example of variation is support stiffness. Due to missing ballast (see picture above), the rail bends under load (graph below) at that specific location (ref [29]).*

8.2.3 Coincidence with resonance frequencies.

The level of vibrations is amplified significantly when the exciting frequency coincides with resonances in either the vehicle or the track superstructure. In nearly all rail systems it is the sleeper-to-sleeper distance (d) that, when driven over by a certain speed (v), will generate a vibrating force with a frequency (f) equal to the speed over distance. With v=24 m/s and d=0,6 m a f=40 Hz is found. When this frequency coincides with the resonant frequency of the unsprung mass of the rail vehicle or a resonance of the track superstructure large vibration amplitudes are generated. This vibration is enlarged when the axle distance in the rail vehicle coincides with the sleeper distance.

8.3 Role of vehicle type

The vibrational level of a train passage depends strongly on the type of vehicle and the condition of the vehicle. In figure 26 results are given from a monitoring post near Thun (Switzerland).

8.3.1 Locomotive

It shows the wide spread in median values of different rail vehicles, but also the spread within a certain vehicle type. Most prominent source of vibration in this study were the Freight locs, the aging Re 420 and Re 620 type but also the newer Bombardier TRAXX F140 type. The cause of the high vibrations of the older freight locs were explained by the irregularities in the wheel geometry, due to spalling and out-of-roundness. The newer TRAXX F140 performs worse relative to the similar Re 460. The difference in median value can be explained by the high unsprung mass of the TRAXX which has a nose-suspension drive (in which the mass of the gearbox and most of the mass of the traction is on the wheel set axle) which results in high dynamic wheel-rail forces and low natural frequencies in the coupled dynamic wheel-track system. This however cannot explain the large differences in max and 95% value. This was explained in [29] by the steerable axles of the Re 460 that prevents damage of the wheel band and thus maintains a better geometry than the non-steerable TRAXX axles.

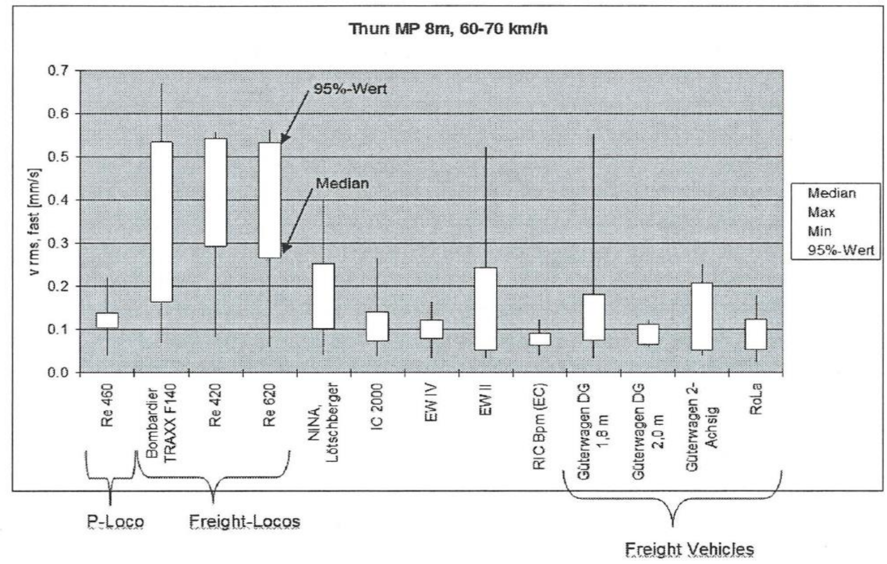


figure 26 Statistics of ground vibration measurements for different vehicle types at WLC measuring point near Thun(Switzerland) (ref [30]).

8.3.2 Wagon

Freight wagons, especially the type with 1,8 m axle distance in the bogie, exhibit lower vibrational levels than the locs but maxima are as high due to the often poor maintenance of the wheels and the resulting high geometrical defects. The high maximum values of the EW II type (a normal passenger coach) might also be caused by poor wheel geometry and Out-of-roundness.

8.4 Evaluation of vibration

Exposure of vibration is evaluated on three aspects:

- damage of building constructions due to movement of the foundation
- annoyance of humans due to exposure of vibration
- reduced performance of fine-mechanical equipment

8.4.1 Damage of buildings

In the Dutch guideline SBR 3 three building categories are distinguished: sensitive (old monuments), average and sturdy building types. For each of these types a maximum vibration level is recommended as a function of the frequency (see figure 27). In case of seldom or not frequent occurrence, these values can be multiplied with a factor of 2,5 and 1,5 respectively).

