RAILWAY NOISE IN EUROPE

State of the art report

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INTERNATIONAL UNION OF RAILWAYS

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Author:	Paul de Vos
Steering committee:	Nick Craven (UIC) Jakob Oertli (SBB) Franck Poisson (SNCF) Martina Fleckenstein (DB) Ferat Goecmen (DB) Ethem Perkin (CER)
Special thanks to:	UIC Noise Expert Network, Marie-Luz Philippe and Andrea Braschi (UIC)
Project leader:	Nicholas Craven (UIC)

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Content

EXECUTIVE SUMMARY

Many essential activities in modern societies cause environmental impacts, including noise. A significant number of residents, particularly those who live close to roads, airports and railway lines, are exposed to noise. Depending on personal attitude and sensitivity, amongst other factors, some of these exposed residents are likely to feel annoyed. Annoyance can have various grades from moderately annoyed to highly annoyed. After a long period of being annoyed, some of the annoyed citizens may experience more serious effects (e.g. high blood pressure). Environmental noise, including railway noise, therefore represents a significant risk to the health of those citizens who are exposed to high noise levels.

Plans for new and upgraded railway lines, as well as growth of traffic on existing lines, sometimes causes strong adverse reactions from residents due to concerns about increased noise. Recently the same response occurs sometimes in relation to expected ground borne vibrations from railway lines. Although rail is widely acknowledged to be the transport mode with the lowest environmental impact, noise and vibration remain an important issue for the European rail sector.

In the past decades a range of noise mitigating measures has been developed and introduced, complemented by further significant improvements thanks to modernization of the rail system. For example: jointed track has almost completely been replaced by welded track; disk brakes have been introduced in modern passenger rolling stock; K-brake blocks have been introduced in new wagons. Installation of noise barriers and sound proof façades is common at sites with high noise exposures.

Reducing noise from rail freight has been identified by the European rail sector itself as a key objective. This issue has a high political sensitivity, particularly in densely populated regions in the centre of Europe close to the heavily trafficked rail freight ‘Corridor 1’ (Rhine Alpine Corridor).

Today, railway noise control is at a turning point. The main noise control strategy adopted by the railways, i.e. retrofitting of the existing freight wagon fleet, has now entered its implementation phase, at least in some countries representing large fleets. The fleets in Germany, both from the former Railway Undertakings and from private fleet owners, will be retrofitted applying low noise technology. Financial instruments have been set up to incentivise all wagons running through Germany, Switzerland and the Netherlands to be treated.

This process was started off by the approval of LL-brake blocks. After a thorough process of development and testing, new types of low noise brake blocks (LL-blocks) have recently been approved. These blocks allow simple and easy exchange from noisy cast iron blocks. The use of this technology is expected to reduce noise from freight wagons by around 8 to 12 dB on well maintained track (with roughness similar to the CEN ISO 3095 limit), a significant and noticeable reduction. It is expected that in 5 to 10 years a majority of all freight wagons in international traffic will be treated, making them comparable to passenger coaches with respect to their noise emission.

However, there is also concern: first about the competitive position of the railways being adversely affected by the additional costs associated with retrofitting (i.e. purchase and installation of low noise brake blocks plus higher maintenance and operational cost). These additional costs pose a major burden to some railways, particularly those of the new member states which have a majority of their wagon fleet dating from before 1989 (including wagons equipped with tyred wheels in which the acoustic modernization comprises more than a simple exchange of brake blocks). However, these railways are aware of the necessity to retrofit those wagons dedicated to international traffic, and have made appropriate provision in their modernization plans. Whilst financial instruments have been introduced to partly compensate for these costs it remains to be seen if these will have a significant impact. Nevertheless, retrofitting of freight wagons with K-blocks has now been completed in Switzerland and good progress has been made in Germany (mostly with LL-blocks), even though the process is ambitious and far from complete.

Clearly this is no time to lean back, as existing issues have not completely been solved yet and new issues arise. For example: high noise barriers are more and more disputed by residents for their impact on landscape and view, thus increasing the pressure to reduce noise at the source. Further challenges may arise as ground vibration and low frequency noise receive more attention from the general public. As there are currently few economically viable solutions, the issue of legislation has to be discussed with authorities. The railways are forced to remain active in their continuous search for better and more affordable noise and vibration performance. In doing so, a distinction has to be made between newly built and upgraded lines on the one side and existing lines (without upgrading) on the other – both in terms of evaluation and in terms of solutions.

Noise exposure and the cost of noise control must be effectively managed if rail is supposed to increase its market share, and in doing so to reduce the total environmental impact of the whole transport sector.

1. INTRODUCTION

Railway transport is the most sustainable transport mode, as it consumes less energy, needs less space and produces less CO_2 than any other transport mode. However, noise has long been the main environmental challenge for railway stakeholders. The public and their political representatives urge railway stakeholders to become quieter. But a lot has been achieved, and more activities are on the way. This report describes the recent developments and their impact.

This report is an update of a previous version, entitled Railway Noise in Europe, which was published in 2010. During the past few years' significant developments have taken place with respect to legislation and approach, approval and application of technical solutions, responsibilities of the various parties involved and ways to persuade stakeholders to engage in common enterprises to improve the noise situation. At the same time, there is greater insight into the effects of noise on exposed residents and a growing pressure on railway enterprises and infrastructure managers to reduce noise where feasible. As a consequence, a significant noise reduction has been achieved for millions of European residents. Passenger vehicles with noisy cast iron brake blocks have been phased out in large parts of Europe. The retrofitting of a significant part of the rail freight fleet with composite brake blocks has started. For example, in Germany by 2020 it is expected that retrofitting will have been completed for 55,000 freight wagons owned by DB Cargo in addition to 60,000 privately owned wagons. In addition, old noisy wagons are scrapped every year and the new wagons replacing them are much quieter. Many kilometres of noise barriers have been constructed, a large number noise insulated windows installed and measures on the track introduced.

The momentum must be maintained and current noise control programs completed so that the full benefits can be realized. This will be only the case when all large fleets of freight wagons used for international traffic are included in the retrofitting operation.

The rail sector has to deal with regulations and demands from the European Commission, national authorities, regional and city authorities, citizen groups and individuals, and to align these requirements with the railways' own strategies. This report describes how this is currently done.

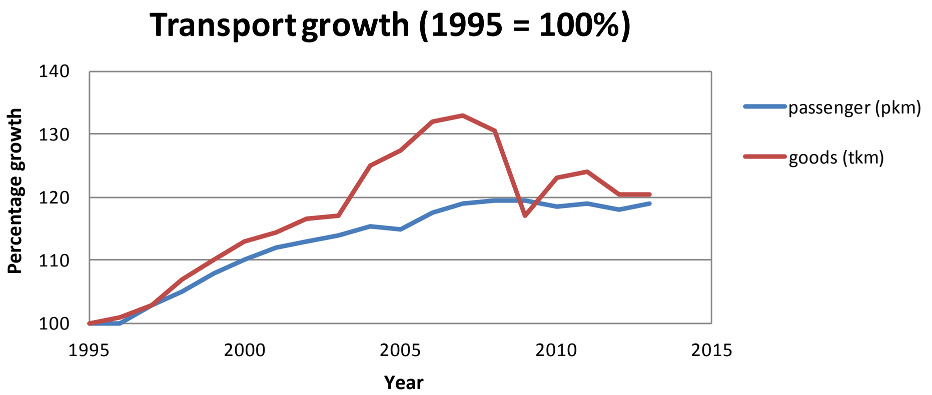
This report is concerned with the operation of **heavy rail** (as opposed to light rail) in Europe. However, many comments, explanations and conclusions will be applicable to light rail systems and to rail systems outside Europe.

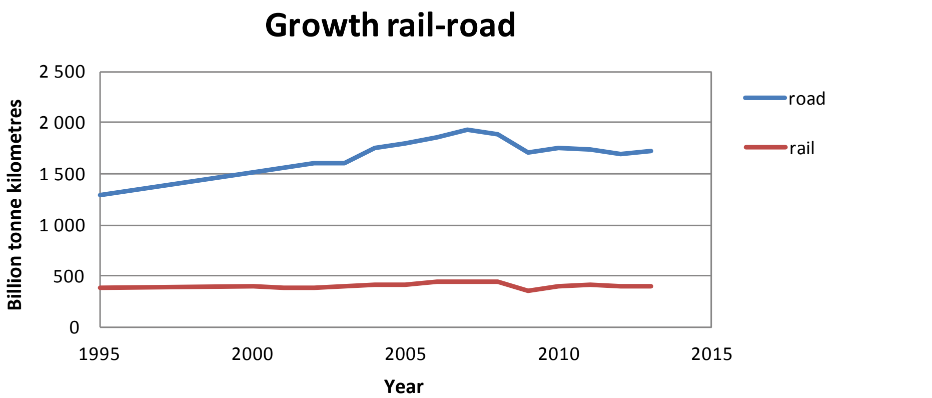
2. THE BIG PICTURE

2.1 The railways' contribution

Railways have an important role in the transport of passengers and goods. Between 1995 and 2013, the performance of rail freight (EU-28) is more or less constant at somewhat more than 400 billion tonne-kilometres per year. It is the third most important transport mode after road (1800 billion tonne-kilometres) and sea (1100 billion tonne-kilometres).[1]

For passengers, heavy rail transport is the fourth most important mode with slightly more than 400 billion passenger-kilometres, after cars (4700 billion passenger-kilometres), air and buses and coaches (both about 600 billion passenger-kilometres). Trams and metro contribute to almost 100 billion passenger-kilometres. The economic and financial crisis has affected the transport market but it seems that restoration is on its way (Graph 1).





