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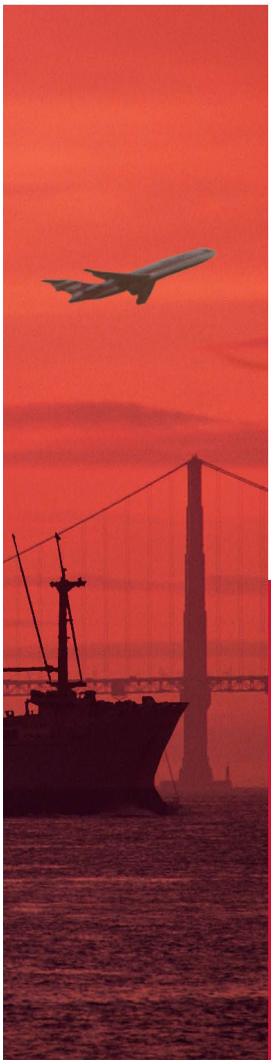
DIRECTORATE-GENERAL FOR INTERNAL POLICIES

POLICY DEPARTMENT B
STRUCTURAL AND COHESION POLICIES



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REDUCING RAILWAY NOISE POLLUTION

STUDY

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TRANSPORT AND TOURISM

REDUCING RAILWAY NOISE POLLUTION

STUDY

This document was requested by the European Parliament's Committee on Transport and Tourism.

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Abstract

12 million EU inhabitants are affected by railway noise during the day and 9 million during the night. This study lists measures, funding and regulations to reduce it. The introduction of modern rolling stock will lower noise most significantly. In the short run, the replacement of cast iron by composite brake blocks on rail freight cars is most important. Developing a regulation scheme for a staged process towards low-noise rolling stock is the heart of a rail noise abatement strategy.

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CONTENTS

LIST OF ABBREVIATIONS

AEA	AEA Technology Rail BV, Netherlands
BIMSchV	Bundes-Immissions-Schutz-Verordnung (Traffic Noise Ordinance of Germany)
BMVIT	Bundesministerium für Verkehr, Innovation und Technologie (Federal Minister for Transport, Innovation and Technology of Austria)
BS	British Standard
BVU	Beratergruppe Verkehr + Umwelt (Consultants for Transport + Environment)
CER	Community of European Railway and Infrastructure Companies
DB	German Rail (Deutsche Bahn)
DEFRA	Department for Environment, Food and Rural Affairs of UK
DG	Directorate-General of the European Commission
DG ENTR	Directorate-General Entreprise and Industry
DG ENV	Directorate-General Environment
DG Research	Directorate-General Research
DG TREN	Directorate-General Transport and Energy
DIR	Directive
EC	European Council
ECML	East Coast Main Line
EEA	European Environment Agency
EMU	Electric multiple unit
EP	European Parliament
ERFA	European Rail Freight Association
ETC LUSI	European Topic Centre on Land Use and Spatial Information
EU	European Union
FM	Friction modifier
FS	National railway of Italy - Trenitalia (former Ferrovia dello Stato)
K-block	Composite brake block

L_{DAY}	Average Noise Level Index day time
L_{DEN}	Average Noise Level Index total day
LL-block	Low-low brake block
L_{NIGHT}	Average Noise Level Index night time
NDTAC	Noise Depending Track Access Charge
ÖBB	Österreichische Bundesbahn (Federal Railway of Austria)
PPG	Planning Policy Guidance
RENFE	Spanish Railways (Red Nacional de Ferrocarriles Españoles)
RFI	Italian railway infrastructure management company - (Rete Ferroviaria Italiana)
SBB	Swiss Federal Railway (Schweizer Bundesbahn)
STIB	Municiple Public transportation company of Brussels (Société des transport intercommunaux de Bruxelles
TAC	Track Access Charge
TOC	Train Operating Company
TOR	Top of Rail
TSI	Technical Specification for Interoperability
UIC	International Union of Railways (Union Internationale des Chemins de Fer)
UIP	International Union of Private Wagons (Union Internationale des Wagons Privé)
UIRR	International Union of combined Road-Rail transport companies (Union internationale des sociétés de transport combiné Rail-Route)
UITP	International Assosiation of Public Transport
UNIFE	Association of the European Rail Industry
VDV	Association of German Transport Companies (Verband Deutscher Verkehrsunternehmen)
VPI	German Association of private wagon owners (Vereinigung der Privatgüterwagen-Interessenten)
WCML	West Coast Main Line
WHO	World Health Organisation

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

According to Member State reports compiled by the European Environment Agency (EEA) in 2010, railway noise affects about 12 million EU inhabitants at day time, with a noise exposure above 55 dB(A), and about 9 million at night time, with a noise exposure above 50 dB(A). In fact, the real figures are undoubtedly higher since the EEA's European noise mapping initiative concentrates on agglomerations with over 250,000 inhabitants and on main railway lines with over 60,000 trains per year. The railway noise problem is concentrated in central Europe, where the majority of the affected citizens live and the volume of rail freight transport is highest (primarily Germany, Italy and Switzerland, but traffic density is high also in Poland, Austria, the Netherlands and France, and noise mapping indicates that significant population is affected in Belgium and Luxembourg).

Noise is an annoying phenomenon, contaminating the environment and adversely affecting the health of people exposed to high ambient noise levels above 70 dB(A) – or even less. The discussion about railway noise has become very important in several European countries as railway transport increases and plays a more important role in greening transportation. For implementing the sustainability goals formulated in the EC 2011 Transport White Paper and the Greening of Transport package, the environmental impact (carbon, energy, noise, etc.) of railway operations needs to be minimised to maintain rail's position as a green transport mode – and thereby promote a modal shift to rail, to reduce the environmental impact of transport overall.

In order to analyse the noise situation in Europe, following current EC legislation, the Member States have to provide noise maps and noise action plans. Noise action plans describe the measures taken to lower environmental noise for identified affected inhabitants. However, legal conditions differ widely across Europe as Member States have different limits or threshold limits for environmental noise emissions, and usually these limits are tested only when building new infrastructure or during major redevelopment.

In general, three different sources of railway noise are identified:

- Engine noise
- Rolling noise
- Aerodynamic noise.

Railway noise is largely a problem of freight trains and trains containing older wagons or engines, and is a particularly severe problem during the night. Rolling noise is generally higher from poorly maintained rail vehicles, and from trains running on poorly maintained infrastructure. Aerodynamic noise is particularly relevant for high speed lines where, in most cases, noise limiting measures like noise barriers are implemented; noise barriers reduce the impact of rolling noise, but are usually too low to have any effect on noise originating at the pantograph. Engine noise is most relevant at lower speeds up to about 30 km/h, rolling noise above 30 km/h and aerodynamic noise dominates above 200 km/h. The most important noise source is rolling noise, which affects all kinds of train.

To reduce railway noise pollution, passive measures at the place of disturbance can be distinguished from active measures at the noise source. The most important passive methods used to reduce the impact of railway noise on the environment are noise protection walls and insulating windows, and for the most part action plans and investments of the Member States concentrate on these methods. However, they are only locally effective, requiring huge investments to protect wider parts of railway networks.

In contrast, source-driven measures lower noise across the whole railway system if they are widely introduced. As an example, the problem of noisy rail freight cars can be reduced by the replacement of cast iron brake blocks by composite brake blocks. This is currently being investigated by the railway industry and would affect about 370,000 old freight wagons. Also, wheel absorbers, aerodynamic design of pantographs and noise insulation of traction equipment (e.g., locomotive engines) are measures to reduce noise at source. According to the current Technical Standard for Interoperability (TSI Noise), rolling stock which was introduced since the year 2000 (including engines and passenger coaches or passenger power cars) are required to lower noise emissions by about 10 dB(A) compared to the equipment of the 1960s and 1970s.

In the authors' opinion, noise should ideally be reduced at the source because these measures have a network-wide effect. Where track infrastructure causes increased noise levels (e.g., structure-radiated noise from viaducts or curve squeal in narrow radius curves), or where the local environment is particularly sensitive to noise (e.g., areas of natural beauty or urban environments with residences very close to the railway line) then additional trackside noise mitigation measures may be necessary. Such measures include friction modifiers, rail dampers, floating (or isolated) slab tracks and of course noise bunds and barriers in various heights. Vehicles and track should all be maintained to eliminate unnecessary sources of noise, e.g., corrugation.

Retrofitting of existing rail freight cars with composite K- or (if approved) LL-brake blocks is the most cost-effective measure on the vehicle side. Additional measures on the vehicle side are wheel absorbers, vehicle-mounted friction modifiers (most effective in urban or sub-urban networks) and (for high-speed trains) aerodynamically optimised pantographs (e.g., shielding or coating). These measures are effective network-wide. Additional research could be made for modified wheel constructions as they are very effective but experiences with accidents lead to reluctance to use new wheel constructions replacing mono block types.

On the infrastructure side, friction modifiers, rail dampers and slab track are cost-effective measures for reducing noise. In densely populated environments and highly trafficked railway sections, the use of noise barriers or coverings cannot be avoided. However, if there is a wide introduction of vehicle-related measures, the number of noise barriers or covers can shrink significantly.

Additionally, wheels and rails need frequent monitoring and maintenance to reduce noise. The surface quality of wheels and rails is a key factor determining rolling noise and deteriorates naturally over time; severely damaged surfaces (out of round wheels or corrugated tracks) are a major noise source.

The European Parliament and European Commission try to encourage the Member States to take more action to reduce railway noise, e.g., by introducing noise-dependent track pricing schemes. Such economic incentives (rail track charging differentiated according to noise emissions) can help to:

- stimulate the use of low-noise technology for the rolling stock;
- foster the use of routes which avoid hot spots for noise;
- foster noise-reducing operational routines and speeds in sensitive areas.

On the regulative side, the Japanese top-runner scheme[1] is an example to come to a long term reduction of noise. The TSI Noise is an appropriate basis for noise regulation in the medium and long term. Presently, the standards for noise emissions are valid for new or modified vehicles only. In the medium and long-term view the TSI can become compulsory for all vehicles. The noise levels in TSI Noise should also be lowered from time to time according to technical development similar to the Japanese example.

In principle, there are three approaches to a noise-dependent track pricing, and each can be configured as a mix of bonus and penalty components:

1. The train-related noise emissions can be measured at critical points in densely populated areas and/or low distances to residential zones and then allocated to the trains causing the noise. The noise mark-up for the track charge then would vary with the local noise level and eventually with the noise exposure of the residential population.

2. The wagons can be classified into noise categories and charged with a noise mark-up or granted with a bonus according to the noise category. The train operator would pay the charge to, or get the bonus from, the infrastructure manager, and pass the bill or grant the bonus to the car owner or operator.

3. Trains can be classified on the basis of the rail car types from which they are composed. In the case of freight trains, the emission category of a train could vary with every change of the train composition in marshalling yards.

The first approach would directly correspond to the polluter-pays principle, but causes high transaction costs for implementation and control. The second approach is the most simple and easy to implement, but neglects the nature of rail noise; a high percentage of noise-reduced cars is required in order to achieve a substantial reduction of train-related emissions. The third approach does not require a sophisticated payment system but needs a functioning (eventually international) information system for wagon control.

The charging schemes can be embedded into appropriate legislative regulations to set a clear framework for long-term activities to reduce railway noise. The following instruments for regulation are possible:

- Limits for stationary and pass-by noise for freight wagons and locomotives;

- Operation and maintenance rules;

- Noise-limiting technology for new rolling stock according to the Japanese top-runner scheme. This scheme aims at reducing energy consumption and climate impact by dynamic setting of emission targets on the basis of current best practice ("top runners' performance");

- Retrofitting programmes for vehicles currently in service (phased obligation schedule).

[1] This scheme aims at reducing energy consumption and climate impact by dynamic setting of emission targets on the basis of current best practice ("top runners' performance").

Noise depending track access charges (NDTAC) should be introduced to encourage the vehicle owners to invest in noise reduction measures. At the first stage they should focus on rail freight wagons but the scheme can include other vehicles or measures later or focus on noise limits without regard to measure to reach the limit.

Importantly, NDTAC should be realised so that no burdens for competitiveness for the rail sector appear. Investment and higher operational costs should be covered. NDTAC should be harmonised in the Member States and each vehicle operating in a national network should be included (also foreign vehicles). To meet the fact that significant noise reductions are only to be achieved if trains are completely equipped with low noise equipment, the NDTAC should favour trains which are nearly fully equiped with these vehicles. To avoid losses in competitiveness lower TAC for low noise vehicles a substantial part should be financed by the Member States. To motivate an early switch to low noise vehicles or retrofitting of existing freight cars also direct funding of investments should be considered for a few years.

Summary of recommendations

As rail freight wagons commonly travel across wider international distances, it is essential to harmonise noise legislation policies across Europe. As a result the authors recommend focusing on the following actions:

- Retrofitting the existing freight wagon fleet with low noise braking systems especially by replacing the cast iron by composite brake blocks as the most important and effective first step of source related noise reduction measures.

- Establishing funding schemes to cover the retrofitting and additional operating costs of the new noise reduction technologies to avoid a reduction of the rail sector’s competitiveness; a substantial part of costs should be covered by the Member States, since quieter trains will reduce the need for, and therefore the cost of, infrastructure noise mitigation measures.

- Introducing rail track charging systems which differentiate the train charges according to the noise category of a train. The noise classification of a train should be determined by the wagon with the highest noise emission level.

- Making activities concerning NDTAC or noise limit regulation depending on the same actions in road transport to avoid losses of competitiveness for the rail sector.

- Making noise limits by TSI Noise ([TSI Noise 2011] also compulsory for existing rolling stock 10 or 12 years after introduction of funding schemes and noise limits for new rolling stock.

- Adjusting limits of TSI Noise in a phased process for a medium and long-run future to foster the development of new noise reduction technologies.

- Monitoring and maintenance of noise development due to abrasion to assure low noise levels also during operation over long periods.

1. DEFINITIONS AND EFFECTS OF NOISE

KEY FINDINGS

- Noise is **sound which is unwelcome** but the annoyingness depends on the individual.
- Noise can be **harmful.**
- The **noise pressure level** is measured in **dB(A)** (deci Bel) with a logarithmic scale.
- **10 dB(A)** increase of noise represents a **ten-fold increase** of noise pressure.
- A change of **3 dB(A) is detectable by the human ear**, with it representing a **doubling of noise pressure.**
- Local **resistance against railway noise increases** especially in Central Europe where most rail freight transport is realised.
- The majority of rail transport is realised in **France, Germany and Poland.**

1.1. Noise and railway noise

Noise is sound that is unwelcome, because of its volume or structure, and can be harmful. Since not everyone responds equally to sounds and the perception is dependent on constitution and mood, noise also contains a subjective component. Therefore, there is no fixed value at which a sound is perceived as noise.

Rail noise is sound emissions arising from the operation of trains and trams. There are a wide variety of sources and causes of rail noise, such as locomotives accelerating, freight wagons braking, squeal noise in curves, vibration from rail corrugation and out-of-round wheels, vehicle coupling in shunting yards, and even the pantographs of high-speed trains.

1.2. Measurement of noise

Sound is vibrations in the air around us causing our eardrum to vibrate. The human ear is sensitive to frequencies in the range 20 Hz – 20 kHz. These vibrations in the air cause pressure changes, and the change in pressure is called sound pressure. Sound, and therefore noise, is measured by measuring the sound pressure. How loud we perceive the sound depends on sound pressure level and duration, but also on frequency and bandwidth. Psychology also affects our perception and tolerance of sound. Besides sound pressure level, the duration of the sound, the time of day, the composition and frequency of the sound must be considered in the assessment of noise. Also, the tonality ("squeak") and impulsiveness ("hammer") play a role.

The measurement of sound pressure level, usually referred to as volume, has the physical unit Bel. Normally the term decibel (dB) (i.e., one tenth of a Bel) is used. The additive (A) behind the unit dB expresses that the noise measurement is A-weighted (a filter defined by IEC 61672:2003 norm), i.e., tuned to the perception of the human ear.

While the human ear can perceive an increase in sound volume as sound energy increases, the relationship is logarithmic. If two identical 10 dB noise sources are placed together, the perceived increase is not a doubling of the volume but rather a 3 dB increase. If ten such noise sources were placed together, the increase would be 10 dB – multiplying the sound energy (and thus the real exposure) by a factor of ten, multiplies the perceived sound volume by a factor of two.

As such, a sound level increase from 45 dB to 55 dB may not look like much on paper, but it represents a ten-fold increase in sound energy and its impact on human health. Humans are usually able to sense a change of 3 dB in sound level, which corresponds to a factor-of-two change in sound energy, but that is about the limit of sensitivity. Measures to reduce noise levels by less than 3 dB would, by themselves, be of no real value.

Sound can also be transmitted as vibration through the ground and directly into the body, and this is also a form of noise pollution.

Three standard measures of average sound pressure level, defined by ISO 1996-2:1987, are L_{day}, $L_{evening}$ and L_{night}, where day is typically 07.00 – 19.00, evening is 19.00 – 23.00, and night is 23.00 – 07.00; these are long-term average A-weighted measurements of all days, evenings and nights, respectively, over the course of a year. L_{den} is a weighted average of these three, adding 5 dB(A) to $L_{evening}$ and 10 dB(A) to L_{night}; this is defined in Annex 1 of European Commission Directive 2002/49/EC. The UK uses also $L_{Aeq,16h}$ which is an average of L_{day} and $L_{evening}$.

1.3. Effects of noise

The faintest audible sound is at 0 dB(A); the pain threshold is about 120 dB(A). If it is louder than 120 dB(A), there is a risk of injury. At a detonated blast of 150 dB(A) the eardrum can rupture.

Noise exposure during sleep such as night flight noise is regarded as particularly critical. So night noise causes health hazards already at individual levels below 45 dB(A), if the difference between the individual level and the background noise is more than 3 dB.

Noise above 55 dB(A) is considered as noise pollution. If noise above this level lasts for an extended period of time, the efficiency and well-being of a person will be reduced. Noise in the range 65 to 75 dB(A) causes stress to the body. This can lead to arterial hypertension (high blood pressure), cardiovascular disease and myocardial infarction (heart attack). Noise can also provide for a reduction of gastric secretion and be the cause of stomach ulcers [WHO JRC 2011].

In the workplace, above 85 dB(A), a contractor is responsible to ensure his employees have suitable hearing protection available. If the noise level is over 90 dB(A), employees must wear hearing protection.

1.4. Results of noise mapping

According to Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise, all Member States have to provide noise maps and noise action plans (for details see section 2.2 on page 29).

The report on the implementation of Directive 2002/49/EC [EC 2011] summarises the number of affected people by environmental noise in the first round of strategic noise mapping (see Table 1).

Table 1: Affected people by environmental noise according to first round of noise mapping

SECTION	NUMBER OF AFFECTED PEOPLE BY NOISE LEVELS ABOVE 55 DB(A) L_{DEN} [MILLION]	NUMBER OF AFFECTED PEOPLE BY NOISE LEVELS ABOVE 50 DB(A) L_{NIGHT} [MILLION]
Agglomerations > 250,000 inhabitants		
All roads	55.8	40.1
All railways	6.3	4.5
Industrial zones	3.3	1.8
Important infrastructures outside agglomerations		
Main roads	34	25.4
Main railways	5.4	4.5
Main airports	1	0.3

Source: EC 2011, Table 2.

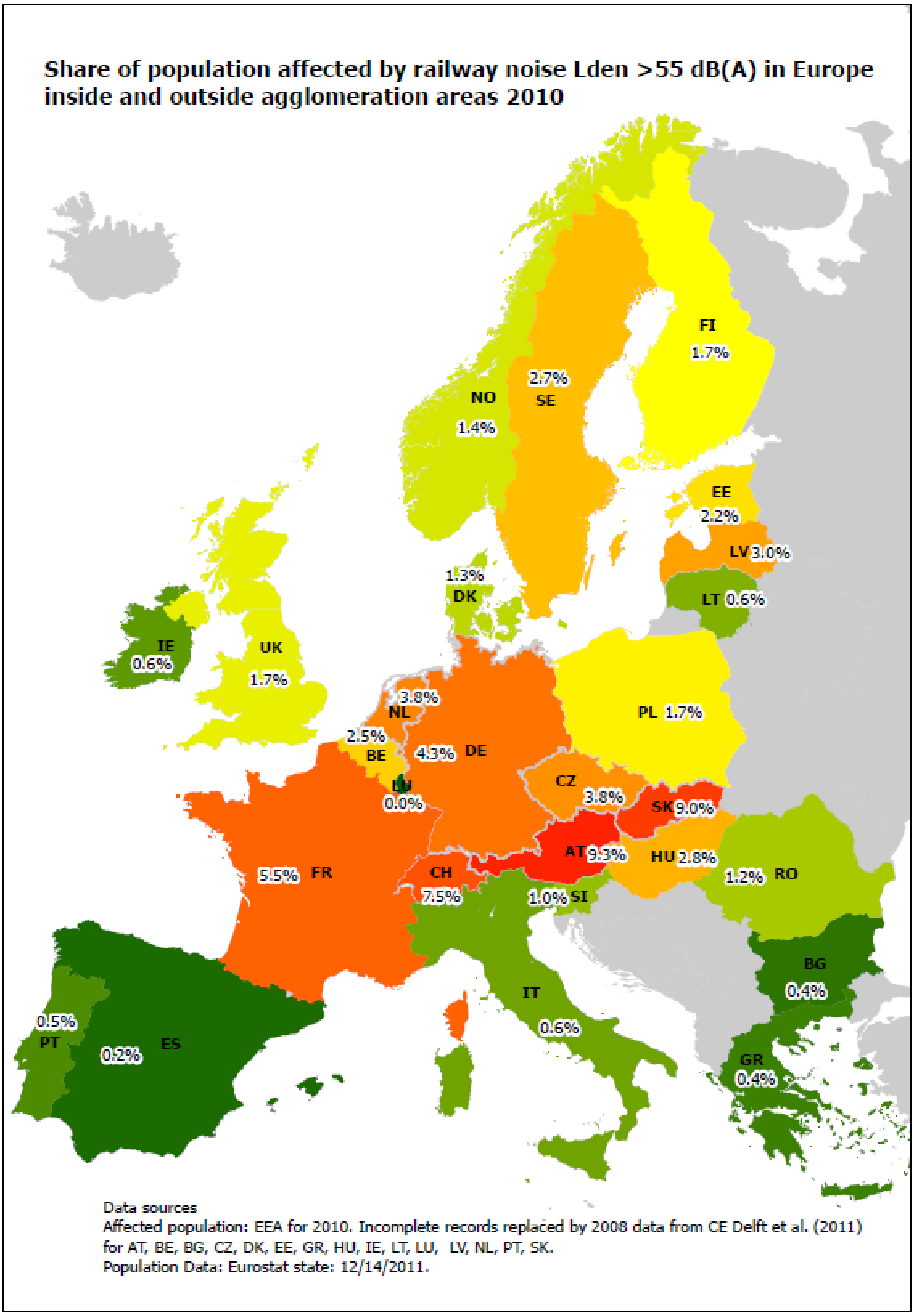
The European Environment Agency (EEA) and the European Topic Centre on Land Use and Spatial Information (ETC LUSI) publishes noise maps on the internet according to Directive 2002/49/EG. The maps are available at [NOISE 2011]. The maps present the population in each country affected by rail noise (distinguishing agglomerations from main lines outside agglomerations). Also, affected population by industry, main road traffic and aviation can be identified. A spreadsheet[2] shows detailed and aggregated figures according to data sent until 30 June 2010. In Annex I of this study (pages 120 - 121) the results of noise mapping for the rail sector are shown for all countries inside and outside agglomerations.

According to EEA data, the following states in Europe are mostly affected by railway noise according to the share of their population that is affected by railway noise with more than 55 dB(A) L_{DEN}: Austria (9.3%), Slovakia (9.0%), Switzerland (7.5%), France (5.5%), Germany (4.3%), Czech Republic (3.8%), the Netherlands (3.8%) and Latvia (3.0%) (see Figure 1).

The following Figure 1 shows the share of affected people in each European country according to the figures delivered by the states to fulfil the requirements of Directive 2002/49/EC.

[2] Summary of noise exposure data – file name is "END_DF4_Results_101005_ETCLUSI_inclBG&SW.xls"

Figure 1: Share of people affected by railway noise in each European country according to EEA data



Source: Figure elaborated by the authors with EEA data.

Analysing the figures in Annex I, it can be seen that about 85% of people affected by railway noise (over 55 dB(A) L_{DEN} or 50 dB(A) L_{NIGHT}) are located in the following six countries in Europe: Germany, France, UK, Austria, Poland and Switzerland. About 60% are located in Germany and France.

If only areas outside agglomerations are considered the figures change significantly. In this case the six countries mentioned above represent 89% of affected people. The share of people affected in agglomerations and outside agglomerations differ very much between the countries. In Germany about 75% of affected people live outside agglomerations whereas in Poland this share is 0 (Switzerland: 15%, Austria: 59%, the UK: 17%, France: 44%).

Although the number of people affected by rail noise is about eight times smaller than that affected by road transport noise, the total number remains high. In total 11.8 million inhabitants are affected by railway noise during the day (L_{DEN}) and 9 million are affected at night time (L_{NIGHT}). The limit in noise mapping remains much higher than the recommendations from WHO (see Table 2 page 24).

1.5. Environmental groups and affected inhabitants

On 7 May 2011, about 1,000 protesters came together in Rüdesheim to protest against the rail noise in their hometowns along the middle Rhine Valley. They carried banners demanding a speed limit of 50 km/h in settlement areas and a ban on night trains, word-playing with the “Deutsche Bahn” as “TaliBahn” and blocking the railway line for 40 minutes. The protests were organised not only by a number of local initiatives, but also by communities and district administrations.

The main discussion is currently about freight trains as they are identified as the main source of noise, and they mostly operate at night.

A recent survey [Schreckenberg et al. 2011] showed that 45% of the inhabitants along the middle Rhine region are highly annoyed by rail noise, compared to only 13% by road noise. The reason is easy to understand: The topography forces the trains to pass through a narrow valley between Koblenz and Bingen. Four tracks, two on either side of the Rhine, cause unbearable noise disturbances in the ears of the inhabitants. Noise maps published recently show noise levels (L_{DEN}) above 65 and 70 dB(A). These extremes are caused by 400 trains per day, oncoming trains, old infrastructure, and noise reflections on the steep valley and on the water. Additionally, the EU plans for a European freight corridor from Rotterdam to Basel will double the number of freight trains of presently 150 per day to 300 per day. Further protests are expected. Further details concerning the Rhine axis will be elaborated in Section 4.2.1, page 85.

Figure 2: Protests in Rüdesheim May 2011, noise map Loreley L_{DEN}

This is not the only protest at the Rhine against rail noise. The plans to increase capacities on the upper Rhine valley caused massive protests from Offenburg to Basel, where presently around 10 local action groups are active. In Offenburg, 45,840 objections were made against the infrastructure plans of Deutsche Bahn, and finally the planning was not approved by the regional administration. As a result, DB started negotiations about a rail tunnel under Offenburg and an alignment with the motorway. In other towns, groups protest against the visual impact of “ugly noise protection barriers” and demand a covered deep-level track near settlements.

The local action groups are supported by a number of environmental NGOs that operate on a national or international level. The wide range of demands concerning rail noise may be summarised as follows:

- Freight trains should bypass settlement areas or be guided through deep-level tracks, tunnels or fully enclosed tracks.
- Equal priorities for noise reduction on existing tracks and new construction projects are required.
- Regarding the legal framework, the equivalent continuous sound pressure level should be complemented by a maximum level measurement combined with frequencies (in other words, peak sound levels and noise frequencies should be considered, not just averaged sound levels).
- Set noise emissions ceilings on railway tracks, in relation to land use and population density. Reduction of the permitted night time noise level to 45 dB(A).
- Introduce protection against vibrations into relevant laws and regulations.
- Set a speed limit of 50 km/h for trains in settlement areas.
- Revise the noise standards for new railway rolling stock (TSI Noise).
- Establish a binding framework for the use of market-based instruments to ensure the polluters pay for their noise costs, including road charges and a framework for rail track access charges which will create an incentive for fast and prioritised retrofitting of rail wagons with quiet brake blocks.

Figure 3: Upper Rhine Valley: Plans for Weil am Rhein and protests in Offenburg

Analyses of transportation data from EUROSTAT show that in 2009 almost 27% of the total rail transportation volume in Europe affected Germany. This underlines the importance of central Europe as a transit region as well as an industrial region and presents the reason why the discussion, or even the battle, concerning noise is the strongest in Germany. Poland in the second place has a share of rail freight volume of 12% and France in the third place has 9%. Concerning passenger transport, Germany has a 20% share and France 21%.

Analyses of the noise mapping results show that the problem is most severe in France, Belgium, Luxembourg, the Netherlands, Austria and Switzerland.

These two aspects are the reason why data, comments, available studies and national policy activities concentrate mostly on central Europe and, there, especially on the German speaking countries and the Netherlands. Regarding the main rail transportation axes in Europe, Germany, Austria and Switzerland are affected by a large volume of transit transportation. This will even rise according to transportation volume forecasts.

The future development of rail freight transport will potentially extend noise problems to other countries through which the TEN-T Corridors pass and which will see rising rail transportation volumes. However, the measures to reduce railway noise which are proposed in this study can help to prevent problems in corridors where transportation will rise in future.

2. LEGAL FRAMEWORK

KEY FINDINGS

- WHO recommends **environmental noise limits between 32 and 42 dB(A) at night** to avoid risks for health.
- About **1 million years of healthy life** are lost every year in the EU due to noise reasons.
- National noise **limits or thresholds differ very much** between the Member States and exceed the WHO recommendations.
- Noise limits are mostly **only binding for new build infrastructure.**
- **Directive 2002/49/EC** requests the Member States to provide **noise maps** and **noise action plans**. This has been fulfilled for the first round of noise mapping which covers main railways, roads, airports and agglomerations. The second round (realised until 30 June 2012) will include smaller railways, roads, airports and agglomerations.
- **12 million** inhabitants are affected by railway noise above 55 dB(A) at day time and **9 million** inhabitants are affected by railway noise above 50 dB(A) at night time (major infrastructure and agglomerations).
- The **Recast** of the first railway package will request the Member States to **introduce noise depending track access charges** to compensate investments for noise reduction measures for railway operating companies.
- The **TSI Noise** sets noise limits for new rolling stock.

The reader can find an overview about all identified and analysed regulation schemes in Annex IV.

2.1. General recommendations, limits and thresholds for environmental noise

In this section some recommendations and thresholds for environmental noise will be introduced.

2.1.1. WHO recommendations on environmental noise

WHO published in 2011 a study about the burdens of disease from environmental noise [WHO JRC 2011]. The study used a quantitative risk assessment approach for the estimation. One result of the study is that, about 1 million years of healthy life are lost in the EU every year due to noise reasons.

Already in 2009 the WHO working group for preparing guidelines for exposure to noise during sleep published recommendations for thresholds of environmental noise levels [WHO 2009]. The recommendations are shown in Table 2.