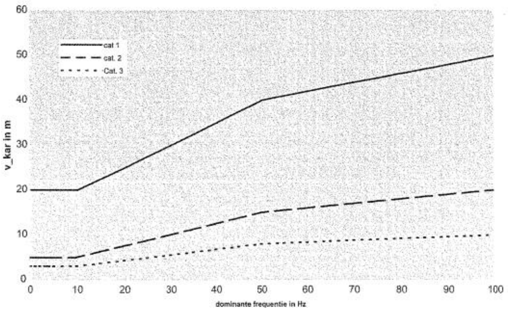


figure 27 Recommended max. levels for three classes of buildings (cat 1sturdy, 2: average, 3: sensitive).

8.4.2 Annoyance for humans

The sensitivity of humans for vibration lies roughly between 1 Hz and 100 Hz (see Wk and Wd curve in figure 28).

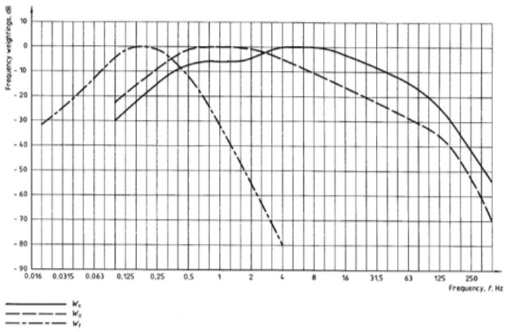


figure 28 Sensitivity of humans for horizontal (WD-curve) and vertical (Wk-curve) vibration (source ISO 2631).

8.4.3 Effect on performance of sensitive equipment

Far below the level that is accepted for annoyance, there can be effect on the functioning of vibration sensitive equipment and facilities. Optical microscopes require levels below 0,1 mm/s while grid electron microscopy and transmission electron microscopy requires levels of max 10 resp. 1 µm/s.

8.5 Mitigation measures

Mitigation measures can be divided into source related and propagation related. As is the case with noise, also source measures for vibration are more effective and efficient than measures in the propagation.

8.5.1 Measures at the source

Measures at the source mainly focus on measures at the track superstructure.

The following measures are well examined and widely applied to reduce the vibrations
- Under-sleeper pads
- Under-ballast mats
- Light mass-spring systems
- Heavy mass-spring systems

Maintenance of the track and the wheels in order to maintain a good quality of the surfaces and to keep irregularities small can also be assessed as a measure at the source.

Under-sleeper pads can reduce the vibration level up to 5 dB to 10 dB in the frequency range over 80 Hz. Under ballast mats may have a reduction effect of about 20-30 dB in the frequency range over 50 Hz. Mass-spring systems can result an insertion loss up to 30 dB. Especially heavy mass-spring systems reduce vibrations in the frequency range over 16 Hz.

Maintenance aspects may be:

Wheel geometry:
Improving the roundness of the wheels and the evenness of the rail is the first step. ABS systems prevent blocked braking and thus the occurrence of flats. Regular maintenance of the wheels prevents the build-up of irregularities in the roundness geometry. For freight wagons, a regular maintenance system is not easy to organize, but regular check of wheel defects is done through monitoring vibration levels of passing vehicles at dedicated measurement posts.

In areas where frequently narrow curves are driven, additional improvement is found by optimal steering of the axles in a bogie. Not only passive steering with spring embedded axles, but active steering with linking systems presents a major improvement in wheel wear and thus geometrical defects.

