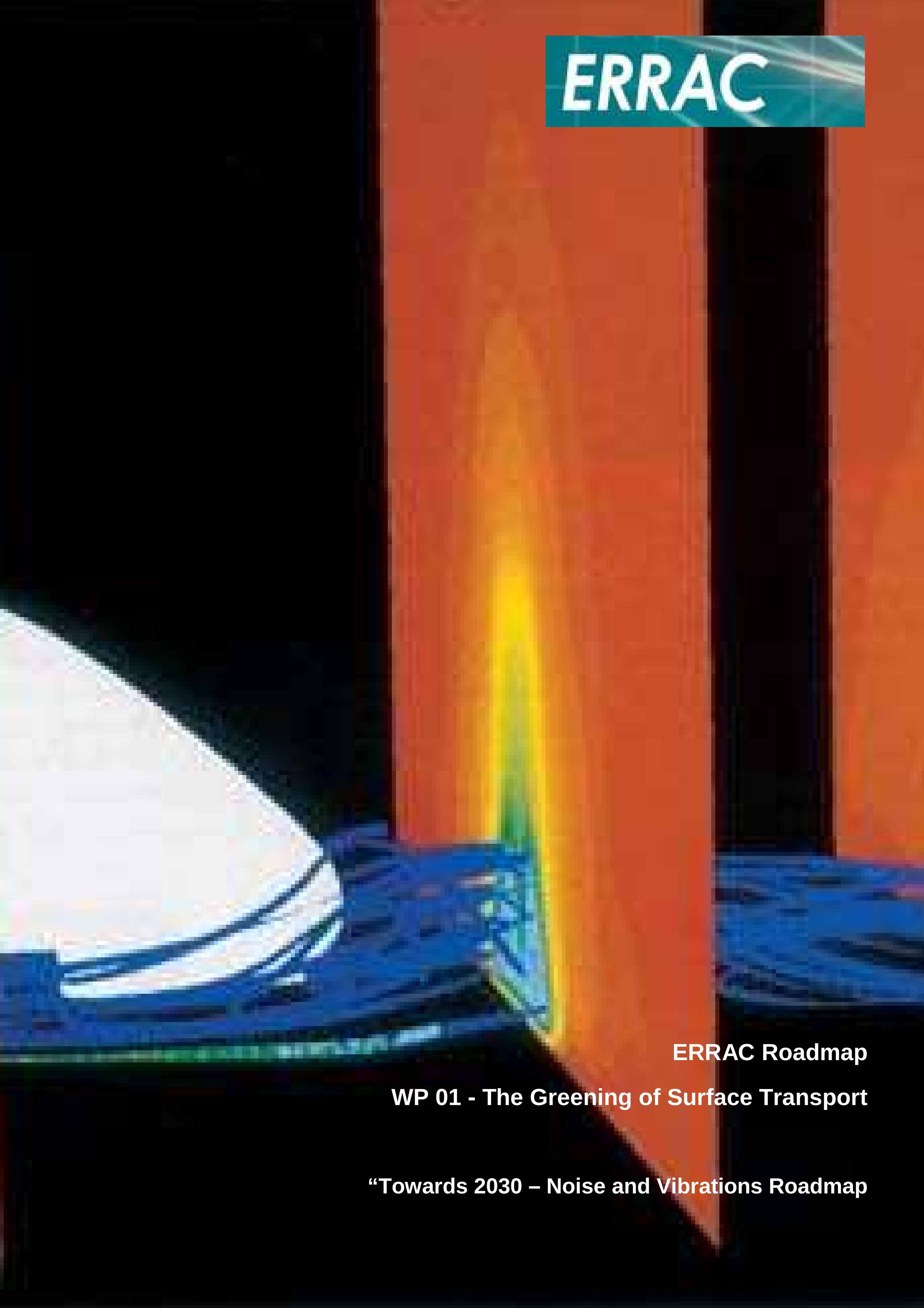

ERRAC

ERRAC Roadmap

WP 01 - The Greening of Surface Transport

“Towards 2030 – Noise and Vibrations Roadmap

ERRAC Roadmap - WP 01 - The Greening of Surface Transport

“Towards 2030 – Noise and Vibrations Roadmap for the European Railway Sector”

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"Towards 2030 – Energy Roadmap for the European Railway sector"
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ERRAC Roadmap
WP 01 - The Greening of Surface Transport
"Towards 2030 – Noise and Vibrations Roadmap for the European Railway sector"

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1. PRESENT SITUATION

1.1. Overview of the situation

Railways are a sustainable and climate friendly means of transport. Nonetheless, railways do influence the environment. The most important effect is noise, especially the noise emitted from freight trains. In comparison to road traffic, railway noise is less of a problem in terms of annoyed number of persons. Also, the relevance of railway noise varies from one geographic region to another. It is greatest in Western and Northern Europe and along the main freight corridors. However, in many cases, noise is considered as Achilles' heel amongst environmental advantages of rail.

Both noise and vibrations have been therefore identified as major challenges for the European railway system with the sector constantly increasing its transport volume. Shifting more transport to rail and increasing the market share of the sector can only be achieved with sustainable noise and vibration mitigation measures. This affects on the one hand the infrastructure and on the other hand the rolling stock causing the vibration transmitted by the rail/wheel interaction.

European Union policy supports noise reduction and has addressed the issue in interoperability directives and corresponding technical specifications. The Environmental Noise Directive (END) requires member states to submit noise maps and action plans. The EU is mostly responsible for noise creation aspects, while member states may additionally enact specific legislation for noise reception. In these cases, noise reception values usually concern only new and upgraded lines; however some countries such as Italy or Switzerland also have noise reception limits for existing lines or have ongoing noise abatement programs for existing lines such as Germany, Austria, Denmark.

Noise has become an even more critical factor for the railways in recent years: planned construction of new (high speed) lines and intensification of traffic on existing ones in combination with more public awareness and concern. Examples are the controversy on the planned high speed line (HS 2) in the United Kingdom and the doubling of passenger train frequency on some lines in the Netherlands or the opposition to the new railway station and railway line in Stuttgart. New lines through populated areas or rural areas evoke considerable opposition, in part to the foreseen noise. For increased passenger services on existing lines a consequence is that freight traffic has to shift to night time or alternative routes, also evoking public concern about noise and vibration, even at the planning stage.

Also the introduction of noise emission ceilings in some countries (e.g. The Netherlands) has raised the pressure to plan line capacity to comply with the available noise quota. This means that running more passenger trains can result in reduced numbers of freight trains or vice versa.

Railways have a long history of noise research and control since late 1980's. Numerous projects have developed and analysed different abatement possibilities. The noise control measures most often traditionally implemented are noise barriers or insulated windows. The largest potential, however, lies in silent vehicles in terms of low hanging fruits. Significant progress can be made by the

Figure 1

introduction of composite brake blocks or disc brakes. Technical Specifications for Interoperability (TSIs) therefore require new rolling stock to be silent. Efficient noise reduction measures rely now on combination of measures on vehicles and tracks.

In order to encourage retrofitting the European Union is considering noise differentiated track access charges as an incentive. This approach is supported by the governments of some member states. Since the railway business is complicated and many different players are involved, it is unclear if this incentive will have an effect. In addition very high transaction costs might occur. The railway sector therefore proposes either direct subsidies as an alternative, or that wagon owners can claim a mileage-based bonus instead of the operators. Several individual countries are also studying or implementing different means of promoting retrofitting. The Netherlands have introduced noise differentiated track access charges. Germany intends to do so in beginning of 2013. Switzerland directly subsidises the retrofitting of the freight fleet in addition to using noise differentiated track access charges.

1.2. Policy drives and constraints

Railways are a sustainable and climate friendly means of transport: The risk of climate change and other environmental aspects are becoming topics of ever increasing importance. Railways are the most environmentally-friendly mode of transport both for freight and passenger traffic. It is therefore necessary to promote the development of rail traffic, as recognised by EU policy as well as many national governments.

Noise is the major environmental issue of the railways: The most significant environmental effect of the railways is noise, mostly caused by freight wagons with cast-iron brake blocks. Railway lines often pass through densely populated areas, especially in central and western parts of Europe. The problem is amplified by the fact that freight trains in particular are also operated at night. High speed traffic, even if noise creation was mitigated for high speed trains can be a problem for our projects.

The railways have a long history of noise reduction: The rail sector acknowledges noise as a problem and has put much effort into understanding noise creation and propagation and into finding solutions to the problem. As a consequence, significant progress has been made in noise abatement over the past 20 years. The systematic study and research of the issue has led to the introduction of disc-braked passenger vehicles, new freight wagons with K-blocks, or the construction of noise barriers along major lines. Not all issues have been solved yet, mainly because of remaining freight wagons with cast-iron brake blocks, their low renewal rate, plus the ever increasing levels of traffic and speed. Some specific questions such as curve squeal, stand-by noise or noise from steel bridges also require further study. One of the main focus of the railway sector lies with the retrofitting of the freight rolling stock from cast-iron brake blocks to composite brake blocks. The main challenges in this endeavour are solving technical difficulties and finding appropriate incentives.

Effects on traffic modes must be considered: Since the railways are a sustainable and climate friendly means of transport, it is important that noise control measures do not change the modal split of transport to favour other modes, thus also increasing the noise emissions of other modes. This risk must be considered, since the railways operate in a very competitive market. It is therefore in the interest of society as a whole to finance railway noise control from outside the system.

Time to bring things together: The large interest in the topic and the recognition of its importance have led many players into the field. It is generally acknowledged that retrofitting the freight fleet is the best path towards silent railways. Incentives must therefore be put in place to promote silent vehicles and further technical developments must be supported in this area. These efforts must now be coordinated as much as possible.

1.3. Financial perspectives

Cost-Benefit Analyses: Anticipating the need to optimise noise control strategies at European level, both the railways and the EU have undertaken cost-effectiveness analyses. One of the first studies was undertaken by the UIC on two freight corridors. This study was followed by the most comprehensive study to date, the STAIRRS[1] project, co-financed by the EU fifth framework programme and by the UIC. In this project the acoustically relevant geographic, traffic and track data were collected for 11,000 km of lines in seven European countries. Standard cost-benefit methodologies were adapted to fit the requirements of the project. An extrapolation mechanism allowed studies to be made on Europe as a whole and more approximate ones on each individual country or region of interest.