Table 2: Thresholds for environmental noise at night time to avoid health risks according to WHO recommendation

EFFECT		INDICATOR	THRESHOLD [DB(A)]
Biological effects	Change in cardiovascular activity	see footnote 3[3]	see footnote 3
	EEG awakening	$L_{Amax,inside}$	35
	Motility, onset of motility	$L_{Amax,inside}$	32
	Changes in duration of various, in sleep structure and fragmentation of sleep	$L_{Amax,inside}$	35
Sleep quality	Waking up in the night and/or too early in the morning	$L_{Amax,inside}$	42
	Prolongation of the sleep inception period, difficulty getting to sleep	see footnote 3	see footnote 3
	Sleep fragmentation, reduced sleeping time	see footnote 3	see footnote 3
	Increased average motility when sleeping	$L_{Amax,inside}$	42
Well-being	Self-reported sleep disturbance	$L_{Amax,inside}$	42
	Use of sleeping pills, etc.	$L_{Amax,inside}$	40
Medical conditions	Environmental insomnia[4]	$L_{Amax,inside}$	42

Source: WHO 2009, page XII.

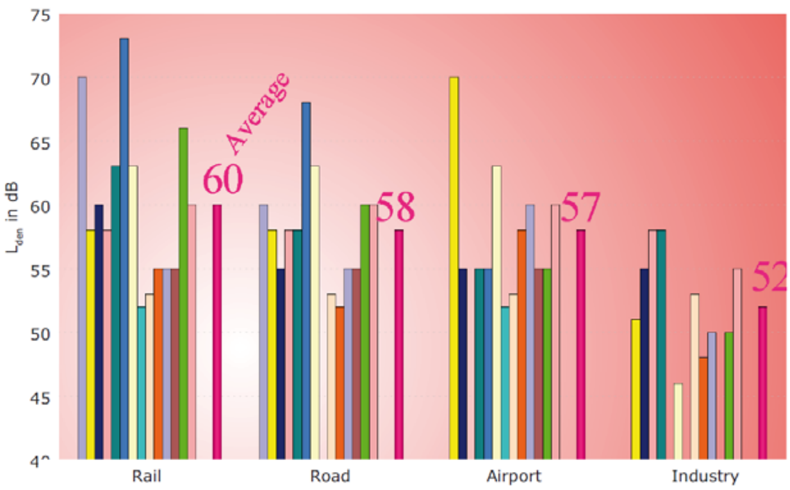
According to the recent UIC study [CE Delft et al. 2011], the social costs of transportation noise are estimated at about 35 billion Euro across the EU plus Switzerland and Norway in 2008, of which about 90% are related to passenger cars and trucks. The costs of rail noise amounts to 953 million Euro or 6% of total noise costs and distributes rather evenly to passenger and freight traffic.

2.1.2. Limits or recommendations for maximum noise limits in the Member States

The European Environment Agency published a comparison of L_{DEN} limits of 14 Member States[5] in November 2010 [EEA 11/2010].

[3] Although the effect has been shown to occur or a plausible biological pathway could be constructed, indicators or threshold levels could not be determined.
[4] Note that "environmental insomnia" is the result of diagnosis by a medical professional whilst "self-reported sleep disturbance" is essentially the same, but reported in the context of a social survey. Number of questions and exact wording may differ.
[5] The EEA report does not specify which 14 Member States provided the information.

Figure 4: L_{DEN} planning values for residential area (as reported by 14 Member States)



Source: EEA 11/2010, page 22.

A standardisation might be useful in order to avoid health risks at the same level in every Member State and to balance competitiveness of all industrial sectors (including transport) as all Member States have to meet the same conditions.

The figures required as well as recommended by Member States are often much higher than the recommendations of the WHO. Some national limits or recommendations for environmental noise are introduced as examples below.

Table 3 shows recommendations for values of threshold for action plans for environmental noise reduction according to the German Federal Environment Agency (Umweltbundesamt) (2006). These figures are not obligations so that the residents cannot claim any specific mitigation measures from these recommendations, if they are affected by environmental noise above these limits. Introduction of measures is a voluntary measure by public bodies.

Table 3: German Federal Environment Agency recommendations of thresholds for action planning

TARGET OF ACTION	PERIOD	L_{DEN}	L_{NIGHT}
Avoiding health risks	Short-term	65 dB(A)	55 dB(A)
Lowering of large disturbances	Middle-term	60 dB(A)	50 dB(A)
Avoiding of large disturbances	Long-term	55 dB(A)	45 dB(A)

Source: 16. BIMSchV 2006.

On the other hand, the levels introduced by German Federal Emission Regulation (Bundesimmissionsschutzverordnung) are required for new built or modified transportation infrastructures; environmental noise levels have to fall below the values mentioned in [16. BImSchV 2006].

Table 4: German maximum environmental noise levels for new built or modified transportation infrastructures

	L_{DEN}	L_{NIGHT}
Near hospitals, schools, sanatoriums	57 dB(A)	47 dB(A)
Pure residential areas and small colonies	59 dB(A)	49 dB(A)
In central areas, villages or mixed areas	64 dB(A)	54 dB(A)
In industrial areas	69 dB(A)	59 dB(A)

Source: 16. BIMSchV 2006.

In comparison to the German legislation the following table presents the Austrian limits or thresholds for noise reduction action planning.

Table 5: Austrian values of thresholds for action planning

TARGET OF ACTION	L_{DEN}	L_{NIGHT}
Road traffic	60 dB	50 dB
Air traffic	65 dB	55 dB
Rail traffic	70 dB	60 dB
Industrial areas	55 dB	50 dB

Source: Bundes-LärmV 2006.

Finally, the British Standard 8233:1999 "Sound insulation and noise reduction for buildings – Code of practice" [BS 8233:1999] states noise limits in the UK for indoor noise caused by environmental noise.

Table 6: UK values of thresholds for indoor noise caused by environmental noise

CRITERION	TYPICAL SITUATION	DESIGN RANGE	
		Good noise level	Reasonable noise level
Reasonable industrial working conditions	Heavy engineering	70 dB(A)	80 dB(A)
	Light engineering	65 dB(A)	75 dB(A)
	Garages, warehouses	65 dB(A)	75 dB(A)
Reasonable speech or telephone communications	Department store	50 dB(A)	55 dB(A)
	Cafeteria, canteen, kitchen	50 dB(A)	55 dB(A)
	Wash-room, toilet	45 dB(A)	55 dB(A)
	Corridor	45 dB(A)	55 dB(A)
Reasonable conditions for	Library, cellular office, museum	40 dB(A)	50 dB(A)

study and work requiring concentration	Staff room	35 dB(A)	45 dB(A)
	Meeting room, executive office	35 dB(A)	40 dB(A)
Reasonable listening conditions	Classroom	35 dB(A)	40 dB(A)
	Church, lecture theatre, cinema	30 dB(A)	35 dB(A)
	Concert hall, theatre	25 dB(A)	30 dB(A)
	Recording studio	20 dB(A)	25 dB(A)
Reasonable resting/sleeping conditions	Living rooms	30 dB(A)	40 dB(A)
	Bedrooms	30 dB(A)	35 dB(A)

Source: BS 8233:1999, page 19.

British standards give acceptable noise levels for properties, and requirements for noise insulation. However, there are no relevant formal limit values in force in England with regard to environmental noise from railways. The Noise Insulation Regulations, defined in British Standard; Sound insulation and noise reduction for buildings [BS 8233:1999], define a threshold level as part of the eligibility criteria. Furthermore, there are guideline levels to be found in Planning Policy Guidance that provides guidance on land use with respect to noise from railways.

Environmental impact is considered as part of the planning permission process for construction, etc., in the UK. Planning Policy Guidance 24 [PPG 24 2006]: “Planning and Noise” provides guidance to local authorities in England on how to minimise noise impact (The Scottish Office issues Planning Advice Note 56 “Planning and Noise” with similar categorisation of noise levels.). [PPG 24 2006] defines exposure categories for residential development. These categories define action depending on noise level categories.

Table 7: Noise exposure categories for dwellings

CATEGORY	DESCRIPTION
A	Noise need not be considered as a determining factor in granting planning permission, although the noise level at the high end of the category should not be regarded as a desirable level.
B	Noise should be taken into account when determining planning applications and, where appropriate, conditions imposed to ensure an adequate level of protection against noise.
C	Planning permission should not normally be granted. Where it is considered that permission should be given, for example because there are no alternative quieter sites available, conditions should be imposed to ensure a commensurate level of protection against noise.
D	Planning permission should normally be refused.

Source: PPG 24 2006, Annex 1.

Noise levels corresponding to the categories are shown in Table 8.

Table 8: Noise levels corresponding to exposure categories for dwellings

NOISE SOURCE	NOISE EXPOSURE CATEGORIES			
	A	B	C	D
Road traffic				
07.00 – 23.00	<55	55 – 63	63 – 72	>72
23.00 – 7.00	<45	45 - 57	57 - 66	>66
Rail traffic				
07.00 – 23.00	<55	55 – 66	66 – 74	>74
23.00 – 7.00	<45	45 - 59	59 - 66	>66
Air traffic[6]				
07.00 – 23.00	<55	55 – 66	66 – 72	>72
23.00 – 7.00	<48	48 - 57	57 - 66	>66
Mixed sources				
07.00 – 23.00	<55	55 – 63	63 – 72	>72
23.00 – 7.00	<45	45 - 57	57 - 66	>66

Source: PPG 24 2006, Annex 1.

Sweden has decided long-term goals for noise limits in 1997. Indoor levels should not exceed 30 dB(A) (L_{DEN}) and 45 dB(A) L_{NIGHT}. Outdoor levels should not exceed 55 dB(A) L_{DEN} and 70 dB(A) as a maximum on a patio [Blidberg 2011].

According to Royal Decree 1367/2007 in Spain, noise action plans are to be made according to the following table [Sierra 2011].

Table 9: Spanish values of thresholds for action planning

TIME FOR ACTION	Situation	L_{DAY}	$L_{EVENING}$	L_{NIGHT}	L_{MAX}
Up to 2020	Existing	65	65	55	-
Now	New	60	60	50	85

Source: Sierra 2011.

Bedrooms in houses located in the 60/60/50 noise contour have to meet 40 dB(A) L_{DAY}, 40 dB(A) $L_{EVENING}$ and 30dB(A) L_{NIGHT}.

Thresholds for noise action planning differ between countries. The differences are even in classifying noise protection areas. In Germany, action plans which lead to a maximum level of noise in defined areas are only required for new built and modified infrastructures.

[6] Aircraft noise: daytime values accord with the contour values adopted by the Department for Transport which relate to levels measured 1.2m above open ground. For the same amount of noise energy, contour values can be up to 2 dB(A) higher than those of other sources because of ground reflection effects.

Austria requires noise action planning for certain environmental noise levels, depending on the source of noise. UK recommendations do not require any action, except in the workplace or for new built and modified infrastructures, and levels depend on use of the rooms; local authorities have a number of legislative powers to control noise emission. Mostly the obliged figures are based on the highest level of the German Federal Environment Agency recommendations.

These examples of legislation rules or national recommendations differ from the WHO recommendation and are often only relevant for new or modified infrastructure.

The result of this comparison shows that reducing environmental noise is a very important action for the environment/health of the population. Many people are affected by rail noise that exceeds the lowest level the WHO Recommendation according to [WHO 2009] demands.

2.2. Environmental Noise Directive 2002/49/EC

The Environmental Noise Directive [Dir. 2002/49/EC] has the following aim[7]:

- “Monitoring the environmental problem; by requiring competent authorities in Member States to draw up "strategic noise maps" for major roads, railways, airports and agglomerations, using harmonised noise indicators L_{DEN} (day-evening-night equivalent level) and L_{NIGHT} (night equivalent level). These maps will be used to assess the number of people annoyed and sleep-disturbed respectively throughout Europe”

- “Informing and consulting the public about noise exposure, its effects, and the measures considered to address noise, in line with the principles of the UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, known as the Aarhus Convention, and signed on June 25, 1998.

- “Addressing local noise issues by requiring competent authorities to draw up action plans to reduce noise where necessary and maintain environmental noise quality where it is good. The Directive does not set any limit value, nor does it prescribe the measures to be used in the action plans, which remain at the discretion of the competent authorities.”

- “Developing a long-term EU strategy, which includes objectives to reduce the number of people affected by noise in the longer term, and provides a framework for developing existing Community policy on noise reduction from source. With this respect, the Commission has made a declaration concerning the provisions laid down in article 1.2 with regard to the preparation of legislation relating to sources of noise.”

According to the Directive 2002/49/EG, all Member States have to provide noise maps and action plans for noise reduction.

The Report from the Commission to the European Parliament and the Council on the implementation of the Directive on environmental noise in accordance with Article 11 of

[7] Expressions coming from http://ec.europa.eu/environment/noise/directive.htm, last visited 14 September 2011.

Directive 2002/49/EC from 1 June 2011 [EC 2011] shows the current status of implementation of the Directive in the Member States.

2.2.1. Status of implementation of Directive 2002/49/EG

The Directive is implemented in all Member States since October 2007 according to [EC 2011]. The 14[8] Member States which did not transpose by 18 July 2004 achieved that by October 2007. According to the EEA Study "Laying the foundations for greener transport" [EEA 7/2011] the data provided is 96% complete in mid 2011. In fact [EEA 7/2011] confirms many aspects concerning limits and the potential risks and limits to avoid risks as the WHO did in its two studies [WHO 2009] and [WHO JRC 2011]. The road map of the Directive is represented in [EC 2011] as follows.

Table 10: Road map for implementation of Directive 2002/49/EG

IMPLEMENTATION DEADLINE	ISSUE	REFERENCE DIRECTIVE 2002/49/EC	UPDATES
30 June 2005	Information on major roads, major railways, major airports and agglomerations according to the upper thresholds, designated by MS and concerned by 1st round of mapping	Art. 7-1	Mandatory every 5 years
18 July 2005	Establishment of competent bodies for strategic noise maps, action plans and data collection	Art. 4-2	Possible at any time
18 July 2005	Noise limit values in force or planned and associated information	Art. 5-4	Possible at any time
30 June 2007	Strategic noise maps for major roads, railways, airports and agglomerations according to the upper thresholds[9]	Art. 7-1	
18 July 2008	Action plans for major roads, railways, airports and agglomerations	Art. 8-1	Mandatory every 5 years
31 December 2008	Information on major roads, major railways, major airports and agglomerations according to the lower thresholds, designated by MS and concerned by 2nd round of mapping	Art. 7-2	Possible at any time
30 June 2012	Strategic noise maps for major roads, railways, airports and agglomerations according to the lower thresholds[10]	Art. 7-2	Mandatory every 5 years

Source: EC 2011, page 4.

8 AT, BE, CZ, DE, EL, FI, FR, IE, IT, LU, PT, SE, SL, UK.

9 Upper thresholds are agglomerations > 250.000 inhabitants, roads > 6 millions of vehicles per year and railways > 60.000 trains per year.

10 Lower thresholds are all agglomerations > 100.000 inhabitants, roads > 3 millions of vehicles per year and railways > 30.000 trains per year.

Additional to the information shown in Table 10 according to [EC 2011] the Directive 2002/49/EC [Dir. 2002/49/EC] defines one more step.

In the first round of noise mapping and action plans only big agglomerations and intensive frequented transportation infrastructure is concerned. The second round also concerns smaller agglomerations and transportation infrastructures.

Table 11: Additional steps in noise mapping according to [Dir. 2002/49/EC]

IMPLEMENTATION DEADLINE	ISSUE	REFERENCE	UPDATES
18 July 2013	Action plans for all roads, railways, airports and agglomerations where limits are exceeded	Art. 8-2	Mandatory every 5 years

Source: Dir. 2002/49/EC.

Concerning noise mapping the following table shows details for the first and second rounds of noise mapping.

Table 12: Schedule for noise mapping and noise reduction planning

ACTION	AGGLOMERATIONS > 250.000 INHABITANTS AND MAIN RAIL LINES > 60.000 TRAINS / YEAR	AGGLOMERATIONS AND MAIN RAIL LINES > 30.000 TRAINS / YEAR
Announcement of railway lines and agglomerations which belong to categories mentioned	June, 30th 2005 (must be updated every 5 years)	December, 31st 2008 (must be updated every 5 years)
Elaboration of noise maps	June, 30th 2007	June 30th 2012 (must be updated every 5 years)
Action plans for noise reduction	July, 18th 2008	July, 18th 2013 (must be updated every 5 years)

Source: Dir. 2002/49/EC.

Table 13 shows the details of the current status of implementation.

Table 13: Status of implementation of Directive 2002/49/EG

CASE	DESCRIPTION	FULL IMPLEMENTATION	PART IMPLEMENTATION
Indication of noise indices and limits	Member States shall indicate their national legal environmental noise limits or recommendations. A European wide noise level was not introduced.	Limits by 19 Member States (AT, BG, BE, CZ, DK, EE, ES, FR, DE, EL, IT, LV, LT, LU, NL, PL, PT, SL, SI); currently reviewed in 3 Member States (LT, LV, RO); recommendations by 4 Member States (FI, IE, SE, UK)	
Strategic noise maps	The Member States have to provide noise maps for main transport infrastructure and agglomerations. They must be updated frequently (5 years) and the update shall indicate the situation in the year before the update.	12 Member States (BG, CZ, EE, HU, IE, LT, LV, LU, PL, PT, SI, UK)	11 Member States reported completely with a few omissions (AT, BE, CY, DK, FI, DE, NL, RO, ES, SE, SK) 3 Member States reported only for part of the sources of noise (FR, EL, IT) 1 Member State did not report (MT)

Source: EC 2011

The range of limits and recommendations for environmental noise differ very much between the Member States. Only four of them considered health care orientated limits (EE, LU, PT, SL and the administration of Brussels in BE).

2.2.2. Noise action plans

Several studies by UIC (see [UIC 2010]) and CER together with UIC (see [CER UIC 2007]) and additional surveys by the authors lead to an overview of the existing noise abatement actions in the Member States and also in other European countries. All data available are presented in Table 14.

Table 14: Actions by European Countries for noise abatement on railways where data are available

COUNTRY	ACTIONS	SOURCE
Austria	• Very important topic in particular in urban and mountainous areas • Noise maps since 1993; environmental noise plans implementing DIR 2002/49/EC (www.laerminfo.at) • 250,000 people exposed to excessive rail noise • Complex national and state legislation • 1.7 million sq. m [m^2] noise barriers constructed along 803 track-km, 2/3 of the planned construction works are completed • Most of the highly affected inhabitants are protected against noise, annually some 10-15,000 new protected citizens • Financial means amount to €16 – 25 million p.a.; 50% of the costs are covered by ÖBB and 50% by the federal states and the community; equipment of new tracks 100% funding by ÖBB • Equipment of 4,500 out of 31,000 wagons from Rail Cargo Austria and Rail Cargo Hungary with K-block brakes through new units. Retrofitting and noise related access charges are not foreseen • Participation at UIC-Project EuropeTrain for testing LL-block brakes	Interviews with country representatives in September 2011
	• Until 2009 450 km of noise barriers for € 355 million	[UIC 2010]
	• Critique to noise action plans: lag of new ways to deal with noise, no concrete specification	[Justice and Environment 2009a]
Belgium	• Regional noise legislation, no national legislation existent • Flanders, Brussels: noise limits • Wallonia: no limits • No programme by SNCB; however protection for new or upgraded lines	[CER UIC 2007]
Bulgaria	• Only interest in composite brake blocks for noise reduction	Interview with Bulgarian railway operator (BDZEAD) in September 2011
Cyprus	• Since 1951 there is no railway line in Cyprus in effect. So rail noise is no problem for Cyprus	http://en.wikipedia.org/wiki/Cyprus_Government_Railway

COUNTRY	ACTIONS	SOURCE
Czech Republic	• Noise abatement compulsory for new railway lines • Upgrading of existing lines with noise barriers • Action plans for END (Directive 2002/49/EC) will form framework of noise abatement programmes • Pilot project with LL brake blocks	[CER UIC 2007]
	• Until 2010 about 115 km of noise barriers	[UIC 2010]
	• Critique to noise action plans: merely containing only measures which have been planned anyway; no estimate of costs and deadlines	[Justice and Environment 2009a]
Denmark	• Few noise barriers in Denmark: 58 km • Passive noise abatement strategy, mostly done at houses	[CER UIC 2007]
	• Research and Testing programmes for optimisation of track construction, acoustic rail grinding, noise partnership with the inhabitants and noise communication management • Until 2009 46 km noise barriers, windows in 8,300 houses, total costs 65 million €	[UIC 2010]
	• Up to 2013 22,100 dwellings will be protected by noise screens and/or offered grant to improved sound insulation • Offer of grant to improved sound insulation of 17,700 dwellings, of which 4.650 dwellings (~26%) have got improved sound insulation. • Intensified grinding of rails on all main railway sections (2009 –2014) Target: Less fluctuation in rail smoothness and reduced noise • Tests of rail dampers on a short section - effect 2,7 dB(2007) • Project Optimized Railway Superstructure (2009 –2014): Survey on influence of different rail pads on noise and vibration at Holmstrup (2010-2011)	[Blumensaadt 2011]
Estonia	• TSI Noise is transformed into national law. • Noise action plans for the City of Tallinn (May 2009) and for major road links (Dec. 2008) have been established. These are not legally binding and are not referring to rail transport. Road measures including noise barriers only. • Provisions by the Tallinn noise action plan to be taken until 2013: o Technical measures at noise sources o Selection of quieter sources o Reduction of sound transmission (e.g. tramway speed reduction)	[Justice and Environment 2009a] [Justice and Environment 2009b]

COUNTRY	ACTIONS	SOURCE
	• Estonian legislation has delayed the deadline for preparing noise maps beyond 30.6.2007 and action plans. This constitutes a conflict with EC legal provisions	
France	• Noise protection for new or upgraded lines • implement noise control at hot spots – mostly noise barriers and noise protection windows – track absorbers homologated • research projects	[CER UIC 2007]
	• Combined optimisation of rail and wheel dampers. Homologation of wheel dampers (STARDAMP project) • Noise plan with € 193 million for noise barriers and rail dampers	[UIC 2010]
Finland	• Noise abatement package being considered by parliament, no retrofitting Problem of noisy Russian freight wagons	[CER UIC 2007]
	• Some noise barriers	[UIC 2010]
	• For the 7 agglomerations, Finnish Transport Agency (FTA) has contracted with the city authorities to include the main roads and railways in their assessments, paying a part of their costs • The total cost for FTA will be about € 800,000, about € 1.50 per probable noise zone inhabitant (cost with roads!) • Experiences with low height barrier come to a reduction of about 10 dB(A)	[Pokolainen 2011]
Germany	• Strong political pressure from citizen's groups and associations • Long-term goal of German railway DB: cut rail noise emissions 2000 -2020 by half, i.e., a noise reduction of 10 dB(A). Costs: € 2.3 m, with € 100 m p.a. duration of programme expected at 25 years • Noise differentiated track access charges will be introduced in December 2012. Wagon holders will receive a bonus financed by 50% through government. The bonus will be paid through a fund that is financed equally by increased track charges and the Noise Protection Programme of the German government • 180,000 wagons are eligible to be retrofitted with new brakes. Costs amount to € 300 m. Number of wagons presently retrofitted: 6,350 • Programme "Quiet Rhine" started that will retrofit 1,150 wagons with new brakes • Voluntary noise remediation programme for existing tracks of the federal railways • Research project "silent train on real track"	Interviews with representatives from DB and national authorities in September 2011

COUNTRY	ACTIONS	SOURCE
	testing innovative vehicle-side technologies • Research programme "silent track" testing track dampers and low noise barriers with funding from the Economic Stimulus Package II • Acoustic rail grinding programme on-going	
	• Testing innovative infrastructure measures: Rail dampers, friction modifiers, low height barriers, absorbers for steel bridges, under sleeper pads • Work on realistic rail/wheel contact: improvement of wheel/rail contact, wheel vibrations and acoustic optimisation of pavement • € 100 million per year, total costs of 2.3 billion until 2030 including noise barriers and windows • Most activities are related to infrastructure side measures • Retrofitting up to 5,000 freight wagons with K- and LL-blocks up from the year 2009 • Definition of a practical approach for the use of LL-blocks • Definition and pre-evaluation of noise differentiated track access charging models	[UIC 2010]
	• In fact, Germany currently invests significant money in noise protection walls in the Konjunkturpaket 2[11]	Additional information by the authors
Hungary	• The national law obligates noise protection on new or modernised railways	[CER UIC 2007]
	• Action plans are not binding and have no implication for national budget rules • Good public involvement in action plan design by establishment of noise committees	[Justice and Environment 2009a]
Greece	• The density of railway lines in Greece is very small. 60% of all railway kilometres belong to one single connection between Thessaloniki and Athens (1565 km). A very small percentage of all Greece inhabitants is affected by railway noise	http://www.griechenland-travel.com/eisenbahn.htm
Ireland	In the Dublin area traffic is the major noise source, but railways do not have a major impact on overall noise levels. Major measures: Promoting walking, cycling, public transport and quieter motor vehicles	[Dublin City 2008]
	Outside agglomerations 23 km of track are above 60,000 passages p.a., but without affecting	[King et al. 2009]

[11] « Konjunkturpaket 2 » (Economic Stimulus Package II) is an extra investment programme of the German government following the recent economic crisis 2008/2009 to support the building industry.

COUNTRY	ACTIONS	SOURCE
	population with L_{DEN}>55 dB(A)	
Italy	• Strict noise legislation including existing lines • action plans • implementation until 2020 • measures to be considered on about 8000 km • costs about € 6.8 billion • legislation does not allow retrofitting	[CER UIC 2007]
	• Measurements of all assets (rolling stock) for noise emissions – example: modification of software of the ETR 500 High Speed trains to lower ventilation and cooling noise • Most measures indeed concentrate on noise barriers and insolating windows • Development of cast iron brake blocks for freight wagons	Answer from Trenitalia (FS) on authors survey in September 2011
	• For the next 15 years on about 3,675 km of existing lines noise barriers and building insulation is foreseen with a budget of about 8.31 billion € (9,025 single actions)	Answer from RFI on authors survey in September 2011
Latvia	• Strategic Noise Mapping was completed in 2008 including only major road sections. It can thus be concluded that rail noise does not play a significant role in Latvia	[EIONET 2011]
Lithuania	• Detailed information on noise action plans have not been available; Communications from the Ministry for Transport and Communications only mention noise reduction programmes for road and air transport • But modal shifts to rail by a cooperation between Lithuanian Railways (JSC) and CargoBeamer (Germany) on combined transport is expected to reduce noise pollution from road haulage	[SUMIN 2011]
Luxembourg	Luxemburg has submitted a draft Noise Action Plan to the EC, which is not accessible to the public	[EIONET 2011]
Malta	• Since 1931 there is no railway line in Malta in effect. So rail noise is no problem for Malta	http://de.wikipedia.org/wiki/ Schienenverkehr_auf_Malta
Netherlands	• Noise abatement legislation since 1987 • Introduction of noise differentiated track access charges in 2008. The bonus is fixed at € 0.04/ wagon-km and is applied to both passenger and freight vehicles with a maximum of € 4,800 over two years. The bonus is granted on a system of self-declaration • Noise Innovation Programme: Launching of numerous studies and pilot projects to test composite brake blocks • Noisy trains will be prohibited starting in 2015	[CER UIC 2007]

COUNTRY	ACTIONS	SOURCE
	• Target noise reduction: 10 – 12 dB(A) • Also measures for shunting yards are planned	
	• € 430 million for noise barriers, windows and rail dampers • Lubrication, removing of rail joints, noise barriers and window insulation in shunting yards • Research projects for friction modifiers against curve squeal, influencing rail roughness • Monitoring noise ceilings and capacity management	[UIC 2010]
Norway	• Rail grinding planned but not yet implemented, noise from freight terminals, tonal noise from accelerating and decelerating trains • Passive noise abatement strategy, mostly done at houses	[UIC 2010] [CER UIC 2007]
Romania[12]	• National noise action plans in preparation since 2008	[CER UIC 2007]
Poland	• Environmental law includes noise abatement • track grinding • noise barriers (50 km), • noise protection windows on new and upgraded lines	[CER UIC 2007]
Portugal	• Noise protection is obligated on all railway lines • Nearly all freight cars are equipped with LL-blocks (no need of admittance of these cars in other countries as Portugal has broad gauge track and so there is no exchange of wagons with the other European countries) • More than 50 km of noise protection walls and in future more are planned	[CER UIC 2007]
Slovak Republic	Action plans are considered very vague and general and not binding and have no implication for national budget rules	[Justice and Environment 2009a]
	To date only Action Plans for road transport have been submitted to the EC	[EIONET 2011]
Slovenia	Action plans are considered very vague and general and not binding and have no implication for national budget rules	[Justice and Environment 2009a]
Spain	• Directive 2002/49/EC is completely implemented in national legislation and for major railway lines and agglomerations noise maps are existing, second phase of noise	Interview with the RENFE in December 2011

[12] According to an Interview with the Romanian Railway Authority there are no problems with noise in this country.

COUNTRY	ACTIONS	SOURCE
	mapping will be fulfilled in 2013 • Currently 62% of rail freight transport is done with low noise wagons (equipped with composite brake blocks) • 32% of all freight wagons are already equipped with composite brake blocks (30,58% K- and 1,37% LL-blocks, as well as Portugal Spain has broad gauge) • Equipment of freight wagons with K- or LL-blocks goes on (600 expected for 2012) • 95% of passenger rolling stock is already equipped with disc brakes and new rolling stock will only have disc brakes	
Sweden	• According to Sweden´s noise mapping: problems also outside of mapping areas; noise mitigation measures such as rail grinding, rail dampers and low height barriers are being studied • Passive noise abatement strategy, mostly done at houses	[CER UIC 2007]
	• Noise abatement programme including insulated windows and local barriers for good acoustic indoor environment and noise protected patio area	[UIC 2010]
	• Sweden also favors retrofitting braking systems of existing rail cars but serious problems are still not solved concerning the braking performance in severe winter conditions	[Blidberg 2011]
Switzerland	• Noise legislation enacted 1987 • Noise differentiated track access charges introduced in 2010 using a bonus system for low-noise wagons • railway noise abatement largely financed through road traffic • specific legislation for railway noise: • – retrofitting of all Swiss rolling stock until 2014 (direct subsidies) – noise barriers with cost-benefit restriction – noise protection windows	[CER UIC 2007]
	• The total national freight wagon fleet will be equipped with composite breaks which lower rolling noise (for details see Section 3.3). The programme is financed by the government which shifts earning from road pricing to the rail sector. Also a noise-dependent track price system has already been introduced and is currently in discussion for enhancements • A cost benefit analysis should show which additional measures will be taken: rail grinding, stand by noise, rail dampers and	[UIC 2010]

COUNTRY	ACTIONS	SOURCE
	steel bridges are among the issues studied • By 2009 111 km of noise barriers and windows, and by 2015 300 km of noise barriers are planned for € 1 billion • Switzerland publishes very detailed information about the status of rail noise abatement and the approach for private persons to gather funding for noise insulating windows for instance (see www.laerm-sbb.ch)	
United Kingdom	• Strict planning policy requires new railway developments to consider noise impact during construction and operation	[CER UIC 2007]
	• British Standards give acceptable noise levels for properties and requirements for noise insulation • Most (approximately 75%) of UK freight wagons have disc brakes or composite brake blocks • The UK uses a variety of noise mitigating technologies including noise barriers, rail lubricators and friction modifiers, rail absorbers, and, usually in tunnels, resilient baseplates and floating slab track • DEFRA (Department for Environment, Food and Rural Affairs) is responsible for the UK's noise mapping and noise action plans • The UK has identified a number of Important Areas for the relevant transport authorities to focus on, as well as a subset of First Priority Locations and a timeline for implementation	Interviews held by partners in September 2011
	• Long-term strategy: Framework for noise abatement incorporating infrastructure provider (NetworkRail) and train operators • Concentration on night time noise and integration of transport and land use planning	[AEA et al. 2004]

Source: Different sources; see column SOURCE.