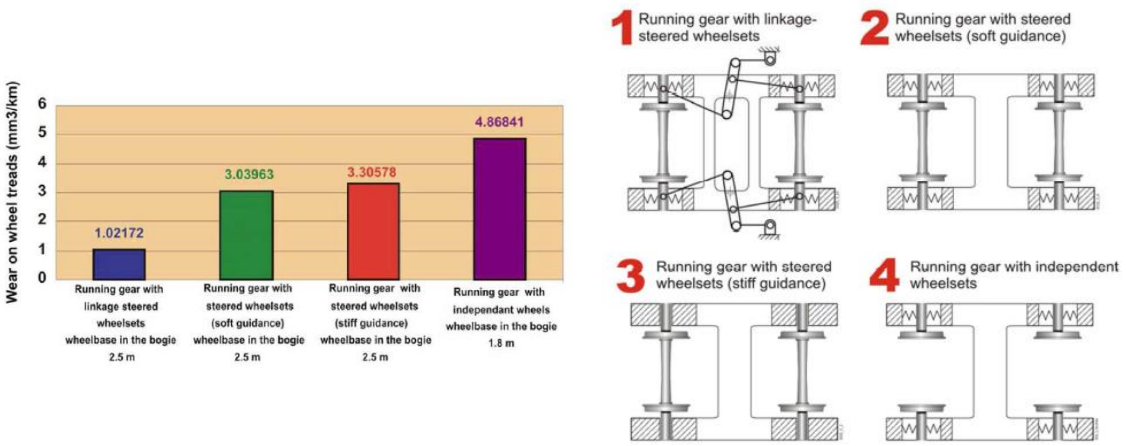


figure 29 *Effect of bogie geometry and axle steering on wear (ref [32]).*

Rail vehicle
Apart from the wheel geometry there are other aspects of the vehicle that define the vibrational effects. As already discussed in 8.3.1 the unsprung mass affects the effect of a wheel or rail defect on the vibrational levels. An example of this is the nose-suspended drive. Test in Switzerland showed that is extremely costly to improve the unsprung mass of an existing vehicle.

Rail geometry:
Removing unevenness in the rail surface can be done by grinding, but only for very small amplitudes. Bends in the rail can be repaired by tamping. The RIVAS project has found that this improves longer (> 3m) wavelengths. Tamping is also beneficial for variations in the stiffness of the rail support.

Varying track stiffness
With adequate design guidelines and regular maintenance stiffness variations can be identified and taken care of. However even in a optimal maintained situation, the sleeper-to-sleeper distance imposes a regular stiffness variation that may cause vibration. It is essential that the axle distance in a bogie is not a multiple of the sleeper distance. Bogies with more axles spread the load over a longer section and are therefore less susceptible for local stiffness variations.

8.5.2 Measures in the propagation

Inserting vibration isolation in the propagation path results in reduced levels at the receiver. This can be done by

- deep cuts and stiff walls in the propagation path may have an effect, but generally rather limited for the lower frequency range, where due to the long wavelength very extensive constructions are required. The reduction decreases fast with the distance to the wall/cut

8.5.3 Measures at the receiver

- Measures in buildings such as sprigs or elastic layers in the foundation are effective, but of course can often only be applied in new situations.

Note:
Vibration isolation is only effective above the resonance frequency *(* f_r) of the mass-spring system. below f_r, no effect is found and at f_r even an increase is to be expected.

Most of the propagation measures are actually applied in and around tunnels under build-up areas where the distance to the foundations of the buildings is small

8.5.4 Combined effects on noised and vibration

Since both noise and vibration issues occur in the vicinity of rail tracks, it is relevant to identify the concepts that are beneficial for both issues and when measures to improve one are worsening the other.

Measures in the propagation and at the reception point

Measures in the propagation and at the reception point generally have independent effects on both noise and vibration. However, the effect of propagation measures such as barriers or tunnels for noise can be limited by secondary immission of noise caused by ground born vibrations.

The following source related measures do affect both noise and vibration.

Measures at the source

- stiffer rail pads

  Application of stiffer rail pads in general increases the decay rate of vibrations of the rail which reduces sound emission from the rail. It however also increases the transmission of vibrations into the sleepers and consequently into the ground, that eventually leads to an increase in vibration levels.
- replacement of cast iron blocks

  Cast iron brake blocks increases wheel roughness in the audible range, but there are indications that also wheel irregularities in the longer wavelengths are affected. The wheel roughness spectra displayed in figure 5 already give an indication for that. Also in the RIVAS project it was noted that C.I. blocks also cause slight roughness increases at the longer wavelengths.
- wheel and rail maintenance

  Rail grinding reduces noise immission and to a lesser extent also vibration emission. Wheel maintenance removes irregularities and out-of-roundness and is beneficial for both. Irregularities in the acoustic range are quickly build up after maintenance in case of C.I. blocks.
- optimal bogie design

  Improved steering of the axles reduce the uneven wear of the wheel and rail surface, Positive effects for noise are found in the suppression of curve squeal.

9 Effect of low noise technology on safety and sustainability

9.1 Safety

Safety is a key element in the implementation of new technologies in the railway business. Freight wagons are applied under widely varying conditions all over Europe, in mountainous areas in the Alpine region, in extreme cold in northern Scandinavia or in extreme heat in mid-summers Italy and Greece.

Since it is shown that improving the noise emission of vehicles implies modification of the braking system, one might suspect that there exists a trade-off between sound reduction and safety.

Besides costs, this aspect was the main issue to be addressed by the EUROPE train project (ref [33]). This project has learned that:

- The braking capabilities of both LL blocks and K-blocks remain adequate under the severe conditions tested in the EUROPE train project.
- The wheel-wear with LL-blocks and K-blocks, especially the conicity, was slightly worse than in case of C.I. blocks, but well within the boundaries set by the UIC for safe usage (see figure 30).