Figure 2

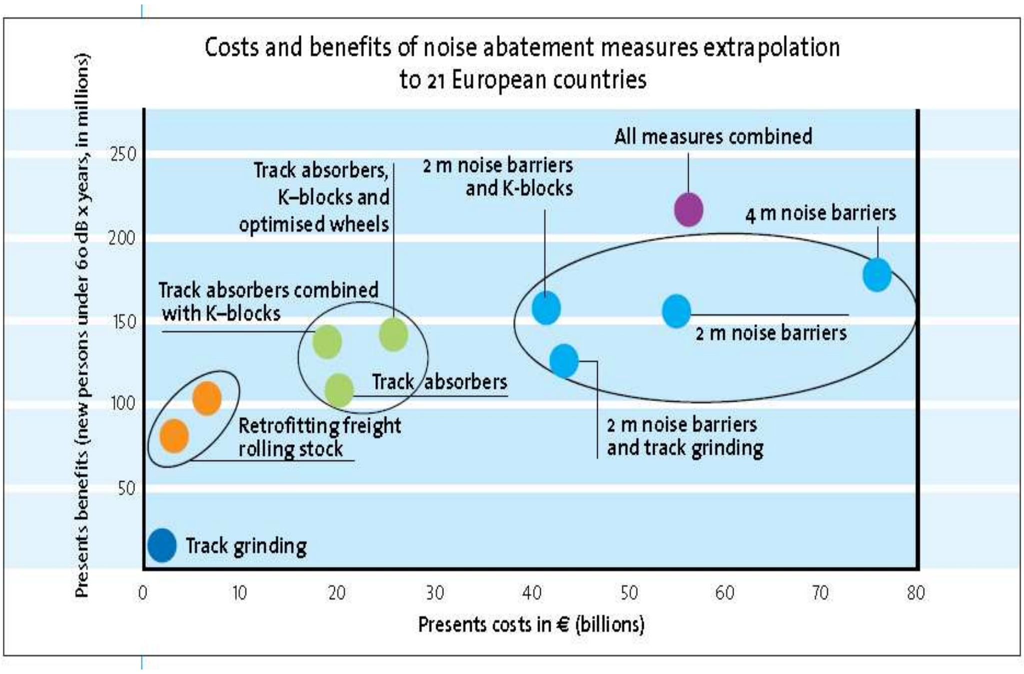

Figure 3 Main results of the STAIRRS project. The graph shows that solutions using composite brake blocks save considerable amounts of money in comparison to noise abatement with only noise barriers.

Retrofitting has best cost-benefit ratio: The main conclusions of the STAIRRS project were:

[1] Strategies and Tools to Assess and Implement noise Reducing measures for Railway Systems

- Retrofitting freight rolling stock has the highest cost-effectiveness both on its own and combined with other measures.
- Noise barriers, in particular high ones, have low cost-effectiveness.
- Combining track measures with retrofitting improves overall cost-effectiveness.
- The conclusions for Europe as a whole are also true for individual countries.

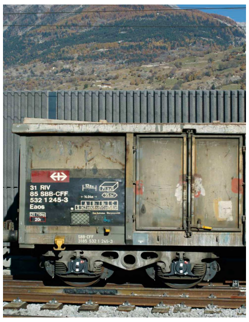

Figure 4

In summary, STAIRRS showed that solutions using composite brake blocks save considerable amounts of money (billions of euros in Europe) in comparison to noise abatement with only noise barriers. These conclusions were supported by studies undertaken in Switzerland, the Netherlands, France and Germany.

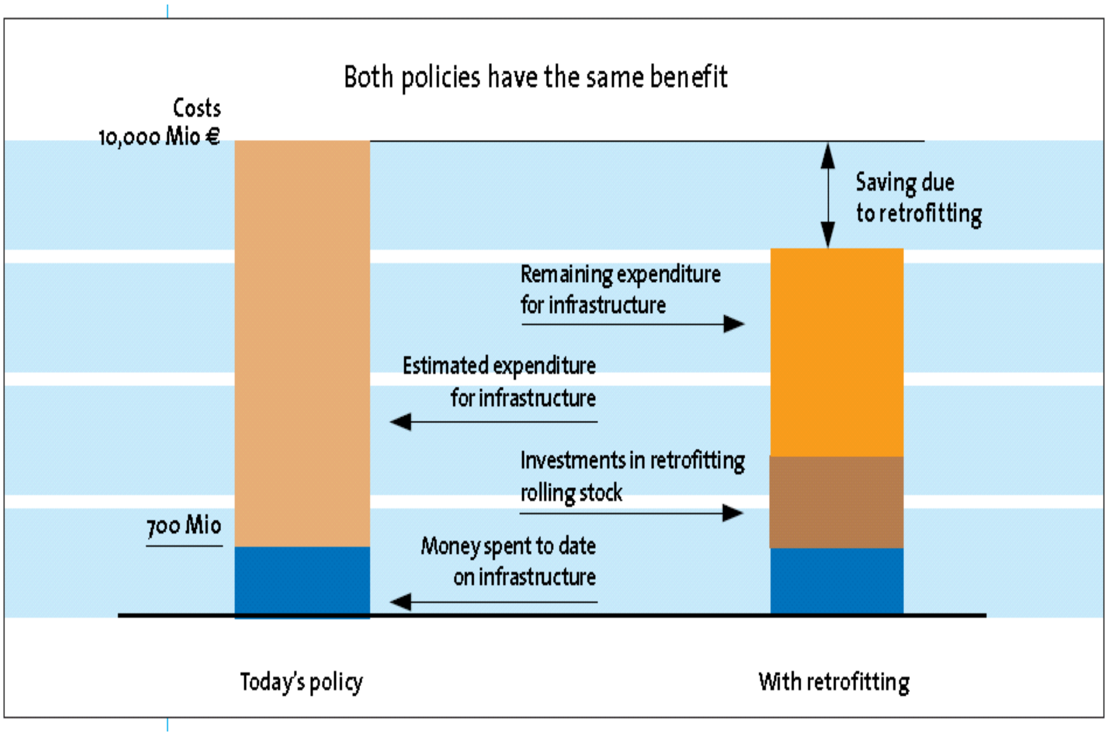

Figure 5 Potential savings in Europe by retrofitting the freight fleet with composite brake blocks

1.4. Legislative framework (EU, National, Regional,…)

1.4.1. General principle of noise legislation

Noise creation is legislated at European level, while noise reception is submitted to subsidiary principles and legislated at national level. Under the Environmental Noise Directive (END) the European Commission (EC) seeks to get an overview on the existing noise situation (noise mapping) as well as the possible noise reduction within its member states (action planning).

1.4.2. European Policy

European policy supports noise reduction: Minimising environmental damage is high on the European Commission's political agenda. As many environmental threats are linked to traffic emissions, environmental policy is linked with traffic policy. A recent activity in this field is the Greening Transport Package[2] published in July 2008. It consists of five elements:

- Greening Transport Communication: The communication summarises the entire package and describes the new initiatives the Commission intends to launch.
- Greening Transport Inventory: This inventory describes the EU action already taken to promote green transport which forms the basis of the package.
- Strategy to internalise the external transport costs: The focus of the strategy is ensuring that transport prices better reflect their real cost to society so that environmental damage and congestion can be reduced while promoting the efficiency of transport and ultimately the economy as a whole.
- Proposal for a directive on road tolls for trucks: This proposal enables member states to reduce environmental damage and congestion through more efficient and greener road tolls for trucks. Revenue from the tolls would be used to reduce the environmental impact and cut congestion.
- Rail Transport and Interoperability Communication: This communication describes how the perceived noise from existing rail freight trains can be reduced by 50% and the necessary future measures the Commission and other stakeholders must take to achieve this aim. This communication focuses on the retrofitting of the existing freight wagons using synthetic brake shoes and proposes several instruments to provide incentives to promote this process.

1.4.3. European noise legislation

Elements of legislation: European legislation on railways and noise is usually addressed in interoperability directives and further specified in TSI (Technical Specifications for Interoperability) under the responsibility of DG MOVE (Directorate-General for Mobility and Transport) or specific directives such as the Environmental Noise Directive under the responsibility of DG ENV (Directorate-General Environment).

Relevant interoperability directives in terms of noise are:

Type of traffic	Relevant EU directive	Corresponding TSIs
High speed traffic	Interoperability of the trans-European high-speed rail system, Directive 96/48/EC	• Technical Specification for Interoperability (TSI) relating to high-speed rolling stock – Commission Decision 2002/735/EC and • Technical Specification for Interoperability (TSI) relating to high-speed railway infrastructures – Commission Decision 2002/732/EC
Conventional speed traffic	For conventional speeds: Interoperability of the conventional trans-European rail system – Directive 2001/16/EC	• Commission Decision 2004/446/EC of 29 April 2004 specifying the basic parameters of the 'Noise', 'Freight Wagons' and 'Telematic Applications for Freight' Technical Specifications for Interoperability referred to in Directive 2001/16/EC (OJ L 193 p. 1) • Directive 2004/50/EC of 29 April 2004 amending Council Directive 96/48/EC and Directive 2001/16/EC (OJ L 164, 30.4.2004)

[2] http://ec.europa.eu/transport/strategies/2008_greening_transport_en.htm

		• Commission Decision 2006/66/EC adopted on 23 December 2005 concerning the Technical Specification for Interoperability relating to the subsystem "rolling stock – noise"

Table 1 Relevant interoperability directives in terms of noise

1.5. Directives, Rail Directives, TSI, Standards

1.5.1. The TSI for railway noise

In the Technical Specifications for Interoperability (TSI) the EU enacts noise creation limits for railway vehicles, both for new rolling stock as well as for renewed or upgraded rolling stock. Different values are defined for the various types of rolling stock (i.e. freight wagons, locomotives, multiple units, coaches) as well as for different operating situations (i.e. pass-by, stationary, starting and interior noise). For conventional railways the limit values for pass-by noise came into force in June 2006. This TSI includes noise emission limits for wagons with retrofitted braking systems. In 2002 a TSI for high speed trains came into force, which also includes noise regulations. A smaller revision, mostly concerning measurement conditions, was concluded in 2010. A major revision will take place 2011/12. The most relevant examples for limits values in the TSI are:

Wagon Type	Limit value
New freight wagons pass-by noise at 80 km/h	82 – 85 dB(A) depending on number of axles per unit length at 7.5 m of distance
Renewed freight wagons pass-by noise at 80 km/h	84 – 87 dB(A) depending on number of axles per length at 7.5 m of distance
Passenger coaches pass-by noise at 80 km/h	80 dB(A) at 7.5 m of distance
Locomotive pass-by noise at 80 km/h	85 dB(A) at 7.5 m of distance
Stationary noise of locomotives	75 dB(A)
Stationary noise of Electric Multiple Units (EMU)	68 dB(A)
Stationary noise of Diesel Multiple Units (DMU)	73 dB(A)
Stationary noise for high speed trains	< 65 dB(A) continuously or < 70 dB(A) intermittently
Noise levels in high speed service	< 87 dB(A) at 250 km/h, < 91 dB(A) at 300 km/h and < 92 dB(A) at 320 km/h at 25 m and a height of 3.5 m

Table 2 Most relevant examples for limits values in the TSI

1.5.2. Environmental Noise Directive

The main aim of Directive 2002/49/EC of 25 June 2002 is to provide a detailed picture of the extent of the noise problem as a basis for tackling the noise problem across the EU. The underlying principles are similar to those for other environmental policy directives:

- 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 exposed to different noise levels 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 Aarhus Convention.[3]
- 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 acceptable. 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 in member states or regions.
- 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. The results of the mapping and action planning may result in further steps including noise reception limits.