Graph 1. Development of transport in EU-28 (EU Transport in figures 2015)

The figures show that rail transport represents roughly 20 % (for freight) to 10 % (passenger) of the road transport contribution. As presented in chapter 4, the noise impact of rail is about 10 % of that of road transport.

1. EU Transport in figures, statistical pocketbook 2015.

2.2 Stakeholders

Rail transport has a complex and evolving structure with many different stakeholders, these include:

- the operating companies (running the trains), mostly indicated as railway undertakings (RU);
- the vehicle owners (often leasing companies);
- the infrastructure managers, responsible for planning, construction and maintenance of the tracks (including signaling and power provisions).

With respect to noise, many more stakeholders are involved:

- The European Commission, particularly DG MOVE, has defined clear objectives for a modal shift from road to environmental friendly modes such as rail, while reducing the number of European residents being exposed to excessive noise. In setting political goals, the Commission is supported by institutions like the World Health Organisation (WHO) and the European Environment Agency (EEA);
- The European Rail Agency (ERA), on behalf of the Commission, sets noise emission limits for railway vehicles being approved for the European market;
- National governments commonly set limits for railway noise reception and, on the basis of environmental impact assessments, approve plans for expansion or significant renewal of the infrastructure;
- Local authorities supply permits for local activities, and may check compliance with the legal limits.

Rolling noise is the most important type of noise associated with the railway system. This occurs as an effect of the interaction between vehicle and track. For this reason a whole system approach involving all of the relevant stakeholders (operators, vehicle owners and infrastructure managers) is often required in order to effectively reduce noise emissions.

2.3 Technology and politics

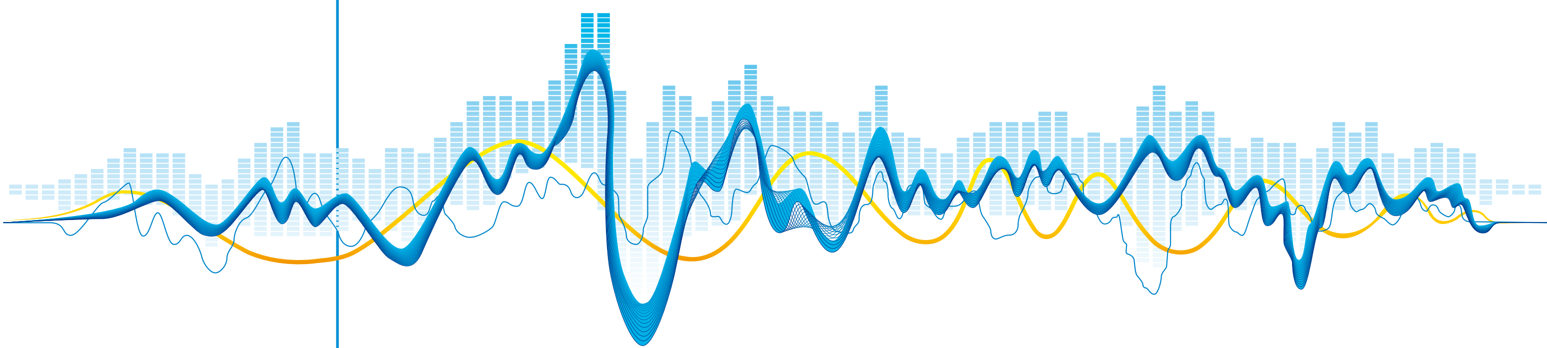
The necessity of a system approach is reflected both in the complex stakeholder structure and in the technological search for cost efficient solutions. Although the need for improvement of the noise performance of rail traffic is broadly recognized, railway undertakings stress that there is little economic scope for investment if it is without return.

The need to achieve and maintain a level playing field with competing transport modes, including road, is an important point. This is particularly true for international traffic, where both the rail operator and European Commission strive for more and better interoperability as one of the instruments to achieve this level playing field.

Railways provide very safe transport with modest revenues for the operators. Noise control solutions can only be implemented after ensuring that they do neither adversely affect safety, nor the economics of rail transport.

Under the guidance of the railway associations like UIC, UIP and CER[2], individual railway undertakings and infrastructure managers have developed noise policies of their own. Retrofitting of the European rail freight fleet, changing from cast iron brake blocks to composite brake blocks, has been at the core of the political and technological intentions since the early 1990's.

In 2012, a significant break-through was achieved following the conclusion of the UIC EuropeTrain project and subsequent approval of two LL-blocks products. Currently a significant part of the European freight fleet, mainly of Swiss and German origin, has been retrofitted, both with K (in Switzerland) and LL (in Germany) blocks. Supporting legislation and incentives have been implemented or are prepared, focusing on existing fleets in other countries. More details are presented in chapter 6.



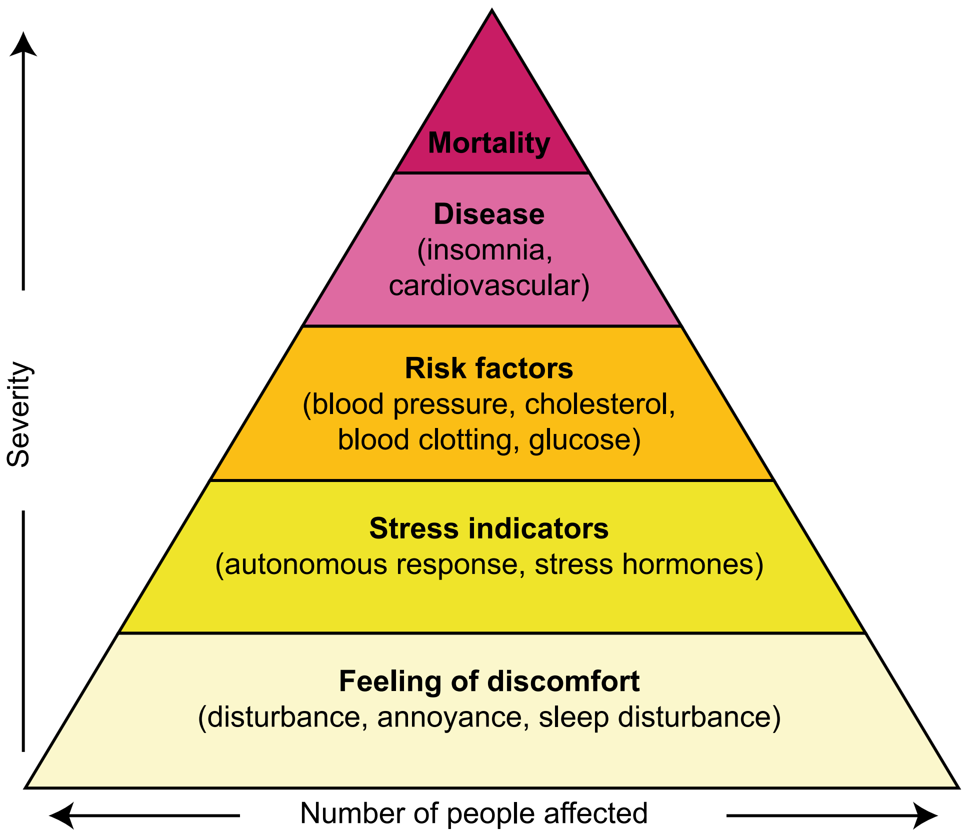
2. UIC: International Union of Railways, UIP International Union of Wagons Keepers, CER: Community of European Railway and Infrastructure Companies.

3. EFFECTS OF NOISE

In our busy society it is difficult to find a calm spot. Environmental noise is almost always around us. Living in an environment where man-made noise is almost permanently present may affect our quality of life.

Exposure to noise may have various effects, depending on the sound level, duration, frequency content, source and the attitude and circumstances of the individual experiencing it. It is important to note that although many people are exposed to environmental noise, only a percentage of them will experience it as annoying, and usually this only occurs after a long period of exposure.

A small group of the exposed population may run a risk of developing more serious symptoms including hypertension and stress. Again, this occurs only after a long period of exposure. These more serious health effects may contribute in rather rare cases to a loss of quality of life and healthy life years. According to the European Environment Agency [10], environmental noise might even cause premature death to a number of people in Europe each year.



Graph 2. Effects of noise, starting from exposure (under) to health effects (top). After WHO

The relationship between noise exposure and its effects is called dose response relationship. Whilst there have been a large number of studies to determine dose response relationships, this is a complex task for which the results are influenced by many variables. Significant variability can be observed between the conclusions of different studies. The WHO has consulted many renowned international researchers, but their consensus findings are still questioned. In light of this uncertainty the results specific studies with a limited scope must be interpreted with caution.