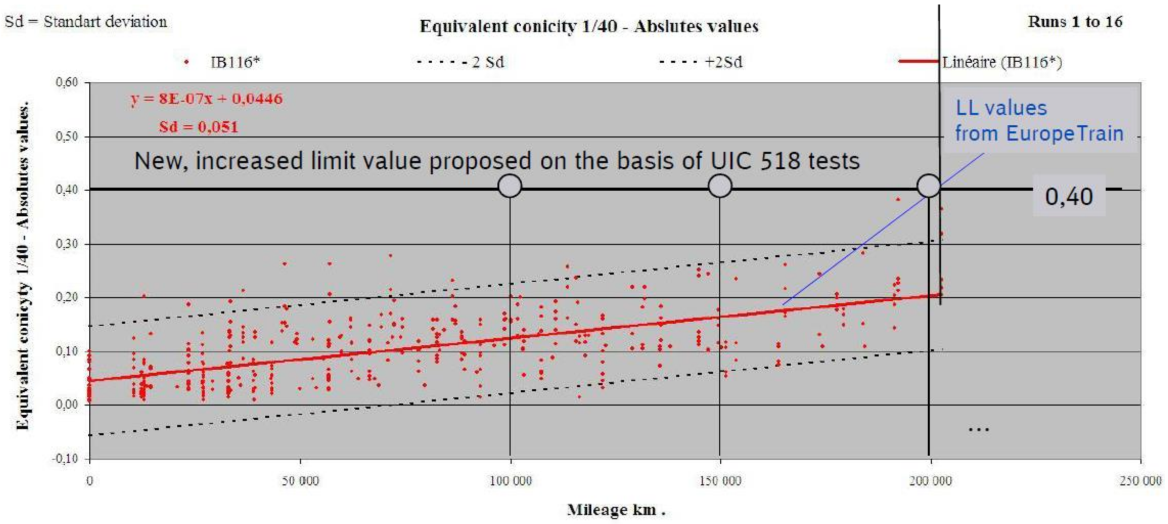


figure 30 Development equivalent conicity of the LL block in the EUROPE train project. After 200.000 km the value is on average about half of the UIC limit value.

Communication with experts learned that in general source related noise mitigation measures do not jeopardize safety of rail transport. An exception to this general conclusion is the application of a vibrating isolating structure inside the wheels of the German ICE, that was found to be susceptible to cracking and caused a serious accident when this cracking occurred next to a bridge pylon.

The case of rail grinding shows that mutual improvement of both noise and safety can be found since it smoothens the rail surface and this improves the noise emission (at least in case of smooth wheels) but also reduces the occurrence of head checks (i.e. the tiny tears in the hardened rail surface). A clear example of this approach is the scheduled grinding of the high speed track between Amsterdam and Antwerp, to control both noise and rail wear.

When in case of barriers the design regulations for objects near the track are followed, it is not to be expected that safety issues appear because of limited sight or other limitations. Positive experience is found for mini barriers. Although originally suspected to hinder free passage on the rail for workers, it was found that they are very effective in defining the safe and the unsafe area.

9.2 Sustainability

Also in terms of CO_2 emission and energy consumption we see no major contradictory effects. Rail transport is already a very efficient transport mode the more when regeneration of mechanical energy into electric energy takes place. One could say that Diesel driven trains are not only noisier due to the traction system, but also do not have the possibility to transfer mechanical energy into electric energy during braking.

10 Discussion and conclusions

- Railway noise ranks third in the environmental noise issues in Europe, after road and air traffic. Its relevance for society lies in the concentration of problems in hot spots near major freight transport corridors.
- The benefit to cost ratio of source related measures such as increasing the smoothness of wheel and rail surface and damping vibrations in wheel and rail is superior to effect related measures such as barriers and façade insulation. Retrofitting cast iron block braked trains is by far the economically best measure.
- The recent homologation of LL blocks creates a great potential for improving the benefit to costs ratio of composite brake blocks and thus of retrofitting freight wagons.
- The present TSI prevents the influx of new stock with noisy brake systems. It does however not affect the existing fleet of about 350.000 freight wagons in use in Europe unless such wagons are renewed or upgraded.
- Implementation of a Noise Differentiated Track Access Charge will invite wagon owners to retrofit their existing fleet. The current bonus however may be too less to have any significant effect.
- The effectivity of the NDTAC depends strongly on the magnitude of financial incentives and the geographical coverage of the system. The most effective one is direct subsidies to wagon owners. This may cause complications with respect to EU rules.
- The costs of the NDTAC depends strongly on the amount of bonus given but also on the administrative and technical system defined to implement the system
- A limited amount of noisy wagons can jeopardize the effect of low noise wagons. Therefore it is recommended to implement an additional NDTAC for 100% low noise trains. An alternative can be to ban all cast iron block brakes.
- Besides noise from railways also vibration is to be considered. Noise annoyance is larger in cases where also vibration is sensed.
- Noise mitigation measures at the source have to take vibration into account. Some measures have contradictory effects for noise and vibration; other measures are beneficial for both.