1.5.3. European policy instruments and incentives concerning noise abatement

Several instruments and incentive systems are available to the EU for enforcing and supporting railway noise reduction which could be part of existing or additional directives and TSIs. Ideas are differential track access charges, noise ceilings or restrictions on the use of cast-iron brake blocks.

General principle – noise reception values for new and upgraded lines: At national level, all European countries have noise reception limit values for new railway lines, and in almost all countries limit values are also in force for upgraded railway lines. Most countries also include a noise annoyance correction factor in their calculation schemes or threshold values, thus including the basic observation that railway noise is less annoying than road noise. It is therefore state-of-the-art procedure to include noise protection measures (mostly noise barriers) in projects for new or upgraded lines. In some countries there are additional elements to the legislation, of which a few examples are given here:

- Noise reception values for existing lines*:* Some countries, notably Italy, Switzerland and Norway, also have noise reception values for existing lines.
- Reception limits for additional areas*:* Usually noise legislation affects noise levels outside of windows. Some countries such as Norway also have thresholds for indoor noise or for gardens.
- Legislation providing for financing or incentives: In some countries legislation includes financing or incentive schemes. For example Dutch legislation includes noise differentiated track access charges as an incentive. In Switzerland the financing of the noise abatement programme is regulated as part of a package to promote public transport and is largely financed by taxes on the road sector. In addition, Switzerland has noise differentiated track access charges. In Italy, noise abatement is financed by a fixed percentage of the infrastructure budget.
- Noise abatement not stipulated by legislation: Many countries such as Germany, France, Austria, Denmark or Sweden spend considerable amounts on providing noise abatement for existing lines even though there are no specific legal requirements. In some cases, i.e. Denmark, the noise abatement of existing lines is regulated in voluntary agreements.

[3] The Aarhus Convention grants the public rights regarding access to information, public participation and access to justice, in governmental decision-making processes on matters concerning the local, national and transboundary environment

- Other legal pathways towards noise abatement: In Sweden noise abatement measures for existing lines are based on parliamentary decisions. There are also limit values for existing lines based on court decisions.

Specifications for rolling stock: The TSIs regulate the noise emitted from rolling stock. A few countries have additional national regulations.

1.6. Increased Pressure on Capacity Management

Capacity management and infrastructure charges are becoming more closely linked to noise production from railway lines. Especially the introduction of emission ceilings is in some countries leading to traffic management depending on noise production, given that traffic and noise do not correspond linearly, i.e. a doubling of the noise adds only 3 dB. Consequently, reliable prediction and availability of noise control measures are required.

1.7. Rail Production factors – Examples of noise mitigation measures

(Figures presented during the 7th UIC annual workshop on railway noise reduction, 8 - 9 Nov. 2011, Paris)

DB Schenker	about 6.700* new freight wagons with low noise brakes in service (July 2011)
DB Netz	362 kilometres of noise barriers constructed (July 2011)
SBB/CFF	6267 freight wagons with low noise brakes in service (mid 2011) Completed noise barriers: 144 km (mid 2011)
RFI	realized 80 km of noise barriers (Not included barriers installed along high-speed lines, new lines and upgraded railway lines)

1.8. Incentives

Several instruments and incentive systems are available to the EU for enforcing and supporting railway noise reduction which could be part of existing or additional directives and TSIs. Ideas are differential track access charges, noise ceilings or restrictions on the use of cast-iron brake blocks.

1.9. Indicators – Noise control possibilities

1) Reduce the noise of all new freight vehicles by introducing TSI limit values. [db(A)]

2) Promote the retrofitting of existing freight vehicles with composite brake blocks.[No.]

3) Build noise barriers and install noise insulated windows. [km]

4) Pursue further solutions in special cases such as acoustic rail grinding, rail absorbers, wheel absorbers, friction modification against curve squeal and many more. The precondition is regular maintenance. [db(A)]; [€]

2. STATE-OF-ART, RECENT PROJECTS, ONGOING RESEARCH

2.1. Noise

2.1.1. Facing the challenges of noise

Noise is a side effect of all major modes of transport. When comparing the two main modes of land transport – railway and road traffic – we can note the following:

- Railway noise less annoying than road noise: Most studies indicate that people consider railway noise to be less annoying than road traffic for the same noise levels. This has led to the introduction of a "noise annoyance correction factor" in the legal calculation schemes in many countries. This noise annoyance correction factor is under discussion in some countries because the frequency of train pass-bys means that railway noise disturbance may reach levels similar to those of road traffic noise.
- Railway noise restricted to narrow corridors: Railway noise is limited to areas around railway lines. In comparison, roads cover all areas.
- Railways produce less noise per journey than road: Comparisons of modal split versus noise show that railway noise affects significantly fewer people per transported person or tonne carried.[4]

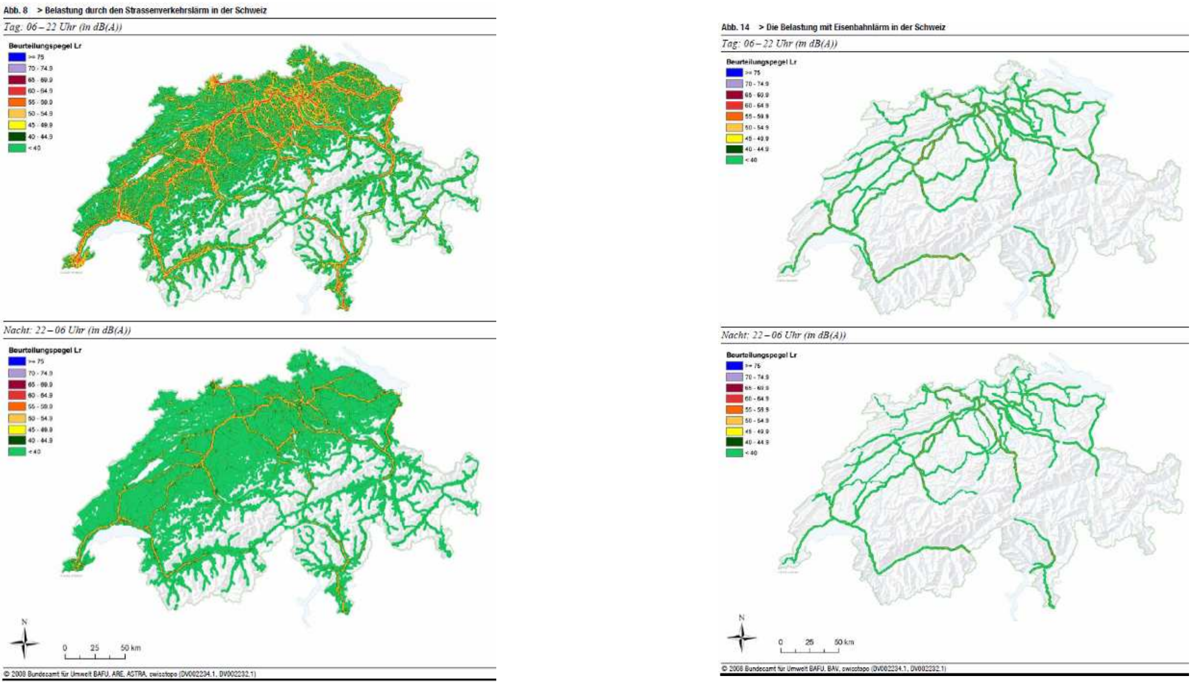

Figure 6 Road noise (right) and railway noise (left) distribution in Switzerland. [5]Despite the fact that Switzerland has one of the highest densities of railway traffic, road noise covers a much larger area.

[4] In the EU 44 % of persons are exposed to noise levels above 55 dBA from road traffic while 7 % of the population are affected by the same levels of railway noise. The corresponding modal split in the EU is 73 % versus 17% for freight traffic. The ratio for noise traffic is 60 % while for railway noise it is only 41 %. Compare Eurostat 35/2008

[5] Source: Noise Pollution in Switzerland, Swiss Federal Office of the Environment, 2009

Environmental Noise Directive (END) mapping gives picture of overall noise situation: The END noise mapping results are available on the European Environmental Agency's website.[6] Figure 3.1 summarises the results. The graph shows that road noise is much more significant than rail noise. Also, for both modes of transport, more people are affected by noise during the day than at night. Nonetheless, noise is still a problem for both modes during the night.