Reports have been suspended for Greece, Malta and Cyprus due to marginality or non-existence of rail networks.

Switzerland and Norway are mentioned as non-member countries as they are also members of UIC as the concerned railway organisation.

UIC (in [UIC 2010]) also mentions an initiative by the group of **The Netherlands, Germany, Switzerland and Italy** ([UIC 2010], page 25). In the Rotterdam - Genoa project, the governments of the states mentioned analysed possibilities to promote retrofitting of freight cars with low noise equipment (particularly composite brakes). The study finally recommended harmonised solutions for bonus systems (not only along the corridors) and to avoid penalty systems.

By the end of 2005, in Europe 1,000 km of noise barriers have been built and approximately 60,000 buildings have been endowed with noise protection windows. The measures resulted in noise protection for about 1,250,000 citizens. The measures comprised annual investments of 150–200 million Euros. The estimated total costs for infrastructure measures are estimated at up to € 10 billion.

Most national activities and investments so far concentrate on infrastructure: noise barriers, rail damping and friction modifiers. Many countries and projects also concentrate or integrate source driven measures like wheel dampers or composite brake blocks.

Interviews conducted with rail industry representatives from DB and ÖBB suggest that noise bonus regulations shall be unique across Europe to increase the incentives for wagon owners and operators to retrofit old rolling stock and to minimise market distortions among rail transportation companies.

2.3. Recast of the First Railway Package

The First Railway Package consists of Directives 2001/12/EC (amending Council Directive 91/440/EEC on the development of the Community's railways), 2001/13/EC (amending Council Directive 95/18/EC on the licensing of railway undertakings) and 2001/14/EC (on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification). This was designed to open the international freight market by setting out the conditions for licensing freight operators in Europe, to define the roles of the infrastructure managers and railway undertakings, and to set out a policy for capacity allocation and infrastructure charging.

The Second Railway Package includes the Railway Safety Directive (Directives 2004/49/EC and 2008/110/EC) and EC Regulations 881/2004 and 1335/2008 which required the establishment of national safety authorities and investigatory bodies who report to the European Railway Agency, responsible for rail safety and interoperability as well as drafting legislation for a harmonised European rail system. The Second Package also includes the Interoperability Directive (2008/57/EC) which defines how the Technical Standards for Interoperability (TSIs) should be developed, e.g., TSI Noise relating to "'rolling stock – noise' of the trans-European conventional rail system", Commission Decision 2011/229/EU (see Section 2.4, page 42).

The Third Railway Package focuses on opening up international passenger services to competition within Europe, and includes Directive 2007/58/EC (amending Council Directive 91/440/EEC on the development of the Community's railways and Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure).

On September 17th 2010, the European Commission delivered a proposal for a Recast of the First Railway Package [COM(2010) 475]. Article 7 of Dir. 2001/14/EC covers "Principles of charging". Noise is not mentioned explicitly in Dir. 2001/14/EC, but the directive allows infrastructure charges to be modified based on environmental impact. This enables Member States to introduce noise-dependent track access charges if this is introduced also for competitive transportation modes or the total turnaround for infrastructure companies does not rise. Article 31 of the proposed Recast, based on Article 7 of Dir. 2001/14/EC, explicitly allows differentiation of track access charges based on the noise emission characteristics of the rolling stock if the same is introduced for road transport.

2.4. TSI Noise

The basis for all subsystems (infrastructure, energy, control-command and signalling, operation and traffic management, telematics applications, rolling stock and maintenance) of the railway system are the "European Railway Technical Specifications for Interoperability (TSIs)". The elaboration of TSIs is introduced in Directive 2008/57/EC. The European Railway Agency (ERA) is responsible for the coordination of development of the TSIs. For this, ERA organises working groups for the different subsystems which consist of experts and authorities. The ERA pays attention that all relevant stakeholders are represented in the working groups.

All TSIs are directly valid for each Member State for new build or modified subsystems. If exceptions must be made, the Member States have to declare this precisely. General exceptions are only possible for underground, tram and regional rail systems; infrastructures / networks which are separate from the rail network and are only used for local and urban transport; private rail infrastructure and vehicles which are only used on the private infrastructure which is only used for freight transport for the owner; infrastructures and vehicles which are only for local use or historical and touristic uses.

The new European Railway Technical Specification for Interoperability (TSI) for Noise (TSI Noise), document No. 2011/229/EU (published on April, 4th 2011) defines maximum noise levels for rolling stock [TSI Noise 2011]. This TSI is part of the subsystem rolling stock. It replaces the version of 2006 [TSI Noise 2006]. Maximum noise levels are defined for stationary and for pass-by noise on defined rail reference tracks and at defined speed. For engines, starting noise levels and interior noise within the driver's cab are also defined where applicable. Interior noise within the driver's cab is not relevant for this study. Details are presented in Annex II. According to Directive 2008/57/EG these limits are directly valid for new build vehicles.

Pass-by noise is defined at a distance of 7.5 metres from track centre line and 1.2 metres above upper surface of the rail. Details about the reference track are to be found in the TSI Noise. The reference track is defined by its roughness and its dynamic behaviour (described by the vertical and lateral track decay rates).

In Commission Decision of 30 May 2002 concerning the technical specification for interoperability relating to the rolling stock subsystem of the trans-European high-speed rail system referred to in Article 6(1) of Directive 96/48/EC (2002/735/EC) noise limits were set to rolling stock of high speed trains [Com 2002/735/C].

2.5. Measuring and computing of railway noise

2.5.1. Legislation according to Environmental Noise Directive

The EU Directive 2002/49/EC demands in its Annex 1 the following formula to calculate the relevant day-evening-night level (on the basis of measured noise levels):

$$L_{den} = 10 \lg \frac{1}{24}\left(12 * 10^{\frac{L_{day}}{10}} + 4 * 10^{\frac{L_{evening}+5}{10}} + 8 * 10^{\frac{L_{night}+10}{10}}\right)$$

in which:

- L_{day} is the A-weighted long-term average sound level as defined in [ISO 1996-2: 1987], determined over all the day periods of a year,
- $L_{evening}$ is the A-weighted long-term average sound level as defined in [ISO 1996-2: 1987], determined over all the evening periods of a year,
- L_{night} is the A-weighted long-term average sound level as defined in [ISO 1996-2: 1987], determined over all the night periods of a year,
- L_{den} is the average noise level for a period of 24 hours (day, evening and night)

and in which:

- the day is 12 hours, the evening four hours and the night eight hours. The Member States may shorten the evening period by one or two hours and lengthen the day and/or the night period accordingly, provided that this choice is the same for all the sources and that they provide the Commission with information on any systematic difference from the default option,
- the start of the day (and consequently the start of the evening and the start of the night) shall be chosen by the Member State (that choice shall be the same for noise from all sources); the default values are 07.00 to 19.00, 19.00 to 23.00 and 23.00 to 07.00 local time,
- a year is a relevant year as regards the emission of sound and an average year as regards the meteorological circumstances; and in which: the incident sound is considered, which means that no account is taken of the sound that is reflected at the façade of the dwelling under consideration (as a general rule, this implies a 3 dB correction in case of measurement) (see [EC 2002], Annex I).

Noise indicators can also be computed (necessary for predictions). Directive 2009/49/EG defines in its Annex II computing methods which have to be used if the Member States have no own legislative computing method which is adapted to Annex I of the directive. For railway noise the calculation method of the Netherlands is prescribed ("Reken- en Meetvoorschrift Railverkeerslawaai '96, Ministerie Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, 20th November 1996") [ReMR 1996].

The calculation scheme defines nine train categories where noise levels for pass by of one of these trains are indicated. Together with the total number of trains of one type, the averages L_{DEN} and L_{NIGHT} level can be calculated. Supplement factors are indicated for different types of bridges.

Germany for example has its own calculation scheme. They use the "Preliminary calculation method for the environmental noise at railways" (Vorläufige Berechnungsmethode für den Umgebungslärm an Schienenwegen) – VBUSch 2006" [VBUSch 2006] for calculations for noise mapping.

All calculations schemes are very complex and exceed the scope of this study, but all schemes classify trains into classes. For each class an emission factor must be calculated and the addition of all factors is done with a logarithmic function.

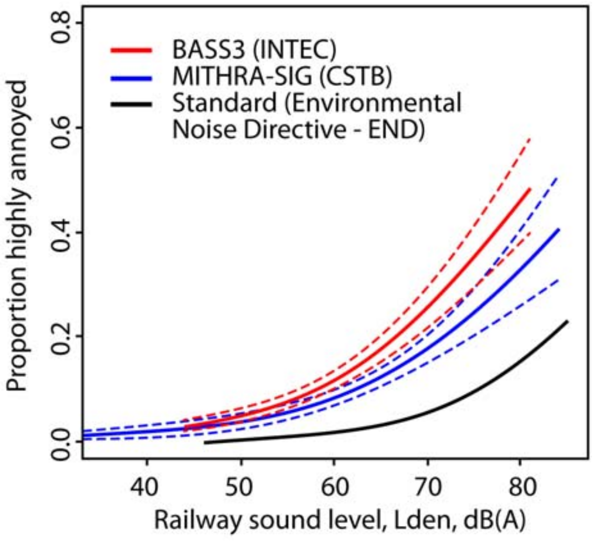
There are currently two main discussions about the calculation schemes - the different results of different schemes and the rail bonus in calculation. Both aspects will be discussed in the following sections.

2.5.2. Different results of different computing schemes

The Dutch scheme uses nine train type categories where the indicators mentioned in the German scheme are already integrated in general calculation factors for the train category.

The calculation in Germany has a common factor for all train types, modified by individual bonus or penalty factors according to indicators, whereas the Dutch calculation scheme has already defined global calculation factors for train categories. So calculation results can differ according to the scheme used; Lercher elaborated an example of these differences in ALPNAP project [ALPNAP 2007-2]. Figure 5 which comes from the ALPNAP project [ALPNAP 2007-2] shows an example of the result of different calculation methods for people annoyed by railway noise. The figure compares BASS3 (INTEC)[13], the MITHRA-SIG[14] and the Standard set by the Environmental Noise Directive.

Figure 5: Comparison of noise calculation methods in ALPNAP project



Source: ALPNAP 2007-2, page 124.

Clearly there would be value in a European calculation (and measuring) standard to make noise effects on the population more comparable.

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13 BASS3 is an implementation of ISO 9613 (acoustics - Attenuation of sound during propagation outdoors) by INTEC-University of Gent.

14 MITHRA-SIG is an implementation of the French standard method NMPB (Méthode de Prevision du Bruit des Routes).

2.5.3. Rail noise bonus discussion

In former, and in some current, calculation or measuring methods (see German Schall 03, for example) a general bonus for rail noise is included. These incentives transfer measured or calculated environmental noise emissions into a balanced value. Railway noise is often seen as less annoying than other noise sources. Amongst others this is accounted due to more times without noise emissions at all. The general discount is between 3 and 10 dB in different countries [ZEUS Möhler 2010].

Recently, several studies analysed whether this discount is suitable and eligible. The study "Lärmbonus bei der Bahn?" (Noise bonus for rail?) [ZEUS Möhler 2010] by Möhler + Partner München; ZEUS GmbH, Hagen, analysed several studies for the German Federal Environment Agency (Umweltbundesamt).

The following table shows the suitability of railway noise incentives according to analysed studies:

Table 15: Analysis of studies about the eligibility of rail noise incentives

ELIGIBILITY OF RAIL NOISE DISCOUNT	TYPE OF STUDY		
	Case studies	Laboratory studies	Total
Yes for a general rail noise bonus	2	6	8
Different kinds of bonus or penalty	6	0	6
No for a general rail noise bonus	0	5	5
Neutral concerning rail noise bonus	1	1	2
Total	9	12	21

Source: Zeus Möhler 2010, page 49.

About 8 out of 21 studies came to the result that a rail noise bonus is eligible. 11 of the 21 studies came to the result that either the incentives have to be variable (for example depending on time, area influenced, noise level; even a penalty should be included), or the rail noise bonus is not eligible. 2 of the studies remain neutral. If only case studies are considered, only 2 of 9 studies agreed that a general rail noise bonus was acceptable, whereas 6 studies suggested a variable noise bonus/penalty system was necessary. The authors of that study also identified mistakes in the studies considered. The rail noise bonus/penalty must be further elaborated, especially considering the current modal split in transportation and the effects of noise at night (interruption of quiet phases), or different noise levels, for instance.

ZEUS GmbH and Möhler+Partner published an article about a census concerning the annoyance by rail and road noise at different times of day (Daytime-related harassment by road and rail traffic noise – Method and empirical results / Tageszeitsbezogene Belästigung durch Straßen- und Schienenverkehrslärm - Methode und empirische Ergebnisse) [ZEUS Möhler 2005]. The authors questioned people about their feeling of harassment from railway and road noise. The most important result is that during the evening and night the noise coming from railways harassed more than at during the day. This would justify a rail noise penalty at evening and night time.

As a result of the ALPNAP[15] project, Lercher et al. studied the use of sleeping pills by people affected by rail noise [Lercher et al. 2007]:

- Use of sleeping pills is increasing already at low levels of railway noise from 50 dB(A) upwards.
- The environment noise level of 60 dB(A) at night which leads to the necessity of action plans is considerably too high.

This leads to the general result that a rail noise bonus is not justifiable both at evening and night time but only eligible during the day and not in the night.

[15] ALPNAP = Monitoring and Minimisation of Traffic-Induced Noise and Air Pollution Along Major Alpine Transport Routes, see http://www.alpnap.org (last visit June, 30th 2011).

3. RAIL NOISE – SOURCES AND PREVENTION MEASURES

KEY FINDINGS

- **Main source** of railway noise is **rolling noise** coming from rail freight wagons.
- **Of minor importance** is engine noise (at lower speeds) and aerodynamic noise (high speed trains).
- Locally also squeal noise can be important.
- Rolling stock which is introduced from the year 2000 on is about **10 dB(A) less noisy** then rolling stock from the 1960s and 1970s.
- Against each source of noise an **enormous number of measures** has been developed in the last years.
- **Rolling noise and wheel noise** can be reduced by **composite brake blocks** (freight wagons), **resilient wheels** or **wheel dampers.**
- **Rail noise** can be reduced by rail dampers, resilient track pads and combinations with noise barriers of different heights.
- Track side or vehicle side **lubrication systems can avoid squeal noise** and are well introduced in tram way systems.
- **The most efficient measure to achieve network wide noise reduction is the retrofitting of freight cars with composite brake blocks.**

This chapter will identify the main sources of railway noise and measures to prevent or to protect from it.

3.1. Sources of railway noise

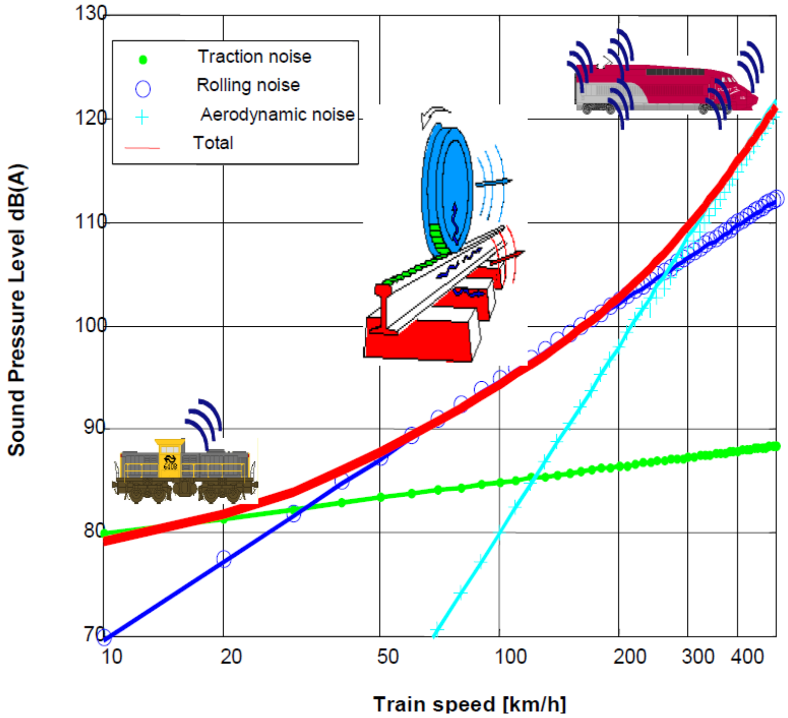
Many studies and publications exist concerning sources of rail noise. The Working Group Railway Noise of the European Commission published its Position Paper on the European strategies and priorities for railway noise abatement in 2003 [EC 2003]. The International Union of Railways (UIC) published its “Environmental Noise Directive Development of Action Plans for Railways” in April 2008 [UIC 2008].

Both studies (and others, see, e.g., the comprehensive review given by [Thompson and Gautier 2006]) identify the following sources for railway noise:

- Rolling noise
- Power equipment noise
- Aerodynamic noise.

The severity and relative proportions of these noise sources depend on train speed. At low speed, power equipment noise is the dominant source, whereas at medium speed the dominant source is rolling noise. Only at very high speed does the aerodynamic noise become an important factor. This effect is illustrated in the following figure.

Figure 6: Sources of railway noise according to train speed



Source: UIC 2008, page 7.

This figure shows that between 30 and 200 km/h rolling noise is the dominant source. This is also the speed range which affects most people living near railway tracks. Low speed is only to be found in shunting yards, near stations or on factory railways. Speeds of more than 200 km per hour are only to be found on high speed lines.

The range between 30 and 200 km/h applies to most other railway lines. Mostly these are older lines built in a time where noise protection was not obligatory. Currently these lines have the right of continuance. There is mostly no obligation to invest in noise protection measures but according to Directive 2002/49/EC, many states in Europe already introduce actions to lower environmental railway noise. The speed range between 30 and 200 km/h is also the speed where freight trains operate (about 100 km/h). Many sources identify freight trains as the noisiest trains and they mostly operate outside high-speed lines. The following table shows the importance of noise sources, depending on train type.

Table 16: Importance of noise sources

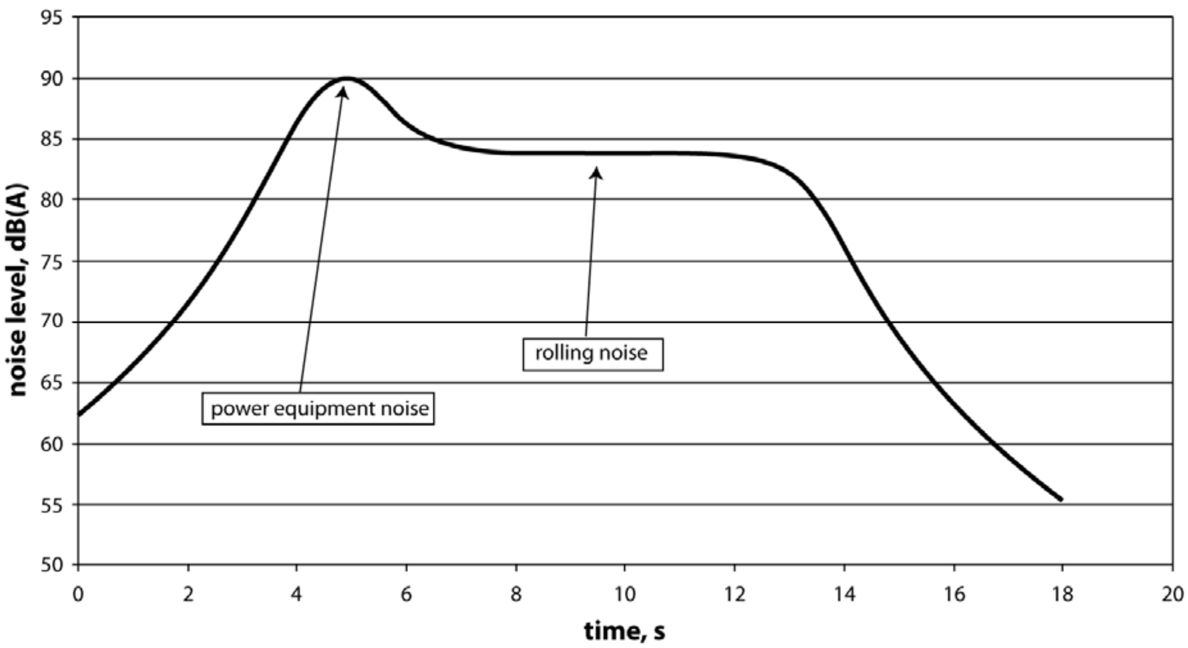
ACTION	ROLLING NOISE	POWER EQUIPMENT NOISE	AERODYNAMIC NOISE
Freight trains	++	+	Not relevant
High speed trains	++	+	++
Intercity or other long distance trains	++	+	Not relevant
City railways (tram)	++	+	Not relevant

Source: EC 2003, page 18.

The table confirms the importance of rolling noise. [EC 2003] considers that passenger trains are already quieter as they are equipped with disc brakes. This measure was not introduced for noise reduction but to enhance performance at speeds above 140 km/h.

The following figure shows the effect of power equipment noise (here a diesel hydraulic engine, built 1968 to 1979, German type 218), when a train passes. The engine noise has a large influence at the beginning of the train passage, but after a few seconds the main influence is the rolling noise.

Figure 7: Development of noise sources while train passing



Source: UIC 2008, page 13.

Concerning shunting yards: there were no reports identified which elaborate this aspect in detail. However, noise sources from shunting yards include:

- Engine noise from shunting engines
  especially many acceleration and braking phases must be considered
- Rolling noise from the wagons
  (especially in the train splitting siding zone behind the hump)
- Brake noise
  - Incoming trains
  - Braking of shunting engines
  - Braking of wagons by hump retarders (one of the loudest noise sources)
  - Testing of brakes of ready trains
- Noise from shunting impacts

Most shunting yards are located outside housing areas and their number has dropped over the years. Single wagon transport has even been abandoned in some countries. On the other hand, single wagon transport is still important and may play an important role in modal shift. There was no literature found concerning noise from shunting yards. Other shunting areas are mostly industrial railways where industrial noise protection rules must be met. Here railway noise is treated together with other noise aspects and is part of the total noise measurement or calculation for industrial plants.

Engine noise is relevant at lower speeds and so mostly near stations. This concerns especially acceleration noise when engines (especially diesel engines) work at high power drain (high motor speed, high inverter and converter noise).

Summary:

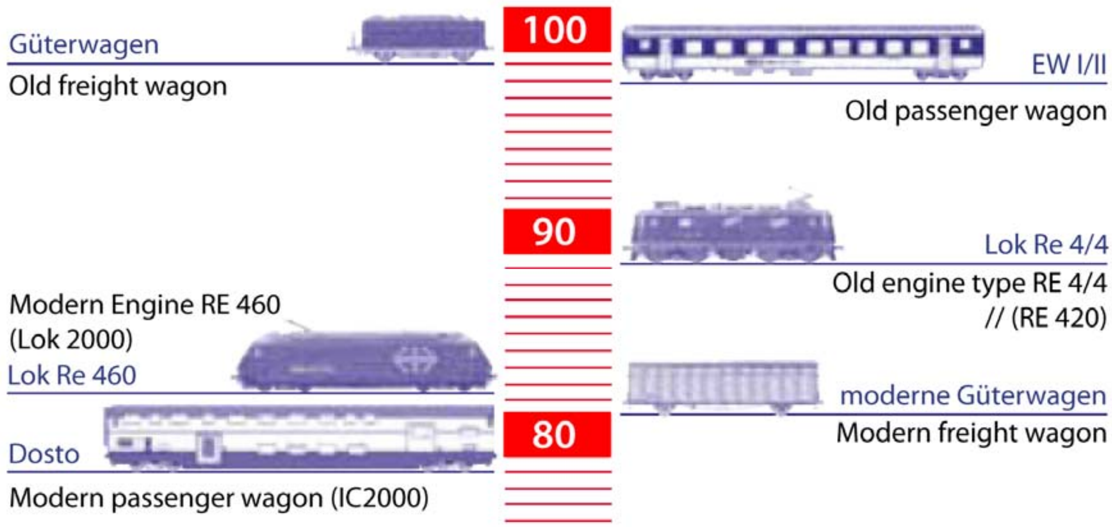
- **The most important source of noise is rolling noise, as this is relevant for both freight and passenger trains.**
- **Aerodynamic noise, especially from pantographs, is very important for high-speed trains.**

3.2. Noise emissions in relation to rolling stock

For existing wagons and engines no changes need to be made according to TSI Noise [TSI 2011]. Only in the case of renewal or upgrading of the wagon or engine is there the need for a new authorisation (to be defined by the national authority); the noise levels must be met with the new authorisation.

The following examples show the development of noise emissions concerning engines and wagons in the past. Since the year 2000, many new vehicles have been introduced all over Europe in freight and in passenger transport. In its brochure "Ruhe bitte" (silent please) [SBB 2011], Schweizer Bundesbahn (SBB – Swiss Federal Railway) showed how pass-by noise differs between old and new rolling stock. The following figure shows the changes between old stock (designed in the 1970s, or earlier) and new rolling stock (designed at the end of the 1990s). For each of the vehicle types, the noise emission measured according to TSI Noise is shown.

Figure 8: Noise emission development of Swiss rolling stock



Source: SBB 2011.

The engine Re 460 (also known as Lok 2000) is still one of the quietest engines and was the quietest vehicle of all trains until the introduction of the IC2000 passenger double deck coaches. Detailed photographs of the modern Swiss rolling stock show that the bogies are well covered by the whole engine body (Annex III).

The TSI Noise demands a maximum pass-by level of 85 dB(A) for electric engines and of 80 dB(A) for passenger wagons at 80 km/h. The Swiss examples are already below the noise level of current European legislation. This is even more interesting as the Lok 2000 was introduced in 1991 and the IC 2000 passenger cars were introduced in 1997.

[Mather 2006] presented an analysis of sources of noise in comparison with the TSI Noise. This shows the current performance of rail vehicles in comparison with the demands of the TSI. The results are shown in the following tables.

Table 17: Maximum and realised noise emissions of existing high speed trains

SPEED	MAXIMUM NOISE EMISSION ACCORDING TSI NOISE	CURRENT EMISSION OF GERMAN HIGH SPEED TRAINS	DIFFERENCE
250 km/h	87 dB(A)	87 – 94 dB(A)	0 – 7 dB(A)
300 km/h	91 dB(A)	91 – 95 dB(A)	0 – 4 dB(A)
320 km/h	92 dB(A)	92 – 96 dB(A)	0 – 4 dB(A)

Source: Mather 2006.

Table 18: Maximum and realised noise emissions of new freight wagons

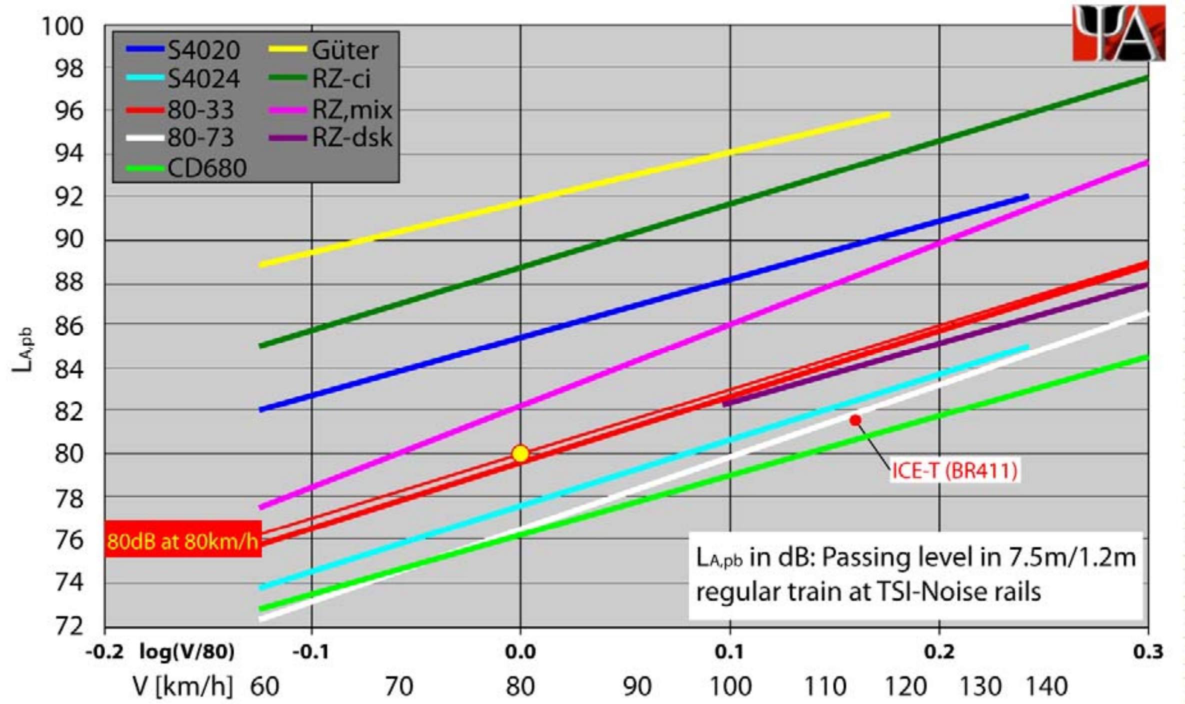
AXLES PER WAGON LENGTH	MAXIMUM NOISE EMISSION ACCORDING TSI	CURRENT EMISSION OF WAGONS	DIFFERENCE
0.15 axles per metre (new car / retrofit car)	82 dB(A) – 84 dB(A)	92 / 94 dB(A)	8 – 12 dB(A)
0.15 – 0.275 (new car / retrofit car)	83 dB(A) – 85 dB(A)	91 – 95 dB(A)	6 – 12 dB(A)
> 0.275 axles per metre (new car / retrofit car)	85 – 87 dB(A)	92 – 96 dB(A)	5 – 11 dB(A)

Source: Mather 2006.

The result is that most actions are still to realise at rail freight wagons and less on passenger trains and modern engines.

Bukovnik, in a presentation about development and measures in rail noise abatement, gives a comparison of old and new rolling stock [Bukovnik 2010]. The following figure shows the effect of new self-propelled vehicles for suburban railways. The vehicle type 4020, built between 1978 and 1987, is - at all speeds - about 8 – 10 dB(A) noisier than the type 4024 (Bombardier electric Talent) built since 2006. At 80 km/h, type 4024 meets or goes below TSI recommendations.