The main sources of environmental noise include road and rail traffic, aircraft and industrial sites, both in cities and in rural areas. It should be noted that road traffic is by far the most dominant source of environmental noise (see Chapter 4).

The following remarks are intended as clarification of the concepts of the main effects of environmental noise:

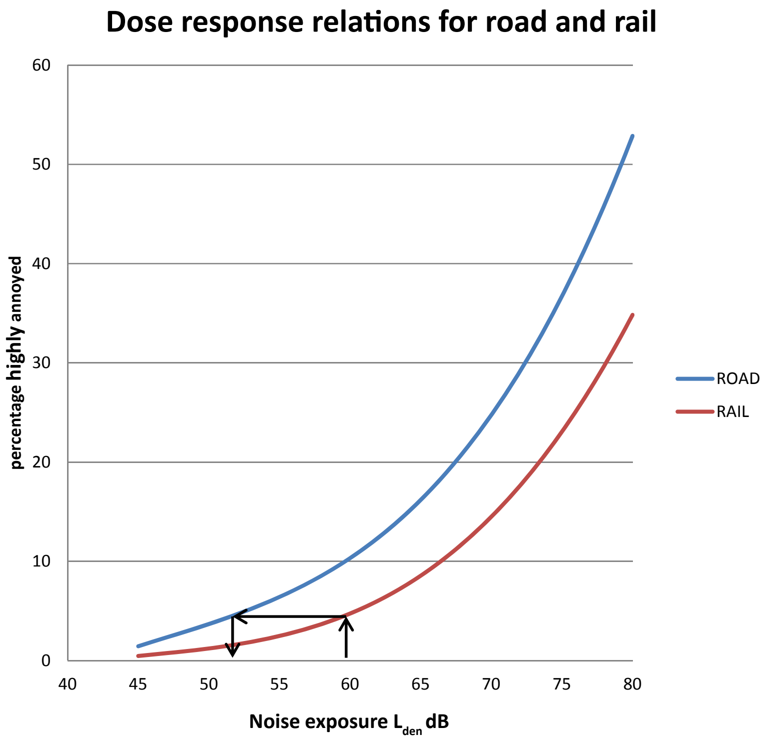
- **Annoyance**

  Annoyance is the most common effect; a general feeling of disturbance or discomfort, usually occurring after a long period of continuous or repeated exposure. By definition, annoyance can only be self expressed, i.e. it is assessed through field surveys by asking people if they feel annoyed. In general, it is unusual for people to experience annoyance when exposed to noise below 45 dB(A) L_{den}[3]. For noise exposures above this level a certain percentage of people may report being annoyed or highly annoyed, with higher percentages for increasing noise exposure. The response depends among others on the type of noise, Graph 3 shows the results of a so-called meta-analysis (encompassing a large amount of previously reported research) of dose response relationships published in an EU position paper.

  Annoyance is dependent of personal and contextual aspects. This introduces significant differences between road noise and railway noise. A few of the factors often mentioned include:

  - Railway noise is largely predictable (i.e. there is a broadly fixed timetable) and often fades in and out so it causes fewer ‘startle’ reactions,
  - Residents living along railway lines often value the open view out of their windows (for most of the time the train is not in sight),
  - Residents living along roads tend to sleep with their windows closed to avoid exhaust gases entering the house.

3. See annex 2 for an explanation of some of the technical terms.



Graph 3. Dose effect relations: percentage of highly annoyed residents against exposure level, for road and rail noise [from EU Position Paper on dose response relationships for transportation noise]. Example: at 60 dB(A) L_{den} of railway noise about 4 % of the exposed people are expected to be highly annoyed. Similar annoyance is established by only 52 dB(A) L_{den} of road traffic noise. The difference represents the correction factor erroneously called the "railway bonus"

- **Sleep disturbance**

Exposure to noise at night may disturb sleep. At moderate exposure, noise may interfere with the rhythm of sleep, i.e. the periodic occurrence of deep sleep and REM[4] sleep. This interference may affect the relaxing and healthy effects of sleep. At higher exposure levels, motility (movement) during sleep may increase and awakenings may occur. All of these effects may lead to fatigue and affect performance, both at learning and during work. Again, these effects are manifest only in a small percentage of the exposed population. For the transport sector see sleep disturbance relations [1].

- **Health**

Long term exposure to noise can represent a health risk. A small percentage of the exposed population may be subject to increased stress which can contribute to heart diseases and high blood pressure (the medical term is hypertension). Hypertension may affect life expectancy, albeit in a very small percentage of the exposed population.

- **Complaints**

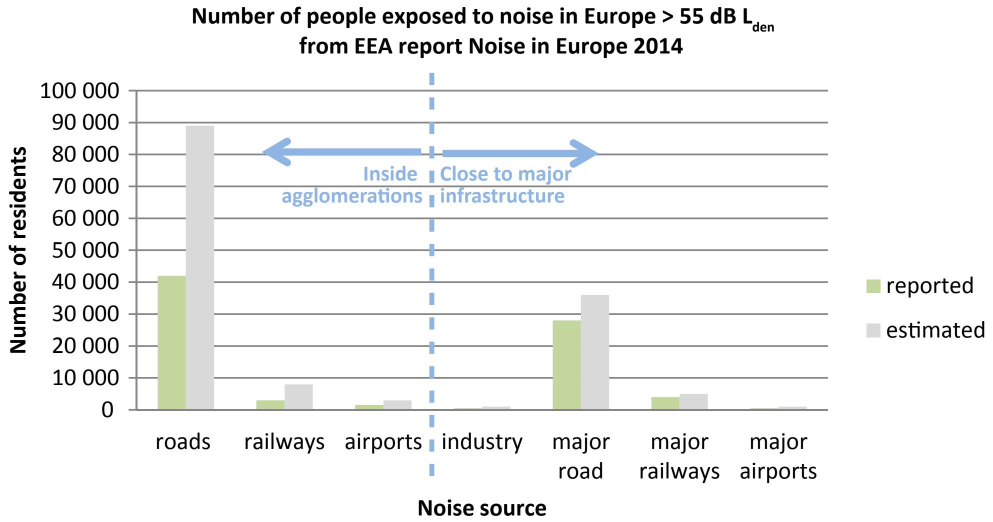
Complaints may be expressed at almost any noise level, even for noises that are just audible above the background level. Expressing complaints is not the same as experiencing annoyance. Complaints are highly subjective and may be provoked by social pressure. Dealing with complaints provides an opportunity to railway infrastructure managers to demonstrate their willingness to take the residents seriously.

4. REM stands for Rapid Eye Movements, characteristic for the phase of light sleep where dreaming occurs.

4. CURRENT NOISE SITUATION

4.1 The European picture

The European Environment Agency report "Noise in Europe 2014" provides an overview and assessment of environmental noise. The report states that about 125 million people in Europe are affected by road traffic noise levels greater than 55 dB L_{den}, which are considered potentially dangerous. The graph below is taken from this report and based on data reported for the EU Directive 2002/49/EC - Environmental Noise Directive (see Chapter 5).



Graph 4. Reported (green) and extrapolated (grey) numbers of people (in millions) exposed to noise over 55 dB L_{den}, for roads, railways, airports and industry, within and outside urban areas (from: Noise in Europe, EEA, 2014)

As can be seen from Graph 4, the majority of residents exposed to noise levels above 55 dB(A) live in agglomerations (data for urban areas shown on the left of the graph). Road traffic is by far the most important source there, with about 9 times as many people exposed as railway traffic. Note that railway traffic inside agglomerations includes trams and metro lines. In areas outside agglomerations, the overall exposure is much smaller than in cities, with approximately the same ratio between road traffic and railway traffic.

The following remarks apply to the information in Graph 4:

- The graph shows an overall picture for the whole of Europe. Obviously far more people are living near a road than near a railway line, which partly explains the differences between road and rail;
- The comparison made above shall not be interpreted as a conclusion that railway noise could be ignored. For people exposed to high levels of railway noise, it is indeed a relevant source and options to reduce it at reasonable cost, within the existing legal framework, should be put into practice;
- In specific cases, where people are living very close to railway tracks, pass by levels could be very high, sometimes higher than encountered along roads. The indicated exposure relates to the long term average noise levels, accounting for quiet periods between passages, as these average indicators are considered to give a better relation with annoyance than the pass by levels.

With respect to the exposure to different classes of noise level, the results for road and railway noise are very similar. This is shown in the following table, presenting the distribution over the noise exposure classes for all people exposed to road and railway noise. These data refer to both major roads and railway lines and networks within agglomerations. The data was provided by Germany, Norway, Sweden and Austria. The following table presents the sum of the data provided for these countries, thus removing any regional differences due to geography, population density, etc. The regional differences are considered in section 4.2 below.

Noise exposure class L_{den}	Road noise	Railway noise
55-60 dB	46 %	46 %
61-65 dB	32 %	29 %
66-70 dB	16 %	18 %
> 70 dB[5]	6 %	8 %

Table 1. Percentages of people exposed to different noise exposure classes for road and rail noise

4.2 The national picture

There are many differences in how rail networks and national authorities across Europe manage environmental noise, this partly due to variation in population density, urbanization and geography, and national noise legislation (e.g. quantities used, cases where the legislation applies to, limit values, etc).