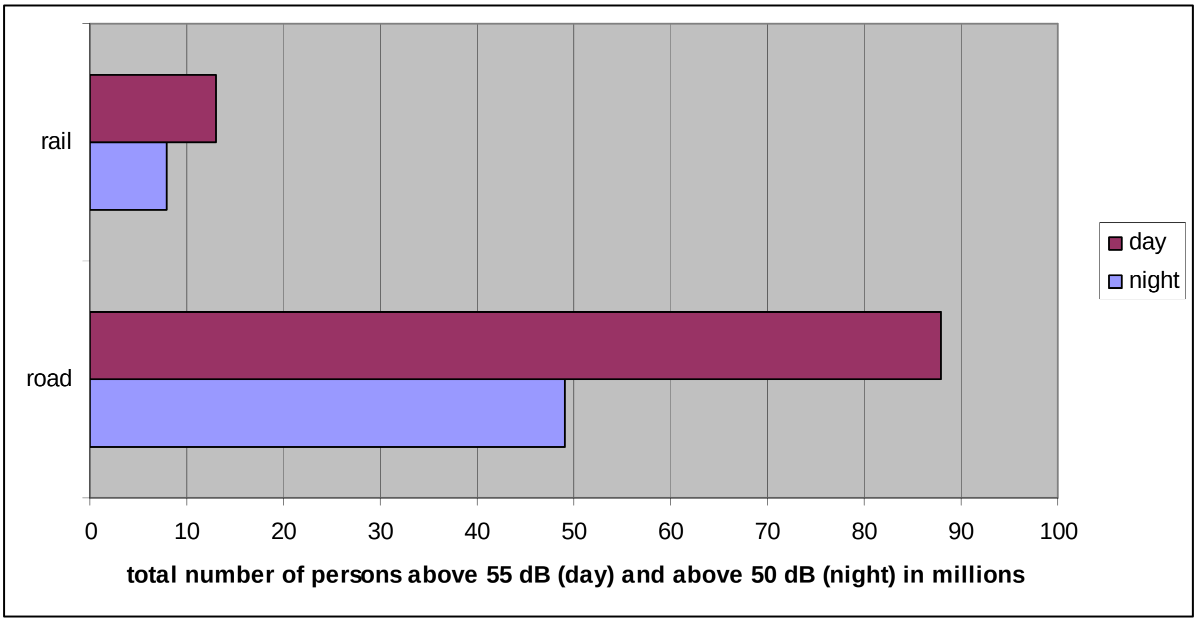

Figure 7 Number of persons affected by rail and road traffic

2.1.2. Regional activities

The railway noise picture varies among the different European regions:

Western Europe including Italy: Because of the high population density and the volume of transit traffic, railway noise is an important issue in these areas. Extreme levels are reached next to north-south corridors such as Rotterdam-Genoa, or along alpine crossings. In many countries the line side inhabitants are no longer willing to accept the current noise situation, especially the noise resulting from freight traffic. As a consequence there is strong pressure on authorities at all levels to either guarantee a decrease in railway noise or to decree operational restrictions such as limits in speed, operational times or train cadences. Much of the traffic in this area is international, therefore common solutions concerning rolling stock must be considered throughout the region.

Central Europe: This area is also characterised by significant rail freight transport. The rail freight market share is much higher in this area than in EU-15 (25 % compared to 15 % on average). A potential retrofit of the freight rolling stock is complicated by the fact that many freight vehicles have tyred wheels which prevent composite brake blocks being fitted due to overheating of the wheels. East-west railway traffic is also expected to increase in the future in parallel to the economic development of these areas.

[6] http://noise.eionet.europa.eu

Northern Countries: Freight noise is less of a problem in northern Europe. Denmark and Norway have little freight traffic and a large part of Swedish freight traffic passes through areas with very low population densities. Also, railway noise abatement programmes are well advanced so there is less focus on railway noise in comparison to Western Europe.

North-eastern Europe: Finland as well as Estonia, Latvia and Lithuania have a wide gauge (1524 mm) railway network that is linked with Russia. Solutions for these areas must therefore include Russia which is outside the scope of this report. Also, population densities are comparatively low, so railway noise is perceived as a smaller problem than in Western Europe.

United Kingdom: Railways in Britain operate under special technical specification because until the opening of the Channel Tunnel, no direct links to the continent were available. As a result, much of the freight traffic in Britain is already silent using either composite brake blocks or disc brakes, which does not comply with the specifications in the rest of Europe. As a result, railway noise is not as big an issue as in the rest of Europe.

Spain and Portugal: Spain and Portugal both have a wide gauge (1668 mm; with the exception of the high-speed network), so they are not affected by cross border traffic from the rest of Europe. This result is that no freight wagons from other parts of Europe circulate in these countries – nor do wagons from these countries circulate elsewhere in Europe. Spain and Portugal can therefore choose a braking system without European homologation. This has led to the widespread introduction of composite brake blocks which do not comply with the requirements necessary for the rest of Europe. The main reason for fitting composite brake blocks was to prevent sparks igniting fires, but they have proven to be economically viable as well.

Other areas: Other areas of the EU such as Greece, Cyprus or Malta either have little rail freight activity or no railways at all and are therefore not considered in this report.

2.1.3. Technical State-of-the-art

Different possibilities exist for controlling railway noise: Traffic noise, including railway noise, can be controlled at several different locations:

- <u>At the source:</u> Rolling noise is caused by small irregularities on both the wheel and the track in the contact area between the two. Noise reduction at the source can be achieved by either reducing this roughness and/or by preventing its growth. This is usually attained by either improving the contact surface between the wheel and rail or by reducing vibration of the noise emitting components.
- <u>Between the source and neighbouring buildings:</u> A further possibility to reduce noise is by preventing its propagation. Noise barriers are the most common method of noise abatement in this case.
- <u>Near the neighbouring buildings:</u> Finally, noise can be reduced in the immediate vicinity of the inhabitant, i.e. on the buildings itself. This is usually done with insulated windows or with façade insulation.

Railways have a long history of noise control: In numerous projects the railway sector has studied the possibilities and effects of different noise control possibilities. The UIC has overseen and coordinated many of these activities with its various expert groups. Some of the major international projects are summarised in Table 5.1.1.

Project[7]	**Timeframe (years)**	**Participation**	**Content**	**Results**
Selection of European projects (UIC, ERRI[8], EU)				
TWINS (Track-Wheel Interaction Noise Software)	Basic components since 1992, continuous improvements	ERRI and others	Models for silent freight and silent track	Basic models available, continuous validation and improvement with additional elements
Optimised Freight Wheel and Track (OFWHAT)	1992 – 1994	ERRI	Tests on test track in Velim with test train	The largest reduction was obtained with wheels with absorbers on optimised track with absorbers
Eurosabot (Sound Attenuation by Optimised Tread Brakes)	1996 – 1999	Consortium of railways, industry and ERRI	Theoretical models for the wheel roughness generation process	Basic knowledge on brake block and wheel interaction, however failed to find LL-block
Silent Freight	1996 – 1999	EU, industry, railways, research	Tests on possibilities to reduce noise from wheels	Development of an optimised wheel shape, tuned absorbers inside wheel, ring dampers, perforated wheels and bogie shrouds
Silent Track	1996 – 1999	EU, industry, railways, research	Optimised rail pad Rail damper Modified rail cross-section Low barriers	Low barriers in isolation with little effect, requires combination with bogie shrouds, has little effect
UIC Cost Benefit Study	1998 – 1999	ERRI	Cost benefit analysis of different measures along two freight corridors	Retrofitting the freight fleet with composite brake blocks has the best cost-benefit ratio
STAIRRS (Strategies and Tools to Assess and Implement Noise Reducing Measures for	2000 – 2002	EU, UIC, CH	WP1: Decision support tool for cost and benefits of different noise abatement measures	WP1: Retrofitting existing rolling stock has best cost benefit ratio, noise barriers have poorest cost benefit ratio

[7] Where not otherwise noted, this table is based on: Thompson, David, 2009, Railway Noise and Vibration, Mechanisms, Modelling and Means of Control, Elsevier

[8] ERRI: European Rail Research Institute (no longer in operation)

Railway Systems)[9]			WP2: Separation tool for wheel and track noise WP3: Consensus building workshops	WP2: Separation tools WP3: Several consensus building workshops still continued to this date
ERS (Euro rolling silently)	2002 – 2005	Railway and industry collaboration	Development of LL-type brake blocks	Pre-homologation of three prototypes
Curve Squeal	2002 – 2005	UIC	Tool box Tests on friction modifiers	Partially modelled in TWINS
Harmonise and Imagine[10]	2001 – 2005 2003 – 2007	EU together with public and private partners	Noise modelling to develop calculation methods for railways	Provides harmonised calculation methods and guidelines, examples and databases to facilitate their use, based on STAIRRS project
Silence[11]	2005 – 2008	EU together with public and private partners	Implementation of European noise policy objectives	Study of annoyance and noise perception. Development of new technological solutions. Tools for city planners. The VAMPASS tool determines best combinations
Q-City[12]	2005 – 2009	EU together with public and private partners	Develop integrated technology infrastructure for road and rail noise based on representative cities	Case studies concerning railways are steel bridge noise reduction, rail damping and noise mapping

Table 3: Summary of major international railway noise projects

Several technical possibilities are available for railway noise control: The many years of research and engineering have led to a package of solutions. Please note that regular

[9] http://www.stairrs.org
[10] http://www.imagine-project.org
[11] http://www.silence-ip.org
[12] http://www.qcity.org

maintenance procedures such as the removal of corrugation of grinding or track renewal are not mentioned. Poor maintenance may lead to noise increases of up to 10-20 dB. Note also that many additional methods are used for specific situations such as friction modifiers against curve squeal or absorbers against steel bridge noise.

Noise abatement method	**Overall noise reduction potential**	**Noise abatement effect**	**Comment/status**
Retrofitting with K-blocks	5 – 10 dB (strongly depending on rail roughness)	Network wide	K-blocks are homologated however require adaptation of the braking system
Retrofitting with LL-brake blocks	5 – 10 dB	Network wide	LL-brake blocks are only provisionally homologated, being under investigation (Europe Train)
Wheel absorbers	3 – 4 dB for high-speed trains and 1 – 3 db for freight trains other conventional trains	Network wide	Effect strongly dependent on local conditions. Wheel maintenance difficulties may occur
Track absorbers	1 – 3 dB	Local	Track maintenance difficulties may occur, effect strongly dependent on local conditions, not homologated in most countries
Combination of wheel and track	2 – 5 dB		Major impact of wheel and track maintenance. The combination of the 2 measures has a local effect.
Acoustic rail grinding	1 – 3 dB or more depending on local hotspots	Local	Effect strongly dependent on local rail roughness conditions, smooth wheels are a precondition for effect
Operational	Variable	Local	Negative effect on operations and railway capacity. Method hinders railway traffic and therefore not in line with efforts to promote sustainable transport
Noise barriers	5 – 15 dB	Local	Effect dependent on height and local geography, negative effect on landscape, influence on railway maintenance procedures
Noise insulated windows	10 – 30 dB	Local	Effect is only achieved when windows are closed

Table 4: Most common railway noise abatement solutions

Technology and costs of retrofitting with composite brake blocks

Smooth wheels on smooth tracks result in less noise: Railway rolling noise is the result of roughness on both the wheel and the track in the contact area between the two. Both the wheel and the track vibrate, when the train is in motion, thus creating noise. A significant portion of the noise can be eliminated if the contact area between the wheels and the track is smooth. The use of cast-iron brakes causes rough wheels. On the other hand, wheels remain smooth using composite brake blocks. The choice of brake block therefore has a large effect on rolling noise.