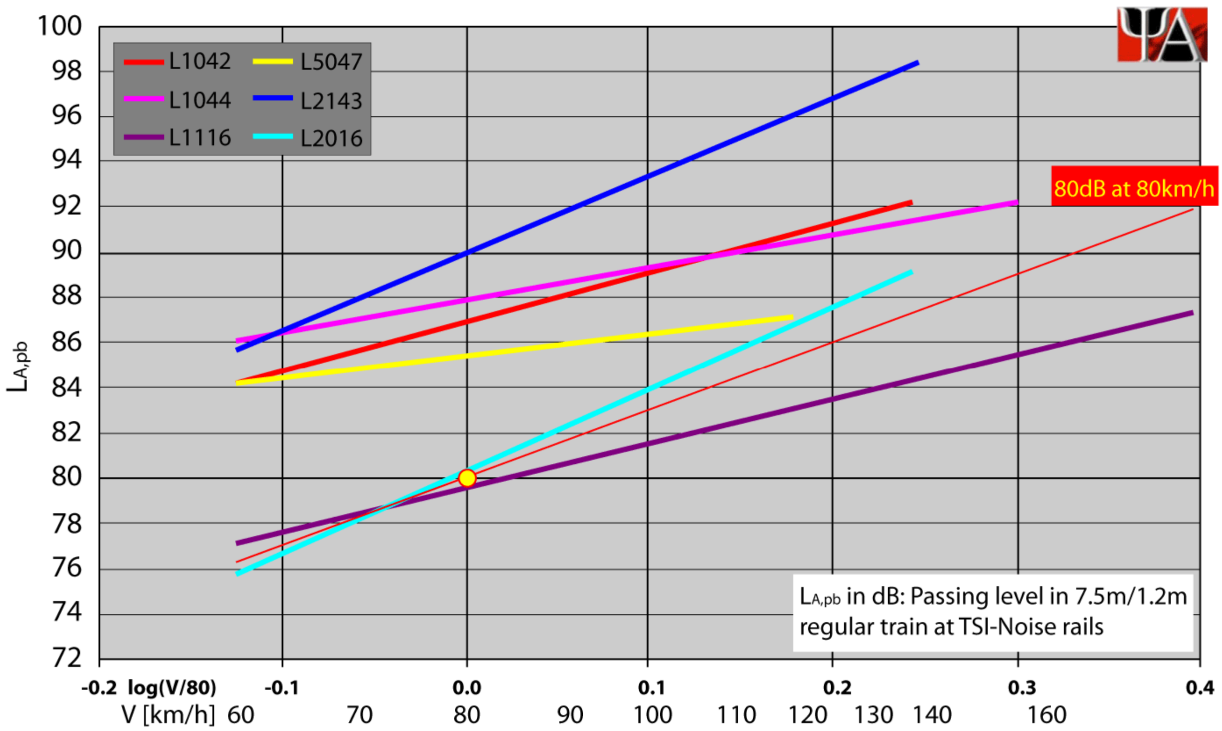
Figure 9: Noise levels of Austrian self-propelled rail vehicles



Source: Bukovnik 2010.

Similar to self-propelled passenger trains, the following figures show pass-by noise emissions of diesel and electric engines. Red lines show electric and blue lines show diesel engines.

Figure 10: Noise levels of Austrian rail engines



Source: Bukovnik 2010.

L1042 and L1044 are old electric engines, designed between 1963 and 1995. L1116 (Taurus) is a new electric engine built since 2000. L2123 is an old diesel engine built between 1964 and 1977; L2016 (Eurorunner) is a new diesel engine built since 2002. A reduction of about 8-10 dB(A) has been realised. With 80 dB(A) at a speed of 80 km/h the new engines are much below the TSI recommendation of 85 B(A).

This shows that the introduction of new rolling stock can lower noise in a big range. Halving of noise was realised since the 1960s and 1970s. Nevertheless there are also negative examples of new rolling stock that may even be noisier than the old equipment. Many sources recognise the modern Class 66 engine as well as the Blue Tiger engine as being as noisy as engines from the 1960s. Both engines were constructed in the 1990s and built since 1998. The great breakthrough to lower noise of engines came according to this since the beginning of the 21st century.

Nevertheless the noise emissions of about 80 dB(A) for new and modernised rolling stock do not lead to a reduction of noise below the WHO levels. Also the levels of the example countries cannot be met with the new rolling stock. But the reduction at the source can lower the additional needs for local noise protection as they can be less extensive or avoided in regions where people live far away from railway lines. There quieter rolling stock can lower the noise measured at far distance to an applicable level.

Summary:

- **Rolling stock introduced since the year 2000 is about 10 dB(A) less noisy in comparison with equipment from the 1960s and 1970s.**
- **So the replacement of old equipment with new ones helps to reduce rail noise.**

3.3. Measures to avoid railway noise

Sources of railway noise can be divided into the following aspects:

- Roughness-Induced Rolling Noise
- Wheel Noise
- Rail Noise
- Squeal Noise
- High Speed Trains
- Other Sources of Noise

The mitigation methods studied or already realised in demonstrators or practice will be introduced with the source of noise.

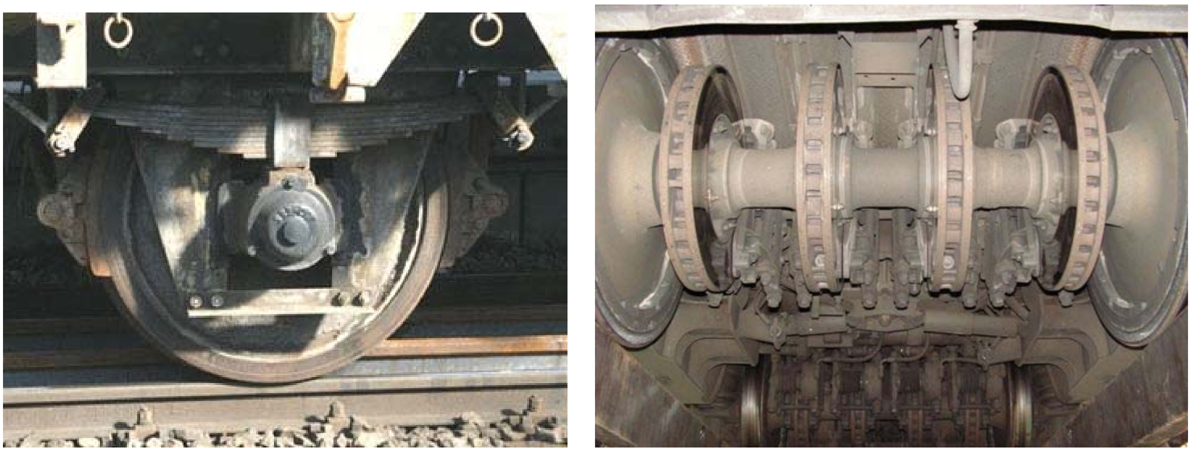
3.3.1. Roughness-Induced Rolling Noise

A major, unavoidable source of noise is wheel and rail roughness. Rail corrugation (which causes intense ground vibration and can increase noise level by 20 dB [CER UIC 2007]) and wheel flats (regular thuds) are extreme versions of this, but poor rail or wheel surface condition should be avoided. Regular grinding of rails and turning of wheels helps to minimise noise. Special ‘acoustic’ grinding can reduce noise levels by about 3 dB [Thompson 2008-1]; grinding strategies to reduce noise levels were studied in the MONA project [Thompson and Gautier 2006].

Both Speno and Schweerbau offer general purpose grinding, which can reduce noise levels by 10-12 dB, and special acoustic grinding, which can achieve a further 3-4 dB reduction [Licitra 2006]. UIC's 2007 report on the state of the art [CER UIC 2007] states that poorly maintained track increases noise levels, so that track renewal can achieve about 10 dB noise reduction, and acoustic grinding can achieve a further 1-3 dB.

Cast iron tread brakes, which are very common in European freight vehicles, tend to induce a corrugation in the wheels which increases noise levels significantly [Thompson and Gautier 2006]. By contrast, disc brakes, which are prevalent in passenger vehicles, are typically about 8 dB quieter [Hemsworth 2006]. The difference between tread brakes and disc brakes is shown in Figure 11. With tread brakes, the brake blocks press against the wheel directly on the running surface (the tread), i.e., the wheel surface which is in contact with the rail; whereas with disc brakes an extra disc is placed on the axle and brake blocks press against this to brake the vehicle. Because tread brakes, particularly with cast iron blocks, damage the wheel, the running surface becomes rough and can develop out-of-roundness, increasing the rolling noise.

Figure 11: Comparison of tread and disc brakes



Source: Hemsworth 2006.

Disc brakes are very expensive and can only be introduced with new freight wagons or expensive retrofitting of existing wagons (the whole bogie needs to be changed). The EU Project EuroSabot (1996-1999) looked into possibilities for retrofitting vehicles with a low-noise replacement for cast iron brake blocks [EUROSABOT 2011], [Hemsworth 2006], [Thompson and Gautier 2006]. This started the quest for composite brake blocks with friction characteristics similar to cast iron brake blocks, and suitable for retrofit; these are called 'LL-blocks'. 'K-blocks' are composite brake blocks used in new vehicle designs.

The advantage of LL-blocks is that the braking system of the wagon does not need to be modified, whereas for K-blocks there is additional effort necessary besides changing the blocks. This is because LL-blocks have similar friction characteristics to conventional cast-iron blocks, whereas K-blocks have a higher coefficient (2.5 times higher).

Both types (K- and LL-blocks) reduce noise levels by 8-10 dB; life cycle costs for K-blocks are similar to life cycle costs for cast iron brake blocks; life cycle costs for LL-blocks are still to be determined [CER UIC 2007] concerning operation costs. Concerning K-blocks, some manufacturers or wagon owners recently detected higher costs due to higher wheel wear [Gilliam 2008] and [Saabel 2011].

The EU Project Euro Rolling Silently (2002-2005) developed three prototype LL-blocks. By 2009, two LL-block types (IB 116* and Jurid 777) were reportedly safe for use in Europe [Dörsch 2009]. ICER Brakes S.A. sell organic LL-blocks which reduce noise by 8 dB compared to cast iron brake blocks [Licitra 2006]; organic LL-blocks are also produced by the Federal-Mogul Corporation.

However, although the new composite LL-blocks are effective at reducing noise, there are still problems to be solved before they can be implemented across Europe. In tests with LL-blocks, the wheels' equivalent conicity increases over time, affecting the dynamic stability of the vehicles. To address this, a consortium of brake manufacturers and vehicle operators has established the EuropeTrain project ([EuropeTrain]) which is using a real train travelling around Europe to speed up testing of LL-blocks.

If the LL-block could be introduced and certified the migration would be relatively easy, simply replacing the existing cast iron blocks by LL-blocks. Concerning the accreditation of LL blocks, Mr Lochman from CER expects certification by the end of the year 2011 and the beginning of introduction mid-2012, whereas Mr Pennekamp, Mr Fleckstein, Mr Mather and Mr Theis from DB expect certification sometime during 2012.[16] As a result, the authors of this study expect certification by the end of 2012, which is more practical.

In addition to EuropeTrain, the following two composite brake projects are being conducted in Europe: Leiser Rhein includes the retrofitting of vehicles, especially in the Rhine Valley, and LäGiV develops improved K-and LL-blocks.

Summary:

- **Roughness of rails and wheels, especially corrugation in rails and out-of-round wheels, is a major cause of rail noise and needs to be monitored and controlled. Infrastructure managers and train operators already have maintenance programmes to control rail and wheel quality, and infrastructure managers use axle load checkpoints to monitor passing traffic and detect severely damaged wheels. Tolerances may need to be tightened to improve quality and reduce noise, requiring additional maintenance.**

- **The use of composite brake blocks rather than cast iron brake blocks will significantly improve the wheel running contact surface and reduce noise levels. Retrofitting existing wagons with composite brake blocks is possible, and the use of LL-blocks in particular (requiring the least effort and cost to retrofit) is currently being investigated by UIC's EuropeTrain consortium. There are still questions about the long-term degradation and the life cycle costs of the new LL-blocks that are holding up widespread implementation.**

3.3.2. Wheel Noise

The EU Project Silent Freight (1996-1999) looked at possibilities of reducing noise emission from wheels [Dörsch 2009], [Hemsworth 2006], [Thompson and Gautier 2006]:

- ring dampers reduce noise by 6 dB;

[16] These statements are the results of interviews held by the project team in July 2011.

- perforation of the wheel is ineffective;
- wheel-tuned absorbers reduce noise by up to 7 dB;
- wheel web shields reduce noise by up to 9 dB.

The following figures illustrate the systems.

Figure 12: Ring damped and perforated wheel

Source: Hemsworth 2006.

Figure 13: Wheel-tuned absorbers

Source: Hemsworth 2006.

Figure 14: Wheel web shields

Source: Hemsworth 2006.

Further noise reduction can be achieved through the use of a bogie shroud [Hemsworth 2006].

Fundamental redesign of the wheel to reduce noise is difficult due to the need to fit with existing tread braking systems and the need to dissipate the heat generated during braking. Reducing the wheel diameter makes the wheel more susceptible to wheel-rail roughness interaction and can increase noise levels. The RONA project (wheel optimisation for high-speed lines) developed a new wheel design, JR13, which reduced noise levels by about 3 dB. The RONA project also developed a wheel, Alu4, with a thick aluminium web and wheel dampers, with a predicted noise reduction of 12 dB. However, following the Eschede derailment in 1998[17], caused by a broken tyre, the industry has been wary of multi-material wheels. Other incidences with broken axles on freight wagons or ICE trains[18] will make innovations of wheels and axles more difficult. The EU Project HIPERWHEEL (2000-2004) tested a constrained layer damping treatment on the ETR500 high speed train in Italy and measured a noise reduction of 4-5 dB between 200 and 300 km/h (see [Thompson and Gautier 2006]).

Lucchini[19] offers a range of special low-noise damped wheels. *Syope* is a constrained layer damping treatment; *Galene* uses tuned absorbers to reduce squeal noise for trams; *Hypno* is a friction damping steel design for tread-braked freight wagon wheels. Valdunes[20] also integrates damping systems into wheels, for example, using damping rings to reduce squeal noise by 10-15 dB (see [Licitra 2006]).

Heathcote Industrial Plastics offers constrained layer dampers which eliminate squeal noise and reduce under-vehicle noise by up to 30 dB. GHH offers wheel absorbers (5-15 dB noise reduction) and damping rings. VSG Vibration Absorbers offers wheel vibration absorbers (10-30 dB noise level reduction at squeal noise peak frequencies). Schrey & Veit offers wheel absorbers which almost completely eliminate squeal noise, and reduce the noise level by 8 dB if squeal does occur (see UIC Curve Squeal Project WP3 [Müller et al. 2003]).

Summary:

- **Resilient wheels can reduce noise and improve ride quality, and can be very effective at reducing squeal noise in tight curves. A variety of technologies are available and in use in high-speed and metro applications.**
- **Following the Eschede disaster in 1998, there is still a reluctance to use non-monoblock wheels in high-speed rail vehicles.**

3.3.3. Rail Noise

Rail dampers – steel masses embedded in an elastomer, fixed to the rail web – were developed in the 1990s by ERRI in the OFWHAT (Optimized Freight Wheels and Track)

[17] At Eschede the broken separate tyre caused the high-speed ICE train to derail at a switch. The rear bogie of one carriage followed the turnout on to a parallel track, and the carriage subsequently hit bridge supports. The bridge collapsed onto the train and the following cars crashed into the broken bridge and cars. 101 people died and a further 88 sustained injuries. The separate tyre technique was only used with ICE trains to solve a primary damping problem with this train type whereas other high speed trains only use full monoblock wheels.

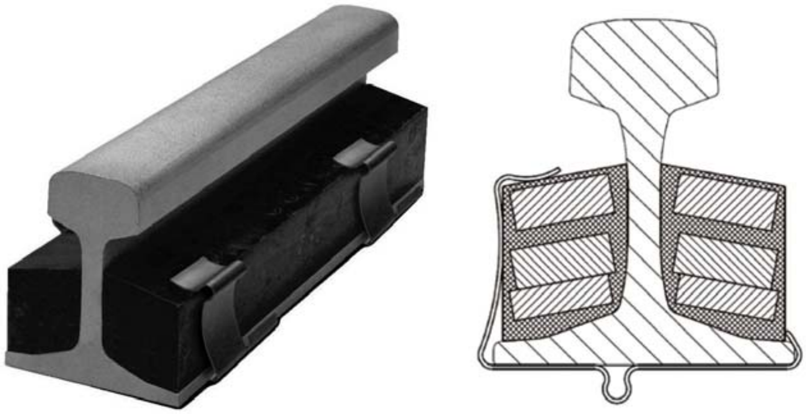
[18] Breaking of an axle of an ICE3-train in Cologne on 9 July 2008; freight train derailment in Viareggio (Italy) 30 June 2009.

[19] Lucchini RS [http://www.lucchinirs.it/] is an Italian company which produces high-speed wheelsets; this is separate from the Russian-owned steel manufacturer Lucchini.

[20] Valdunes [http://www.ghh-valdunes.com/] is a major European wheelset manufacturer based in Germany, France and Belgium.

project and SNCF in the VONA project (low-noise track designs for high-speed lines) [Thompson and Gautier 2006]. The EU Project Silent Track (1997-2000) developed these rail dampers further; the new design reduced noise by 6 dB [EUROSABOT 2011], [Hemsworth 2006], [Thompson and Gautier 2006]. The Dutch IPG project[21] tested rail dampers and found the silent track dampers and also the Schrey and Veit (S&V) VICON-ASMA 5RQ absorber to be effective, reducing noise levels by 3 dB [Thompson 2008-2]. Further testing of rail dampers is presented by van den Dool [van den Dool 2007].

Figure 15: Tata Steel SilentTrack tuned rail dampers



Source: Tata Steel; images from product brochure.

Tata Steel offers the 'SilentTrack' tuned rail damper system (see Figure 15), with a noise reduction of 3-7 dB. The rubber at both sides of the metal rail causes the noise reduction. Over 200 km of SilentTrack are in operational use around the world, including the Netherlands, Germany and the UK.

Trackside barriers can also be used to reduce noise levels [Hemsworth 2006], [Thompson and Gautier 2006], but rail dampers can make barriers and screens unnecessary [van den Dool 2007].

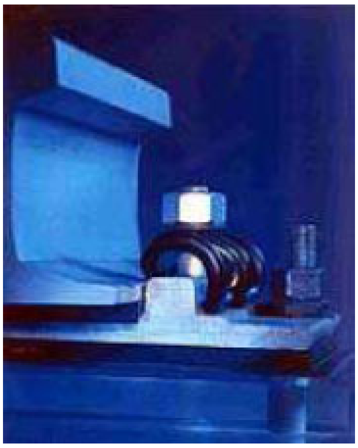
The VONA project also developed optimised rail pads which reduced noise levels by 3-4 dB [Thompson and Gautier 2006]. Rail pads were also developed in the Silent Track project, reducing noise levels by 2 dB.

Saargummi and CDM offer a range of resilient rail pads designed to damp noise and vibration; CDM and Getzner Werkstoffe offer under-sleeper pads and ballast mats and a range of solutions for slab track and embedded track systems [Licitra 2006].

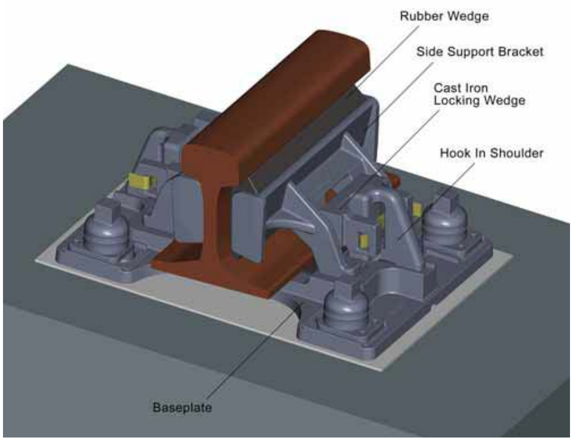
Pandrol's VANGUARD uses resilient padding to attenuate noise, but also supports the rail at the web to prevent rail roll. This system is used in the London Underground (Victoria Line) and the Channel Tunnel Rail Link, for example, and recently in the new development of Belgrade Central where vibration reduction was a key consideration. When tested in Hong Kong's MTRCL test track on plain slab track, the VANGUARD system reduced average noise levels by 7.3dB in the 20Hz-500Hz range; and by 13dB in the 40Hz-80Hz range. These tests showed even greater noise reduction was possible by using the VANGUARD on an Isolated Slab Track (IST); IST has a rubber ballast mat and is easier to install than floating slab track, but is not as effective.

[21] Innovatieprogramma geluid (IPG) voor weg- & spoorverkeer [http://www.innovatieprogrammageluid.nl/].

Figure 16: Left: Saargummi rail pad; Right: Pandrol Vanguard resilient web support



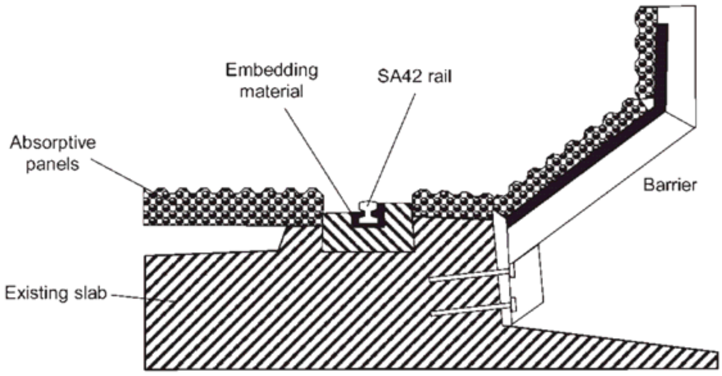
Source: Licitra 2006



Source: Pandrol Vanguard; product brochure

The Silent Track project developed a new rail section with a narrower fit, along with a new fastening system and a new twin-block sleeper design; this reduced noise levels by 3 dB. The Dutch project Quiet Rail Traffic (STV) developed a new, smaller rail section, SA42, for slab track (see Figure 17); the rail is continuously supported by a stiff embedding material, and this acts as a damping mechanism. The noise reduction compared to slab track with UIC 54 rails is 5 dB. Barriers at the side of the track, with a height of 0.7 m, further reduced noise levels by 6 dB (see [Thompson and Gautier 2006]).

Figure 17: Slab track section SA42 from Quiet Rail Traffic project



Source: Thompson and Gautier 2006.

The Edilon Corkelast embedded rail system, which provides a noise reduction of 5 dB, has been implemented in the rail steel bridge over the Arno in Pisa [Licitra 2006].

Balfour Beatty Embedded Rail System (BBERS) has been shown in a test in Medina, Spain, to reduce noise level by 2 dB or more, compared to ballasted track [InnoTrack D2.3.3].

Summary:

- **Noise and ground-borne vibration are a major concern in urban areas, and bridges and underground railways require special measures. Resilient rail pads are a common solution, but for locations where a greater level of damping is required then floating or isolated slab track is a possibility, or under-sleeper pads and ballast mats for ballasted track; an alternative to**

rail pads is a more advanced resilient rail support system such as VANGUARD.

- **Resilient rail support solutions interact with each other and also with resilient wheel technologies, and the whole system needs to be considered and modelled in order to minimise noise and vibration in the required frequency range.**

- **Noise barriers have a large on-going maintenance cost, have a high visual impact and create problems for track access. Rail dampers can be tuned to the local needs of the railway and left in place for the life of the track; these can be an effective alternative to noise barriers.**

3.3.4. Squeal Noise and Friction Modifiers

Squeal noise is the high pitch noise (2-4 kHz) sometimes emitted when vehicles are curving. This is caused by lateral stick-slip behaviour of the contact between the wheel and rail exciting high-frequency resonances in the rail and wheel. Many wheel and rail damper solutions target squeal noise.

Friction modifiers are used to change the interaction of wheel and rail to prevent squeal noise and corrugation. As of 2005, UIC's position on friction modifiers was that there is no optimal solution. Friction modifiers can be lubricants, e.g., greases, designed to reduce friction to 0.2 or less, and usually applied to the gauge face of the high rail in curves where the wheel flange often makes contact, creating a grinding sound and high levels of wear. Lubrication is primarily used to reduce wear, and is not desirable on the top of the railhead where high levels of friction are required for traction (train acceleration and braking). Top-of-rail (TOR) friction modifiers (FM) control friction to be in the range 0.3-0.35. To prevent squeal noise, friction modifiers need to have 'positive friction' characteristics, so that friction increases when the wheel slips. TOR FM can also be effective at reducing short-pitch corrugation (a major noise source) on the low rail in curves, and has been used successfully in the Heathrow Express to combat corrugation[22].

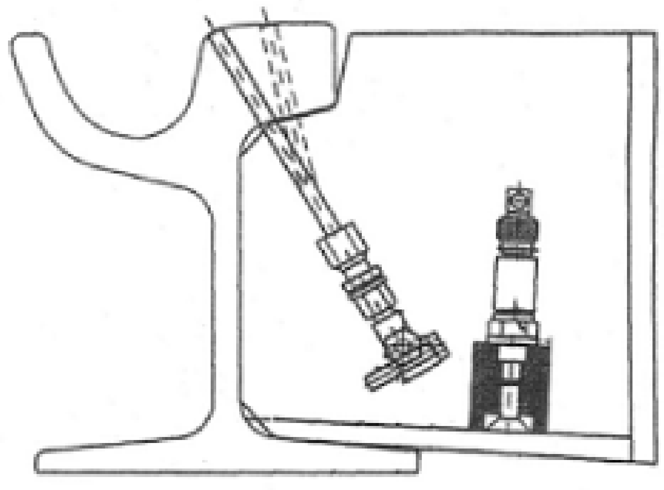
Alternatively, special asymmetric rail sections can be used to prevent squeal ('Anti-Squeal Profile'), and the track layout can be adjusted to avoid dynamic conditions of the vehicle which cause squeal noise. Special surface layers or coatings can be designed with special friction characteristics, such as Duroc AB's particle-impregnated rail surface. Based on laboratory tests, this layer has a low coefficient of friction when dry, and is also effective at reducing rail wear, and even the corresponding wheel wear is relatively smooth (see [Hiensch et al. 2007]).

The EU Project Q-City (2005-2009) tested vehicle and track lubricators for squeal noise suppression. On-board lubrication was tested in the Antwerp network and found to be effective at reducing squeal noise, and for a relatively low cost. A wayside lubrication system was tested at the STIB depot; the wayside lubrication was very effective, decreasing squeal noise by at least 16 dB. In general, electric power is required on site for wayside lubricators, and access to hydraulics for maintenance may be difficult in urban

[22] M. Chestney, N. Dadkah and D. Eadie (2009) The Effect of Top of Rail Friction Control on a European Passenger System: The Heathrow Express Experience, 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009), Firenze, Italy. [For a summary of this, and a general look at TOR FM, see also: http://www.therailengineer.com/railtex2011/Day-2-No-06-Kevin-Portec.pdf].

environments (see [Q-City 2009]). These techniques, indeed, are only tested for municipal railways (light rail, underground systems).

Figure 18: Principle of way-side lubrication systems for friction modifying



Source: Q-City 2009.

The particular through-hole lubricator prototype developed by Lion Oil was found to be unreliable (see Figure 18). The figure shows the injection device to lubricate the rail-wheel-contact area. Other similar systems are on the market, and the annexes of [Q-City 2009] give quotations for: (A) Clicomatic rail through-hole grease lubrication system; (B) FluiLub rail lubrication systems (vehicle-mounted and track-based).

ELPA d.o.o. offer another through-hole wayside application for suppressing squeal noise, both in curves and during braking (particularly useful at marshalling yards) [ELPA], [Licitra 2006]. The ELPA system uses an environmentally friendly composite friction modifier.

Other track-based rail lubrication / friction management systems are: Portec trackside Friction Management System (5-15 dB noise reduction); Schreck-Mieves Electronic Rail lubrication; and KLS Lubriquip. Other on-board friction management systems: REBS (rail lubrication, 20-28 dB reduction at 2500 Hz, and wheel-flange lubrication); TracGlide (rail lubrication); Vogel AG (wheel-flange lubrication); Kelsan/Lubriquip (wheel-side, 2-7 dB reduction); Barnt Green Birmingham (water spray); SBB (water spray) (see UIC Curve Squeal Project WP 3 [Müller et al. 2003]).

Summary:

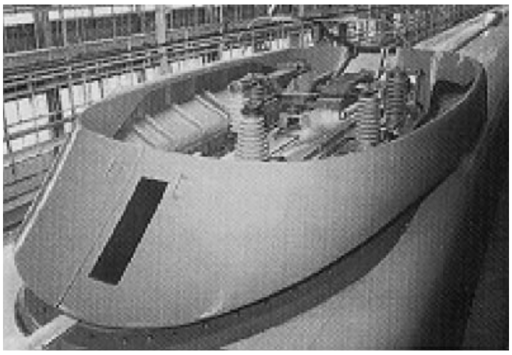
- **Gauge-face lubrication is the traditional means for controlling wear of the high rail in narrow-radius curves, which has a secondary effect of reducing noise levels, including squeal noise in some cases. The main technological developments in this area focus on the applicators.**

- **Top-of-rail friction modifiers are a relatively new extension of this technology, and are used to prevent corrugation of low rails and squeal noise in curves, as well as brake squeal in shunting yards.**

3.3.5. High-Speed Trains

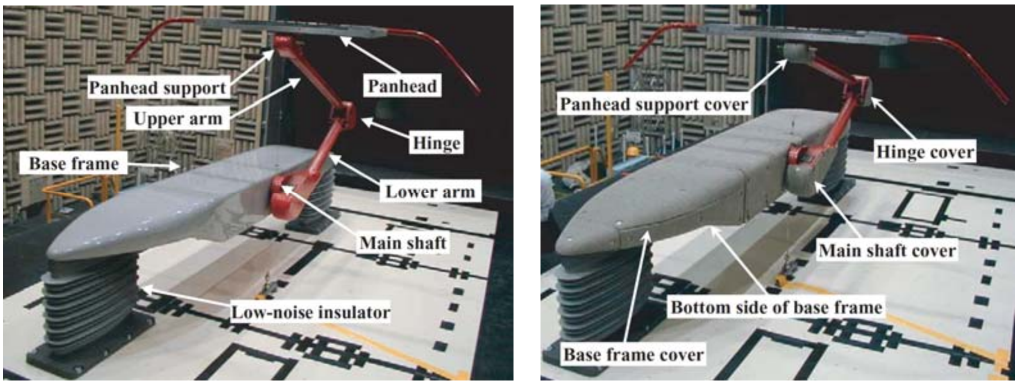
Aerodynamic noise becomes significant at high speed (over 200 km/h) reaching a noise level similar to rolling noise. For electric trains, pantograph noise is also significant at high speed. Pantographs and the leading bogie are the two main sources of aerodynamic noise. Pantographs can be shielded (see Figure 19) and/or carefully shaped, and thereby achieve noise reductions of 5-10 dB in each case (see [Talotte 2000], [Talotte et al. 2003]). [Sueki et al. 2009] have shown that porous covers can reduce aerodynamic noise of pantographs.

Figure 19: Shield of pantograph of Japanese Shinkansen Series 700



Source: Talotte 2000.

Figure 20: Porous coating of pantographs



Source: Sueki et al. 2009.

Vibrations caused by vehicle-track interaction travel through the ground at a speed that depends on the ground type; propagation is slower in softer soil. If train speed exceeds the ground vibration propagation speed, then this creates a ground-borne vibration 'boom', analogous to a sonic boom when aircraft break through the sound barrier. In practice this means there is a threshold train speed above which ground vibration increases sharply. For peat and clay soils, this critical speed can be as low as 150 km/h, but bogie spacing and axle spacing also influence the critical speed [Madshus and Kaynia 2000].