5. The highest class (> 75 dB) has been omitted since it contains only low figures.

4.2.1 National legislation

Many countries have a national legislative scheme dealing with noise reception, which may cover all or parts of the following principles:

- *Prevention*: this applies to changes to the existing situation which are expected to have a noise impact to citizens. Such changes may be the construction of new lines or significant upgrades of existing lines. The authority responsible for the planning and realization of the line is responsible for compliance with the relevant noise limits.
- *Abatement*: this applies to existing situations where noise levels exceed a limit value. Some countries maintain a sanitation regime. Usually the state provides budget for this regime (Germany, The Netherlands, Switzerland). The Environmental Noise Directive requires Member States to draft a five year Action Plan. Sanitation measures may or may not be part of that Action Plan.
- *Sustaining*: apart from the physical changes with a noise impact, the growing traffic on existing lines may also lead to (future) higher noise levels at nearby façades. In the Netherlands, this fact is acknowledged and prevention is provided to maintain the existing situation. This existing situation is defined within a so-called ceiling or noise contingency.

Noise receptions limits are commonly specified as a long term (yearly) average noise level such as L_{den}[6], these are assessed outside of the house at the exposed façade. Limits differ from country to country but in most cases lie between 55 and 70 dB(A) L_{den}. It is common practice to set the external noise limit based on an assumed level of façade sound insulation and a desired internal noise level. In some cases it is permissible to increase the noise limit provided that the façade is treated with a high level of sound insulation.

Planning authorities have an important role to play; to ensure appropriate land use for new development and also require that adequate noise mitigation is included where noise sensitive development must be cited close to transport infrastructure.

4.2.2 National approaches

Some member states or networks have developed specific noise control aspects of their own, which are worth mentioning merely as example of possible approaches:

- Italy has a legislation that requires mitigation of noise for the existing network. The law requires the infrastructure manager to spend 7 % of the annual track maintenance budget on noise abatement measures;
- Germany spends an annual budget of 150 million Euro for noise abatement. The budget is provided by the federal government (voluntary federal noise abatement program - Lärmsanierungsprogramm);
- Belgium has focused on the track roughness level, has made a monitoring process of track roughness operational and applies corrective grinding to bring and keep the noise levels below reasonable limit values;

6. For a description of L_{den} see Annex 2.

- Germany, The Netherlands and Switzerland have agreed to collaborate in providing noise-differentiated access charges for freight vehicles on their national lines. The collaboration intends to achieve a Single Entry Point for parties who apply for a bonus, the objective being to reduce the administrative burden on keepers and railway undertakings;
- Germany intends to have reduced the perceived noise levels by half (-10 dB) by 2020;
- The Netherlands have recently started a large noise mitigation operation, lasting until 2023 and including 140 km of barriers, 120 km of them higher than 7 m, 540 km of rail dampers and 3,000 dwellings to receive sound proofing;
- The Netherlands have introduced a system of noise ceilings, i.e. calculated noise levels at 65,000 reference points along the whole network. The ceiling values reflect the actual situation in the years 2005, 2006 and 2007. Actual annual noise levels are not allowed to exceed ceiling levels;
- Switzerland has introduced legislation to ban freight vehicles that do not meet the TSI NOI limits by the year 2020. As mentioned earlier, the retrofitting of the Swiss fleet (with federal budget) was completed in 2015, so a ban would not affect Swiss wagon owners;
- Austria has 850 km of noise barriers erected (network length 5,000 km), in 1993 a ‘noise renovation programme’ had been established (noise barriers and noise protection windows in dwellings) with estimated overall cost of approximately 800 million Euro. Currently more than 70 % of the measures has been implemented. Since 2007 new freight wagons are equipped with K-brakes;
- Poland has developed the noise barriers of the length of 67 km.

5. EU POLICY AND LEGISLATION

5.1 The EU policy with respect to rail transport

In 2011 the European Commission published the Transport White Paper entitled “Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system”. The declared goal of the EU is to develop a low-oil and low-carbon European transport system so that carbon emissions in transport are reduced by 60 % by 2050.

By 2050, key goals will include a 50 % shift of medium distance intercity passenger and freight journeys from road to rail and waterborne transport.

With respect to the cost associated with the impacts of noise and local air pollution, the Commission intends to develop a common approach for the internalisation of these external costs to be applied across the entire transport system in the longer term.

There is a serious challenge for the rail sector to reduce noise at reasonable cost. Reducing noise is important to ensure the social acceptance of higher volumes of rail traffic, whilst managing the cost of noise mitigation is important to prevent any harm to the rail sectors’ competitiveness. These are both important issues if the rail sector is to increase its market share and through this modal shift to improve the overall environmental impact and sustainability of the transport sector.

5.2 EU’s policy related to noise control at source

The European Commission has a range of policies designed to foster the development of a single European railway. In support of this, a set of common technical specifications, known as Technical Specifications for Interoperability (TSIs) have been developed by the European Railway Agency (ERA).

The Noise TSI (Regulation 1304 of 26 November 2014 known as TSI NOI) sets out noise limits for new rail vehicles in addition to renewed or upgraded wagons. These include stationary, starting and pass-by noise for all types of rolling stock, as well as noise limits for the level in the driver’s cab. Provided that it complies with these requirements, it is not possible for a Member State to refuse access to a rail vehicle on the basis of its noise performance.

For environmental noise, the limits for pass-by noise are the most relevant. These are presented in the following table.

Limit values for pass-by noise (dB)		
Category of the rolling stock subsystem	$L_{Aeq,TP}$ at 80 km/h	$L_{Aeq,TP}$ at 250 km/h
Electric locomotives and OTMs with electric traction	84	99
Diesel locomotives and OTM's with diesel traction	85	n.a.
EMUs	80	95
DMUs	81	96
Coaches	79	n.a.
Wagons (normalised to APL = 0.225)	83	n.a.
APL = the number of axles divided by the length between the buffers (per m)		

Table 2. Limits for pass-by noise for various rail vehicle categories and two different train speeds (from EC 1304/2014). $L_{Aeq,TP}$ is the averaged level during pass-by measured at 7.5 m from track center and 1.2 m height.

The pass-by noise limits for wagons are such that wagons equipped with cast iron brake blocks, as most of the current fleet is, can't comply with the limits. Wagon types entering the market for the first time, or existing wagons having been renewed or upgraded, must therefore be equipped with alternative brake types. For new wagons, composite brake blocks know as K-blocks[7] are frequently used (although some wagons are equipped with disc brakes). For existing wagons it is common to retrofitting with another type of composite blocks, called LL-blocks (although K-blocks have also been used). All of these systems have a far better noise performance (8 to 12 dB(A) on a smooth track - with roughness similar to the CEN ISO 3095 limit) than the cast iron brake blocks used in the majority if the existing fleet.

5.3 EU's policy with respect to incentives for retrofitting

In March 2015, the European Commission adopted the Commission Implementing Regulation (EU) 2015/429 "setting out the modalities to be followed for the application of the charging for the cost of noise effects." The publication follows on the Recast Directive 2012/34/EU which, in article 31, gave the European Commission the power to adopt implementing measures for the application of noise- differentiated track access charges (NDTAC), also known as 'noise charges'.

7. For an explanation of K-blocks, see chapter 8.

In a system of noise-differentiated track access charges (NDTAC), the fee that the operator pays to the infrastructure manager for running a train on the track differs depending on the noise emission: lower track access charges are offered as an incentive to retrofit wagons and operate 'silent' trains. It is asssumed that these savings will be passed on by the operator to the wagon keeper and that this will incentivize the retrofitting of existing wagons.

According to the Regulation, each Member State should be free to decide whether to implement NDTAC. However, where schemes are in operation they must comply with the provisions laid down in the regulation. These state that NDTAC schemes must include a mandatory bonus (or reduction of charges) for retrofitted wagons and may also offer further bonuses to 'silent' trains, very quiet wagons and very quiet locomotives. Only when a bonus has been established then a voluntary malus may also be applied to 'noisy trains'. All additional revenue raised from the malus must be used to finance the bonus so that there is no net gain to the infrastructure manager.

The implementing Regulation sets the minimum level of the bonus at 0,0035 Euro per axle-km in order to be effective as a compensation of 50 % of the additional retrofitting cost for wagons running at least 45,000 km per year during 6 years.

In addition to the above, the European Commission has published a Staff Working Document (SWD) in December 2015 on rail freight noise reduction. The working document proposes a policy mix that includes:

- The harmonisation of noise-charging principles;
- A recommendation on financial support to retrofit freight wagons;
- Development of noise-related standards of railway tracks;
- The gradual applicability of TSI NOI limits to existing freight wagons that serve international routes, followed by an obligation for all freight wagons circulating in the EU to be TSI NOI compliant.