Two types of composite brake block: Currently two types of composite brake block are being developed and implemented: The K- and the LL-block. K-blocks have a higher coefficient of friction than cast-iron blocks and friction has a different velocity dependency. Because of this they require an adaptation of the braking system. LL-blocks simulate the braking performance of cast-iron brake blocks and therefore only minor adaptations of the braking system are necessary. The reason for the difference in braking performance lies in the variation in the coefficient of friction at different speeds for different brake blocks. Both solutions must safeguard a similar braking performance for the entire train. Currently, two types of K-block are available and the homologation of LL-blocks is in progress.

Cost of retrofitting with composite brake blocks: Costs are incurred by the retrofitting itself (retrofitting costs) and by additional costs during operation (life cycle costs, LCC). In 2010 it is possible to give cost data based on practical experience for retrofitting and operation of K-blocks. For LL-blocks the retrofitting cost can be derived from the costs of retrofitting with K-blocks, while almost no experience on the operation of LL-blocks is available. The operating costs of LL-blocks are likely to be similar to K-blocks.

Current cost data: Cost data has been gathered in several studies and by several consultants. Table 4 provides a summary of these estimates and investigations.

Year	Source	**Retrofitting costs for K-blocks (€/wagon)**		**Retrofitting costs for LL-blocks (€/wagon)**		**Additional LCC using K-blocks (€/wagonkm)**	**Additional LCC using LL-blocks €/wagonkm)**
		2-axled wagons	4-axled wagons	2-axled wagons	4-axled wagons		
2001	UIC Steering group noise reduction freight	3756 – 5961	5471 – 9981	418 – 2623	836 – 5246		
2004	ERRI report					0.007 – 0.025	Not investigated
2004	AEAT assessment	3812 – 6678	5471 – 11,110	418 – 2623	836 – 5246	Not quantified in €/wkm	Not quantified in €/wkm
2007	PWC DG TREN	7022 (average value		1360 (average value		0.004	0.0041

	assessment	used in the study)		used in the study)			
2008/09	UIC NRTAC report	3000 – 10,000		1000 – 5000		only dealt in qualitative matter due to lack of data	
2009	KWC DG TREN Study	3000 – 6000	6000 – 10,000	250 – 4800	500 – 6600	0.0053	0.0054
2010	German rail sector data (Leiser Rhein)	Not investi-gated	5650 – 7450	Not investi-gated	1250 – 2280 No ss-wagons	0.020 – 0.026	0.017 – 0.020

Table 5: Summary of known costs to date

Overall costs for retrofitting the European freight fleet: It is expected that a total of about 400,000 to 500,000 freight wagons will need to be retrofitted in Europe. At an average cost of an estimated € 7,000 per wagon (retrofitting with K-blocks), the total cost in Europe would amount to € 2.8 – 3.5 billion.

Homologation of the LL-brake block

Definition: Homologation is the certification of a product or specification to indicate that it meets regulatory standards.

Purpose: The purpose of LL-brake block homologation is to develop and approve a brake block that has similar braking characteristics as the cast-iron brake blocks. This should enable a low cost retrofit because no adaptation of the braking system is required. The brake block must fulfil all safety requirements in mixed train traffic.

Problems: The currently developed brake blocks cause excessive wheel wear. In particular the limit value for "equivalent conicity" is reached after low mileage. Equivalent conicity is a measure for the interaction of wheel and rail and must remain under a certain value to achieve a proper running behaviour and to prevent derailment. The increased wheel wear leads to higher life cycle costs that defeat the original purpose of this brake block.

Ongoing work: The UIC has recognised this problem and the relevant technical committees are working on a solution at three levels:

a) Adapt the contours of the brake blocks so that the shape of the block remains intact for more kilometres thus reducing the life cycle costs.

b) Evaluate the limit value for equivalent conicity. Adaptation and review of higher limits could allow more mileage before expensive re-profiling of the wheels becomes necessary. Safety levels must be safeguarded however.

c) A dedicated test train termed "Europetrain" should reduce the time needed for in service testing and therefore promote LL-block homologation.

Other efforts: Aside from the UIC, other European and national efforts to homologate and develop the LL-brake block are:

- EU LIFE+: The project DECIBELL undertaken by Faiveley Transport intends to develop a brake block for homologation.

- German projects Leiser Rhein (Silent Rhine) and LäGiV (Lärmarmer Güterverkehr mittels innovativer Verbundstoffsohlen) promote the development and homologation of the LL and K brake shoes.

Current state: LL-brake block development and homologation is a difficult undertaking. Increased coordination is necessary. At the same time, it is unclear whether the effort will be successful. It is hoped that the opened question is solved by 2013. If not, further research may be required but a back-up scenario with K-blocks is being envisaged throughout the process.

The years of research in railway noise abatement have led to the following conclusions:

- Smooth wheels on smooth tracks result in less noise*:* Railway noise is the result of roughness on both the wheel and track in the contact area between the two. Both the wheel and the track vibrate when the train is in motion, thus creating noise. A significant portion of the noise can be eliminated if both the wheels and the track are smooth.
- Smooth wheels can be achieved with the use of composite brake blocks: Both K- and LL-blocks achieve a noise reduction of 8 – 10 dB. Where in use, K-blocks demonstrate a considerable decrease in noise.
- Smooth track mostly a question of maintenance*:* Smooth tracks can be achieved with proper maintenance and perfected in certain cases with acoustic grinding. Proper maintenance is considered a given for the purposes of this report. Acoustic grinding, while used in certain countries, still has an unclear noise reducing potential because the mechanisms of roughness growth are still largely unknown.
- Noise barriers provide the most used method of noise control in the propagation path**.** Also, unquestionably, noise barriers are a tested means on noise control and are currently the most used. Correspondingly, if the number of noise barriers could be reduced by noise reduction at the source, considerable savings could be made.

Figure 8 – Noise Barrier in Switzerland

- Other technical possibilities such as track absorbers and wheel dampers have an effect of 1 – 3 dB and in combination may result in a noise reduction of up to 5 dB.

2.2. Vibrations

2.2.1. Facing the challenges of vibrations

The issue of ground vibration is closely related to noise as it can lead also to considerable disturbance of residents. Hot-spots with high levels of vibration in line-side buildings are usually hot-spots for rolling noise as well. Noise and vibration are often perceived as weaknesses in rail's environmental credentials. While noise is an issue for all modes of transport, vibration is specific to rail and therefore stands out all the more as a criticism of rail transport.

For these reasons a great deal of research has been supported and funded by the EC in recent years to reduce the impacts of noise from freight, high-speed and urban traffic **[SILENT FREIGHT/TRACK, Eurosabot, STAIRRS, NOEMIE, HARMONOISE, Imagine, SILENCE, QCity]**. These have led to new noise reduction technologies and implementation strategies which are currently being implemented by the railways. Although noise has received this increased attention in terms of research and implementation of mitigation technology, the related issue of ground vibration has not because noise was more important in the perception. Nevertheless public sensitivity to vibration issues has also increased in recent years because noise disturbance is beginning to decrease. Most complaints of high levels of vibration addressed to mainline railways concern freight traffic on surface lines. This is a significant hindrance to the upgrading of lines for them to become part of a European Freight Corridor.

In the case of new lines, vibration mitigation already features heavily in the cost of making them acceptable to the public. Opposition to new lines is as much about the effects of vibration as any other topic, including noise.

A number of mechanisms of vibration generation can be significant. Dynamic forces are generated by trains rolling with irregular wheel profiles over irregular track profiles. This is a similar mechanism to the excitation of rolling noise but much longer wavelengths of 'roughness' are involved. On the wheel it is represented by out-of-roundness. Additional dynamic forces are generated as the wheels traverse switches and crossings or badly maintained rail joints. Uneven track support (at sleeper pitch or at longer wavelengths) may give rise to additional dynamic displacements under the loads of the vehicles.

Another generation mechanism arises from the time-dependent displacement of the ground beneath the moving axle loads. This is sometimes called the 'quasi-static' excitation mechanism. For conventional train speeds this vibration remains in the near field (about 1/4 of a wavelength from the track). However, for very soft grounds the wavelengths are long, so buildings can be affected.

Various types of rail traffic give rise to vibration in different frequency ranges from different mechanisms.

The most important frequencies in vibration range from about 1Hz to 100Hz, Table 1 indicates wavelengths of roughness which excite various frequencies of vibration as a function of train speed. The shaded area in the upper right of the table indicates the range of frequency that is excited at different speeds by track irregular profile measure as 'track top quality' by track recording cars. Conversely the shading in the lower left of the table indicates that which is excited by wavelengths in the 'acoustic roughness' range.

	40 km/h	80 km/h	160 km/h
5 Hz	2.2 m	4.4 m	8.8 m
10 Hz	1.1 m	2.2 m	4.4 m
20 Hz	0.55 m	1.1 m	2.2 m
50 Hz	0.22 m	0.44 m	0.88 m
100 Hz	0.11 m	0.22 m	0.44 m

range of acoustic roughness   range of track recording car data

Table 6 Example wavelengths of 'roughness' exciting vibration at different frequencies from trains running at different speeds

Measurements in buildings show that generally freight traffic is the most important source of vibration and vibration-induced noise. A special problem arises for very soft grounds. Freight traffic causes more vibration at very low frequency (below 10 Hz) which can then be strongly perceptible up to distances of the order of 100 m from the track. Vehicle parameters favouring vibration generationfactors include single stage suspensions (typical for freight wagons), large un-sprung masses, friction suspensions, old braking systems, the regular spacings of two-axled wagons, heavy axle loads and long trains.