Concerning high speed trains on high speed lines, often ballast-less tracks are used. As this superstructure is a hard soil the noise can increase due to the hard concrete plate, low absorption of noise and strong transference. The normal solution is to cover the ballast-less tracks with dampers.

Summary:

- **Pantographs are generally higher than noise barriers, and for high-speed trains these are a major source of noise. Rather than making noise barriers**

even higher or all-enclosing, an alternative approach is to focus on aerodynamic design and new materials.

3.3.6. Other Sources of Noise

Other sources of noise include locomotive exhaust, traction motors, cooling fans, bridges and train horns [Talotte et al. 2003]. Resilient baseplates are effective at reducing bridge noise (the Pandrol VIPA system reduced noise by 6 dB in one study [Wang et al. 2000]). Schrey & Veit (S&V) also offer a tuned absorber system for railway steel bridges [Licitra 2006] with also approximately 6 dB noise level reduction.

It should be noted, finally, that poor or infrequent maintenance can cause increased noise levels, particularly from components with moving parts, e.g., bearings, vehicle suspension.

3.3.7. Other options to reduce noise

Other options, such as speed limits and land-use planning, are rejected in [UIC 2008]. Speed limits need to be substantial (50 km/h) to have a considerable noise impact and thus "are not compatible with the operation of a commercially competitive railway" (although the benefits of speed reduction should be considered on a case-by-case basis). Land-use planning measures are of little effect, since further than 50 metres from the source "noise level is insensitive to even medium changes in distance".

The redirection of trains is not always suitable. In some cases there may be alternative lines, but here also people can be affected. So this solution may only be a shift of the problem. In some cases, for example the Rhine axis, there are no (realistic) alternatives.

3.4. Result for main reduction measures

The following table shows a summary of measures, effects and costs, collected from the different sources.

Table 19: Measures, effects and costs

MEASURE	AVOIDED SOURCE OF NOISE	IMPACT (LOCAL, NETWORK WIDE)	EFFECT	COSTS / UNIT[23]
K-blocks	Rolling noise	network wide	Up to 8 dB(A) – 10 dB(A)	4,000 – 10,000 € per wagon[24]
LL-blocks	Rolling noise	network wide	Up to 8 dB(A) – 10 dB(A)	500 – 2,000 € per wagon[25]
General grinding of bad track	Rolling noise	local	10 – 12 dB(A) (up to 20 dB(A) at very bad tracks)	Shall be established in normal maintenance

[23] Cost information comes from [UIC 2008] page 25.
[24] Retrofit, for new wagons there are no additional costs; additional operating cost still to be analysed.
[25] Retrofit, for new wagons there are no additional costs; additional operating cost still to be analysed.

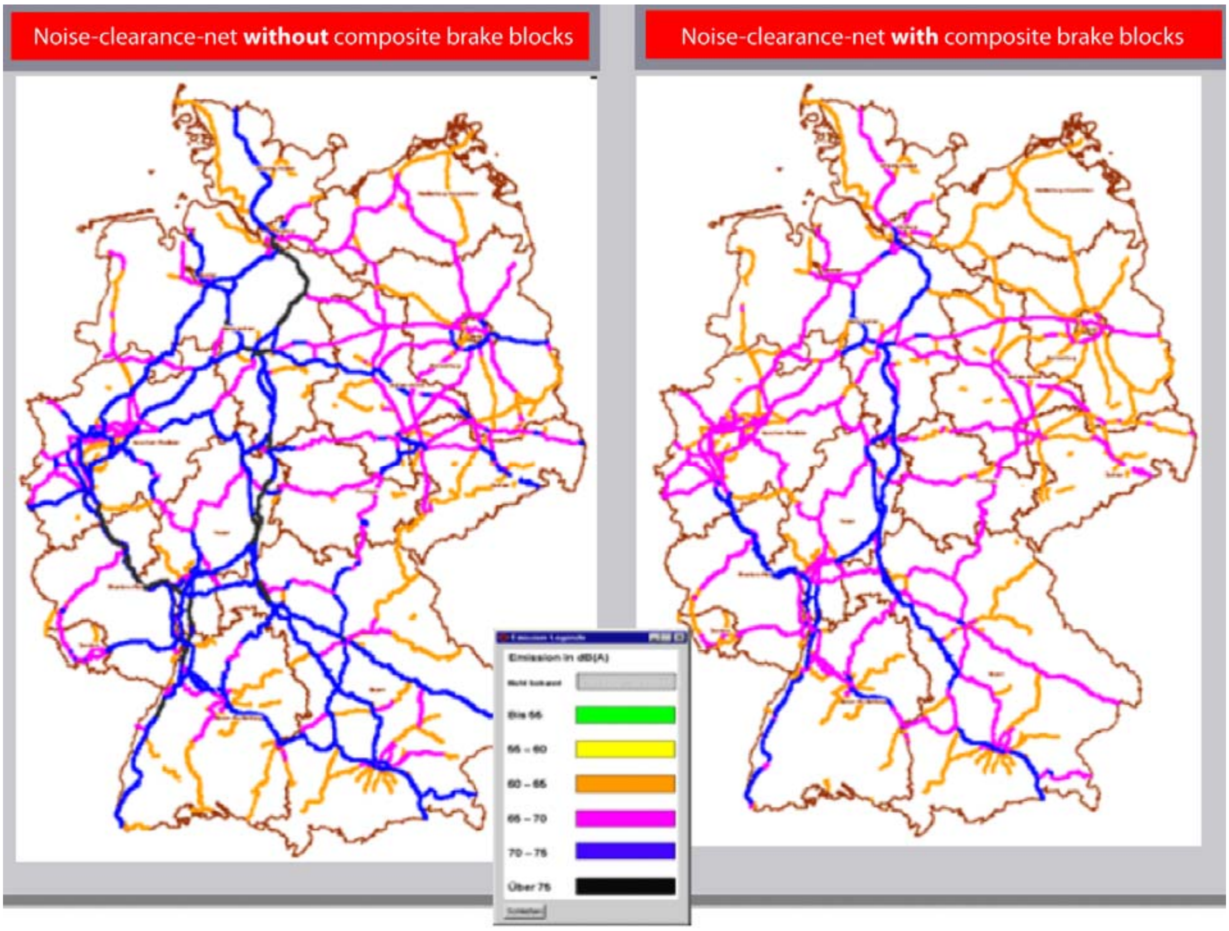
MEASURE	AVOIDED SOURCE OF NOISE	IMPACT (LOCAL, NETWORK WIDE)	EFFECT	COSTS / UNIT[23]
Special acoustic grinding	Rolling noise	local	1 – 4 dB(A) (depending on local rail roughness conditions), mostly around 2 dB(A) attended	
Disc brakes	Rolling noise	network wide	10 dB(A)	Meanwhile mostly established in passenger cars
Wheel-tuned absorbers	Wheel noise	network wide	2 – 7 dB(A)	3,000 – 8,000 € per wheel → (24,000 – 64,000 per 4-axle wagon)
Bogie Shrouds together with low height barriers	Wheel noise	local	8 – 10 dB(A)	
Rail dampers	Rail Noise	local	3 – 7 dB(A) (mostly around 3 dB(A) attended)	300 – 400 € per metre (two rails)
Slab tracks	Rail noise	local	5 dB(A)	
Rail pads	Rail Noise	local	3 – 4 dB(A)	
Different measures to lower squeal noise	Squeal noise	local	Up to 20 dB(A) depending on local conditions	
Shielding of pantographs	High speed trains	Global but only at high speed up from 200 km/h	5 – 10 dB(A)	
Barriers 2 meter high	All sources	local	10 dB(A)	1,000 €/m
Barriers 3 – 4 meter high	All sources	Local	15 dB(A)	1,350 €/m (3 metres high) 1,700 €/m (4 metres high)
Insulated windows	All sources	In house only	10 – 30 dB(A)	3,000 – 8,000 € per house (4 windows)

Source: Elaborated by the authors from different sources.

Deutsche Bahn has published two graphs in its Statement for Noise Reduction [DB 2010] Figure 21 shows, on the left, the current noise levels on German railway lines; and, on the right, the results of a simulation with the assumption that composite brake blocks for rail freight wagons have been introduced. The graphs show that the network affected by high noise emissions will shrink by introducing modified tread brake blocks. Fewer lines will be affected by noise levels between 70 – 75 dB(A) and 65 – 70 dB(A). Nevertheless, there are many lines which will remain affected by these noise levels.

However, the introduction of low noise wagons with the help of composite blocks lowers the number and length of rail sections where local (expensive) measures must be taken.

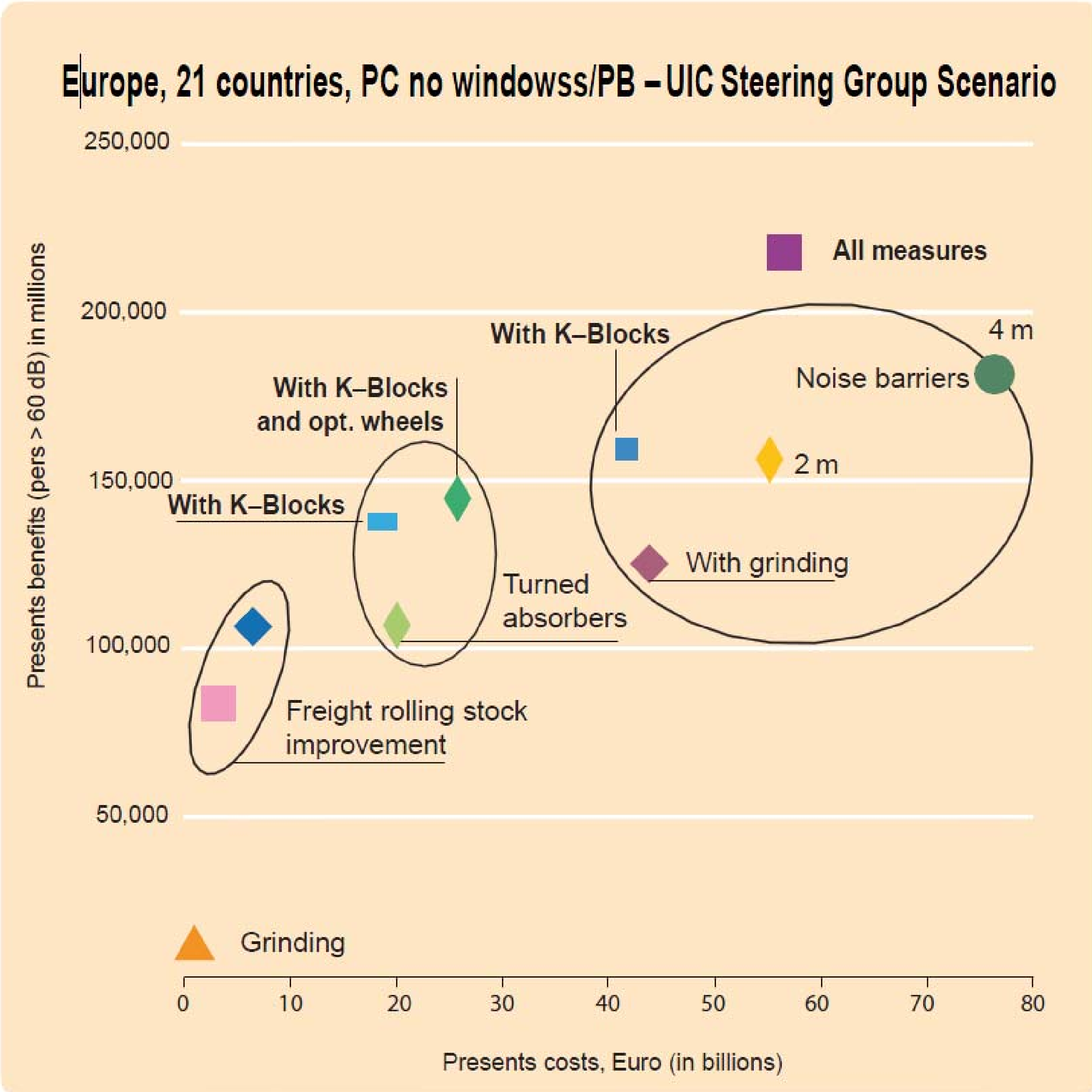
Figure 21: Shift of noise levels on German railway lines due to introduction of composite iron soles for rail freight wagons



Source: DB 2010, page 3.

The UIC published in its report "Railway Noise in Europe – A 2010 report on the state of the art" a diagram where the costs and benefits of different measures and combinations are presented [UIC 2010]. Figure 22 represents the main result of the STAIRRs Project (funded by the EU 5th Framework Programme). The graph shows that the most cost effective measure to lower railway noise is the retrofitting of freight wagons with composite blocks. It costs about 5–10 billion Euro and lowers noise for about 100 million people. The combination of composite blocks with rail-tuned absorbers will raise costs up to 20–40 million and affect 100–150 million people. In comparison, noise barriers (without any changes in vehicle technology) will cost about 80 billion Euro and affect about 180 million people. As a result, the introduction of composite brakes saves a considerable amount of money in comparison with noise abatement only realised by noise barriers.

Figure 22: Cost benefit analysis of measures to reduce noise in STAIRRS project

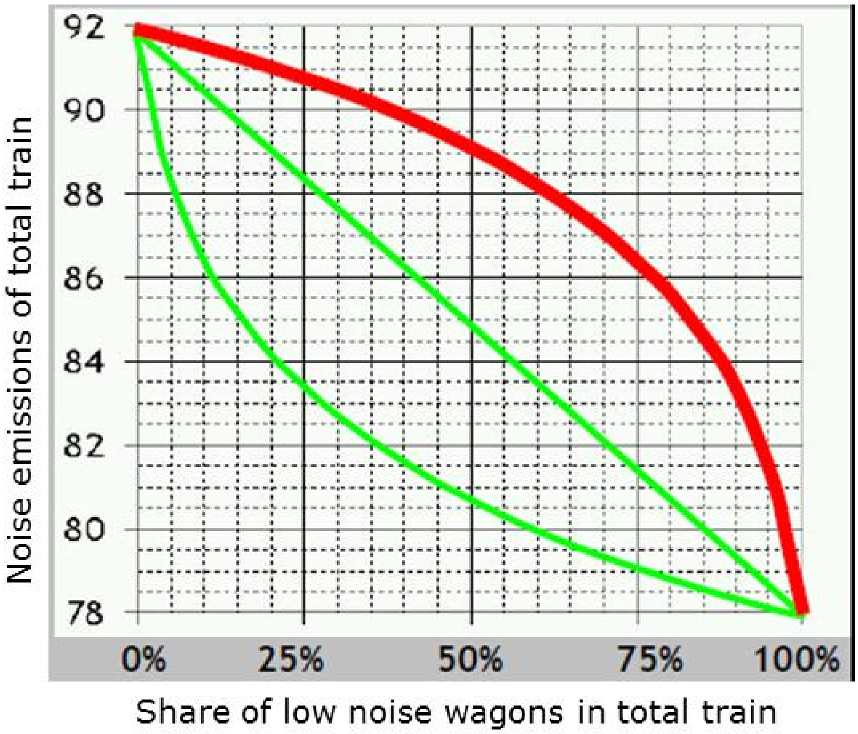


Source: UIC 2010, page 15.

Concerning the equipping of freight wagons with composite blocks: The noise reduction effect of a complete train depends in a logarithmic form on the number of wagons equipped with composite blocks. This effect is illustrated by [Bukovnik 2010].

The red line in Figure 23 is the relevant one. It shows the effect of the total noise emission (y-axis) of a train in which a certain share of wagons is equipped with low noise brakes (x-axis). The assumption for Figure 23 is that wagons equipped with composite brakes cause noise emissions of 78 dB(A), whereas the others cause emissions of 92 dB(A). The figure shows that noise reduction for a whole train follows the share of noise-reduced wagons and is disproportionately low until about 75% of the wagons have composite brakes, and after that the total noise decreases faster.

Figure 23: Effect on total noise according to share of wagons equipped with K- or LL-blocks



Source: Bukovnik 2010.

If 50% of the wagons were equipped with composite blocks the total noise would only be reduced to a noise level of 89 dB(A) (21% of total possible lowering). Only if about 98% of wagons were equipped would a total level of 80 dB(A) (86% of possible lowering) be reached. This means that the lead time until significant noise reduction is achieved will be very long if the modified wagons are introduced by normal replacing of old wagons by new ones after the normal operation time of a wagon (about 40 years).

To achieve a significant and noticeable effect, a large share of wagons has to be equipped with K- or LL-blocks as soon as possible. LL-blocks can be completely introduced according to the normal operational lives of blocks (which in some cases is less than one year as normally – operation time for cast iron blocks is about 60,000 km, whereas wagons for combined transport run about 100,000 km per year). K-blocks can be introduced in about 6–8 years providing the possibility for wagon owners to modify the braking system with the general inspection.

Conclusion:

Regarding the costs and the associated effects, and current experience of noise measures, the authors conclude that:

- Noise should ideally be reduced at the source because these measures have a network-wide effect.
- **A relatively cheap way to reduce noise on freight routes is to retrofit braking systems of rail freight wagons with composite brake blocks as quickly as possible.**
  - Freight trains are currently identified as the noisiest trains.
  - Most freight trains operate at night which is the most sensitive time of day.
  - Most passenger trains already have disc brakes due to higher speeds and enhanced comfort for passengers, so these trains are quieter than freight trains.
  - Wheel dampers are very expensive and cause additional efforts for maintenance but can significantly reduce noise emission.
- In case of high-speed trains, advanced pantograph designs should be considered, especially for routes through noise-sensitive areas where noise bunds and barriers shield against rolling noise but may not shield pantograph noise.
- Where track infrastructure causes increased noise levels (e.g., structure-radiated noise from viaducts or curve squeal in narrow radius curves), or where the local environment is particularly sensitive to noise (e.g., urban environments with residences very close to the railway line (especially agglomerations) or areas of natural beauty) then additional trackside noise mitigation measures may be necessary.
  - Rail-tuned absorbers can be effective against curve squeal and rolling noise, reducing noise levels typically by 3-7 dB(A). These can be a low-cost solution which avoids visually intrusive noise barriers.
  - Noise bunds and barriers can be effective against noise propagation, but can create problems for track access and have high on-going maintenance costs.
  - Curve squeal and corrugation of the low rail can be prevented using top-of-rail friction modifiers.
- In the long term, new wheel concepts can be introduced, but these need more research and testing before they can be introduced especially into high speed vehicles.
- In dense populated areas with high frequencies of trains, noise protection walls or insulating windows still need to be introduced. Their number could shrink in case of well introduced source related measures or modified tracks.

3.5. Number of rail freight wagons to be retrofitted

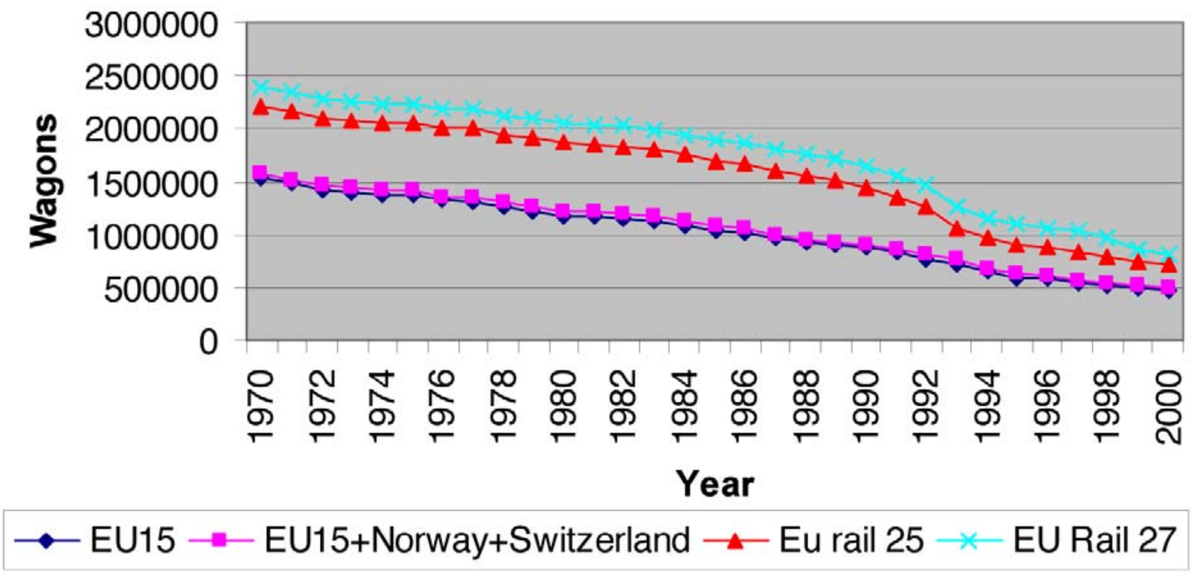
To identify the value of retrofitting freight cars with composite brake blocks, an analysis of the age structure of the fleet must be done. One question is the number of wagons it is worth retrofitting. Another is the number of wagons that will be replaced by new ones in the near future, since these are not worth retrofitting.

Unfortunately the only study available concerning the freight wagon fleet is from the year 2004 [AEA et al. 2004]. The figures from that report will be updated by some recent reports or news from European railways, wagon owners and wagon manufacturers.

The AEA study mentions on page 38, that Trenitalia has made a detailed survey of the European fleet in the year 2000. If a retrofitting programme had begun in 2005, the retrofitting would have affected 650,000 wagons out of 1.2 million.

In general, the AEA study points out that determining the size of the fleet is very difficult due to the lack of data from some countries. Also, the authors did not get data from each of the railway companies or countries because the number and age of freight cars is often confidential for competition reasons. The estimated total number of freight cars in Europe is given in Figure 24. The age structure of the total fleet of the year 2000 is presented in Table 20.

Figure 24: Estimated number of freight cars



Source: AEA et al. 2004, page 39.

Table 20: Age structure of freight wagon fleet in the year 2000

Building year	Share
Before 1970	10%
Between 1970 and 1980	46%
Between 1980 and 1990	22%
after 1990	10%

Source: AEA et al. 2004, page 42.

To update the figures given in the AEA-study, the authors have made additional analyses using other sources.

Recent documents from VDV, UIC and others indicate that in Europe 600,000 rail cars still exist or are relevant for noise reduction programmes. The UIC indicates a total number of 600,000 old wagons to be retrofitted [UIC 2009]. Also VDV together with VPI, DB Schenker and DB Netz indicate 600,000 wagons where retrofitting must be checked [VDV et al. 2010].

For retrofitting activities the railway alliances UIC, CER, UIRR, ERFA, EIM and UIP together answered a Consultation document of the Commissions Services [UIC et al. 2007]. Their statements concerning the worth of retrofitting focus on the number of years a retrofitted wagon will be used. This is about 4–6 years (one revision cycle) but realistically 10 years. The normal durability of a freight wagon is about 40 years, so the oldest wagons to be retrofitted may be about 30 years old. According to the figures mentioned in Table 20, only 264,000 of the fleet of the year 2000 are valid for retrofitting (only the categories up from the year 1980). General figures about the total number of wagons currently operating in Europe are 600,000 or 650,000. The difference between the wagons up to 30 years and the highest number of wagons in operation makes 386,000 wagons which either have been built since the year 2000 or before 1980. Estimating that the normal life time of freight wagons is 40 years, almost 80% of wagons produced between 1970 and 1980 are still in use. That makes about 300,000 wagons. So about 86,000 wagons must have been produced since the year 2000. Together with the fleet worth retrofitting, from between the years 1980 and 2000, this makes a total of 350,000 wagons.

An interview with Mr Kerth from VDV by the authors came to an estimate of 350,000 to 370,000 wagons to be retrofitted. Also KCW indicates a total number of 370,000 freight cars to be retrofitted [KCW 2009].

Summary:

- **Although the exact number is not known, a reasonable estimate is that there are currently 370,000 freight wagons suitable for retrofitting with composite brake blocks.**

4. CASE STUDIES

KEY FINDINGS

- This section describes some general noise situations in regions and rail sections and effects of realised or proposed measures to lower / avoid noise.
- On the **Rhine Axis** the situation on the currently realised/planned upgraded line **between Karlsruhe and Basel** and the existing line in the narrow Rhine Valley between **Bingen and Koblenz** is described. A **simulation** of the introduction of noise barriers on the one hand and of composite brake blocks on the other hand is made.
- For **alpine regions** general findings from a research project on noise are represented.
- For the **Inn Valley in Austria** the current situation, development of rail transport and the intensive activities of Austria concerning the **installation of noise protection walls** are described.
- For the **Fréjus Corridor between France and Italy** the noise situation is described.
- For the **UK activities** and noise situations for the new built projects **Thameslink** and the **two High Speed Lines** are represented.

This chapter is divided into two main sections. Section 4.1 on page 71 describes selected regions or countries and includes some general local aspects of noise emission and noise spreading in mountain areas. Section 4.2 on page 83 analyses selected railway lines in more detail. The effects of sample measures which are described in Section 3.3 on page 53 are calculated.

4.1. General descriptions of environmental railway noise in selected areas or countries

4.1.1. Rhine Axis

The Rhine Axis beginning at the ARA ports and ending in Basel with the continuance via Gotthard and Lötschberg to north Italy represents one of the most important freight corridors.

The main areas where the discussions about railway noise are currently the strongest are the section between Bingen and Koblenz and the new build “Rheintalbahn” between Karlsruhe and Basel. The section Bingen – Koblenz is the narrowest section of the Rhine Axis where railway lines are located on both sides of the Rhine. The rail track follows the river with many sharp turns. The section Bingen – Koblenz will be described in Section 4.2.1 on page 84. This section focuses on the Rheintalbahn.

In 1993 the first sections of two extra tracks between Karlsruhe and Basel were introduced for operation on the “Rheintalbahn”. In the following years more and more sections got into operation. They are mostly located next to the existing railway line but also some of the new sections are constructed next to the motorway A5 (example: bypass Freiburg for freight trains) or use completely new corridors (like the Rastatt tunnel or the Katzenberg tunnel). The sections between Rastatt and Offenburg are in operation. The sections Karlsruhe – Rastatt and Offenburg – Basel are still in planning or partly under construction. There are many objections against the project especially due to noise pollution reasons.

BMU and Intraplan Consult published a prediction about numbers of trains between Offenburg and Basel. The study firstly comes to the result that about 1,300,000 people are living in the affected area of the railway[26] line ([BVU INTRAPLAN 2008], page 11).

The following table gives the result of predicted numbers of trains for sample sections (rural and urban areas).

Table 21: Prediction of numbers of trains on Rheintalbahn

SECTION (SAMPLES)	TRAIN TYPE	2007	2015	2025
Denzlingen – Freiburg (agglomeration)	Long distance trains	66	76	78
	Regional trains	124	152	190
	Freight trains	160	286	304
	Share of freight trains	47%	56%	53%
Müllheim – Auggen (rural area)	Long distance trains	66	76	78
	Regional trains	50	76	76
	Freight trains	160	280	304
	Share of freight trains	58%	65%	66%

Source: BVU INTRAPLAN 2008, page 38.

The predictions for regional trains as well as for long distance trains come from existing planning for extensions of public transport services.

The figures show that in the corridor the number of freight trains will rise about 100% in all sections. In the Freiburg agglomeration, the number of regional trains also will rise. The share of freight and passenger trains differs between agglomeration and rural areas. In agglomerations the share of freight trains is about 50% whereas in rural areas the share will rise up to 66%. So the influence on total noise is different.

The share of trains during day and night time for 2015 is shown in the following table.

[26] Cities of Freiburg, Ortenaukreis, Landkreise Breisgau-Hochschwarzwald, Emmendingen and Lörrach.

Table 22: Share of numbers of trains on Rheintalbahn between day and night time

SECTION (SAMPLES)	TRAIN TYPE	DAY (6 – 22 H)	NIGHT (22 – 6 H)
Denzlingen – Freiburg (agglomeration)	Long Distance trains	60	16
	Regional trains	132	20
	Freight trains	129	155
	Share of freight trains	40%	81%
Müllheim – Auggen (rural area)	Long Distance trains	60	16
	Regional trains	64	12
	Freight trains	125	155
	Share of freight trains	50%	85%

Source: BVU INTRAPLAN 2008, page 39.

At night the share of freight trains rises from 40 / 50% up to 81 / 85%. Almost 55% of freight trains are operated at night. As night time is a period with a higher sensitivity to noise this is important.

The figures show that a concentration on measures to reduce noise at the source - for freight wagons, as the first step - is an important measure to reduce or avoid extra railway noise.

The current situation is represented by the noise action plans of the cities of Freiburg and Offenburg. In its noise action plan the city of Freiburg published the number of inhabitants affected by railway noise.

Table 23: Affected inhabitants of railway noise in Freiburg

L_{DEN}		L_{NIGHT}	
Noise level [dB(A)]	Affected inhabitants	Noise level [dB(A)]	Affected inhabitants
		> 45 – 50	32,820
> 55 – 60	22,820	> 50 – 55	19,020
> 60 – 65	8,950	> 55 – 60	7,530
> 65 – 70	4,380	> 60 – 65	3,820
> 70 – 75	2,680	> 65 – 70	2,410
> 75	2,340	> 70	1,880
Total	41,170	Total	67,480

Source: Freiburg 2009, page 5.

According to the noise action plan, Deutsche Bahn is currently installing about 9 – 10 km of noise protection walls and noise protection windows in about 1,500 apartments. The target of Deutsche Bahn is to meet the emission levels of 70/72/75 dB(A) at day time and 60/62/65 dB(A) at night time (residential zones / mixed zones / industrial zones).

In the noise action plan of the city of Offenburg [Offenburg 2009] the number of inhabitants affected by railway noise is published as follows.

Table 23: Affected inhabitants of railway noise in Offenburg

L_{DEN}		L_{NIGHT}	
Noise level [dB(A)]	**Affected inhabitants**	**Noise level [dB(A)]**	**Affected inhabitants**
> 55 – 60	7,150	> 50 – 55	5,890
> 60 – 65	2,910	> 55 – 60	2,310
> 65 – 70	920	> 60 – 65	770
> 70 – 75	450	> 65 – 70	410
> 75	450	> 70	410
Total	11,880	Total	9,790
Total above 70	900	Total above 60	1,590

Source: Offenburg 2009, page 6.

Actions for environmental railway noise mostly consider the building of a freight train tunnel for the next section of the new Rheintalbahn and noise action plans in special areas.

Concerning the new built areas and sections of the third and fourth track, mostly noise protection walls are foreseen. Discussions with the neighbours are often made due to different opinions of calculation about the associated noise emissions and the resulting number, length and height of noise protection walls. Especially the difference between the calculation scheme for noise mapping according to Directive 2002/49/EB [VBUSch 2006] and for new build infrastructure [Schall 2003] (for details see Section 2.5 on page 43) is currently in discussion. The rail noise bonus which is still valid for German infrastructure caused many struggles.