11 References

[1] COMMISSION DECISION of 21 February 2008 concerning a technical specification for interoperability relating to the ‘rolling stock’ sub-system of the trans-European high-speed rail system (notified under document number C(2008) 648), (2008/232/CE)

[2] COMMISSION DECISION of 4 April 2011 concerning the technical specifications of interoperability relating to the subsystem ‘rolling stock – noise’ of the trans-European conventional rail system, (2011/229/EU)

[3] European Parliament, DG for Internal Policies, “Reducing Railway noise pollution”, Report nr. IP/B/TRAN/FWC/2010-6/LOT4/C1/SC2, d.d. March 2012

[4] European Commission, DG TREN, “Impact assessment study on rail noise abatement measures addressing the existing fleets, Final Report”, reference TREN/A1/46-2005, December 10, 2007

[5] Umweltbundesambt, “Ermittlung des Standes der Technik der Geräuschemissionen europäischer Schienenfahrzeuge und deren Lärmminderungspotentiale mit Darstellung von Best-practice Beispiele“, Stefan Lutzenberger and Christian Gutmann, Müller-BBM, Bericht M81916/12, November 2012. (

[6] Umweltbundesambt, “Summary“, Stefan Lutzenberger, Müller-BBM, Bericht M81916/13, January 2013.

[7] F.Fischer, „the low noise freight wagon in Switzerland“, presentation on 5th IGNA meeting, Amsterdam April 2014.

[8] 7th annual workshop on railway noise reduction, 8 - 9 November 2011, UIC Headquarters, Paris. Presentations are available here.

[9] 8th UIC Railway Noise Workshop, 11 June 2013, UIC Headquarters, Paris. Downloads of presentations are available here.

[10] UIC, “Railway noise in Europe, a 2010 report of the state of the art”, J.Oertli and P.Hübner, d.d. September 2010

[11] UIC and SBB CFF FFS, “Rail Dampers, Acoustic Rail Grinding, Low Height Noise Barriers, A report on the state of the art”, , E Scossa-Romano and J Oertli, Bern, October, 2012.

[12] DB Netze, “Innovative Maßnahmen zum Lärm- und Erschütterungsschutz am Fahrweg“, Schlussbericht 15.06.2012

[13] Deutscher Bundestag,“ Umsetzung von Maßnahmen im Kampf gegen Schienenverkehrslärm“, Drucksache 17/13360, 30. 04. 2013

[14] Paul de Vos, “Real noise reduction of freight wagon retrofitting, Supporting communication on noise reduction, Synthesis report”, report nr. MD-AF20120302, version : 7January 2013. UIC

[15] Paul de Vos, “The real cost of railway noise mitigation, A risk assessment”, report nr. MD-AF20130168-LOK, 30 January 2013, UIC.

[16] European Commission, DG TREN, “Analysis of preconditions for the implementation and harmonisation of Noise-Differentiated Track Access Charges”, reference TREN/E2/287-2008, October 2009

[17] Stefan Dörsch, “State of the Art UIC-Project „Technology of Composite Brake Blocks“, Paris, 10.11.2009ANALYSES OF PRECONDITIONS FOR

[18] European Commission, DG TREN, “The implementation and harmonisation of noise-differentiated track access charges, final report”, TREN/E2/287-2008, KCW | Steer Davies Gleave | TU Berlin, October 2009.

[19] Bundesamt für Verkehr BAV, “Lärmsanierung der Eisenbahnen, Standbericht 2012”, Dezember 2012

[20] Produktkatalog Netzzugang, „Zugtrasse, Zugfahrt und sonstige Leistungen 2013“, der ÖBB-Infrastruktur AG

[21] DG MOVE, http://ec.europa.eu/transport/media/consultations/2013-railnoise_en.htm

[22] DG MOVE,”ROADMAP Effective reduction of noise generated by rail freight wagons in the European Union”, 04/2013

[23] COWI, “Effective reduction of noise generated by rail freight wagons in the European Union, preliminary findings of the public and stakeholder consultation”, Brussels, September 10, 2013

[24] U.Reichart et al, “Determination of the state of the art the noise emissions of European rail Vehicles & TSI Noise Revision”, AIA DAGA Merano, 2013 http://www.deutschebahn.com/de/hidden_rss/pi_rss/3984248/ubd20130531.html

[25] SBB, Leistungskatalog Infrastruktur 2013, Gültig für die Bestellung und Durchführung von Verkehren vom 1. Januar bis 14. Dezember 2013, März 2013, http://www.sbb.ch/content/sbb/de/desktop/sbb-konzern/sbb-als-geschaeftspartner/zugang-zum-bahn-netz/onestopshop/leistungen-preise/_jcr_content/contentPar/downloadlist/downloadList/leistungskatalog_sbb_1.spooler.download.pdf

[26] RIVAS project website: http://www.rivas-project.eu/index.php?id=9

[27] Anita Gidlöf-Gunnarsson et al. “Railway noise annoyance and the importance of number of trains, ground vibration, and building situational factors”,

[28] H.Heckelmüller, “Acoustic Pass-by tests of the Europe train”, DB systeemtechnik GmbH T.TVI32 (3). Munich, October 22nd, 2012.