Addressing the relevant measures at EU level in particular the Commission's SWD, CER adopted a rail freight noise strategy in February 2016. It sets the mid-term strategic direction for noise policy for the rail sector and outlines steps to tackle the noise issue in the upcoming years while maintaining the competitiveness of the rail sector vis-à-vis other modes.[8]

5.4 EU's contribution in terms of funding

A European funding is offered through the Connecting Europe Facility, according to Regulation (EU) No 1316/2013. Requests for funding should be submitted in response to a periodic Call. The first call received two requests. A second call is expected in 2016. The funding covers 20 % of the attributable (eligible) costs. In total, the program's budget is 260 million Euro.

5.5 National and joint approaches

5.5.1 Noise differentiated track access charges (NDTAC)

The NDTAC schemes harmonized according to the Regulation are likely to replace existing schemes in EU Member States from December 2016. Such national schemes exist in Germany and the Netherlands, plus Switzerland

8. Community of European Railways and Infrastructure Managers (CER) www.cer.be/publications/latest-publications/cer-rail-freight-noise-strategy

(although not an EU Member State). These three countries are relevant for the important Rhine-Alpine corridor (freight corridor 1, Rotterdam – Genova) which carries high volumes of freight traffic. An incentive for retrofitting, which is the objective of NDTAC, applies to many existing freight wagons on this line. By the end of 2014, almost 10 % of the 160,000 wagons registered in Germany had already been retrofitted and the process is speeding up. The duration of the NDTAC scheme is until 2021.

5.5.2 Funding

The Swiss Federal State has financed the retrofitting of the entire fleet (both passenger and freight) registered in Switzerland. This could not happen similarly in EU Member States because of the standard 50 % co-funding limit that is specified in the EU state aid rules. Limited additional support to cover the cost of the retrofitting has been made available in Germany. The German Federal Railway Agency offers a federal grant to wagon owners who operate in Germany to cover 50 % of the retrofitting cost.

5.5.3 Limited effect

The national initiatives with respect to incentives for retrofitting appear to be effective. However they can only have a limited effect as long as they apply only to (1) the wagons registered in the particular country and (2) the wagons that circulate on the particular national network.

In ten years there potentially will be 400,000 wagons circulating on the Trans European Network. Although the Swiss fleet and the German DB Cargo fleet, together with the private wagons registered in Germany, represent a significant part of that European fleet, it is of great importance that wagons registered in countries other than the three mentioned and used in international traffic are also retrofitted or replaced by silent stock. The challenge is that this applies to freight fleets based in countries which do not have a national legislative incentive for retrofitting. Further it is not currently expected that these countries will make budgets available for retrofitting in a similar way to the German and Swiss governments. Therefore, in order to realize the full benefit offered by retrofitting, more financial support is required for the many wagons based in countries other than Germany and Switzerland.

Notably, the Swiss Federal Government has announced a unilateral ban of wagons that do not meet the TSI NOI limits, due to be implemented from 2020. Although Switzerland is not a EU Member State it has many bilateral agreements with the EU. The German government is presently considering other options for discouraging the operation of wagons that do not comply with the TSI NOI limit values.

In the Staff Working Document, the EC expresses serious concern about these initiatives, fearing that they could be a risk for the open market, the principles of inter-operability and thus cause disruptions to the cross-border rail services. This in turn could lead to a reverse modal shift from rail to road.

The EC proposals in the Staff Working Document therefore must be seen as an attempt to prevent individual member states to set up such regulations and to set up joint and consistent regulations instead. It should also be noted that there is a risk of reverse modal shift where railways have difficulty financing retrofitting.

5.6 The EU policy with respect to environmental noise

The European Directive on the Assessment and Management of Environmental Noise (2002/49/EC), known as the Environmental Noise Directive, intends to support a harmonized approach across the EU Member States, and increase public awareness of noise exposure. It requires Member States to publish strategic noise maps every five years starting from 2007. These enable the assessment of the exposure of citizens living in agglomerations (large urban areas) and close to major transport infrastructure to noise from road, rail and air transport in addition to industrial sites.

The Directive also requires the drafting of Action Plans. These should be designed to prevent and reduce environmental noise where necessary and particularly where exposure levels can induce harmful effects on human health and to preserving environmental noise quality where it is good.

The Directive does not replace national legislation; in particular it does not affect the national authority to set limit values for the maximum allowable exposure of citizens. This authority is considered to be subject to the so-called subsidiarity principle[9] (article 5 of the Treaty on European Union).

In its 7th Environmental Action Plan, the Commission announced the objective to move the exposure to environmental noise significantly closer to the World Health Organisation recommendations by the year 2020. Moreover, a refit process has been launched, evaluating the so-called regulatory fitness of the Directive. Elements to be evaluated are the effectiveness, efficiency, coherence, relevance, added value and prospect of the legislation. The conclusions of this refit process are expected not earlier than by the end of 2016.

5.7 World Health Organization guidelines

The World Health Organization (WHO) recommendations referred to by the Commission include very low noise levels identified in the Night Noise Guidelines (NNG), these are 55 dB L_{night} as an interim target and 40 dB[10] L_{night} as an ultimate objective. Given the difficulty in reaching these very low levels whilst maintaining a socially and economically active society, the WHO recommends Member States to gradually reduce the proportion of the population exposed to levels over the interim target within the context of meeting wider sustainable development objectives.

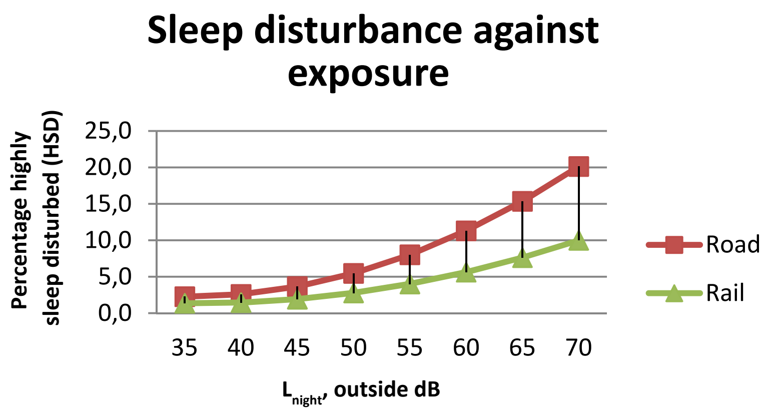
9. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV:ai0017
10. This value is without the penalty for night time noise of 10 dB which is included in the L_{den} value.

Although the subsidiarity principle may prevent the European Commission from specifying noise reception limits at Europe level, it is possible that the refit process and subsequent revision of the Directive may consider a recommendation for Member States to set their own noise limits.

The indicated levels are expressed in L_{night} which is the average level over the nighttime period including the pauses between passing vehicles. Maximum levels during passages may be much higher. In busy cities, the 55 dB level at night would be experienced only in relatively quiet areas such as a narrow street with less than 50 cars passing during the night. 40 dB L_{night} is a value seldom found in a normally habituated area. In densely populated countries this might only be experienced out in countryside, on a calm night, far from any road and particularly avoiding flight paths of the international air traffic. For railway lines with nightly freight traffic, it would be impossible to reach these levels within reasonable distance from the track, unless high noise barriers and in some cases tunnels and complete covers of the track would be installed.

40 dB L_{night} is significantly more stringent than commonly applied limits for new railway lines or new dwellings. Achieving such low levels certainly in existing situations, could necessitate drastic and expensive measures like enclosures and tunnels.

The WHO NNG report confirms that sleep disturbance is higher for road than for rail noise with equal exposure, however this difference is not taken into account for example in a differentiation of the recommended night time level.



Graph 5 - Percentage of highly sleep disturbed persons against L_{night} (from "Night Noise Guidelines" page 78)

If the recommendations of the WHO publication would be implemented and strictly enforced, this would have far reaching social and economic impacts, including making night time rail freight traffic virtually impossible. It is of high importance to explain this to decision makers interpreting the WHO recommendations. Implementing these limits to rail transport would almost certainly impede the other environmental advantages that rail transport offers, like low air pollution, low energy consumption and low land use.

6. THE CONSISTENT NOISE STRATEGY OF THE RAILWAYS

From an early stage, railway companies were concerned about their noise performance. They have long stated their willingness to take the necessary actions, provided that there is a level playing field with competing transport modes, i.e. above all road, but also inland shipping and airplanes.

Focus on the technology to effectively reduce rolling noise:

In the early nineties, in a common effort under the direction of UIC and CER, they invested in research to better understand railway noise. It was found that cast iron brake blocks applied on the wheel treads would cause high levels of surface roughness and therefore rolling noise. For many years the only low noise brake blocks available were the so-called K-blocks which have a different friction performance to cast iron blocks. However, in order to achieve a compatible braking performance when wagons using different brake blocks were coupled in the same train it is necessary to make further expensive changes to the braking system of wagons retrofitted K-blocks. The total cost of replacement brake blocks and changes to the braking system has proved to be prohibitively expensive for most rail companies and prevented the wide scale retrofitting with K-blocks.

In the STAIRRS[11] project, carried out in the late 90-ies, various noise control options were compared in terms of their cost and efficiency to reduce noise. It was found, that the most cost efficient solutions would include retrofitting, i.e. replacement of the cast iron blocks, of the existing freight fleet. The least cost efficient solutions would include erecting noise barriers. The conclusion of STAIRRS was reconfirmed in a UIC study in 2013 [9].