Suburban, interregional and high-speed passenger trains may also cause significant levels of low-frequency, feelable vibration. However, urban traffic, metropolitan and light rail vehicles more often give rise to vibration that has a greater content at higher frequencies than vibration from freight trains. Vibrations, transmitted through the ground, from about 30 Hz to about 250 Hz, may excite bending in the floors and walls of a building which then reradiate noise directly into its rooms (Fig. 2) (vibration–induced noise). This is recognised by humans as highly annoying ‘rumbling’. Only the dynamic and possibly the sleeper passing excitation mechanisms are significant at this frequency range. Vibration-induced noise may also be caused by trains running in tunnels, when vibration is transmitted via tunnel floor and ground into nearby buildings.

High-speed trains can travel under certain circumstances at speeds exceeding the wave speed in the ground. This effect is similar to the ‘sonic boom’ from supersonic aircrafts and can cause large amplitudes of ground vibration.

2.2.2. Technical State of the art

In contrast to noise, where e.g. noise screens provide an effective mitigation measure for a large number of cases, there are no generally applicable vibration mitigation measures for low frequency vibration from railways. Solutions have to be chosen individually depending on the dominant excitation mechanism and on track and ground properties. This implies a high importance of prediction tools for vibration in order to enable the optimum choice of vibration mitigation technologies for a given application case in practice. A state-of-the-art review of vibration mitigation technologies has been worked out in the RIVAS-project (RIVAS Deliverable D3.1 – www.rivas-project.eu).

The need for better quantitative prediction of these measures being implemented in tunnels was addressed in the EU 5th framework project **CONVURT** (Control of Noise and Vibration from Underground Railway Traffic) [10]. The project provided an engineering method for estimating the insertion loss from a tunnel wall, as well as a more accurate model for the prediction of the expected response of buildings in the vicinity of railway and metro tunnels. The models developed are applicable to the present project focus of surface vibration.

At the same time as the CONVURT project other researchers improved the modelling capabilities that are now available in research organisations [13, 18]. An inherent limitation of accuracy due to uncertainties in crucial parameters has been identified [24]. This indicates the need for supporting experimental work.

UIC member railways started a project, **RENVIB II** [11]**,** as a joint research activity in 1997, with the long term objective to develop a general, semi-empirical model to predict vibrations from railway lines. The project, carried out between 1997 and 2003, produced a framework to combine different models, a validated semi-empirical prediction tool with validated accuracy, a common database structure (intended to gather and exchange data), measurement protocols and a mitigation guideline. All these results were based on theoretical modelling and existing mitigation measures only because new field and laboratory testing had to be abandoned for budget reasons. The development of solutions was not within the scope of the project. The results of the CONVURT and RENVIB projects will be directly used in the starting point of RIVAS. Following

Subsequently to the RENVIB project, the UIC initiated further work, orientated to the **application of under ballast mats, finishing 2010, and under-sleeper pads (phase 1 finished and phase 2 start in 2010 for two years)**. The sleeper pad work is not directed towards ground vibration, but on track improvement rather than on ground vibration. Nevertheless, the ballast mat work nevertheless provides results in the ground vibration area.

This work will not be repeated within the context of RIVAS, both projects will be linked in to the RIVAS studies.

International levelwork is being carried out in the field of standardization, for instance **ISO 14837-1** (2005): ***Ground borne noise and vibration arising from rail systems****.* This standard provides a general guidance, including validation of prediction methods. New parts of this standard are expected not before 2013, indicating measurement methods, guidelines for mitigation, suggested target values and prediction models.

Initiatives have also been taken on a national level, for instance:

- The Austrian project LEO (low noise and vibration track), has the objectives to produce a **database of measured results**, an evaluation of mitigation measures, prediction models and assessment methods. Mitigation of vibrations from switches was also part of the content of the project **R.E.W.I. – R.O.S.E** ('Frame type sleepers – new type of track switches – Optimisation of noise and vibration characteristics' – Austria 2001 – 2005)
- **Banverket** launched a comprehensive investigation in 1999 in connection with the vibration problems at Ledsgard (high-speed trains on very soft soil)see above). Measurements of vibrations and trackbed movements were carried out before and after the countermeasures were installed. The increasing effect of the soil improvement was investigated over a period of two years. The field measurements were supplemented by laboratory tests on soil properties and computer simulation. The data produced was of high quality and was widely made available. Good agreement has been shown with a theoretical model when the level of parameter measurement detail is sufficient [25].
- Several **DB studies** and research work between the years 1992 and 2002, for example: on the **perception and annoyance of vibration and vibration-induced noise**, development of a simple and practical calculation method for vibration-induced noise, an initial assessment of mitigation measures in tracks and on the transmission path. The main experiences and results have been summarized and published [12]
- **SBB** has performed research work and investigations including experiments for under sleeper pads, under ballast mats resulting in a guideline, and state-of-the art reports on improved subgrade and transmission barriers. SBB's first measurements show a big potential for vibration reduction measures for rolling stock.
- The two semi-empirical **VIBRA** models VIBRA-1 and VIBRA-2 developed and implemented by **SBB** can calculate vibration levels for low frequencies and also for higher frequencies relevant for vibration induced noise taking into account rolling stock, train

velocities and ground conditions and dealing with different national standards in Europe. The models are already validated by measurements.

- Measurements of soil properties, investigations of the behaviour of different track systems (ballasted track and slab track systems), analyses of reduction measures at the track and in the propagation path using numerical and experimental approaches were part of **national German research projects**. A practice-orientated prediction model for vibrations was developed in the project **'Vibration caused by railways – forecast methodology for daily business'** (projects no. 19U0039A-C). The excitation mechanisms and components have been identified and quantified (the regular and irregular quasi-static component, the long- and short-wavelength irregularities of the wheel and track, the sleeper-passage component) and practice-oriented prediction software has been developed by approximating the results with simpler models.
- Several projects have been carried out in **France whether by the SNCF or by RATP** in order to reduce ground vibration levels for railway traffic. For example, SNCF leads, for 3 years, a project funded by RFF called VIBSOL: measurement campaigns were realised to evaluate ground vibration levels and soil dynamic properties related to; few numerical models have been tested, mostly based on coupled Finite and Boundary Elements methods and a particular attention has been paid to the characterisation of source-terms that means long wavelength irregularities of wheel and rail, and influent parameters that means dynamic properties of vehicle, track and soil; a catalogue of solutions has also been computed. A specific PREDIT project between SNCF, CSTB and SATEBA, has emerged from VIBSOL dedicated to Freight traffic, called VIBSOLFRET. In this project, the partners have enlightened the specificities of the Freight traffic on ground vibrations and in the next year, they will work to propose adapted solutions of reduction.
- Within the frame of the **Belgian project "Study of determining factors for traffic induced vibrations in buildings"**, a numerical model has been developed for the prediction of vibrations due to trains running at grade. The model has been validated by means of elaborate in situ experiments on the high speed line between Brussels and Cologne during the passage of InterCity and high speed trains at a wide range of train speeds. This has allowed for a better understanding of the problem of railway induced vibrations.

Track dynamics and track-subgrade interaction are closely linked with the emission of vibration from railways. Therefore previous and ongoing projects in this area are also relevant for RIVAS, most notably **SUPERTRACK** (FP 5) and **INNOTRACK** (FP 6), and their results will be taken into account. SUPERTRACK has developed strategies for improved performance of ballasted track based on a better understanding of dynamics and long-term behaviour of ballast. This included e.g. comprehensive monitoring of high-speed lines in Spain, where the dynamic behaviour of rail and sleeper was measured together with contact pressure between sleeper and ballast, stresses in the ballast and subgrade, and ground vibration at different distances from the track. INNOTRACK's main objectives are reducing LCC and improving availability, maintainability, and safety of conventional railway lines with mixed traffic.

The RIVAS project (Railway Induced Vibration Abatement Solutions)

RIVAS is an innovation project within the framework of FP 7. It started in 2011 and will terminate in 2013. RIVAS' mission (project runtime 2011- 2013 under FP 7) is to reduce the environmental impact of ground-borne vibration while safeguarding the commercial competitiveness of the railway sector. **For many problem areas vibration should be reducible to near or even below the threshold of perception. The project's goal is therefore to provide the tools to solve vibration problems for surface lines by 2013.** It therefore aims to contribute to relevant and world leading technologies for efficient control of people's exposure to vibration and vibration-induced noise caused by rail traffic. These technologies will be applied to vibration 'control at source' and on the transmission path(improved maintenance of track and wheel as well as rolling stock and track) and this scope covers propagation measures close to the track as being still within the railway infrastructure. RIVAS will also include effects at the receiver location (i.e. annoyance and exposure of residents to vibrations).

The exploitation of RIVAS results will

- focus primarily on freight lines
- be applicable to other rail sector operations (local (suburban), regional and high-speed networks)
- increase attractiveness of rail traffic
- increase acceptability of railways to Europe's residents
- strengthen competitiveness of railway transport as a mode
- strengthen Europe's railway industry also in the market place outside Europe.

Main technical objectives

Efficient vibration mitigation requires:

(1) **a toolbox of efficient vibration reduction technologies** (rolling stock /track/transmission) for a wide variety of applications

(2) **clear procedures for the assessment of the effect of vibration reduction technologies** both in terms of physical parameters and human perception

This enables and simplifies the optimum choice of mitigation measures and therefore considerably decreases costs for railway infrastructure and increases the benefits for residents.

RIVAS combines reflects this by combining technical innovation with the development of unified measurement and assessment procedures.

Its main objectives are therefore:

- the development of technologies to reduce vibration 'at source'. The focus will be on measures that can be implemented on existing lines (retrofit). They will be applicable to
  - rail vehicle design
  - rolling stock maintenance
  - track design
  - track maintenance
  - sub-grade engineering
  - the transmission path within the railway infrastructure
- the development of cost effective test procedures including a measurement protocol to monitor and control the performance of vibration reduction measures, hence making results comparable throughout Europe
- a 'technology assessment' in terms of cost-effectiveness, safety issues, operation, potential impact on rolling noise emission, social aspects.

3. VISION

By **2030** noise mitigation measures will be integrated naturally in all relevant processes of the railway, offering sustainable and practical solutions, implemented using a toolbox of various innovative and homologated techniques.

The European railways will strive towards noise and vibrations no longer being considered a problem for the railways and its neighbours – meaning that noise levels are socially and economically acceptable and allow for 24-hour passenger and goods operations by **2050**.