[29] Eric Berggren, Trafikverket, EBER Dynamics, “Stiffness and irregularity measurement”, 3rd RIVAS Workshop.

[30] Ph. Huber, B. Nelain and R. Millier, “Experimental analysis of SBB ground vibration measurements and vehicle data”, RIVAS - Mitigation measures on vehicles, (WPS).

[31] A.Ziegler, M.Birchmeier and R.Müller, „VIBRA-1-2-3: Einfaches Model für die Erschütterungs- und Körperschallberechnung beim Schienenverkehr“, Lärmbekämpfung nr. 2, Train Induced Ground Vibration –

[32] B. Asmussen, “Optimised Rolling Stock Mitigation Measures and their Parameters”, Deliverable D5.4 RIVAS, date: März 2013.

[33] Dr. Stefan Dörsch, DB Systemtechnik GmbH, „Europetrain and the Homologation of a Low Noise Brake System with LL Brake Blocks“, Speaker UIC Working group B126.13, CBB, 8th UIC Railway Noise Workshop, Paris June 2013.

12 Results from State-of-the-art study TSI limits (UBA)

The German Environmental Agency (Umweltbundesamt or UBA) has commissioned Müller-BBM GmbH to investigate the state-of-the-art of noise control for new and renewed rolling stock. The study is reported in [5] with an English summary in [6].

12.1 Definition of state-of-the-art

The proposed limit values are based on the level of the state-of-the-art.

Four levels of state-of-the-art according to ISO 11689 and EN ISO 12100 have been distinguished:

1. Low noise control performance level that is exceeded by only 17,5% of the investigated vehicles
2. Moderate state-of-the-art defined as the median of the existing noise emission (i.e. 50% of the existing vehicles comply with this level)
3. Ambitious state-of-the-art defined as the lower quartile of the existing noise emission (25% fraction of compliance)
4. High noise control performance level that selects the quietest 10% of the investigated vehicles

At this moment studies are performed to be able to determine these levels for different stock and different conditions.
On base of these data the proposed TSI limit values were derived as follows:

1. Short term applicable limit value = ambitious state-of-the-art value increased with a measurement uncertainty of 2 dB. This level however must not exceed the low noise control performance level.
2. Medium term applicable limit value = High noise control performance level increased with a measurement uncertainty of 2 dB.

12.2 Data base

The study used a well-founded data base with values from acoustic type testing of newly homologated railway vehicles according to the TSI 2006 and 2011 procedures. The values were used to determine the 25 % and the 10% cumulative levels that serve as basis for the ambitious state-of-the-art level and the high-noise-control level.