The conclusions of STAIRRS paved the way for the Railway Noise Action Plan, agreed by the railway umbrella organizations (UIC, UIP and, CER[12]). The Action Plan focused efforts on the following objectives:

- Increase the railways transport output,
- Reduce the environmental impact, in particular noise.

More specific, the Action Plan included:

- Cost neutral equipping and retrofitting of wagons with cast-iron brake blocks to composite brake blocks (K/LL),
- Gradual introduction of "Low Noise Technology".

11. Strategies and Tools to Assess and Implement noise Reducing measures for Railway Systems.
12. UIC: Union International des Chemins de fer, UIP: International Union of Wagons Keepers; CER: Community of European Railway and Infrastructure Companies.

For the Action Plan, the focus was on reducing noise from rail freight. After all, this was causing the main noise problems due to night time operation (with a legal penalty in the noise exposure level) and use of noisy cast iron brake blocks. The concrete target would be to retrofit the main part of the European wagon fleet with low noise brake blocks.

In order to maintain a level playing field, economic support from public bodies, preferably from the European Union, was requested to compensate the retrofitting costs. This should include both investment for the retrofitting and possible increases in operational cost due to higher wheel wear and brake block price.

In their search for cost-effective noise mitigation the railways launched a program to develop a new type of brake block, the LL-block, that could achieve a similar friction performance to cast iron blocks, but with a smoother wheel surface. This would allow simple substitution with cast iron blocks (without major changes to the braking system) and therefore low cost retrofitting. The UIC EuropeTrain project successfully concluded in 2013 following which two LL-blocks have been approved for use.

In addition to the cost of LL-blocks and retrofitting workshop costs, the experience shows higher operational costs due to wheel wear and more frequent inspection and servicing.

The railways continue to proceed with noise reduction in operations based on the available technology, and complying with national legislative limits:

- For new passenger trains, disk brakes make the rolling stock TSI NOI compliant,
- For stationary noise, the TSI NOI would be fulfilled by new locomotives and multiple units,
- New freight vehicles would be TSI NOI compliant as well, following the application of either K-blocks or disk brakes,
- For existing freight vehicles with substantial mileage in international traffic and sufficient remaining economic life time, retrofitting of the cast iron brake blocks with LL-blocks would be considered, provided that remaining financial, technical and administrative concerns are addressed,
- For new track, optimized rail pads would be selected,
- For existing track, the rolling surface of the rail would be well maintained,
- In cases with new or significantly altered track, compliance with legal limits is usually achieved either by constructing noise barriers as a measure complementary to the above list. Noise barriers are usually financed from the infrastructure budget and can be installed provided that they meet cost-benefit criteria, which may differ from one country to another. If barriers are not cost efficient (for instance in the case of a solitary dwelling close to the track) façade insulation may be offered to the residents. Similar to the barrier cost, this is usually financed from the infrastructure budget.

Noise control measures are presented in more detail in chapter 8.

7. NOISE ASSESSMENT METHODS

7.1 Long term average noise levels and use of calculation

The propagation of noise outdoors is strongly influenced by geometrical and meteorological conditions, terrain and obstructions. Close to a source, the strength of the sound as experienced by a receiver is much higher than at greater distance. These effects change the 'colour' of the sound: at large distances thunder sounds like a rumble; close by it produces a more cracking sound. Sound propagating over soft ground (e.g. a corn field) is absorbed more than over a reflective surface (e.g. frozen ground). Under humid conditions more sound is absorbed than under dry conditions. Under downwind conditions (wind blowing from the source to the receiver) noise levels can be significantly higher than under upwind conditions.

When characterizing a given noise situation, e.g. assessing an exposure level outside in front of a façade near a railway line, these effects complicate matters. The main objective is to find an indicator which relates well to the effects on human beings exposed to the sound under concern. As the more serious effects, including health risks, occur only after a long period of exposure, the focus generally is on the longer term. The corresponding indicator is the long term average level, known as "equivalent noise level", noted as Leq. This indicator is internationally acknowledged as producing the best correlation with long term health effects of noise. When applied to railway noise, this indicator takes into account "quiet" periods between train passes, and, for long term effects, it takes into account the "quiet" days with adverse wind as much as the "louder" days with downwind conditions. It should be noted that for this reason the indicator is often lower than expected by the layperson. Residents often focus on train passages and ignore intervening quiet periods. In public consultations, the use of averaged levels may provoke suspicion amongst the residents who do not know the details of this indicator and why it was chosen.

It is very difficult to assess long term noise levels by means of measurements, as it would involve long surveys encompassing a range of typical propagation conditions. This is one of the reasons why it is common practice to use a nationally approved calculation method to predict noise exposures. The use of such a standardized method allows a high level of reproducibility. This means that, when two different users apply the same software and the same input data sets, they will most likely get similar or identical results. If the results are needed in legal procedures, reproducibility is of great value. The big disadvantage of this approach is that can suffer from low credibility with the general public and with politicians as they have neither control of, nor insight into the method of calculation.

Proper communication with residents and local stakeholders can help to explain these choices.

7.2 The common assessment method

The European Commission has recently published a new common method for the calculation of noise levels. The application of this common method will be mandatory when completing the noise mapping for the Environmental Noise Directive in the year 2022 round of noise mapping. Prior to this Member States are able to choose their own method provided that it produces 'equivalent' results to a defined interim method.

For railways, the use of the new common method is expected to have the following implications:

- Rail roughness is required as a source related parameter. This is probably the most important change. To simplify the process it may be desirable to determine to use a single, national average value. However care must be taken as the Directive recommends that "in general there shall be no reliance on default values"; in other words: parameters that could have an effect of more than 2 dB to the final result should be assessed separately;
- Including curve correction factors will lead to significant changes (depending on former national regulations), because new resp. higher correction factors are applied compared to existing (national) regulations. New research results in Austria indicate that these factors are depending from train/vehicle type and differences of up to 5 dB might occur;
- The railway method, "Appendix G", does not give emission values for different types of train, instead to require the user to combine different parameters, such as wheel diameter, rail pad stiffness, in order to 'build' various sound power related quantities that shall be used as a starting point for the computation.

The consistency of the method has been thoroughly tested for standard situations. Nevertheless, significant differences with previous assessments (using national methods) are likely to occur.

8. NOISE CONTROL METHODS

8.1 Introduction

The classical approach to outdoor noise problems is to distinguish three options for mitigation:

- At the source (generally the most cost efficient),
- At the propagation path (by setting up barriers or by keeping distance),
- At the receiver (by installing sound proof windows).

In practice, barriers and sound proof windows are applied most frequently. Usually, when installing barriers, a cost efficiency consideration is made. For a single house at some distance from the track, a barrier would have to represent substantial length of track, and would most likely turn out to be very costly.

On the other hand, for dense urban zones close to the track, barriers are often applied.

Due to the visual interference, residents are often opposed to noise barriers and prefer different measures.

The most relevant options are discussed below.

8.2 System approach to rolling noise

With rolling noise being the predominant source in railway noise, the control needs to be based on a system approach. The system to be looked at consist of:

- The vehicle, with the wheel, the brakes, the bogie or axle and the vehicle body, all connected by springs and dampers,
- The track, with basic elements the rail, the rail fixation with rail pads, the sleeper, the ballast and the sub-soil.

These two sub-systems meet at the contact patch between the wheel and the rail, it is the combined roughness at this location that causes the rail and the wheel to vibrate and radiate noise. Even apparently smooth surfaces have some roughness and can cause noise.

In this complex system, the following options can be considered:

For the vehicle:

- The most important option: Reduce the wheel roughness by replacing the cast iron brake blocks (which cause rough wheels) by K- or LL-blocks or using disk brakes.

- Isolate the wheel tread from the wheel web by a resilient layer (resilient wheel); this type of wheel is hardly ever applied in heavy rail (especially for wagons with block-brake).
- Screen off the noise radiated by the wheel with wheel shrouds (disc brakes mounted on the wheel may serve as wheel shrouds) or bogie enclosures; a measure that is generally rejected by the operating companies because of the interference with visual inspection of the wheel and the axle box.
- Optimise the size and the shape of the wheel in order to reduce its vibration. This is only feasible in new vehicles and has a limited benefit.
- Some networks have monitoring stations to evaluate the success of retrofitting.

For the track:

- Reduce the rail roughness by regular monitoring and preventive/curative grinding;

  Almost all networks monitor the geometric track quality as implement a regime of curative and preventive grinding. Only a few networks currently monitor the acoustic quality (“roughness”) of the track on a regular basis. Acoustic grinding is applied only occasionally. In Germany, a limited number of tracks is ground acoustically, allowing a subtraction of 2,5 to 5 dB in the calculated noise level (besonders überwachtes Gleis).
- Optimise the rail pad stiffness (softer rail pads allow the rail to vibrate more so that waves travel further from the contact point; this is called: a smaller track decay rate). In using this option, both track quality and acoustic quality need to be taken into account.
- Add a (tuned) rail damper;

  Approximately 240 km of **rail dampers** have been installed in Germany, Czech Republic and The Netherlands. In some networks the test results gave disappointing results and rail dampers have since been discarded (due to safety issues; rail wear, with negative noise effects). The reason for this difference is probably the regional preference for either “hard” or “soft” rail pads. Rail dampers are expected to be more efficient the softer the rail pads.