In Offenburg the planning foresees to build the new tracks along a new corridor through the city. Noise emissions will affect many people. Alternatives like a tunnel solution are presented by citizens´ initiatives. As this solution is very expensive it is refused by the building owner. The current plans of the building owner were refused by the planning and authorisation body (Regierungspräsident Freiburg) as they were not finished and could not meet legal checks.

In Rastatt a tunnel already was planned but it was adjourned indefinitely at the beginning of 2010. Local action groups are struggling against this as noise pollution in Rastatt is expected. The Federal Ministry of Transport, Building and Urban Development argues that Rastatt is not a bottleneck and the building activities have to concentrate on the section Offenburg – Basel.

In fact, for high frequency railway lines and, especially for construction of new railways, the citizens become more and more aware of noise items. This must be kept in mind for all planning.

4.1.2. Alpine regions

4.1.2.1. General aspects

This section provides general aspects concerning railway noise in Alpine and mountain regions and presents details about two railway corridors in the Alps.

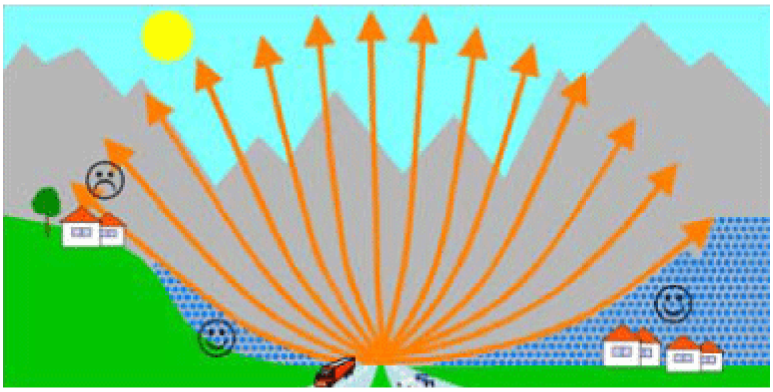
Important and interesting aspects about noise impacts in alpine regions come from the ALPNAP project.

ALPNAP has been a European research project [ALPNAP 2007-2] funded by INTERREG IIIB in ERDF Funds. The main target was to develop exact but also practical calculation methods for air and noise pollution prediction. As there is a gap between difficult scientific calculation and practical approach (easy formulas and assumption methods), the project aimed at the development of methods that were acceptable and sufficiently precise.

The project partners made many measurements for pollution and environmental noise emissions in defined areas like the Brenner corridor with Inn Valley and Edige/Etsch valley and the Fréjus corridor with Maurienne valley and Susa valley.

Concerning environmental noise (in general) one important result of the project is that the spread of noise depends on weather conditions and time of day. Examples are shown in the following figures.

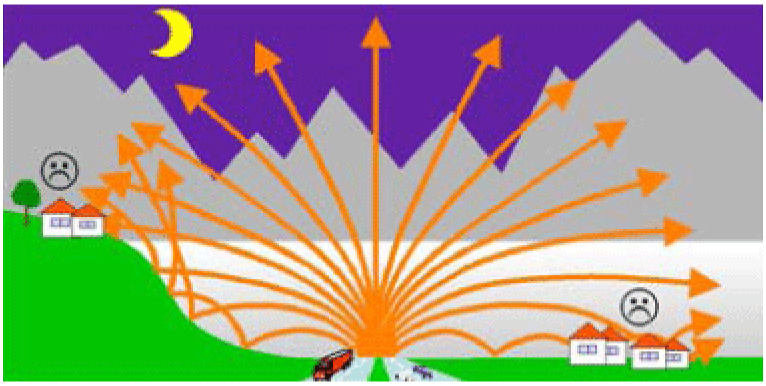
Figure 25: Direction of sound spreading (sound rays) during day



Source: ALPNAP 2007-1, page 10.

During the day, the temperature decreases with height and the sound is refracted upward. In the dotted blue areas ("acoustical shadow zones") on the valley bottom the noise is reduced significantly because the upward refracted sound rays cannot reach there.

Figure 26: Direction of sound spreading (sound rays) during night



Source: ALPNAP 2007-1, page 10.

During the night, the temperature increases with height in an inversion layer (shown grey) and the sound is refracted downward. Acoustical shadow zones do not appear. Instead the sound is reflected at the ground.

Wind speeds and wind directions have an impact on environmental noise. Also, in valleys reflections can spread environmental noise up to high altitudes. Mostly low frequencies are spread very wide as higher frequencies are well absorbed by air.

The most severe problem for transportation and its emissions in mountain areas is that transportation infrastructure (both rail and road) as well as residential or industrial zones are concentrated in (partly narrow) valleys. So all sources of noise are located very close together.

Noise in mountain regions is even more annoying or economically harmful as the area is used for tourism which is an important employment factor.

The figures above also show one important incident for protection measures. As noise in valleys can spread up to very high altitudes where also inhabitants can be affected by noise, protection walls have a lower influence on noise reduction.

4.1.2.2. Alpine regions - The Inn Valley

The Inn Valley between Kufstein and Innsbruck is the major access line to the Brenner railway line where a tunnel has been planned for a long time. The Inn Valley was examined in the ALPNAP project and will become more important for freight trains when the Brenner tunnel is opened. An estimation of future rail traffic was made.

In the year 2005, 40 regional passenger trains, 16 long distance passenger trains, ([Kummer et al. 2006], page 24) and about 100 freight and RoLa-trains are operating on the Brenner line. Taking into account the rise of freight trains - about 4.3% per year between 1999 and 2005 - a total rise of about 52% is expected for 2015. ÖBB (Austrian Federal Railway) expects 186 freight trains in 2016 ([Kummer et al. 2006], page 25). Passenger trains will remain at about 46 regional and 26 long distance trains. This shows that freight trains have a share of 64 to 68%. So they have the majority on the Brenner line which affects the Inn Valley.

Austria may be considered as good practice regarding rail noise abatement. More than 12 years ago noise emission inventories were compiled and on this basis plans for the implementation and financing of noise abatement measures along railway lines were developed. In recent years, the annual financial means amounted to some 30 million Euros. It is expected to spend the same amount in the years to come as well. The costs are carried 50% by the Austrian railways ÖBB and the remaining 50% by the federal states and the community [ÖBB - BMVIT 2008].

Through this programme, Austria has realised considerably more protection measures as foreseen in the first phase of the EU Noise Directive 2002/49/EC. In 2008, the programme had achieved the following results:

Table 24: Results of the Austrian rail noise abatement programme

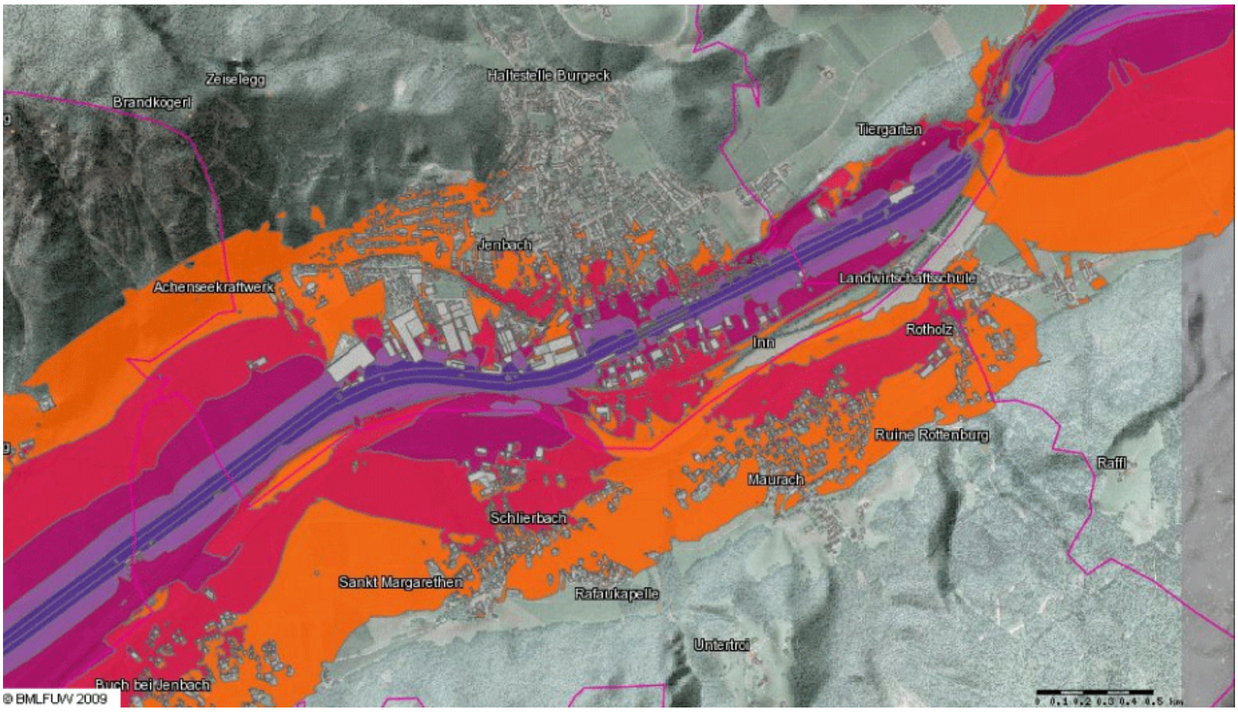
ACTION	FIGURES
Planning in communities	236
Implementation in communities	185
Inhabitants covered in plans	250,280
Inhabitants benefitting from implementation	183,603
Noise barriers [m^2]	1,263,706
Length of noise barriers [m]	413,016

Source: ÖBB – BMVIT 2008.

In 2008, 72% of the citizens covered in the plans benefited from noise protection measures. Since then, the size of the rail noise barriers has increased to some 1.7 million sq. m [m^2]; in 2011 two thirds of the planned construction works are completed and most of the severely affected inhabitants are protected against noise. Through the continuation of the programme, 10–15,000 additional citizens annually will be protected against rail noise.

The effects of noise barriers in the mountainous Inn Valley can be seen on the map below, where the inhabitants of the small town of Jenbach are protected against high noise levels that show up in the unprotected outskirts of the settlement. However, the map shows as well the effects of noise reflection from the adjacent mountains.

Figure 27: Impacts of noise protection barriers in Jenbach, Inn Valley, Austria



Source: Austrian Noise mapping, http://gis.lebensministerium.at/geoinfo).

4.1.2.3. Alpine regions – The Fréjus line

The Fréjus line is the rail freight corridor between France and Italy. Additional to this it is part of the planned high speed and rail freight corridor between Lyon and Turin.

The Frésjus-Coridor, especially the Susa (between City of Susa and Modane) and the Maurienne Valley (between Modane and Aiguebelle), was also examined in the ALPNAP project. For the Fréjus line the numbers of daily trains on the Italian side (Susa Valley) of the total line are published in [ALPNAP 2007-2] on page 241. The table is represented below.

Table 25: Example of railway traffic data in the Susa Valley; Number of trains for an average workday

SECTION	TYPE OF TRAIN	DAY	EVENING	NIGHT	SPEED [KM/H]
Borgone Susa – Bussoleno	Regional	35	14	3	120
	International	3	3	0	130
	Freight	21	11	13	85
	Goods	49	23	29	95
Bussoleno – Susa	Regional	18	7	3	120
	International	0	0	0	130
	Freight	0	0	0	85
	Goods	0	0	0	95

SECTION	TYPE OF TRAIN	DAY	EVENING	NIGHT	SPEED [KM/H]
Bussoleno – Salbertrand	Regional	9	4	0	110
	International	2	2	0	110
	Freight	11	5	6	75
	Goods	24	12	14	85
Salbertrand – Bardonecchia	Regional	17	7	0	110
	International	3	3	0	110
	Freight	21	11	13	75
	Goods	49	23	29	85
Bardonecchia – Modane	Regional	1	0	0	75
	International	3	2	0	75
	Freight	21	11	13	70
	Goods	49	23	29	70

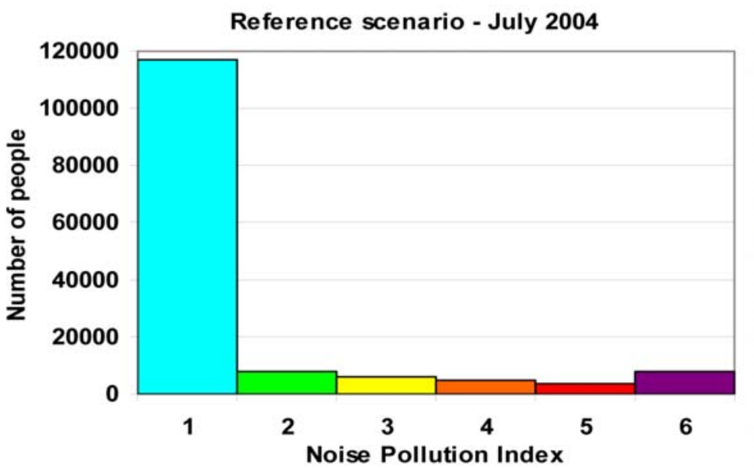
Source: ALPNAP 2007-2, page 241.

Here freight and goods trains have the majority on the main line, especially at night (as in the Inn Valley) and in the sections between Bussoleno and Modane. The share of freight trains is higher than on the Brenner line / in the Inn Valley.

The study has already shown that rolling noise is the most important environment noise source from trains at speeds between 30 and 200 km/h and that freight trains are the noisiest trains. Considering this, the most important starting point to lower noise, particularly in mountain areas, is to avoid rolling noise directly at the original source (contact zone of rail and wheel).

For the Fréjus Corridor the ALPNAP project produced a noise pollution index which shows the number of people which are affected by a certain noise pollution index (see Figure 28). The meaning of the indices is declared in Figure 29 and Figure 30.

Figure 28: Noise pollution in the Fréjus Corridor



Source: ALPNAP 2007-2, page 288.

The noise pollution index defined by ALPNAP project is represented in the following figures:

Figure 29: Noise pollution index (NPI) due to simultaneous exposure to rail and road sources

	$L_{den-railway}$ (dB)						
$L_{den-road}$ (dB)	45	50	55	60	65	70	75
45	1	1	1	2	3	4	5
50	1	1	2	2	3	4	5
55	2	2	2	2	3	4	5
60	3	3	3	3	3	4	5
65	4	4	4	4	4	4	5
70	5	5	5	5	5	5	5
75	6	6	6	6	6	6	6

Source: ALPNAP 2007-2, page 154.

Figure 30: Interpretation of the NPI values

NPI value	Exposure to noise
1	Very low
2	Low
3	Moderate
4	Pronounced
5	High
6	Very high

Source: ALPNAP 2007-2, page 154.

The NPI shows the exposure to noise in dependence of the L_{DEN} noise level caused by both road and rail traffic.

Although train traffic is high in the Fréjus-Corridor, about 30,000 out of 146,000 people (see [Alpnap 2007-2] page 286) are affected by NPI levels higher than 1.

An interesting result of the ALPNAP Study is that a modal shift from road to rail will lead to an increase of people affected by NPI 5 to NPI 6. The reason is that the motorways in the Fréjus-Corridor are already well equipped with noise protection walls in populated areas in comparison with the railway lines.

There are many protests against the project of a high speed railway line between Turin and Lyon especially concerning the affected valleys. In detail the high-speed line will consist of about 200 km new build railway lines including the new Mont-Cenis-Base-Tunnel (56 km). This tunnel will completely pass by the Susa-Valley between Modane and Susa. On the Italian side the Bussoleno-Tunnel will directly follow the Mont-Cenis-Base-Tunnel (12 km) so only a short part of the railway line will remain outside in the area of Susa. On the French side also two long tunnels (Bolledonne Tunnel, (20 km) and Chartreuse Tunnel (20km – freight trains only) are foreseen passing by big parts of the Maurienne-Valley

[Transalpine]. With all these tunnels only short parts of the new line remain uncovered in the Valleys.

Protests against this project concern air pollution (due to excavations of asbestos and uranium), general threats for the nature of the valleys and disturbances due to building works (15 – 20 years). During the building phase economic losses due to shrinking of tourism in the affected areas are expected. Noise is also mentioned in some of the publications but is not a main aspect of the protests. Most relevant are disturbances during the building phase.

4.1.3. United Kingdom

The UK uses a variety of noise mitigating technologies including noise barriers, rail lubricators and friction modifiers, rail-tuned absorbers, and, usually in tunnels, resilient base plates and floating slab track. Approximately 75% of the UK freight wagon fleet has disc brakes or composite tread brakes instead of the noisier cast-iron tread-braked wheels.

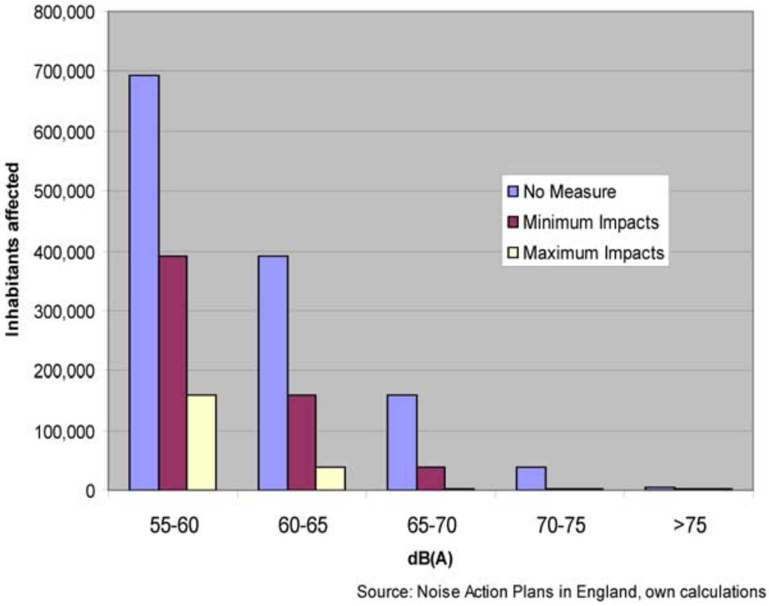
In England[27], 23 Noise Action Plans were designed to address the management of noise issues and effects in agglomerations. According to these plans, 1.3 million inhabitants of agglomerations are affected by rail noise; of these, 68% live in Greater London. Outside agglomerations, only 4,000 inhabitants are included in Noise Action Plans.

The theoretical study in this section estimates the potential impact of building noise barriers with 2m height along all railway lines in English agglomerations. It is assumed that noise barriers reduce the noise levels by 5–10 dB(A). Due to these rough assumptions, only the magnitude of the impact may be estimated. The number of affected inhabitants would decrease by 54–84%. This implies that in English agglomerations only 200,000 to 600,000 inhabitants would be affected by rail noise, compared to 1.3 million without noise protection measures. Figure 31 shows the range of impacts of noise barriers in English agglomerations.

The environmental cost of rail noise in English agglomerations may be estimated at 144 million Euros per year. These costs would be reduced through the implementation of noise barriers by annually 86 to 126 million Euros.

[27] UK not including Scotland, Wales and Northern Ireland.

Figure 31: Effects of rail noise barriers on the number of inhabitants of agglomerations in England



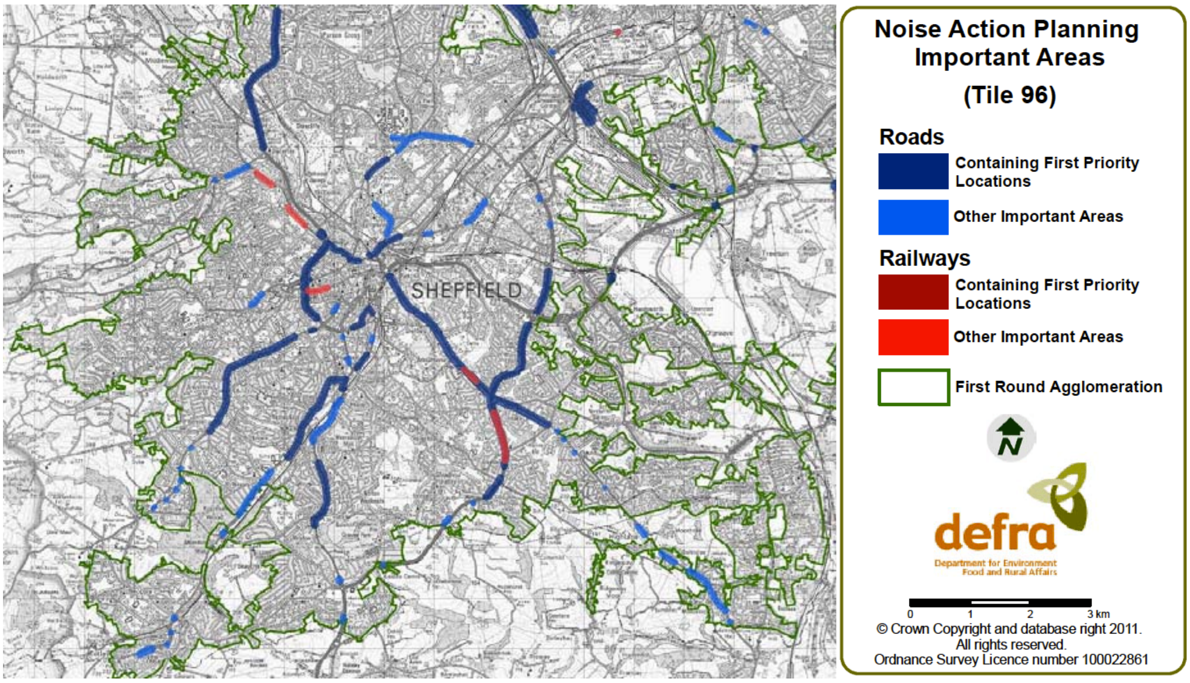
Source: calculation by the authors according to Noise Action Plans in England.

For rail noise protection in England it has been decided that the important areas with respect to noise from major railways will be where the 1% of the population that are affected by the highest noise levels from major railways are located according to the results of the strategic noise mapping ("Important Areas"; see Figure 32). In addition, those locations where the $L_{Aeq,18h}$ is at least 73 dB(A) according to the results of the strategic noise mapping have been identified as "First Priority Locations". The following timeline for railways was developed:

April 2010 – Oct 2011	Relevant rail authorities investigate Important Areas (giving priority to those that contain First Priority Locations)
April 2011 onwards	Relevant rail authorities implement any actions or secure budget for actions
April 2012 onwards	Relevant rail authorities investigate remaining Important Areas and implement any actions or secure budget for actions

An example of Important Areas arising from the English Noise Action Planning is given in Figure 32.

Figure 32: Important Areas, Noise Action Plan for Sheffield, England



Source: DEFRA 2010.

4.2. Detailed analysis of selected sections

This section describes effects of noise reduction measures for selected sections of the rail network. Assessments for effects of noise reductions are made with the use of defined measures from Section 3.3 on page 53).

The authors made a general analysis of the sections as detailed examinations in real situations were not possible. Some generalisations have been made. For example, noise barriers were assumed to be built in each location where inhabitants are affected, not taking into account if this will be technically feasible or whether installations already exist. Therefore, a range of noise impacts of the different measures had to be defined as given in Table 26. These figures were again adapted to the local conditions, i.e., used rolling stock, number of trains and share of train types (long distance, regional, freight trains). For replacement of cast iron by composite block brakes or equipment of freight cars with wheel absorbers, a 100% endowment of all relevant wagons is assumed.

Calculations were made with the actual state and the if-case (if-case = the measure is introduced completely in the section).

Table 26: Range of noise reduction

MEASURE	MIN REDUCTION	MAX REDUCTION
Composite brake blocks on freight wagons	8 dB(A)	10 dB(A)
Noise barriers (2m high)	5 dB(A)	10 dB(A)
Wheel absorbers	2 dB(A)	7 dB(A)
Rail tuned absorbers	3 dB(A)	7 dB(A)

Source: own summary according to section 3.3.

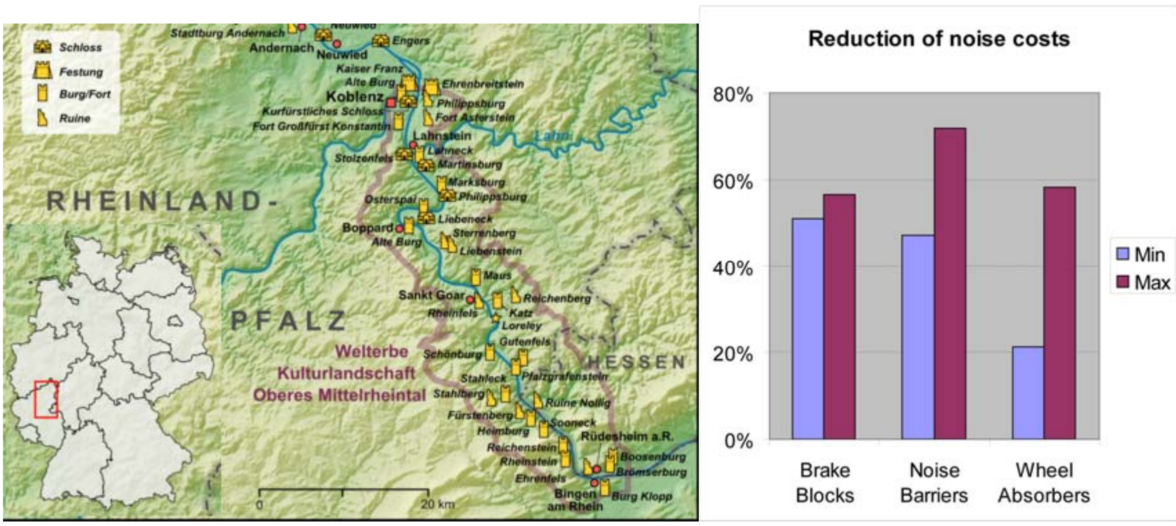
The following elaboration also includes an assumption of noise reduction effects by reduction of external rail noise costs. For cost calculation the same method was applied as the study "External Costs of Transport in Europe 2008" commissioned by the International Railway Union (UIC) in 2011 [CE Delft et al. 2011]. The study quantifies the monetary impacts of steady noise exposure of people at different levels by a review of European studies of housing prices and assesses additional medical costs by the increased risk of cardiac infarctions based on latest epidemiological research. The resulting non-linear noise exposure cost function is then applied to national statistics on noise affected inhabitants by 5 dB(A) L_{DEN} noise classes.

4.2.1. The Rhine Axis section Koblenz – Bingen

The selected section between Koblenz and Bingen represents an area in a narrow valley with high frequency railway lines on one of the main European transportation corridors (see also Section 4.1.1 on page 71).

The location of the section is given in Figure 33. The valley has four tracks, two on each river bank. The essential data and results of the assessment are given in Table 27.

Figure 33: Section Koblenz - Bingen, impacts of measures



Source: Own calculation by the authors.

In this section of the Rhine Valley, nearly 68,000 people are affected by rail noise above 55 dB(A). Rail noise causes damages in the order of 11 million Euros per year. However, these may be reduced significantly: The strongest impacts are achieved through the construction of noise barriers. If - theoretically - the whole valley were protected, only 17,000–36,000 inhabitants will still be affected afterwards and the environmental costs will be reduced by 47%–72% (Figure 33). However, this would imply considerable costs, as well as strong visual intrusions. If new brake blocks were implemented, the environmental costs could be reduced by 51-57%. The lower value is due to the fact that passenger trains are not affected by this measure. Wheel absorbers reduce environmental costs by 21-58%.

Table 27: Impacts of noise reduction measures in the Middle Rhine Valley

ITEM	VALUE
No of freight trains / day (both directions)	265
No of passenger trains / day (both directions)	157
No of remaining inhabitants affected by rail noise (>55dB(A))	
Without measures	67,550
With noise protection barriers	16,850 – 36,200
With low-noise brake blocks (K and LL)	28,985 – 32,907
With wheel noise absorbers	28,460 – 55,010
Remaining annual external rail noise costs [million €]	
Without measures	10.7
With noise protection barriers	4.4 – 8.4
With low-noise brake blocks (K and LL)	4.6 – 5.2
With wheel noise absorbers	4.4 – 8.4

Source: Own calculation by the authors.

4.2.2. United Kingdom section Thameslink near Blackfriars in London

In order to have an example about a railway line in a dense populated agglomeration with a large frequency of trains per hour, Thameslink was chosen as a case study. Rail noise of railway lines in metropolises by nature affects a lot of people. So it is very important to find good solutions for inner-city lines. Thameslink is considered to be a good example because it represents an area with dense population and a planned extension of traffic.

Thameslink runs through the heart of London, crossing the River Thames at Blackfriars Bridge, operating along a 225km route between Bedford in the north and Brighton on the south coast. The service stops at King's Cross / St Pancras International, Luton Airport and Gatwick Airport, and an offshoot (the Wimbledon Loop) passes through south-west London. An estimated 75000 people every day use Thameslink to get in and out of London.

Thameslink 2000 is a £5.5bn programme[28] to increase service capacity and frequency on the Thameslink route, with longer trains and eventually new rolling stock. The route from St Pancras to London Bridge is being upgraded, and Blackfriars station is being rebuilt to

[28] Thameslink 2000 Programme website: http://www.thameslinkprogramme.co.uk/.

span the river, with a new entrance on the south bank; the station will be ready for 12-car trains by December 2011, and completed in time for the 2012 Olympics. The Thameslink 2000 project was originally proposed in 1991, and, following a public inquiry in 2005, planning permission was finally granted in 2006.

As a result of the public inquiry, many of the relevant documents are available to the public through the Inquiry's website[29] or on request.

As part of the Environmental Impact Assessment, Temple Environmental consultants Ltd produced the 'Noise & Vibration Specialist Report' in June 2004 [Thameslink 2004], and the 'Blackfriars Noise Assessment Report' in 2005 [Thameslink 2005]. These reports include calculations and predictions of rail noise, using ISVR's NORBERT[30] model, and make recommendations regarding the use of noise mitigation technologies.

One of the goals of the Thameslink programme is to run 24 trains per hour, each way, between Blackfriars and St Pancras Midland Road; and 18 trains per hour, each way, between Blackfriars and London Bridge. Blackfriars Railway Bridge is a steel decked bridge across the Thames (see Figure 34 and Figure 35) with ballasted track. In 2004, the traffic across the bridge during the day was 233 Thameslink trains and 133 other trains; during the night, the traffic was 39 Thameslink trains and 11 other trains. The target is to increase this to 672 Thameslink trains and 70 other trains during the day, and 74 Thameslink trains during the night.

Figure 34: Left: View of Blackfriars Railway Bridge from the south bank. Right: First Capital Connect Class 319 EMU.

Source: Thameslink 2005.