table VIII *Overview of the data base with noise levels used in the UBA study*

category	noise	TSI limit dB(A)	average dB(A)	standard-deviation dB	average of the most quiet 33 %	median dB(A)	lower quartile dB(A)	upper quartile dB(A)	number of data (overall 378)
diesel locomotives	standstill noise	75	68.1	2.8	64.7	69.0	65.5	70.5	33
	starting noise P>=2000 kW	89	82.7	3.3	79.5	82.5	81.0	84.0	16
	starting noise P<2000 kW	86	83.4	2.1	81.2	84.0	82.5	85.0	18
	pass-by noise 80 km/h	85	83.7	1.5	81.9	84.0	82.5	85.0	21
electric locomotives	standstill noise	75	62.2	4.3	57.8	61.0	57.8	66.3	12
	starting noise P>=4500 kW	85	81.9	1.2	80.7	82.0	81.0	82.5	9
	starting noise P<4500 kW	82	80.3	0.6	80.0	80.0	-	-	3
	pass-by noise 80 km/h	85	83.5	1.4	82.3	84.0	82.5	84.3	10
EMU	standstill noise	68	55.4	5.0	50.5	55.0	52.0	59.0	33
	starting noise	82	73.8	3.2	70.9	72.0	71.0	76.5	33
	pass-by noise 80 km/h	81	76.2	1.4	74.9	76.0	75.0	77.0	24
DMU	standstill noise	73	66.9	4.0	62.4	68.5	63.0	70.0	14
	starting noise P>=500 kW	85	79.4	3.3	77.0	77.0	77.0	83.0	5
	starting noise P<500 kW	83	81.1	2.1	78.7	82.0	79.5	83.0	9
	pass-by noise 80 km/h	82	78.9	2.4	77.0	79.0	78.0	80.5	10
passenger coaches	standstill noise	65	60.1	4.7	57.0	62.0	59.0	63.0	7
	pass-by noise 80 km/h	80	76.8	0.8	76.0	77.0	76.0	77.5	5
freight wagons	standstill noise	65	-	-	-	-	-	-	0
	new wagons, apl up to 0.15 1/m, 80 km/h	82	78.2	2.8	75.5	78.5	76.8	80.3	6
	new wagons, apl higher than 0.15 1/m up to 0.275 1/m, 80 km/h	83	80.1	2.4	77.5	80.0	78.0	82.0	43
	new wagons, apl higher than 0.275 1/m, 80 km/h	85	80.9	2.8	77.6	81.5	78.3	83.0	32
	renewed wagons, apl up to 0.15 1/m, 80 km/h	84	83.0	-	-	-	-	-	1
	renewed wagons, apl higher than 0.15 1/m up to 0.275 1/m, 80 km/h	85	-	-	-	-	-	-	0
	renewed wagons, apl higher than 0.275 1/m, 80 km/h	87	-	-	-	-	-	-	0
	renewed wagons, apl bis 0.15 1/m, 190 km/h recalculated 80 km/h	82	80.0	0.0	80.0	-	-	-	2
	new wagons, apl higher than 0.15 1/m up to 0.275 1/m, 190 km/h recalculated 80 km/h	83	81.9	1.1	81.0	82.0	81.8	83.0	14
	new wagons, apl higher than 0.275 1/m, 190 km/h recalculated 80 km/h	85	81.7	2.9	78.7	83.0	80.0	83.5	17
	renewed wagons, apl higher than 0.15 1/m, 190 km/h recalculated 80 km/h	84	83.0	-	-	-	-	-	1
	renewed wagons, apl higher than 0.15 1/m up to 0.275 1/m, 190 km/h recalculated 80 km	85	-	-	-	-	-	-	0
	renewed wagons, apl higher than 0.275 1/m, 190 km/h recalculated 80 km/h	87	-	-	-	-	-	-	0

The study included pass-by levels, stationary levels and starting levels for the different types of stock. An example of the data is given in figure 31 where pass-by levels of freight wagons are given as a function of the number of axles per m. The less axles per length, the lower are the expected pass-by levels and related to that the TSI limit values. The spread in the noise emission of freight wagons is significant.

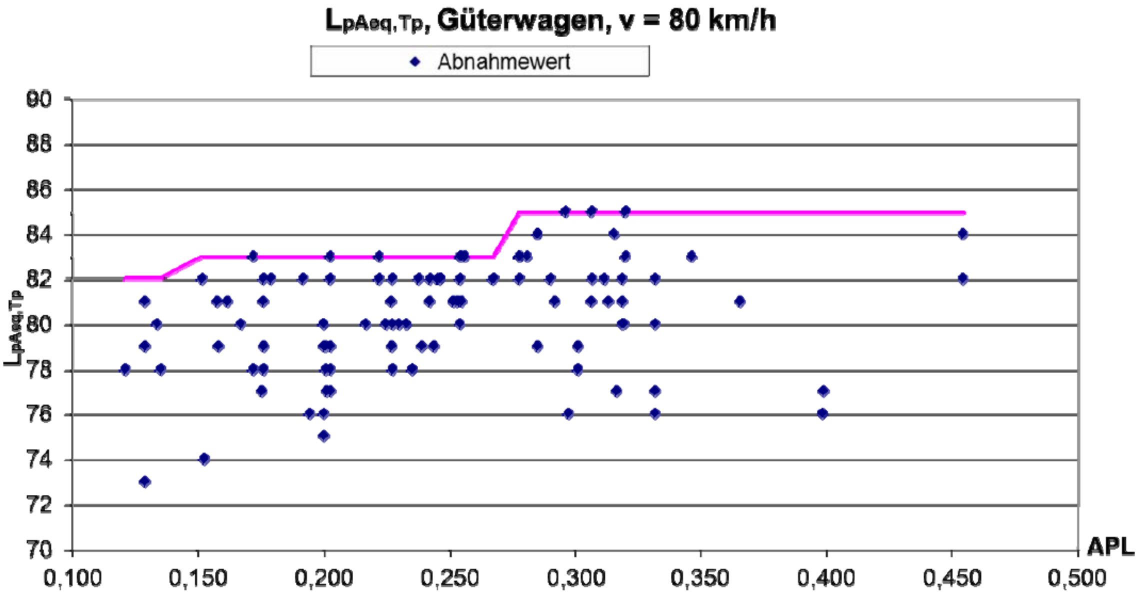


figure 31 *Test results of pass-by noise levels of freight wagons under TSI conditions. The pink line presents the present limit value for new wagons as a function of the number of axles/meter.*