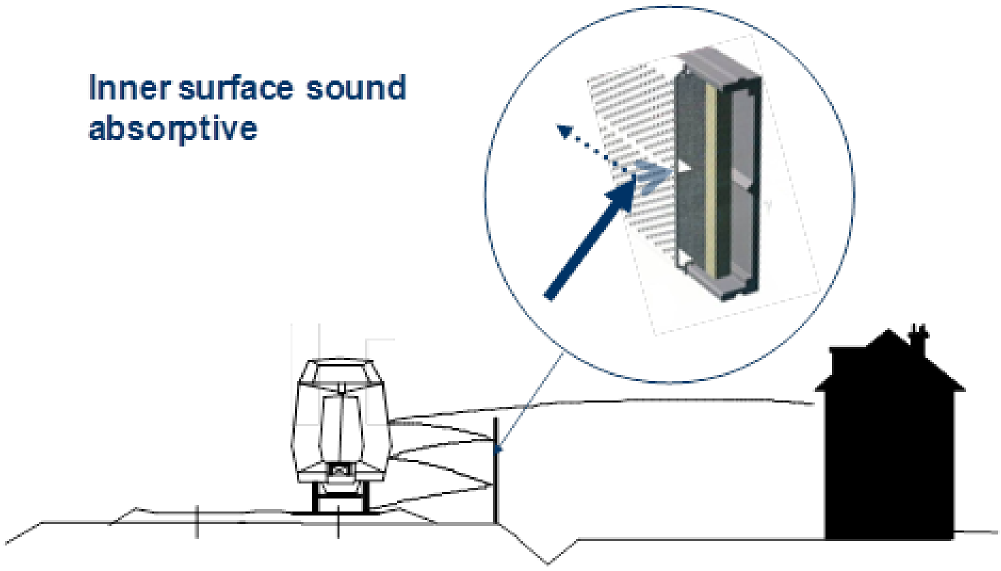
  Rail dampers are costly, although their increased application has reduced the purchase cost. The effectiveness is limited to 0 to 3 dB(A) depending on the characteristics of the wheel rail system they are applied to. Some questions remain regarding increased maintenance cost, safety issues (occurring when rail dampers are loosening from the rail or due to excessive rail corrugation) and impact on rail roughness growth (both positive and negative effects are reported).

8.3 Noise barriers

Noise barriers are the most commonly used mitigation measure; in only 7 networks overall more than 3,000 km of barriers with average height of 2 to 3 meters have been installed. Another 500 km are expected to be installed in the next 10 years.

By comparison the use of **low height noise barriers** is rare, with only 10 km having been installed in Germany, the Czech Republic and the UK. In Austria legal aspects are not yet clarified (employee protection law).

Noise barriers are applied in many cases, both with new rail infrastructure, significantly changed infrastructure and as noise abatement in existing situations. As the dominant noise source (the wheel rail contact surface) is close to the track, noise barriers are highly effective as long as the receiver position is in the shadow zone (i.e. there is no direct sight from the receiver to the source). Most noise barriers near railway lines are between 1 and 4 meters high, but very high barriers (up to 10 meters) are erected in exceptional situations. The key parameter for the barrier effectiveness is the geometry, i.e. the location of the upper edge of the barrier with respect to the source location.



Graph 6. Illustration of the "canyon"effect and how it can be prevented by an absorptive lining

An important effect is the reflection of sound between the barrier and the train car body, which may affect the achievable reduction. This so-called canyon effect can be avoided with a lining with high absorption coefficient of the barrier side facing the tracks. Alternatively, the barrier may be put in an inclined position, in order to direct the reflections towards the sky (barriers inclined backward) or towards the ballast (barrier inclined to the track). An inclined position is chosen with transparent barriers, which can't achieve the sound absorption on the track side.

Well designed and located noise barriers can be effective with attenuation of 10 dB(A) or more at the façade of the receiver (when the barrier comfortably blocks line of sight between the noise source and receiver).

To residents, barriers are often experienced as an intrusion to their visual quality. In planning procedures, when strict noise limits need to be adhered to, residents tend to contest the arguments leading to the barrier being built, and may demand alternative solutions. One way to solve this dilemma is to allow residents to be involved in the decision and the esthetical design of the barrier.

In some types of new train design items of auxiliary equipment (even including the diesel engine) have been mounted on the roof of the coaches. This design significantly affects the efficiency of noise barriers, which would then have to be built higher to have the same effect as for more conventional rolling stock design.

8.4 Façade insulation

Sound proof glazing and ventilation is often the chosen solution in cases where barriers are not cost efficient or not sufficiently effective. Depending on the legal limits the façade insulation must be improved from a standard glazing (typically 15 dB for single glazing to 20 dB for thermal double glazing) to a sound proof glazing with up to 33 dB insulation. Ventilation is provided either by a forced airflow through silencers or a natural airflow through special sound proof devices.

Sound proofing has limited interference with the normal housing design in climate zones with severe winters (Scandinavia) but can have a higher interference in warmer climates and houses without air-conditioning.

8.5 Other common noise sources

In railway traffic, there are many sources other than rolling noise. Most of these occur in special situations only and therefore have less relevance than rolling noise. The most important sources are:

- **Aerodynamic noise**

  Relevant only at speeds of 300 km/h or more, aerodynamic noise is controlled by an optimized design of the high speed vehicle. Noise barriers screen off the aerodynamic noise from the bogie region, but the noise from the higher pantograph can't be screened efficiently unless the barrier is very high. The doses response relation for aerodynamic noise is a source of ongoing discussion, particularly in countries still maintaining a railway "bonus" in the legal limits. Some parties argue that the limits would need to be lower than for a conventional speed train.

- **Curve squeal**

  Curve squeal occurs in narrow curves where wheels fixed to the axle and locked in bogie pairs slip on the rail head. Curve squeal can be controlled with friction modifiers, including water spraying. The effect on residents is very local but often provokes complaint. Mitigation is usually on a voluntary basis as the curve squeal is not part of the legal prediction methods.

- **Brake screech**

  Brake screech occurs mainly in disk brakes. Solutions are not obvious and therefore are still subject of research.

- **Depots**

  In depots, rolling stock is parked and services. Depots are often located close to stations and therefore in town centers. Noise sources are stationary equipment such as air compressors, transformers and ventilation, stationary noise from diesel engines, starting noise and impulse noise in joints and switches. Specific measures are applied in cases where residential areas are located close to the depot site. In some countries, from a legal point of view, depots are considered industrial sites and have to comply with limits lower than usual for rail traffic.

Shunting yards

In shunting yards, depending on the type of yard, both locomotive noise, rail brakes and buffer noise as well as rolling noise through joints and switches is present. Rail brakes have become more sophisticated and are found to produce less noise.

Steel bridges

A steel bridge is vibrating when the train runs over it, particularly when the rail is directly fixed on to the steel construction. The bridge is likely to produce a rumble like noise, which can be noticed by residents even at greater distance. The combined noise of train and bridge can be substantially louder than the train running on a normal track. Careful design of new bridges may control this effect. For existing bridges, measures consist of sandwich panels on large steel plates of the bridge (that is if the bridge can carry the weight), or else screens, optimized rail fixation and rail dampers.

Ground borne vibrations

Passing trains may generate vibrations in the ground. These are generally low frequency vibrations between 10 and 50 Hz. In adjacent dwellings they may be notices as either re-radiated noise, low frequency noise, rattling (for example of pottery), and sensible vibrations. Both prediction and mitigation can be extremely difficult & expensive.

Other than the above sources, rolling noise is the most common source of railway noise. In the following sections, rolling noise is addressed.

9. RESEARCH

The railways have a long history of research. From the early nineties, about 20 important noise and vibration projects have been completed, both on national and international – collaborative - level, some partly funded by the European Union, many delivered on behalf of UIC by the former European Rail Research Institute.

An overview of many of the projects carried out in the past decades is presented in Annex 3.

Today, the European Rail Research Advisory Council (ERRAC) plays an important role in advising the European Commission on future research priorities.

In the coming years a large amount of EU research funding will be managed by the Shift2Rail Joint Undertaking (S2R JU) (a type of public-private partnership). The main objectives of Shift2Rail include:

- Cutting the life-cycle cost of railway transport (i.e. costs of building, operating, maintaining, renewing and dismantling infrastructure and rolling stock) by as much as 50 %;
- Doubling railway capacity;
- Increasing reliability and punctuality by as much as 50 %.

Whilst the detail of the work packages is still in development, some are expected to include noise and vibration. Specific noise and vibration related topics are addressed in Calls for proposal.