In addition to increasing the number of trains, capacity will be further increased by replacing 8-car trains with 12-car trains during peak hours; during off-peak hours, 4-car trains will be replaced by 8-car trains. To some extent the increase in noise from the additional traffic will be offset by the introduction of quieter rolling stock. In 2004, Thameslink operated Class 319 EMUs primarily, and have since acquired all Class 319 vehicles still operational[31]. These are disc-braked; the last of the Class 421 and 423 EMUs with cast iron tread brakes were phased out during 2004. The Class 319 fleet was manufactured during 1987-90. First Capital Connect (who took over the Thameslink franchise in 2006) have recently acquired 23 Class 377/5 EMU 4-car trains (Electrostars),

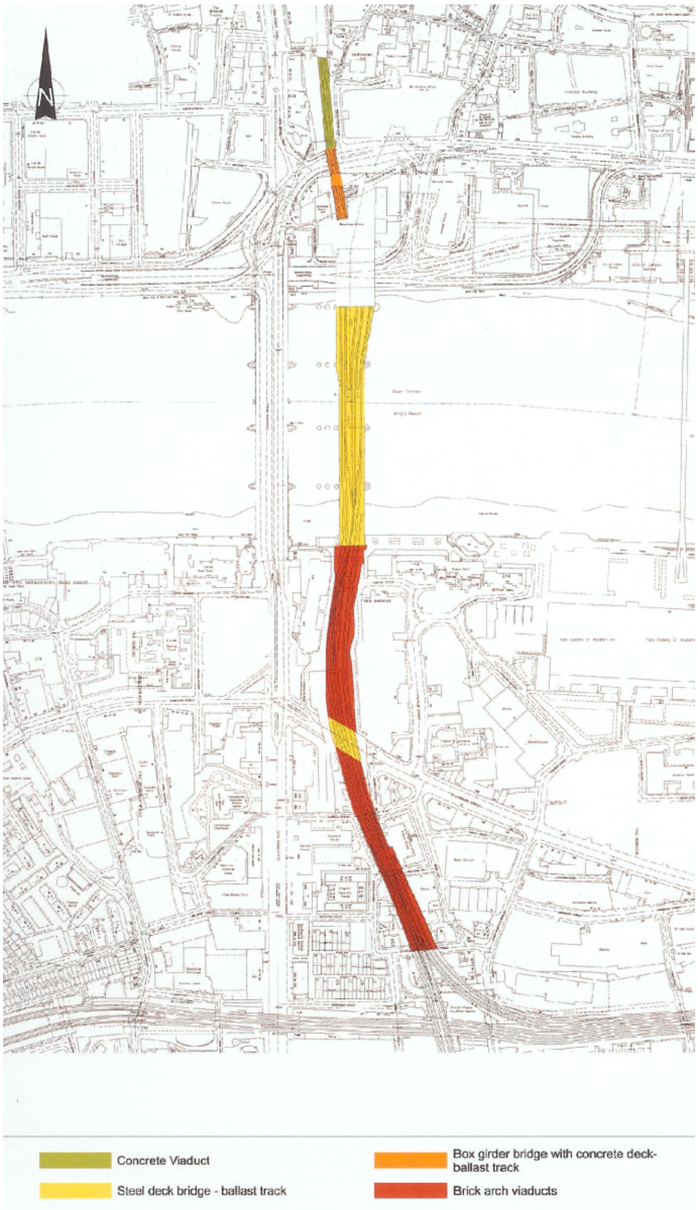
[29] Thameslink 2000 Public Inquiry website: http://www.tl2000inquiry.org.uk/.

[30] ISVR's NORBERT model calculates structural radiation of bridge noise using a detailed model of track and bridge structure, rail roughness and rolling stock type. (Thompson, D.J., Jones, C.J.C., Bewes, O.G., 2005, 'NORBERT – Software for Predicting the Noise of Railway Bridges and Elevated Structures, Version 2.0,' ISVR Contract Report, CR 05.12; also see David Herron, 2009, 'Vibration of railway bridges in the audible frequency range,' Thesis submitted for Engineering Doctorate, University of Southampton.)

[31] The Class 319 is a dual-voltage EMU, and therefore able to operate both north of the River Thames, which uses a 25kV AC overhead supply, and south of the river, which uses a 750V DC third rail.

manufactured in 2008-09. The train noise correction for the Class 377/5 is 8.4 dB(A), compared to 11.3 dB(A) for the Class 319.

Figure 35: **Overview of viaducts / bridges near Blackfriars station**



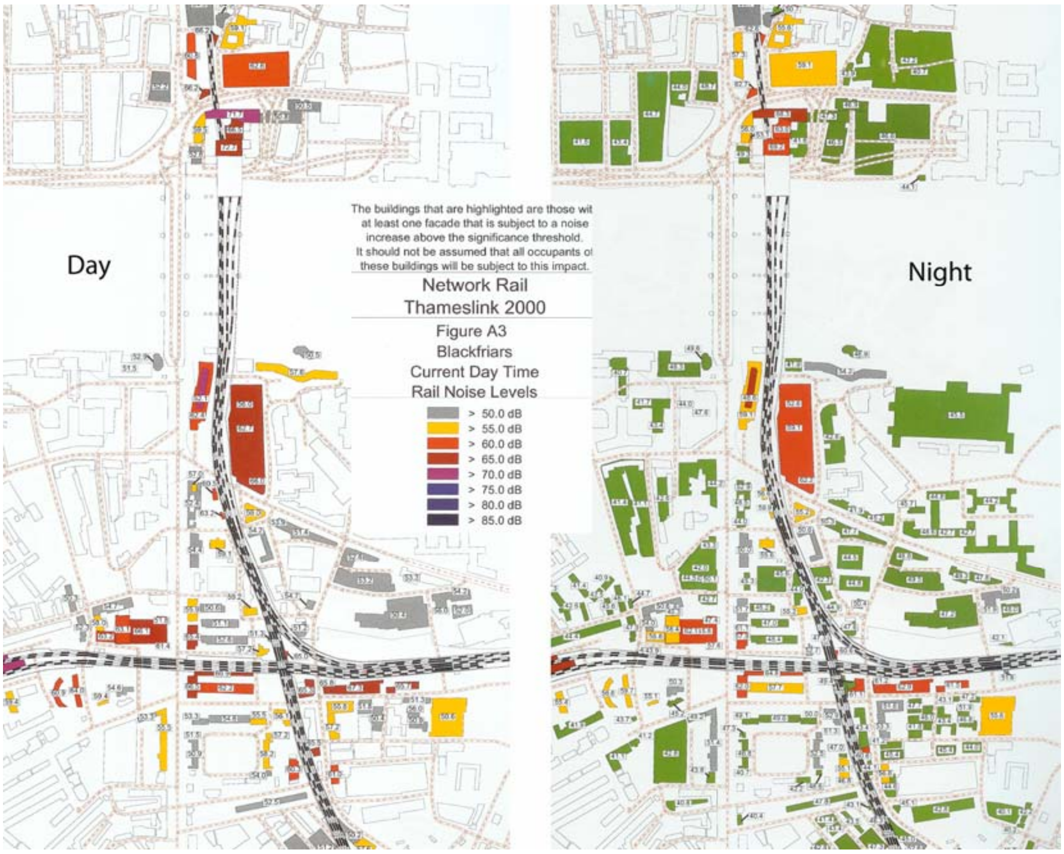
Source: Thameslink 2005.

Regarding further rolling stock noise mitigation measures:

- wheel dampers may provide a cost-effective means of reducing curve squeal and flange contact noise;
- for vehicle mounted lubricators or wheel dampers Network Rail will work with TOCs and other stakeholders to install them to the existing rolling stock where it is found that such measures are reasonably practicable.

However, the EMUs are disc-braked and there is little scope to reduce rolling noise; future design innovations in the suspension systems are not expected to reduce ground borne noise and vibration; and, in general, train speed is not an effective means of vibration reduction.

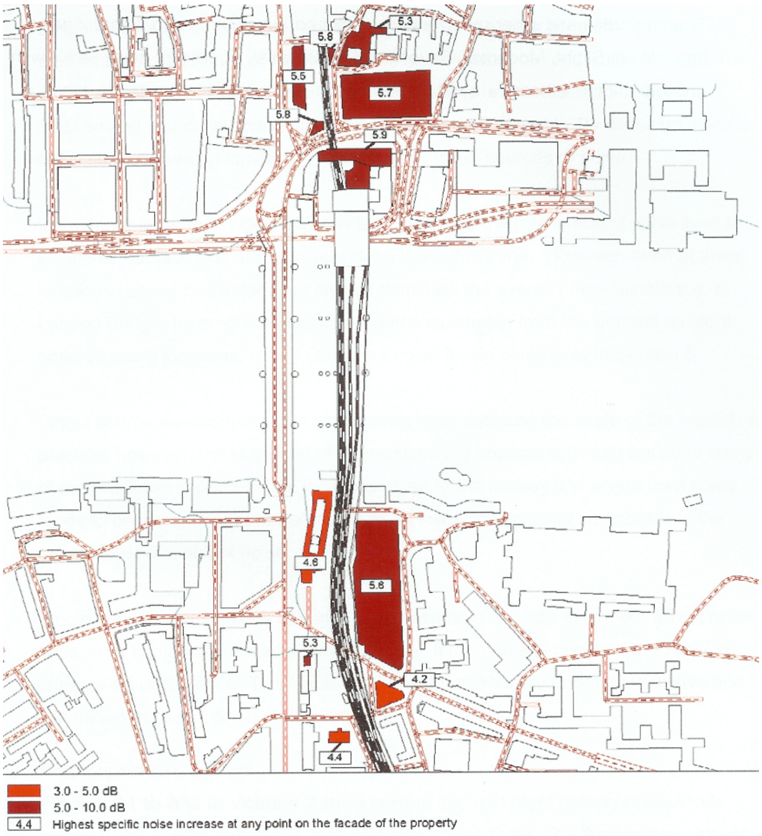
Figure 36: **Measured noise levels in Blackfriars area**



Source: Thameslink 2004.

Noise level projections for 2026, with or without the Thameslink upgrade, were used to assess the impact of noise on local properties. The Thameslink programme was predicted to reduce the number of affected residential properties from 44 to 24, and the number of non-residential properties from 14 to 8. In either case, the majority of these impacts are either slight or moderate. The reason why so few properties are affected is that, even close to the railway, rail noise does not dominate over the ambient noise level. Predicted noise level increases near Blackfriars Railway Bridge are shown in Figure 37.

Figure 37: **Predicted noise increase by 2026 at nearby facades as a result of daytime railway operation**



Source: Thameslink 2004.

One distinctive source of noise at Blackfriars is the jointed track, which gives rise to the characteristic 'pounding' noise. Removal of joints will reduce the noise level by about 3.1 dB(A), and will significantly improve the subjective impression of the bridge noise. Regarding track renewals and remodelling between Blackfriars and London Bridge:

- All jointed track will be removed as far as practical where track is renewed and replaced with Continuously Welded Rail or Long Welded Rail. Any unnecessary Switches and Crossings (S&Cs) will be removed and joints to remaining S&Cs will be welded. All new or replacement expansion joints will be scarfed.

Another source of noise, about 6 dB(A), is flange contact on the curve south of the bridge (Falcon Point). As part of the renewal programme, this section will be replaced with modern track to a high specification, avoiding sudden changes in curvature at rail joints. Where necessary, flange lubricators will be installed or replaced.

Network Rail has a regular inspection and maintenance programme, and is committed to removing any corrugation. In addition, vehicles are monitored for wheel flats. No significant benefit in noise level is expected from imposing more frequent grinding or an enhanced wheel set maintenance regime.

Where effective and safe, Network Rail is willing to use rail dampers[32]. However, rail damping is not effective when used with stiff rail pads. In the Blackfriars area (in 2005), the rail was supported on stiff pads or no pads at all. Rail dampers would not have affected the bridge noise component, and only a 0.8 dB(A) reduction would have been achieved in the direct rolling noise.

Noise barriers are a visual intrusion, particularly since they are a target for graffiti; they have a high cost, and cause problems for track access. Their effectiveness depends on their absorption properties, their height, and the proximity of the barrier to the noise source and/or to the receiver. At Blackfriars, noise barriers will not be particularly effective since the railway is multiple-track, and many of the affected properties overlook the track. However, the new station roof will incorporate sound absorbent material which will help to increase the noise attenuation provided by the barriers, and a new Vitreous enamel clad Bridge 412 enclosure will shield 1 Puddle Dock.

A variety of noise mitigating trackforms were considered for reducing noise levels around the Blackfriars Railway Bridge, including ballast mats (which can be problematic for maintenance and tamping), resilient baseplates, booted sleepers, and Pandrol's VANGUARD (which clamps the rail around the web and under the head, as well as under the foot) on ballasted track; and slab track with soft rail pads or baseplates. While these track designs reduce noise levels significantly when compared with the reference design, they do not provide any meaningful reduction in overall train noise levels. At Falcon Point, railway noise is expected to reduce by 3–4 dB at the upper floors closest to the Bridge. This benefit would affect some 6 dwellings. The cost will be disproportionately high in relation to the scale of the potential benefit. There is no justification to install resilient baseplates on Blackfriars Railway Bridge.

4.2.3. Noise Impact of High Speed Lines in the UK

The East Coast Mainline (ECML) operates between Edinburgh and London King's Cross and the West Coast Mainline (WCML) operates between Glasgow and London Euston. The lines are rated for 200 km/h for the most part, and even for 225 km/h in places. However, UK legislation requires in-cab signalling for train speeds over 200 km/h, which has prevented operation at 225 km/h on these lines. Currently the only line in the UK operating at speeds over 200 km/h is High Speed 1 (HS1). High Speed 2 (HS2) is currently in the early planning stages and is expected to start operation in 2025.

4.2.3.1. High speed 1 (HS1)

High Speed 1 is the route from London to the Channel Tunnel which started operation in 2007. After leaving St Pancras, the line crosses the ECML and immediately enters a tunnel which passes underneath London for 20 km (line speed for this stretch is 230 km/h, but other tunnels on the route have a speed limit of 270 km/h); the bridge across the ECML to the tunnel entrance is fully enclosed by a tube with acoustic grey cladding to shield the local environment from noise (although this is not completely effective). Pandrol's VANGUARD and a variety of other noise mitigation technologies are implemented along the route: noise bunds and barriers (including low barriers on viaducts), Sateba booted sleeper track system (Slab track SAT SB12), and GERB's floating slab track (also used in London's Docklands Light Railway).

[32] Blackfriars Station will be the first site in the UK to install Tata Steel's SilentTrack noise damping system – this is scheduled for February 2012.

There is no noise map for HS1, but there are a few comments on noise in the written evidence in the Transport Committee HS2 report:

- ‘experience in Kent and elsewhere shows how the noise footprint of HSR trains can be mitigated’
- ‘the experience of HS1 is that fears expressed before its construction have mostly not been realised’
- ‘it would appear from the lack of complaints related to HS1 operation that the noise impact can be overrated by objectors at the planning stage’
- ‘HS1’s impact has been masked to some extent by the route passing close to existing busy roads’

Overall, HS1 has been a positive development with very few complaints about noise.

4.2.3.2. High Speed 2 (HS2)

This section refers to the Tenth Report of Session 2010-12 of the House of Commons Transport Committee, regarding High Speed Rail (HSR), specifically High Speed 2 (HS2), and associated written evidence. HS2 is planned for 2025.

Remit:
‘HS2 Ltd was established as a Government company to examine the case and develop proposals for a new high-speed railway line between London and the West Midlands, and potentially beyond. Its remit was to identify a route between London and the West Midlands with the primary aims of increasing passenger capacity on the corridor and optimising journey times. It was a requirement of the remit that the route should include an interchange between HS2, the Great Western Main Line and Crossrail, with convenient access to Heathrow.’

Proposal:
‘HS2 Ltd has proposed a London – West Midlands route that avoids any significant demolition of property except for the Euston station area; about half the route would be in deep cutting or tunnel, to reduce noise and visual intrusion on adjacent areas.’ The proposal focuses on 400 km/h high speed rail route. This is expected to free up capacity on the West Coast Mainline and allow greater rail freight utilisation.

Noise Issues:
No Environmental Impact Assessment has been carried out for HS2, and none is planned until after the current consultation exercise. An Appraisal of Sustainability (AoS) has been published which includes a technical report on noise and vibration.

Following England’s Noise Action Plan and the Noise Insulation (Railways and Other Guided Transport Systems) Regulations, the noise measure LAeq,18h (noise averaged over the period 06.00–24.00) has been used as the primary indicator of noise level, with an imposed limit of 73 dB – since noise levels higher than this would make the route a ‘First Priority Location’, i.e., an immediate target for noise mitigation.

While such a strategy might be acceptable for already noisy areas, part of the proposed route runs through an Area of Natural Beauty (AONB) where the environmental impact of the railway is a major concern. Consequently, there has been fierce opposition to HS2 along this section of the route, including complaints about noise levels:

- 'Acceptable' noise levels do not follow WHO guidelines or English Planning Permission (PPG24) guidelines. The latter would limit noise levels to 66 dB, or even less considering the rural environment. The former recommends that peak noise levels be considered, not just the average, and for high speed trains the difference between these is large.

- Concern over the visual impact of noise barriers, coupled with the concern that these will not block aerodynamic noise from pantographs. In addition, in the noise prediction modelling, pantograph noise has been modelled as a noise source at rail track height, which is not appropriate and underestimates the noise impact. (The AoS assumes a 3 dB reduction in noise emissions based on improved noise control measures in future rolling stock, and notes the importance of mitigating the source of aerodynamic noise. 100 km of 2–3 metre high noise barriers are included in the model.)

- The noise impact from the ground-borne Raleigh shock wave of high-speed trains travelling at 400 km/h over flood plains, soft alluvial ground, etc., has not been considered, nor has the cost of mitigation measures against this.

- The number of trains used in the noise modelling is 432 per day, but the potential train throughput could be up to 576 trains. The system needs to be modelled at full operational capacity, otherwise noise regulations will put a severe constraint on route utilisation.

- Noise modelling has been carried out for a maximum speed of 360 km/h, even in places where the design speed is higher.

In summary, the HS2 assessment of noise levels both uses an arguably too-high definition of acceptable noise level, and underestimates noise levels arising from pantographs, ground-borne shock waves and full system capacity. This highlights the need for a full Environmental Impact Assessment and a clearer remit on noise and vibration levels in the AONB.

The strongest arguments against HS2 can be countered by lowering the line speed from 400 km/h to, e.g., 240 km/h in sensitive areas. Although this will increase journey time, and weakens the economic case for HS2, it will significantly reduce the environmental impact of construction and of operational noise and energy requirements. A lower design speed also allows the route to follow the existing M1 motorway, further reducing environmental impact.

5. EVALUATION

KEY FINDINGS

- There are different possibilities for financial support and regulative activities to foster the introduction of noise reduction measures.
- **Noise depending track access charges** are one possibility next to direct support for low noise measures.
- Noise depending track access charges shall bear in mind that **relevant noise reduction effects** are only coming from **trains which are (nearly) completely equipped** with low noise rolling stock and that noise reduction measures may cause **extra operative costs** (next to investment cost).
- Regulation can focus on the **TSI Noise** where noise limits for new rolling stock are regulated. They **shall be compulsory for existing rolling stock** after about 10 – 12 years and **lowered from time to time** according to latest technical possibilities.
- Currently **Switzerland** and the **Netherlands** have introduced noise depending track access charges, **Germany** is planning to introduce them at the end of the year 2012.
- **Competitiveness of rail transport** in comparison with other transportation means must be borne in mind in all activities, so all financial and regulative measures shall not burden the rail sector.

This chapter describes and evaluates different methods for financial support of noise reduction measures with the focus on promoting the retrofitting of freight wagons with new braking systems. This is currently the most important discussion. Regulation possibilities are also discussed.

5.1. Economic incentives

Economic incentives through rail track charging differentiated according to noise emissions can help to:

- stimulate the use of low-noise technology for the rolling stock,
- foster the use of routes which avoid hot spots for noise and
- foster noise-reducing operational routines and speeds in sensitive areas.

In general, there are two possibilities for the design of mark-ups for noise emissions: First, the mark-ups can be added to the rail infrastructure charges of high noise polluters while low noise polluters would be free of additional charges. In this case revenues are generated which can be used for subsidising noise abatement investments for railway cars.[33] Second, the mark-ups can be designed in a way that they are neutral with respect to the total burdens from rail track charging, i.e., additional charges would be levied on high noise

[33] We discount the option to allocate the revenues to the infrastructure manager, because they do not reflect infrastructure costs.

polluters while low noise polluters would receive a bonus. Penalty and bonus payments would balance after aggregation. This scheme would be comparable to the charging scheme for heavy goods vehicles on motorways according to Directive 2006/38/EC (variant of differentiating the charges on the base of EURO emissions standards).

The recast of Railway Directive 2001/14/EC foresees the differentiation of rail track charges according to noise (see [Com(2010) 475] Article 31. There are several options to be analysed:

- Differentiation of rail track charges according to measured noise emissions (see Section 5.1.1);
- Differentiation of charges for wagons according to their noise classification (see Section 5.1.2);
- Differentiation of charges for trains according to the composition of wagons (see Section 5.1.3);
- Bonus payments for new and retrofitted cars (see Section 5.1.4);
- Combined bonus systems (see Section 5.1.5).

5.1.1. Differentiation of rail track charges according to measured noise emissions

The object of charging would be the train. The train-related noise emissions would have to be measured at critical points in densely populated areas and/or low distances to residential zones and then allocated to the train. The noise mark-up for the track charge then would vary with the noise level, eventually in a progressive way.

Such a scheme would perfectly implement the polluter-pays principle. It works independently from the car or wheel technology and cannot be manipulated by wrong classification or changing electronic identification plates. However, it would require many measurement posts or gentries alongside the tracks and a complex information, payment and administration system. As a result, the implementation cost of such a system could be very high.[34]

As the charge will be paid initially by the train operator, the question is open how the train operator (the railway enterprise) will pass on the costs to the cars' owners/operators or to the shippers.

5.1.2. Differentiation of charges for wagons according to their noise classification

The simplest way to differentiate track charges according to noise is to classify the wagons into noise categories and charge each wagon separately with a noise mark-up. The train operator would pay the charge to the infrastructure manager and send the bill to the car owner or operator.

[34] Some form of infrastructure for dynamic measurement and reporting of vehicle noise may be necessary anyway to reflect changes in the vehicle's status, e.g., wheel out-of-roundness, which significantly affect noise levels; this could be coupled with existing trackside measuring stations. Higher-than-expected noise levels may indicate an urgent need for vehicle maintenance.

This scheme presupposes the introduction of noise standards for rail wagons (comparable to EURO categories for road vehicles) and a rail-car-based km charge. While the technology of charging, control and monitoring can be kept simple there is one serious caveat: The noise emission curve is shaped in a strictly concave way ("diminishing marginal noise emissions") with increasing share of low noise cars. This means that a 50% share of low noise cars in a train will lead to a noise reduction of only 1.5 dB(A) compared with a high noise train, so that the exposed population will hardly notice the progress. The share of low noise cars should be very high to achieve a significant noise reduction of a train. If, for instance, 100% of freight cars are equipped with silent brakes the noise reduction can be as much as 10 dB(A), which implies cutting noise by half.[35]

In conclusion, this scheme is simple to implement, but does not fully reflect the polluter-pays principle, i.e., a train composed of 50% low noise cars would pay reduced charges for 50% of the cars although the noise reduction is negligible. There is a risk, furthermore, that identification plates (e.g., RFIDs) are manipulated to get wagons classified in favourable categories.

5.1.3. Differentiation of charges for trains according to the composition of wagons

To avoid the caveats mentioned in Section 5.1.2 on page 94, an alternative is to classify the trains instead of the wagons. In this case, the trains will be classified on the basis of the rail car types from which they are composed. This presupposes the introduction of noise standards for rail wagons (as in 5.1.2 on page 94) and, in addition, the classification of trains on the basis of the expected noise emissions.

In the case of freight trains, the problem arises that the emission category of a train would vary with every change of the train composition in marshalling yards (single wagon traffic). Indeed, the problem is that only block trains which do not change wagon types from start to end can be easily classified. In single wagon transport, this classifying is much more difficult as train composition changes with every shunting activity. If charging followed the polluter-pays principle, then adding a few high-noise cars to a low-noise train would imply a very high mark-up for the train, while adding a low-noise car to a high-noise train would not lead to a change of the train charge. This will not be accepted by the market players (i.e.: investment in low noise cars will not pay if these cars are often integrated in high noise trains), so such a scheme should be modified in a more pragmatic way.

Nevertheless, the problem remains that the railway undertaking would have to charge the car owners/operators/shippers, accordingly.

5.1.4. Bonus payments for new and retrofitted cars

Against the background of the manifold problems of noise-related rail track charging and the possible second round effect of losing market share to road transport, if the noise charges are really high but lead to the desired noise reduction, the easiest way to come to low noise technologies is to pay public subsidies for new low-noise cars and for retrofitting used cars. Certainly this is the approach which will be most readily accepted by the market players.

[35] Because of the logarithmic scale of the noise curve, details see Section 3.4 and Figure 23

While this burden should not fall on the tax payer, nevertheless this instrument can be an element of an overall strategy to introduce an incentive-based system and to achieve a high rate of penetration within a short period of time – much shorter than the lifetime of railway cars, which can be estimated at about 40 years.

5.1.5. Combined bonus systems

Whenever charging schemes are considered, companies worry about higher costs and the possibility of losing market shares to the road transport mode. This is a relevant argument, in particular in a political environment which aims at increasing rail freight market shares for environmental reasons and to meet climate challenges.

Public financial assistance should be given in the initial phase of a charging scheme with noise mark-ups. This could be implemented by a bonus payment for the purchase of new cars which are equipped with noise reducing technology, and/or for retrofitting used cars.

5.1.6. Current status of track charges

As the European Commission has decided on 27 September 2011 to allow charging for emissions of road vehicles (see Directive 2011/76/EU of the European Parliament and of the Council of 27 September 2011, amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures, as published OJEU L 269 on 14.10.11 [Dir. 2011/76/EU]) the way is also free for track charges according to noise emissions on railways without regard for total earning of the infrastructure company (see Recast of Railway Directive 2001/14/EC in [Com(2010) 475] Article 31).

The European Commission established a working group in 2011 to harmonise and implement Trace Access Charge systems including noise depending instruments. The recommendations from this study shall be considered by this group.

UIC has published (in [UIC 2010]) an overview about the current status of noise abatement legislation in different countries. The Netherlands and Switzerland already have track charges with a noise bonus and penalty. Since 2002, Switzerland has granted a bonus for all wagons which are equipped with low noise brakes of 0.01 CHF (0.0075 €, exchange rate November 2010) per axle-kilometre. The bonus is financed by the state, as well as the retrofitting programme of all Swiss wagons. The Netherlands grants a bonus of 0.04 € per wagon kilometre for all low noise wagons. The bonus is granted for two years up to a total maximum of 4,800 € per wagon.

In Germany, a system will be introduced in 2012 in which a bonus will be granted only to single freight wagons which are newly retrofitted with low noise equipment like composite brake blocks after the introduction of the bonus scheme. Furthermore, a bonus is planned for whole freight trains which consist of only low noise wagons. In this second part of the bonus scheme, new and recently retrofitted wagons are also considered. Both parts of the bonus will be realised as a discount on the track charge according to wagon kilometres. This will be granted directly from the infrastructure company to the wagon owner.

In Switzerland there is a discussion about modifying the existing system. Both the German and Swiss plans include a funding of owners of low-noise freight cars. The funding will be organised and calculated by the infrastructure companies. They rely on the owner notifying which freight cars are low-noise. The funding depends on axle-kilometres in both countries. There are also discussions about the costs for the implementation and operation of the accounting system. For VDV (in [KCW 2011]), KCW calculated the operating costs for different kinds of funding systems for low-noise freight wagons. Funding for new wagons which are equipped with LL-blocks (if they are admitted) is currently being discussed.

In detail, Germany plans to fund retrofitted freight cars with 0.0028 € per axle-kilometre on German tracks up to a total of 1,688 € per axle. The total comes from estimated investment costs of about 2,120 € per axle minus 432 € as opportunity saving for replacement of an old cast iron block by a new one. The costs for the bonus will be covered 50% by the German state and 50% by a general increase of track prices for all freight trains.

In a study for the European Commission, KCW proposes a funding of 0.008 € per axle-kilometre for K-block equipped wagons and 0.0025 € per axle-kilometre for LL-block equipped wagons [KCW 2009]. The figures mentioned are for a funding period of 8 years. For a potential funding period of 12 years the figures are 0.0045 € per axle-kilometre for K-blocks and 0.002 € for LL-blocks.

Irmhild Saabel from WASCOSA AG held a presentation at Forum Güterwagen (forum freight wagons) in May 2011 about costs coming from K-blocks [Saabel 2011]. The total costs for blocks and wheels increase by a factor of 1.5 to 2.6. Although K-blocks have a life cycle of about 110,000 to 130,000 km, the wheels need reprofiling each 120,000 to 310,000 km (instead of 450,000 to 500,000 km) and have a life cycle of about only 360,000 to 1,140,000 km (instead of 2,700,000 to 3,500,000 km). Also Mr Gilliam from the AAE reports higher operating costs, from first experiences, caused by abrasion of wheels with modified blocks[36].

Costs for railway undertakings or wagon owners, related to composite brake blocks, arise not only from investment but also from operating.

To harmonise NDTAC on an EU-wide scale in 2011, the Commission established an expert group under the DERC Committee [Rapacz 2011].

- The main aim: to discuss and propose practical solutions on how to harmonise NDTAC schemes across Member States, focusing on financial aspects.
- The result of the work of the group could be a set of guidelines for the Member States on NDTAC harmonisation / implementing measure adopted by the Commission on the basis of the recast.
- The group is to be restarted in 2012, following the recast developments.

[36] Early trials with composite tread brakes in the UK in the 1970s–80s found similar results.

5.2. Analysis of regulation possibilities

The number of regulations on railway noise in the EU Member States is large. A brief overview of the national noise measures is listed in Annex IV.

In 2003, the Working Group on Railway Noise of the European Commission [EC 2003] was of the opinion that "a solution to the major railway noise issues is possible within 10 years if the proposals are implemented as a cost-effective combination of the instruments described".

The most relevant standardisation issues for railway rolling stock have been formulated in the TSI documents (Technical Specifications for Interoperability). In the latest TSI Noise [TSI Noise 2011], the following regulations for noise emissions of rail vehicles are defined:

- Limits for stationary and pass-by noise for freight wagons and locomotives (for details see Annex II of this study),
- Operation and maintenance rules,
- Application to new rolling stock, and
- Retrofitting programmes.

While the rail noise problem is well understood and the technical possibilities are clearly described in the European Commission documents, a timetable for introducing new noise standards – comparable to the Euro standards for HGVs – is missing until now. However, because rail cars are clustered tightly (i.e., grouped as trains), the equipping of rail cars with low noise technology is only effective if a large proportion of the cars use this technology (see Section 1.2 on page 15).

Retrofitting the current freight fleet with composite brake blocks will be a slow process since a charging scheme is required that creates an incentive to retrofit without increasing the overall cost of rail freight transport relative to other transport modes. The planned funding in Germany (see Section 5.1.6 on page 96) is not attractive enough for a part of wagon owners, since a negative impact on railway transport costs would be inevitable.

Therefore, developing a regulation scheme for a staged process towards low-noise rolling stock must be the heart of a noise abatement strategy for railways. The economic instruments developed in Section 5.1 on page 93 then would serve as incentive engines, for instance as a motivation for top runners to start early with retrofitting or purchasing new noise-reduced cars and for the followers to reduce their costs.

5.2.1. Regulating technology for noise emissions?

Currently the discussion focuses on the braking system of rail cars. Most noise in railway operations is caused by rough running surfaces of wheels and tracks. If both can be kept smooth, noise can be reduced significantly [CER UIC 2007]. The conventional cast-iron brake blocks cause a fast deterioration of wheels and rough wheel surfaces and high noise levels are a consequence. If this braking technology can be exchanged by modern composite brake blocks the noise emissions can be reduced by up to 10 dB(A).