In order to be able to compare different axle configurations, a normalization is applied to a reference value of 0.225 axle/m. Normalization is based on the following formula:

(1) $$L_{pAeq,Tp}(APL_{ref}) = L_{pAeq,Tp}(APL_{wag}) - 10 \cdot log\left(\frac{APL_{wag}}{APL_{ref}}\right) \quad with\ APL_{ref} = 0.225\ /m$$

The resulting data, configured in a histogram is given below (see figure 32).

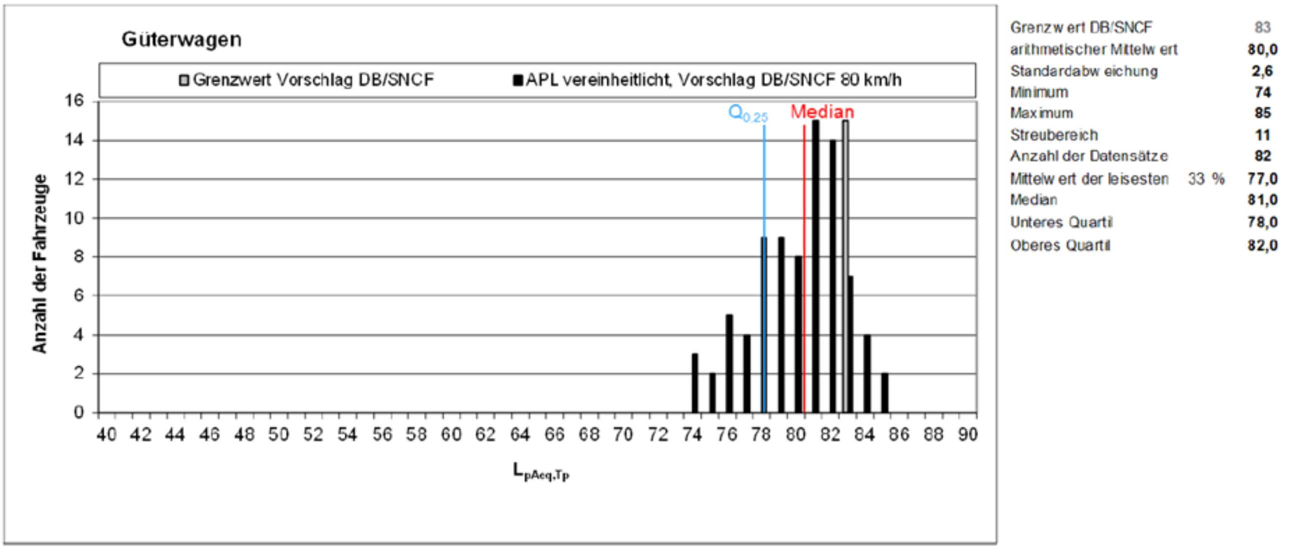


figure 32 *Histogram of test results of 82 pass-by noise levels of freight wagons under TSI conditions, normalized to 0.225 axle/m. Indicated are also the median and the 25% percentile value.*

Based on the results of the statistical analysis of the data base with the noise levels and the definitions formulated in paragraph 12.1, the following proposal for the limit values for the TSI revision are formulated (see table IX)

table IX *Overview of the present TSI limit values and the proposals formulated in the UBA study. Short term refers to the 25% lowest values found in the study, mid term refers to the 10% lowest values found in the study. Both are increased with 2 dB for measurement uncertainty.*

Train category	**Stationary level [$L_{pAeq,T}$ in dB]**			**Starting level [L_{pAFmax} in dB]**			**Pass-by [$L_{pAeq,Tp}$ in dB]**		
Limit value	**present**	**short term**	**mid term**	**present**	**short term**	**mid term**	**present**	**short term**	**mid term**
Diesel-electric locomotive	75	68	67		80	80	85	85	83
Diesel-hydraulic locomotive					84	84			
Electric locomotive (P < 4500 KW)		63	59		82	81	85	85	83
Electric locomotive (P >4500 KW)					83	81			
Diesel multiple unit		65	63		79	79	82	80	77
Electric multiple unit		57	53		73	73	80	77	77
Passenger coach		57	53	--	--	--	80	77	76
Freight wagon	--	--	--	--	--	--	82/83/85	80*	78*