Based on many years of research and experience, the railway sector's noise control strategy is the following. A precondition, of course, is proper maintenance of the track.

Noise & vibration reduction strategy for the railway sector:

The main priorities are noise and vibration control at the source and in the transmission path and improvement of acoustic comfort in passenger vehicles. Noise control at line-side receiver locations has less priority as source and transmission measures are more effective.

Priority 1 - Noise & vibration control at source

This includes all sound and vibration generation and radiation from the vehicle and track, up to the boundary of the clearance gauge. It is by far the most efficient and cost-effective. Main topics are:

- Smooth wheels on smooth rails:

  This is a prerequisite for low rolling noise and implies both low roughness of running surfaces and avoidance of irregularities including wheel flats. It implies that maintenance of wheels and rails needs to be optimal and that all components that affect roughness growth or surface deterioration should be optimised, including braking systems.
- Vehicles and tracks with low sound radiation:

  For rolling noise, besides the surface roughness of wheel and rail, the vibration and radiation from the wheels and tracks offers potential for noise reduction through improved design and application of damper and shielding systems. For other sources including traction and cooling systems, and aerodynamic noise, source levels need to be reduced on the vehicle.
- Reducing the track contribution

  The noise contribution from the track is known to be significant. Although design solutions to reduce it are known, they are often not applied in the initial design stage due to lack of information or incentives and are not included in regulation. Several dB and significant savings may be gained by correct application Therefore strategies have to be developed to enable and stimulate this type of measure.
- Interior Noise

  The interior acoustic noise level is currently acceptable. Designing the interior ambiance for passenger is the key issue in order to attract more passenger to railways in the same way as the automotive sector is performing.

Priority 2 - Noise & vibration control in the transmission path

All noise control measures beyond the clearance gauge are in the transmission path and include noise barriers, embankments and covering. Main issues for future research are

- Innovative noise barriers, especially innovative, landscape friendly and socially accepted design

4. ROADMAP DEVELOPMENT

4.1. Keeping the acoustic performance of the system (train and infrastructure) throughout its whole life

4.1.1. Cost effectiveness of solutions for an implementation in commercial and operational solutions

So far solutions which have emerged from research projects are mainly prototypes, even if they were service line proven or implemented in some situation for a significant time: the key issue is to further integrate these solutions concepts in the vehicle and infrastructure design, operation and maintenance process. The main actions to be taken are the following:

- Develop optimized, cost-efficient, and system integrated (from operational and maintenance point of view) solutions for rail grinding, track absorbers (and to a less extent wheel absorbers, the latter being more frequently implemented)
- Develop low cost disk braked freight bogies or single wheel set running gears

4.1.2. Monitoring and maintenance of the system vehicle and infrastructure from a maintenance point of view

Even if noise-reduced solutions are available from the design solutions, events happening during the life of vehicles and infrastructure, and may have consequences of deterioration of the performances of the train + infrastructure system, are generally not explicitly taken into account so far in the maintenance practices of both vehicles and infrastructures.

The main subjects to be addressed to progress in that field would be the following:

- Standardization of the monitoring devices and processing methods for pass by monitoring of vehicles, getting further insight in flat and roughness generation.
- Identification of wheel flats from their acoustical point of view and management of maintenance with the less possible incidence on the vehicle maintenance point of view
- Developing and standardizing operational monitoring systems for track (roughness and track decay rates) along with the associated operational measures for an affordable maintenance policy
- Developing the concepts and tools for economic maintenance of track taking into account the increased knowledge in roughness generation.

4.2. A new breakthrough in noise reduction - minus 5-10 dB or more!

4.2.1. Rolling noise revisited

Rolling noise is normally the most important noise source in a wide speed range. The fundamental thing to accomplish is to have *smooth* wheels running on *smooth* rails. Despite that considerable efforts have been devoted to this area in the recent decades there are still untapped potential for further progress.

- new wheel and rail materials / surface coatings (initial smoothness and low roughness growth)
- shielding - combination of low barriers and vehicle skirts
- more efficient rail and wheel dampers

- understanding more precisely roughness growth in combination with keeping the adhesion properties for traction and breaking
- more fundamental modelling on switches and crossings with developing time domain modelling
- efficient noise reduction methods for existing (steel) bridges
- construction principles for low noise wheels and track components

4.2.2. More research on aerodynamic noise, generation, propagation and control - Improved prediction methods and design solutions for aero acoustics of high speed trains

Relevant for high speed trains aerodynamic is typically becoming dominant around 300 km/h but this depends to some extent on the track quality. A 5-10 dB reduction of a VHS train would most likely mean that both aerodynamic and rolling noise need to be reduced.

- Improved design of train nose, leading bogie and integration of roof equipment
- Improved assessment methods, computational and experimental to quantify the source strength, location and the sound transmission enabling systematic optimization of detailed design

4.2.3. Target annoying noise, tonal noise - Further reduction for traction noise / equipment noise / screech / squeal

All kinds of tonal and squeal noise are considered very annoying and since these noise normally occur in densely populated areas a large number of people are affected. Eliminating such noise must be high on the agenda. It shall also be remembered that the replacement of cast iron brake blocks is already identified as high priority for freight wagon rolling noise and will lead to a reduction in brake screech also.

- New cooling concepts / thermal management / intelligent control to reduce cooling fan noise, in combination with further optimization of fans to ensure the effective implementation for the concepts developed
- Smart management of auxiliary systems during standstill in stations start and braking stages
- Electric braking to zero speed to avoid brake screech
- New brake pad materials / disc brake optimisation to avoid brake screech
- (Active) radial steering bogies to avoid curve squeal

4.2.4. Indicators beyond the dB (A) level

Additional noise indicators other than the equivalent A-weighted level can be relevant for complaints including sleep disturbance and annoyance in particular situations such as shunting yards, stations and start/stop and standby locations. Indicators for impulsive noise, tonal and low frequency noise may be helpful in diagnosing and managing complaints. Not only the indicators but also their dose-effect relationships and management strategy is expected to help resolve this category of situations. New indicators may also be useful for interior sound quality. So further work and standardisation is necessary on

- Choice of indicators
- Management strategies for the above situations

4.2.5. A system approach for noise reduction

This statement holds for most aspects of railway noise – in particular where there is a vehicle-track interaction (rolling noise, squeal noise)

- Optimisation of vehicle/track design parameters to minimize rolling noise / squeal noise
- Standardization of noise sources definition for railway noise modelling
- Harmonisation of global modelling tools

4.2.6. Demonstrator: Green Silent European Train & Track - Real train and track where green solutions are implemented and tested in operation

The Gröna Tåget (Green Train) project in Sweden has been extremely successful the past five years as a test bench to implement new technical solutions in a real train under real operating conditions. The same setup could be used on the European level with an association of manufacturers and operators.

4.3. Improvement of interior acoustic comfort for passengers

Rail transport has to play a key role in a sustainable transport system by offering efficient services with low environmental noise impact, but also with a better acoustic comfort for passenger. Improving the acoustic comfort will increase attractiveness for passengers on-board and attract more passengers to the railways.

A lot has been done but the research efforts should go on: reducing noise from individual sources on train (freight trains, reductions from diesel engines on trains, etc.), technologies for active noise and vibration control.

The way from interior noise reduction to interior acoustic design is to be considered.

Software tools will assist the development of methods to reduce noise at source, to derive technologies and to enhance system assessment and decision-making processes. For instance, one of the challenges in controlling the interior noise levels in vehicles was the identification of the main noise and vibration transmission paths.

Now, we need to go further and beyond these first approaches of comfort.

- Define estimators and the associated scale enabling to relate the sound intensity to the discomfort/annoyance perceived for train's passengers

  In some studies[13] [14] loudness has been found to be better correlated to annoyance than the Sound Pressure Level in dBA. Other studies [15]have found sharpness as an important parameter related to acoustic comfort. Further work should research on the different possibilities in order to harmonize estimators used and relation it with perceived comfort. A scale should be defined with sounds representative of interior train noises.

- Characterise the background interior noise to define which aspects sound comfortable and which aspects sound annoying or uncomfortable

[13] F. Poisson, F. Dubois, C. Gallais, C. Talotte, « Acoustic comfort inside trains: research to develop indicators of background noise and temporal and spectral emergences", WCRR 2011

[14] Sunghoon Choi, Buhm Park, JunhongPark, Choonsoo Park and Jin-Sung Paik, "Acoustic comfort indicator for the assessment of interior noise in Korean high-speed trains", WCRR 2011

[15] Oriol Giberta, Joan Sapena, Begoña Mateob, Nicolás Palomares, "Development of a prediction model of acoustic discomfort in high-speed train passenger cars", EURONOISE 2009

Some studies 16have shown that the background noise of the train can be felt comfortable because reassuring and covering some noise from equipments or other passengers. Understand what component of the background noise is appreciated will allow to focus the noise attenuation, when necessary of the most critical sources.

- Define when sounds emerging from the background noise are perceived annoying or uncomfortable

Some studies 17 found that increasing the level of the background noise may improve comfort because it covers some more annoying/uncomfortable noises that may emerge. Understand how sound can emerge from the background noise18 and define when it become annoying and uncomfortable will be useful to know where the efforts for a better comfort should be made.

- Define physical criteria allowing the specification of various types of sound experiences: representative of different types of trains or different areas within the train

Sound identity is important to give to a product a powerful image in the mind of the customer. It is used in the automotive industry to make cars sound as it is expected by the customers (a sport car will sound differently than a luxury saloon car). Sound can be defined with criteria so it is adapted to the image the operator wants to associate with his train. Within the train, different types of qualities of sounds can be expected: family coaches, business coaches, platform…; physical criteria can be defined to reach these various sound qualities, and we could obtain perceived comfort targets for different types of use of rolling stock. Adapted predicting methodologies for interior noise have to be developed and improved to be able to predict acoustic comfort.

- Express the relationship between the perception of vibration and sound in the overall subjective perception of comfort or discomfort

Some studies[19]have found that noise and vibration are closely associated in the perception of comfort for the train's passengers. Another study[20] showed that reducing the noise only may not provide a benefit on the overall perception of comfort. A certain type of vibration produces a certain type of noise and passengers may feel uncomfortable if they feel one without perceiving the over one. Sounds produced by vibration and perceived by the passengers should be identified. For those, studies should also include a work on vibration.

- Tools to evaluate the perceived acoustic comfort of users during design and pre-design phases.