Retrofitting with composite brake blocks targets brake noise and elevated rolling noise, but there are other sources of noise, locations which require an even greater noise reduction than can be gained by retrofitting alone, and there are many railway vehicles which do not have cast-iron tread brakes. Noise reduction can also be achieved by rail- and wheel-tuned absorbers and other technical measures. Furthermore, technological development may yield new technologies in the next years to come. This brings up the question whether the regulation towards a particular noise reduction technology makes sense. In any case, the regulation should allow for alternative technologies if they have proved to achieve at least the same reduction performance. The Japanese Top-runner scheme gives an example for an incentive compatible regulation scheme. The current best technology is set as a standard in the medium term (e.g.: 5–7 years).

An alternative way of regulation consists of setting upper limits for local noise emissions. Directive 2002/49/EC gives the basic definitions of indicators, methods of measurement and mapping of exposed population. The Member States are obliged to identify hot spots where noise limits are exceeded and to prepare action plans not later than July 2013. The national legislation for noise control is well developed for new investments which lead to additional traffic and noise production. The big challenge remaining is the noise protection of population alongside existing railway tracks. In principle it would be possible to prepare a noise directive comparable to the Air Quality Directives 1999/30 and 2008/50, which limit the local concentration of exhaust emissions like NOx and PM. Analogously, a noise quality directive could limit the noise levels alongside the tracks at maximum thresholds, depending on the environment and the exposed population.

The advantage of emission dependent regulation is that the industry is free to find the best technologies to meet the limit values set. A disadvantage is that it will take some time to achieve a consensus of the Member States on noise limit values. After the painful experiences gained with the introduction of Directive 1999/30 (Council Directive 1999/30/EC of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air) one can expect that the Member States will check such values carefully to avoid massive investments in their transport infrastructure for noise abatement.

Therefore, the most promising way for the medium term future is to start from the platform of TSIs and the Recast of the Railway Packages (see [TSI Noise 2011] and [Com(2010) 475]). This can be formulated in a way that the expected noise reduction is clearly defined while the technology used is not specified in detail, leaving options open for technological progress.

5.2.2. Regulation authorities

The European Railway Agency (ERA), established in 2006 in Valenciennes following the second railway package, is responsible for TSIs and can take responsibility for developing the appropriate noise regulation for railway cars as well. This regulation can be controlled by the national railway regulation authorities – following the first railway package the establishment of national railway regulators is obligatory for each Member State.

From this follows that the existing national bodies can be involved in the control of rail noise emissions more intensively and with the necessary administrative power. A close coordination with the road and air transport regulators is necessary to avoid market distortions stemming from unbalanced regulation.

5.3. Analysis of stakeholder remarks on economic incentives and regulation

Since it is not possible to reflect the position of each railway stakeholder in Europe within this framework, the position of the International Railway Union (UIC) is provided. UIC makes frequent statements of the issue which generally acknowledge the need for noise reduction measures. UIC favours the following strategies [UIC 2010]:

- Reduce the noise of all new freight vehicles by introducing TSI limit values.
- Promote the retrofitting of existing freight vehicles with composite brake blocks.
- Build noise barriers and install noise insulated windows.
- Pursue further solutions in special cases such as acoustic rail grinding, rail absorbers, wheel absorbers, friction modification against curve squeal, etc. The precondition is regular maintenance.

UIC considers LL-brake blocks to be a “promising noise reduction measure; however they still require further improvement before they can be used on a large scale in Europe”.

Other options, such as speed limits and land-use planning are rejected [UIC 2008]. Speed limits need to be substantial (50 km/h) to have a considerable noise impact and thus “are not compatible with the operation of a commercially competitive railway”. Land-use planning measures are of little effect, since at distances further than 50 metres from the source “noise level is insensitive to even medium changes in distance”.

UIC's main concern is that noise reduction measures might burden the railways in a manner that the competition with the road sector is distorted. The burden may be created either through high investment costs or excessive administrative tasks. “Due to fierce competition, wagon owners do not have sufficient resources to finance the retrofitting of their fleet. Any incentive system should neither weaken the overall market share of the freight sector nor disadvantage any freight market player” [UIC 2011].

Therefore, the cost efficiency of the measures (see Section 5.1 on page 93) is a major UIC decision criterion. For example, the retrofitting with composite brake blocks is considered as more efficient than the construction of noise barriers. UIC argues that an incentive scheme should be developed, where public funds for retrofitting are diverted from the railway network operators to the wagon owners. Additionally, UIC criticises the above-mentioned studies commissioned by the EU [PWC 2007] and [KCW et al. 2009] for its “too low cost assumptions related to the use of composite brake blocks. These assumptions combined with too high an estimate of the average annual mileage may lead to a differential track access charge which is insufficient for promoting retrofitting.”

Since direct funding does not take into account the wagon mileage, [UIC 2011] proposes a bonus system combined with access charges: “national authorities should fund the retrofitting of freight wagons by means of a noise reduction bonus … [which] would be granted based on the mileage travelled on lines of the respective national networks. The bonus would compensate the investment costs as well as the additional operating, transaction and administrative costs.”

In an interview with the authors in July 2011, Mr Kerth from VDV mentioned that the total costs for retrofitting are about 0.008 € per axle-km if the additional operating costs and financing costs are included in the calculation. Currently, the interest of the wagon owners in retrofitting existing wagons due to this funding scheme is very low. A problem for the rail sector can also rise because part of the financing of the bonus system will be financed by an increase of track prices for the total freight train sector. This increase also affects existing wagons which are already equipped with composite brake blocks. The press release of VDV and VPI concerning the financing of the bonus from July 5th 2011 announces the 50% share of the rail sector as unfair [VDV VPI 2011]. It is the first time a transportation mode would be burdened by costs for noise and it would only fund recently retrofitted wagons, while existing low-noise or new-build wagons have to carry the increased track prices.

In general, the planned funding scheme in Germany is accepted by the rail sector as it is a direct funding of wagon owners and the system is not too complicated. The implementation costs seem to be acceptable (see the elaborations in [KCW 2011]). Nevertheless, many details still have to be clarified and agreed, such as the size of the bonus and its financing. Also the inclusion of additional operating costs is still in discussion. If they are included, this could lead to a lower share of the German state as this part of the funding is limited to 152 million Euros per year [VDV-2011-2]. VDV expects only 15% share of costs will be carried by the Germany state if the additional operating costs remain to the rail sector.

UIC, CER, UIRR, ERFA, EIM and UIP comment in their position paper on a Consultation document of the Commission concerning rail noise abatement measures in 2007 [UIC et al. 2007]. In this respect they point out that the funding scheme should not burden the rail freight sector with additional costs and the funding and monitoring scheme should not be cost-intensive itself.

6. CONCLUSIONS

Reducing railway noise is an important activity for the environment and citizens' health in Europe and for the acceptance of the railways as a driving force for ecological and economic development of Europe. Therefore, the acceptance of railways by citizens living near railway lines, especially the main rail freight corridors, is vital.

In freight corridors, the number of trains will increase, and so noise for the citizens will increase as well. Therefore, measures to reduce noise levels are essential to prevent health risks and to have the acceptance of the neighbours. Without this acceptance, the risk remains that the increase of capacity on main railway lines will be inhibited for a long period of time, which will cause losses for the rail sector and for the total economy.

6.1. Recommendations of measures

The recommendations cover the following three main aspects, considering the revival of the rail sector as one of the most important measures for greening transportation and meeting climate change targets:

- identifying effective technical measures;
- providing effective regulation and economic incentive schemes which do not distort competition with other transportation modes;
- funding the necessary investments.

Technical Measures

On the technical side, the noise reduction measures focus on two pillars: vehicle-related measures and infrastructure-related measures.

There are several **vehicle-related** measures:

LL-blocks: One of the main sources of railway noise is freight wagons, particularly those with cast-iron tread-brake blocks. The cast-iron blocks damage the running surface of the wheels, making the surface rough and increasing the noise level at the wheel-rail interface. High-speed trains and passenger trains use disc brakes rather than tread brakes; new vehicles can be fitted with composite tread brake blocks (K-blocks), but these are not suitable for retrofitting. There are still about 370,000 freight wagons with cast iron brakes which are worth being retrofitted in Europe, and finding a cost-effective composite brake block replacement (LL-blocks) for retrofitting is a priority for many railway operators. The current estimate for retrofitting the 370,000 freight wagons is between 2.2 and 4.2 billion Euros, but the impact of LL-blocks on wheelset maintenance costs is yet to be established.

Noise can also be a problem on railways with no freight traffic, so other vehicle-related measures are important:

- **Wheel absorbers** are used to reduce rolling noise and can be effective against curve squeal. A range of wheel noise absorption technologies and products have been developed. The interaction of wheel noise absorbers and any track noise absorbers needs to be considered for optimum system performance.

- A number of **modified wheels** have been developed in recent years but the accident with an ICE in Eschede in 1998 has left the industry wary of modified wheels for high-speed trains. However, these developments have had significant noise reduction potential and it is worth continuing research in this area.

- Vehicle-mounted top-of-rail **friction modifiers** (TOR FM) or flange lubrication systems can be used to combat curve squeal (as well as to reduce wear). A range of technologies and products are available. These are appropriate for closed systems where the vehicles are regularly monitored and maintained, such as local commuter networks; urban systems also have tighter curves and consequently more problems with curve squeal.

- Pantograph noise is a problem with high-speed electric trains, particularly since the pantograph is usually higher than noise barriers, if present. **Aerodynamic designs** like shielding or **special materials** like porous coating of pantographs can be used to reduce aerodynamic noise.

Additionally, new rolling stock, introduced since the year 2000, already have lower noise emissions by 10 dB(A) in comparison with equipment produced in the 1960s and 1970s. This shows the importance of replacing old rolling stock as soon as possible.

The effectiveness of vehicle-related measures has the best cost-benefit ratio. So the introduction of composite brakes on freight wagons should be approached with the highest priority. Other measures can be done complementarily.

A wide variety of **infrastructure-related** technologies have been developed to combat noise and vibration. Mostly these fall into three categories:

- Noise barriers and bunds are usually large earth mounds creating an artificial cutting for the railway; these require several metres of land to the side of the railway which is not normally an option for existing railways or urban environments. **Noise barriers**, on the other hand, are suitable for existing railways and urban environments, but to be effective they need to be at least two metres high. Noise barriers have a poor visual impact, especially since they are a target for graffiti; they create problems for track access and incur a high on-going maintenance cost. Special acoustic enclosures are sometimes used to surround the railway above as well as at the sides.

- Track-side lubricators are a traditional method of reducing curve squeal (as well as reducing wear) and **friction modifiers** are used also to reduce brake squeal (in shunting yards, for example). Top-of-rail friction modifiers (TOR FM) are also effective at reducing corrugation (a major noise source) on the low rail in curves.

- Resilient track forms and technologies include: floating slab track, ballast mats, resilient base plates, rail pads of various stiffnesses, rail clips that clamp the web under the railhead, tuned **rail dampers**, and booted sleepers. Tunnels under urban environments, such as the Channel Tunnel Rail Link and Crossrail in London, are targets for such technologies. (As noted earlier, the interaction of wheel noise absorbers and track noise absorbers needs to be considered for optimum system performance.)

Additional considerations:

- Wheels and rails need to be monitored so that (a) out-of-round wheels (and especially wheels with flats) can be turned, and (b) corrugated rails can be ground. Out-of-round wheels and corrugated rails are a source of increased rail noise, as well as a cause of increased wheel-rail forces and consequent damage.

- Track geometry and substructure should be designed and maintained to avoid sudden changes in direction or stiffness, both of which increase noise emission, wheel-rail forces and consequent damage.

- Rail joints should be avoided (insulated rail joints are an exception) and continuously welded rail used instead; expansion joints should be scarfed.

Large infrastructure-related investments have already been made in several countries, including Sweden, Denmark, The Netherlands, Germany, Poland, Czech Republic, France, Switzerland, Austria, Italy and Portugal. These measures are necessary, particularly in densely populated areas. Noise-reducing infrastructure-related measures are usually introduced with new construction or major redevelopment of railway links according to new standards where these measures are a requirement, whereas for the existing infrastructure there is no obligation to lower noise.

Intelligent combinations of vehicle- and infrastructure-related measures help to bring rail noise down to long-term sustainability levels for a reasonable cost. The analyses of this study show that infrastructure-related measures can be reduced if effective vehicle-related measures are also taken. Therefore, a fast retrofit of the existing freight wagon fleet is the most urgent action to be taken.

Regulation and economic incentive schemes

International examples such as the Japanese top-runner scheme[37] underline that a sound **regulation scheme** is the heart of any successful pollution reduction strategy. This holds in particular for noise, because an effective reduction of noise through vehicle-related measures presupposes that almost all internationally operating rail wagons are equipped with low-noise technology.

The TSI Noise is an appropriate basis for noise regulation in the medium and long term. Presently, the standards for noise emissions are valid for new or modified vehicles only. In the medium and long-term view the TSI can become compulsory for all vehicles. The time schedule for validation of the noise levels for all vehicles should be long enough to allow for an adjustment of technology without major additional investment costs. We propose a time period of 10–12 years, which covers 1–2 revision cycles and is half of the normal life time of rolling stock (a quarter for freight wagons). The noise levels in TSI Noise should also be lowered from time to time according to technical development.

Economic incentive schemes consist of charging and bonus/penalty systems. Rail track charging is an important element of an incentive-compatible penetration strategy for low-noise rail technology. The principles and request for introducing noise emissions into the track access charging system are formulated in the Recast of the First Railway Package (proposed in 2010) and can be implemented by the Member States as the revision of

[37] This scheme aims at reducing energy consumption and climate impact by dynamic setting of emission targets on the basis of current best practice ("top runners' performance").

Directive 2006/38/EC (Eurovignette) has been adopted on 27 September 2011 (see [Dir. 2011/76/EU]) as the existing Directive 2001//14/EC already allows NDTAC if the same is allowed for other transportation means. The Directive 2011/76/EU allows for mark-ups reflecting environmental costs (including noise) for HGVs on motorways and highways. This means that in the future a balance can be found between road and rail pricing for noise emissions which does not disturb competition between the transport modes. It is important to take into consideration that a substantial noise reduction requires that a large proportion of rail cars are equipped with modern technology. This suggests that lower tariffs should be offered only to trains which consist entirely of noise-reduced cars. Such a system can be implemented without installing further electronic devices in the rail cars, if an effective reporting system is established. The example of the proposed German rail track charging and retrofit-funding scheme shows that this requirement can be fulfilled. This underlines that the transaction cost of a noise-differentiated charging system can be held low, which is an important argument, because many objections against the introduction of such systems are based on the presumed high transaction costs.

Further alternative or complementary incentives can be introduced through bonus/penalty systems. In particular, in the transitory phase, bonus payments can motivate the rail car operators to switch to new technology as early as possible. The railway companies will call for wide use of this instrument if the state pays for the bonus. From the viewpoint of setting incentives right, at least a part of financial contributions should be covered by the rail car owners/operators.

Funding schemes

After assessing the best combinations of technical and economic measures, the financial implications have to be considered and the impacts on stakeholders have to be analysed. In our view, the adjustment of braking systems is the most urgent and promising strategy, complemented by infrastructure-related measures at noise hot-spots. There are different funding sources, which have to be developed for these measures.

Infrastructure-related measures are financed by the state and/or the rail infrastructure managers. In the latter case, the additional costs for the infrastructure managers are passed on to the railway undertakings through the rail track charges. This implies that the state will have to cover a substantial part of the infrastructure-related costs if the competitive balance between road and rail is not to be affected.[38]

Vehicle-related measures have to be financed by the car owners/operators in the long term. In the short and medium term, subsidies by the state or the European Union, for instance bonus payments for retrofitting, can accelerate the change of technology. Member States will have to decide on the magnitudes of bonus payments and the method of refinancing. In this context it is crucially important that the territoriality principle will be fully applied with the rail track charging system, which means that retrofitted rail cars get a lower tariff regardless of which country they have been licensed in and where the owner/operator is located.

The vehicle-related funding scheme should be a limited programme for some years (e.g., 10 years) and should focus on retrofitting existing vehicles. Existing low-noise vehicles can also be included if the cost of the noise-reduction measure can be verified (former

[38] Note that the mark-ups for noise, as suggested by the Commission, are rather low for HGVs on motorways and freeways and the Member States are not obliged to implement them.

retrofitting without funding of the measure, price differences between normal and low noise vehicle of the same type).

Funding and regulation schemes should be harmonised in the EU to minimise distortions of competition as many freight transport companies are operating internationally, carrying a high share of freight rail cars cross-border. “Noise leakages” should be avoided, which could occur if noisy freight cars, registered in a “low noise cost” country, are operating in “high noise cost” countries. Therefore a common regulation scheme is necessary, accompanied by a widely harmonised system of pricing and funding. Variations from this general rule could only be accepted to the positive side, i.e., to motivate top runners to start early with appropriate actions. In this context, the trade-off between low noise policy and competition policy could be more balanced in favour of low noise in the medium-term. The reason is that rail freight as a whole may lose market share in the medium term if the noise problems cannot be solved appropriately, and the resistance of the affected population might impede full capacity utilisation and the removal of capacity bottlenecks.

6.2. Recommendations for parliamentarian activities

To support and accelerate the introduction of noise reduction measures, the European Parliament could – in the second reading of the Recast of First Railway Package – only accept the Recast if the following issues are fulfilled:

- Including an obligation for a harmonisation of charging of railway noise in all Member States within a reasonable short time period.
- Integrate the dependence of the introduction of Noise Depending Track Access Charges (NDTAC) from the same introduction in road transport.
- Including an obligation to create “Noise Depending Track Access Charges (NDTAC)” for the introduction and use of noise reducing measures in each Member State according to the levels in TSI Noise (COMM. DEC. 2011/229/EU).
    - The NDTAC could include funding / covering of higher operational costs if the noise reduction measure causes extra costs.
    - The NDTAC could also include a significant special bonus for trains which are completely equipped with noise reduction measures (in addition to funding of individual equipment of single rolling stock units).
- Including an obligation for the infrastructure managers to maintain the infrastructure in a way to avoid noise caused by poor infrastructure conditions (rail roughness).

Additional to this, the European Parliament could request the European Commission:

- Creates an European Funding Scheme for vehicle-related noise-reduction measures, and to motivate Member States to introduce noise-reduction funding for internationally operating rolling stock.
- Modifies the latest TSI Noise, introduced with Commission Decision (2011/229/EC) of 4 April 2011, so that the maximum noise levels are also obligatory for existing rolling stock about 10–12 years after introduction of the modification of TSI Noise.

- Lowers the maximum noise levels introduced by TSI Noise in a staged process for the long-term future, with adjusted obligations for new and existing rolling stock (top runner scheme).

To harmonise the competitiveness between rail and road sectors, the European Parliament could request the European Commission:

- Prepares a Directive for a network-wide regulation and charging of lorry noise, at least for the TEN-T roads (comprehensive network) – eventually embedded in a concept of full internalisation of external costs under explicit consideration of noise-reduction targets, extending the optional noise-related motorway charging as in Directive 2011/76/EU.

To lower noise at hot spots which cannot be solved by the introduction of vehicle-related measures, the European Parliament could:

- Observe the introduction and fulfilment of noise action plans concerning hot spots in rail and road sectors.

- Include noise-reduction measures at noise hot spots of the TEN-T (comprehensive network including existing links and nodes) into the EU funding facilities (in particular the Connecting Europe Facility).

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ANNEX I: ENVIRONMENTAL NOISE EMISSIONS IN MEMBER STATES AND AGGLOMERATIONS

		Rail noise outside agglomerations									
		Nr of people exposed to different noise bands (Lden) [dB(A)]					**Nr of people exposed to different noise bands (Lnight) [dB(A)]**				
Country	***km***	*55-59*	*60-64*	*65-69*	*70-74*	*>75*	*50-55*	*55-59*	*60-64*	*65-69*	*>70*
Austria		217,300	121,700	47,900	16,900	7,500	194,200	98,900	36,700	13,300	5,600
Belgium		33,300	19,700	16,100	13,400	3,900	25,700	17,200	15,000	7,500	1,800
Czech Republic	270	13,300	2,600	1,100	300	0	6,700	2,000	800	200	0
Denmark	1,776	20,200	5,500	1,900	1,200	100	12,100	3,300	1,600	800	0
Finland		15,100	5,900	2,300	200	0	8,800	4,000	800	0	0
France	1,435	624,200	420,000	250,300	139,500	105,200	519,600	348,400	207,100	112,900	70,000
Germany	17,282	1,588,700	693,400	218,200	87,900	58,000	1,392,500	547,600	175,700	73,100	44,800
Hungary	32	0	0	0	0	0	0	0	0	0	0
Ireland	58	0	0	0	0	0	0	0	0	0	0
Italy	591	89,900	61,900	37,300	33,000	24,800	87,000	67,300	35,600	31,300	25,400
Luxembourg	20	100	100	0	0	0	100	0	0	0	0
Norway		4,500	2,600	2,000	700	900	3,600	2,100	1,300	500	600
Poland	16	900	200	100	0	0	700	100	100	0	0
Portugal	115	21,200	11,600	8,000	7,200	4,400	14,900	9,400	7,500	5,500	1,100
Romania		3,900	1,000	0	0	0	5,500	3,400	700	0	0
Slovenia	68	5,600	2,600	1,100	400	300	4,700	2,400	1,000	400	300
Spain	742	45,700	23,500	11,000	1,600	0	34,900	19,300	6,000	500	0
Sweden		58,100	33,800	12,300	4,800	1,700	43,900	21,200	7,700	2,500	1,200
Switzerland		39,500	23,600	12,500	8,800	3,800	30,400	16,700	10,700	6,100	2,400
United Kingdom		80,800	50,300	32,500	14,100	2,100	56,400	36,400	18,500	3,800	100
Total general		2,862,300	1,480,000	654,600	330,000	212,700	2,441,700	1,199,700	526,800	258,400	153,300
Total EU 27		2,818,300	1,453,800	640,100	320,500	208,000	2,407,700	1,180,900	514,800	251,800	150,300

		Rail noise in agglomerations									
		Nr of people exposed to different noise bands (Lden)					Nr of people exposed to different noise bands (Lnight)				
Country	Inhabi-tants	*55-59*	*60-64*	*65-69*	*70-74*	*>75*	*50-55*	*55-59*	*60-64*	*65-69*	*>70*
Austria	1,610,578	107,000	81,100	57,900	35,500	9,500	101,900	76,700	41,900	28,800	4,100
Bulgaria	2,084,000	18,400	5,800	500	100	0	16,300	6,100	200	0	0
Czech Republic	1,852,955	74,800	59,500	65,900	14,500	0	63,300	69,800	32,000	400	0
Denmark	1,071,714	19,400	7,400	2,600	1,000	100	12,500	4,900	1,500	600	0
Estonia	401,140	10,600	6,900	3,500	900	0	9,000	5,700	2,500	300	0
Finland	560,905	27,500	25,400	16,700	200	0	27,600	21,500	2,000	0	0
France	13,664,912	1,488,600	208,800	117,700	63,500	43,000	1,426,900	148,200	63,700	34,300	12,800
Germany	17,265,322	478,300	246,700	122,400	31,400	5,700	393,800	194,400	75,800	16,700	3,300
Hungary	2,065,230	132,500	50,600	19,600	7,900	1,200	110,700	40,900	16,400	6,000	700
Ireland	1,150,000	10,600	6,800	2,800	500	0	7,700	3,500	1,400	100	0
Italy	4,190,684	34,000	30,900	24,800	6,400	1,400	34,500	37,800	19,500	4,600	2,100
Latvia	806,993	28,400	20,100	6,300	800	100	25,500	9,400	4,700	400	0
Lithuania	932,847	9,100	5,000	1,100	300	0	8,600	2,800	800	200	0
Netherlands	5,026,059	118,600	60,700	25,000	8,800	1,000	94,100	40,800	12,700	4,100	1,200
Norway	822,800	19,200	15,500	16,000	4,900	0	18,300	18,100	7,900	600	0
Poland	7,446,365	323,600	197,900	98,100	38,500	6,900	191,800	108,100	37,300	700	100
Romania	4,079,364	135,700	90,700	15,700	1,300	100	184,200	111,700	44,600	4,800	200
Slovakia	528,129	95,100	67,600	38,500	16,600	3,700	92,300	54,200	32,900	8,700	2,600
Slovenia	266,251	6,700	3,500	900	0	0	5,800	2,300	500	200	0
Spain	8,116,104	16,300	7,200	1,300	500	0	9,700	2,900	1,000	200	0
Sweden	1,548,886	84,900	37,800	13,400	5,400	1,500	56,300	22,100	7,100	2,800	300
Switzerland	5,300,000	182,700	126,600	98,500	62,300	25,900	156,100	107,700	85,000	41,600	16,900
United Kingdom	25,613,309	395,500	291,400	157,900	46,800	6,000	321,000	193,700	69,600	14,000	2,200
Total general	106,404,547	3,817,500	1,653,900	907,100	348,100	106,100	3,367,900	1,283,300	561,000	170,100	46,500
Total EU 27	105,581,747	3,615,600	1,511,800	792,600	280,900	80,200	3,193,500	1,157,500	468,100	127,900	29,600

Source: ETC 2010.

ANNEX II: MAXIMUM NOISE LEVELS OF ROLLING STOCK ACCORDING TO TSI NOISE

Table 1: Limiting values LpAeq,Tp for the pass-by noise of freight wagons

Wagons	LpAeq, Tp in dB
New wagons with an average number of axles per unit length (apl) up to 0,15 m^{-1} at 80 km/h	82
Renewed or upgraded wagons according Article 20 of Directive 2008/57/EC with an average number of axles per unit length (apl) up to 0,15 m^{-1} at 80 km/h	84
New wagons with an average number of axles per unit length (apl) higher than 0,15 m^{-1} up to 0,275 m^{-1} at 80 km/h	83
Renewed or upgraded wagons according Article 20 of Directive 2008/57/EC with an average number of axles per unit length (apl) higher than 0,15 m^{-1} up to 0,275 m^{-1} at 80 km/h	85
New wagons with an average number of axles per unit length (apl) higher than 0,275 m^{-1} at 80 km/h	85
Renewed or upgraded wagons according Article 20 of Directive 2008/57/EC with an average number of axles per unit length (apl) higher than 0,275 m^{-1} at 80 km/h	87

Table 2: Limiting value LpAeq,T for the stationary noise of freight wagons

Wagons	LpAeq, Tp in dB
All freight wagons	65

Table 3: Limiting values LpAeq,T for the stationary noise of electric locomotives, diesel locomotives, OTMs, EMUs, DMUs and coaches

Wagons	LpAeq, Tp in dB
Electric locomotives and OTMs with electric traction	75
Diesel locomotives and OTMs with diesel traction	75
EMUs	68
DMUs	73
Coaches	65

Table 4: Limiting values LpAFmax for the starting noise of electric locomotives, diesel locomotives, OTMs, EMUs and DMUs

Vehicle	$LpAF_{max}$ in dB
Electric locomotives P < 4 500 kW at the rail wheel	82
Electric locomotives P >/= 4 500 kW at the rail wheel and OTMs with electric traction	85
Diesel locomotives P < 2 000 kW at the engine output shaft	86
Diesel locomotives P >/= 2 000 kW at the engine output shaft and OTMs with diesel traction	89
EMUs	82
DMUs P < 500 kW/engine	83
DMUs P >/= 500 kW/engine	85

Table 5: Limiting values LpAeq,Tp for the pass-by noise of electric and diesel locomotives, OTMs, EMUs, DMUs and coaches

Vehicle	LpAeq, Tp in dB
Electric locomotives and OTMs with electric traction	85
Diesel locomotives and OTMs with diesel traction	85
EMUs	81
DMUs	82
Coaches	80

ANNEX III: COMPARISON OF COVERAGE OF BOGIES FROM DIFFERENT MODERN ROLLING STOCK EQUIPMENT

Well covered bogies by engine body of Swiss Engine type RE 460 (Lok 2000)

Open bogie of modern Bombardier Engine Traxx (example German type 186)

Well covered bogies of Swiss passenger wagon IC2000

Open bogie of modern German double deck wagons

ANNEX IV: IMPORTANT AND ANALYSED REGULATIONS

EU Political Papers and Directives	Relevant Contents with Respect to Railway Regulation and Railway Noise
Political Papers	
White Paper 2001	EU transport policy for 2010. Shifting the balance between the modes of transport. Revitalising the railways. Towards multi-modal corridors giving priority to freight.
White Paper 2011	A true internal market for railway services. Standards for controlling noise pollution. Among the ten goals for achieving a competitive and sustainable transport system: Shift 30 (50)% of road freight over 300 km to rail and IWW by 2030 (2050).
Directives	
Directives 1991/440	Framework and legal requirements for a competitive railway system. Commercial organization of companies. Separation of infrastructure management and service undertakings. Open access to the railway network. Liberalized cross-border transport.
Directives 2001/12-14	Comprehensive railway regulation framework, e.g.: Clear separation of public and commercial issues. Freeing companies from old debt. Separate bookkeeping and balance sheets for infrastructure management and service provision. Capacity provision and pricing for infrastructure provision.
Railway Packages 2001, 2002, 2004	Specification of open access, essential facilities. Specification of regulatory requirements. Establishment of national and EU regulatory bodies (European Railway Agency). Rail track charging principles (marginal cost plus mark-ups). Market opening for freight (2007) and passenger long-distance (2010) transport. Regulation of passenger rights and freight transport quality. EU train driver license.
Recast of the First Railway Package 2010 Status: Under discussion.	Comprehensive specifications for establishing a single European railway area. General objectives: Establish an internal railway market with high degree of competitiveness and harmonious, balanced and sustainable development of economic activities. Revitalization of railways, modal shift. Horizontal objectives: Legal simplification, clarification and modernization to facilitate implementation. Specific objectives: Ensuring sustainable funding of the infrastructure. Avoiding distortions of competition. Providing effective and independent regulation. Applied principles of rail track charging under consideration of external effects (e.g. noise). 12 appendices with detailed specifications for application

Related COM Decision	
COM 2006/66 (TSI Noise)	Technical Specifications for Interoperability related to the subsystem 'rolling stock-noise'. Functional and technical specification of the sub-system. Limits for pass-by and stationary noise. Limits for locomotives, multiple units and coaches. Measurement, assessment, application to new and existing rolling stock.
Related Directives	
Directive 2002/49	Assessment and management of environmental noise. Noise indicators, noise measurement and assessment. Obligation to publish noise maps. Obligation to develop noise action plans. Obligation for reviews and regular reporting. 6 Annexes with detailed specifications.
Report from the Commission to the EU Parliament and to the Council on the Implementation of Directive 2002/49	First implementation report based on the implementation deadlines 2005 – 2012. Noise indicators and limit values widely transposed. Significant achievements with harmonized measurement and statistical reporting/noise mapping. Difficulties still existing with health-based noise assessment and heterogeneous situation with country-based action plans.
Directive 2006/38 revised	Charging heavy goods vehicles on motor- and freeways for infrastructure use. Basis: Allocated infrastructure costs plus mark-ups for noise and air pollution. This was the pre-condition set in Dir. 2001/14 for including noise costs in the rail track charging scheme.

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