ANNEX 1 | References

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[13] SysBahnLärm-study, see Anwenderhandbuch Systemische Bahnlärm-bekämpfung, ETR Austria, December 2013

[14] CER Rail Freight Noise Strategy, February 2016

[15] UIC Real noise reduction of freight wagon retrofitting, January 2013

ANNEX 2 | Explanations and definitions

Concept	Explanation
Sound	Vibration of particles in air, audible to a healthy human being
Frequency	The number of vibrational cycles per second of an air particle (Hz = Herz). Audible sound has frequencies between appr. 16 and 16,000 Hz. In-audible sound below 16 Hz is called infrasound. In-audible sound above 16,000 Hz is called ultrasound. A frequency spectrum is a picture that indicates the energy of sound for every different frequency or for all frequencies within a certain frequency band.
Noise	Noise is the general expression for unwanted sound
Environmental noise	The single or collective noise from road, railway and air traffic and from industrial sites
Noise level	A indicator either for the energy emitted by a specific sound source (production) or for the incident intensity at a specific spot (reception). The noise level is expressed in deciBel. A noise level of 0 dB by definition is at the threshold of hearing for young healthy humans.
decibel, abbreviated as dB	The decibel scale is difficult to understand. Every step of+ 10 dB increase sounds to our ears as a doubling of loudness. A doubling of sound production (two similar sources instead of one) results in a step increase of only + 3 dB.
A-weighting	Weighting of a measured sound, in such a way that the frequencies for which the human hearing is less sensitive (usually the low frequencies) are suppressed and the frequencies where the human ear is more sensitive are emphasized
Equivalent noise level, abbreviated as Leq	The level of an imaginary sound source with an output constant in time, which over a given period emits a sound energy similar to that of the source under concern which emits a output varying in strength over time
Pass-by noise level	The equivalent level of an entire pass by event
Maximum level	The highest value of the noise level during a given period where the sound level varies in strength
Day level, abbreviated as Ld	The equivalent level over a 12 hour period between 7:00 am and 7:00 pm

Night level, abbreviated as Ln	The equivalent level over an 8 hour period between 11:00 pm and 8:00 am
Day-evening-night level	The weighted average of the day level, the evening level + 5 dB penalty and the night level + 10 dB penalty. The weighting takes into account the differences in duration of the day (12 hours), evening (4 hours) and night (8 hours)
Exposure level	Yearly average value of L_{den}, measured or assessed outside in front of the façade, at a height of 4 m above ground. As the exposure relates to incident sound only, 3 dB has to be subtracted from the measured level as this is supposed to be representative for the sound reflected back from the façade
Production and reception	Sound production (also: sound creation or sound emission) is the power emitted by a sound source. This can be expressed as LW, sound power level, quantity dB. Sound reception (also: sound immission) is the intensity incident on a receiver point, expressed as sound level L, quantity dB.
Noise reception limit	A value for the exposure level which should not be exceeded in specific circumstances (usually: averaged over a year period)
Noise production limit	A value for the power level which should not be exceeded under representative operation of the source. Often, the sound power is represented by a sound reception level at a position close to the source. For example, for railways, a sound reception level at 7.5 or 25 m from the track axis, is considered to be representative for the sound production of that track
Propagation	When propagating from source to receiver, sound is attenuated. The most relevant is the attenuation with distance. For a single point source, the distribution of sound energy is hemispherical, meaning that the sound level will decrease by 6 dB for every time that the distance from the source is doubled. For a line source, such as a railway line, the sound energy is distributed cylindrical, meaning that the sound level will decrease with 3 dB for every time that the distance from the source is doubled. In addition to this distance attenuation, air absorption may contribute to dissipation of sound energy. All the other effects of propagation attenuation are expressed together as excess attenuation. Elements of excess attenuation may be absorption and reflection to the ground and screening by barriers.

Table 2. Explanation of some concepts in environmental Noise

Note that the daily exposure to environmental noise is expressed as the noise level averaged over the whole 12 hour daytime period, so including e.g. the quiet periods between car or train passages (and similar for the evening and night time period).

Typically, environmental noise exposure in urban areas is between 55 and 70 dB(A) (outside at the façade during day time). In the relevant European 'Environmental Noise Directive' (END, 2002), for the whole diurnal day, three periods are distinguished, i.e. day (7:00 – 19:00)[13], evening (19:00 – 23:00) and night (23:00 – 7:00). The corresponding average levels L_{day}, $L_{evening}$ and L_{night} are typically weighted with penalties of 0, +5 and +10 dB and then averaged to make up the day-evening-night level L_{den}. L_{den} is the standard quantity to express exposure to environmental noise.

Sound level	Representative for:
20 dB(A) equivalent	Quiet sleeping room
40 dB(A) equivalent	Calm rural area at night
55 dB(A) equivalent	Inside a well designed running train coach
70 dB(A) equivalent	Inside a busy covered railway station
75 dB(A) equivalent	On the sidewalk next to a busy road with 70 km/h speed limit
105 dB(A) equivalent	25 m from the stage of a pop concert

Table 3. Some representative situations and the corresponding sound levels

13. Some countries use different definitions of the diurnal periods.

ANNEX 3 | Previous research and results

Reference is made to:

www.uic.org/IMG/pdf/erri-summary_noise-research.pdf

Project	Topic	Reference	Started in program
Euroécran	Noise barriers along railways	http://cordis.europa.eu/project/rcn/22814_en.html	FP3, 1994
Composite Brake Blocks	Development of requirements on K brake blocks and coordinate of product development	UIC B 126/RP 33 (Jan. 2004) *Fragen des Bremswesens – Einsatz von Verbundstoffbremsshlen in Güterwagen – Zusammenfassender Bericht K-Sohlen*	1999
STAIRRS	Strategies and tools based on efficiency approach	www.stairrs.org	2000
Eurosabot	Brake block materials	www.conforg.fr/internoise2000/cdrom/data/articles/000843.pdf	FP4, 1995
Silent Freight	Measures for freight rolling stock	http://cordis.europa.eu/project/rcn/30970_en.html	FP4, 1996
Silent Track	Measures for quiet track	http://cordis.europa.eu/project/rcn/34519_en.html	FP4, 1997
Renvib and Renvib II	Railway vibrations	www.fcp.at/de/projekte/renvib-railway-environmental-vibration-project	
Euro Rolling Silently	Test of brake blocks	www.2020-horizon.com/E-R-S-Euro-rolling-silently(E-R-S-)-s40357.html	2002
Silence	Transport noise control	www.silence-ip.org/site/index.html	2005
Q-City	Transport noise in urban situations	www.qcity.org	
Convurt	Vibrations from railway tunnels		
Noise Reduction	Development of requirements on LL brake blocks and coordinate of product development	UIC B 126/RP 36 (May 2009) *Braking - Use of composite brake blocks in freight wagons - Summary report on LL brake blocks, ISBN 978-2-7461-1691-7*	2005
Metarail	Measurement methods for railway noise	ftp://ftp.cordis.europa.eu/pub/transport/docs/summaries/rail_metarail_report.pdf	FP4, 1997
Acoutrain	Vertical certification of acoustic performance of new trains	www.acoutrain.eu	2011
Harmonoise	Common prediction methods for road and rail noise	http://infoscience.epfl.ch/record/120520	
Imagine	Common prediction methods for all environmental noise sources	http://cordis.europa.eu/result/rcn/47869_en.html	2006

Project	Topic	Reference	Started in program
OfWhat	Optimised Freight Wheels and Track	www.uic.org/IMG/pdf/erri-summary_noise-research.pdf	
Rona, Mona, Vona	Solutions for noise from rolling stock and track	National program France	
STV	Quiet Railway Traffic	National Dutch Program, www.bibliotheek.nl/catalogus/titel.190368802.html	
Stardamp	Characterisation of rail dampers	Collaboration between DB and SNCF	2010
LZARG	Quiet train on regular track	National program Germany www1.deutschebahn.com/laerm/forschungsprojekte/abgeschlossene_forschungsprojekte.html	2010
Optimisation of Composite Brake Block Contour / Limit value for equivalent conicity	Optimisation of composite brake block contour in terms of wagon running stability	UIC B 126/DT 441 (June 2014) *Braking questions - Optimization of the contour of composite brake blocks to reduce the equivalent conicity - Synthesis of the results of final phase*	2010
LäGiV	Composite brake blocks	National Program Germany www1.deutschebahn.com/laerm/forschungsprojekte/abgeschlossene_forschungsprojekte.html	2011
Europe Train	Test of composite LL brake block: Validating some solutions to prevent the fast degradation of equivalent conicity of wheel braked with LL-blocks; Verification of vehicle stability by continuous in-service measurement and track tests; Verification that LL blocks are capable of bearing all climatic, operational and topographical conditions in Europe under affordable LCC.	**UIC B 126/RP 43 (Feb. 2013)** ***Braking questions - Synthesis paper on the EuropeTrain operation with LL brake blocks - Final Report, ISBN 978-2-7461-2179-9***	2010
Innotrack	Optimised track	www.innotrack.net	FP6
RIVAS	Railway vibrations	www.rivas-project.eu	FP7
CargoVibes	Effect of railway vibrations	www.cargovibes.eu	FP6, 2011

Note: The above table is not complete. It merely intends to give an impression of the work carried out in relation to railway noise and vibration research.

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