Tools need to be developed, including acoustic simulators, listening environments, vibroacoustic mock-ups,… These tools should include capabilities to apply virtual changes in the design to be able to evaluate it from a comfort point of view.

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[18] S. Khan, « Evaluation of acoustical comfort in passenger trains », Acta Acustica United with Acustica, Vol. 88 (270-277), 2002

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4.4. Ground borne vibration and vibration induced noise: From better understanding of the phenomena to efficient vibration control

Efficient vibration reduction is generally based on three fundamental building blocks:

1. Reliable prediction methods for choosing the optimum vibration mitigation techniques already at a very early stage in the planning process for new railway lines and for railway lines undergoing major reconstruction.

2. Low vibration rolling stock and tailored vibration reduction technologies for hot-spots.

3. Well-defined assessment criteria for noticeable vibrations in buildings and the closely related issue of low frequency vibration induced noise.

Compared to air-borne noise, knowledge of vibration from railways is far less advanced. This holds basically for all aspects, including most notably the generation mechanism, transmission in the ground and in buildings, and assessment of the impact on humans. Even very basic quantities like e.g. the threshold of perception of vibration by humans are the subject of controversial discussion. Sustainable vibration mitigation therefore has to start with a better understanding of the underlying phenomena.

4.4.1. Better understanding of the generation mechanisms

There is a strong need for better mitigation measures that have predictable benefit and have proven practically. This should provide a solid base for deciding the best solution in a wide range of cases. Such decisions can only be made on the basis of a thorough understanding of the phenomena in the complete system, i.e.:

- the generation of vibrations in the interaction between vehicle and track,
- the interaction between the track and the subsoil,
- the transmission of long-wavelength vibration in the layered soil,
- the interaction between the soil and adjacent buildings.

On vehicle level, a thorough identification of all relevant vehicle related parameters and the quantification of the influence on the dynamic forces is needed. Optimized vehicles can be designed, where functional constraints, cost efficiency aspects and low vibration emission are not in conflict with each other. For freight traffic, a particular challenge consists in designing cost efficient maintenance and retrofit solutions to reduce ground borne vibration. In this case, the lack of a (soft) secondary suspension and poorly maintained wheel geometries result in the particular problems encountered in the case of freight traffic.

It is commonly agreed that irregular track geometry is an important source of ground borne vibration. The range of wavelengths important for ground borne vibrations is relatively broad, however, and surpasses the range usually recorded by track recording cars. Furthermore, other mechanisms such as spatial variation of support stiffness contribute as well to the dynamic excitation of the vehicle. It is important to get a better insight in the role of these different sources, as this will determine how infrastructure based mitigation measures will perform.

Finally, in the interaction between the vehicle and the track, both vertical and horizontal dynamic forces should be considered. Horizontal forces may play an important role in the generation of ground borne vibrations in curves or switches.

4.4.2. Modelling

Numerical modelling addressing ground vibration from trains plays a central role in the understanding of vibration transmission in the ground and in buildings. These are commonly based on a combination of Finite Element (FE) and Boundary Element (BE) methods. Generally, the FE method is used to model the detail of track structures close to the track (embankment, walls, tunnel, receiver building) and the BE method to model the ground of infinite extent. Models may also include reception at the foundations of the building.

Refining and enhancing theoretical modelling will allow for full analysis of the vehicle, track and propagation through the ground. Of particular importance is correct modelling of propagation of vibration in the foundation of the track, the sub-grade and the layered soil. This must properly take into account the top "weathered" layer of soil as well as very low frequencies and both quasi-static excitation and dynamic excitation of vibration.

Numerical models are available that take into account the vehicle, track, and subsoil, thereby allowing for predictions in the free field, i.e. in absence of any structures next to or close to the track. A difficulty in applying these models for predictions in existing situations, however, remains in the choice of the track model parameters. Adequate in situ test procedures for the determination of parameters such as the rail pad, ballast and subgrade stiffness that depend on the preloading by the train are still missing.

Whereas numerical modelling, supplemented by in situ testing, plays a key role in improving insight in the physical mechanisms, it often considers simplified geometries or has difficulties in accounting for all structures and buildings close to the track. A particular challenge therefore consists in designing adequate modelling and prediction strategies in an urban environment.

Modelling on the level of academia and research must be supplemented by a strategy to transfer sophisticated modelling tools into practical application in planning processes. Reliable prediction tools for vibration and vibration induced noise to be used as practice oriented models in the planning process are an inevitable prerequisite for choosing the optimum vibration mitigation technologies which on one hand guarantee optimum protection of residents while preventing over-engineered solutions on the other hand.

4.4.3. Innovative vibration mitigation technologies

Unlike in the case of (low-level) noise, there is no threshold, where whole-body vibration is noticeable but not annoying. Consequently sustainable reduction of annoyance of line-side residents requires technologies capable of reducing vibration levels below the threshold of human perception. A substantial contribution to low-vibration rail traffic may be expected from optimized rolling stock. Nevertheless, the biggest reduction potential is brought in by optimised maintenance, infrastructure based vibration reduction technologies and measures on the transmission path. The latter having the advantage of being typical retrofit solutions as they can be installed without interference with the track. As the initial situation without any protection measure varies considerably from hot-spot to hot-spot, a toolbox of vibration mitigation measures is needed in order to choose the optimum solution with optimum cost-benefit ratio. Hereto, combinations of infrastructure based solutions and measures on the transmission path may be a way to achieve vibration reduction in a broad frequency range. Future solutions should also consider the combination of noise and vibration reduction, as both problems usually occur simultaneously. An example could be a noise screen, where the foundation acts as impedance barrier for Rayleigh waves.

4.4.4. Standards for the assessment of vibration

Various standards for assessing vibration at a location are in use in Europe like e.g. ISO 2631, the British standard BS 6841 or the German standard DIN 4150. The British standard uses different weighing curves for the acceleration in vertical and in lateral direction, while the German standard refers to a filter characteristic to be applied to a measured velocity signal. A high demand exists for setting unique standards on a European level.

4.4.5. Annoyance

Noise reduction and vibration reduction are closely linked. Hence, sustainable reduction of the negative impact of noise and vibration on residents necessitates a holistic approach. Studies indicate that the presence of vibration increases the annoyance due to noise so that, without also reducing vibration, the effect of noise mitigation is impaired [*E. Öhrström, A. Skånberg, A.-B., A field survey on effects of exposure to noise and vibration from railway traffic, J. Sound and Vibration 193 (1996)*]. This means that, were only noise to be mitigated, an additional 10 dB(A) reduction would have to be implemented to reduce the annoyance from the experience of combined railway noise and vibration unless the vibration is also reduced. In order to efficiently reduce annoyance of residents of railway lines at hot spots, where both noise and vibration occurs, clear procedures are required to assess vibration in terms of physical parameters as well as to assess the combined effect of vibration, vibration induced noise and air-borne noise in terms of human perception.

4.4.6. Clear responsibilities

Most like in the case of noise, vehicle based vibration reduction technologies and infrastructure based measures shall complement each other. This in turn necessitates to separate the responsibilities for optimized vibration performance between vehicle manufacturer and railway operator on the one side and infrastructure manager on the other. Therefore the constraints must be defined for vehicle and track at component level, but aiming at an improved performance at system level. This should lead to the definition of a standard track quality in terms of input impedance and track unevenness, which is to be used as design parameter for the vehicle manufacturer, much like it was done in the current TSI Noise with the reference track roughness and decay rate for noise. Furthermore, a methodology should be developed to assess and monitor the requirements set up for the vehicle and the track infrastructure.

4.5. Improved communication strategy for noise and vibration

Annoyance is not only caused by objective physical phenomena like noise and vibration, which are quantifiable in terms of sound pressure level and vibration velocity level but also by psychological factors. In some cases, vibration annoyance seems to be closely interrelated with fear for structural damage and loss of property value. The thresholds in guidelines for structural damage due to ground borne vibrations, however, are seldom met in case of railway traffic. Taking these aspects into account may provide an efficient means to improve the acceptance of rail traffic in general and reduce the annoyance experienced by residents. An important keystone is the communication between infrastructure managers/railway operators on one hand and the local community on the other hand.

There is a high demand for strategies to improve this communication beyond the requirements laid down in the environmental legislation. Such strategies should include for instance the organization of information sessions with local residents with easy and clear presentations, showing what is understandable to minimize suspicion, and communication channels, where people can bring in their expectations.

5. CONCLUSIONS

In conclusion, noise and vibration remain an important topic for the European railway system. By the last 20 years, the research activities concerning those domains have been impressive.

Rolling noise is now understood and the low-hanging fruits are a decrease of noise levels up to 10 dB A by implementation of disc brakes, alternative (composite) brake blocks. Complementary solutions as absorbers for wheels, track absorbers are at the beginning of effective implementation in real railway operations.

Aerodynamic noise, squeal and screech of brake need further research and development even if mechanisms start to be understood and practical mitigation solution are being developed.

Propagation of noise and ground-borne vibration still need research (meteorology, ground effects), for modelling and development of solutions.

A set of relevant stakeholders, coming from railway manufacturing industry, railway operators (infrastructure managers and railway undertakings), engineering activities, academic research and universities) have chosen as relevant the following research topics, as ERRAC research priorities towards 2030, through which the efforts should be focused:

- keeping the acoustic performance of the system (train and infrastructure) throughout its whole life
- revisiting noise generation to generate new paradigm for railway noise reduction and a new breakthrough that will lead to new solutions for aerodynamic noise, noise of auxiliary systems, squeal and screech of brake, etc.
- improving the interior acoustic comfort for passengers
- ground borne vibration and vibration induced noise towards efficient vibration control

Noise and vibration remain a real challenge for the railway system!

6. RESEARCH AND INNOVATION ROADMAP FOR RAILWAY NOISE AND VIBRATION: A PICTORIAL VIEW

(R)esearch (D)evelopment (I)mplementation	2012	2015	2020	2025	2030
R&D&I		**Keeping the acoustic performance of the system (train and infrastructure) throughout its whole life**			
D&I	Cost effectiveness of solutions for an implementation in commercial and operational solutions				
R&D	Monitoring and maintenance of the system vehicle and infrastructure from a maintenance point of view				
R&D&I					**A new breakthrough in noise reduction - minus 5-10 dB or more!**
R&D	Rolling noise revisited				
R&D	More research on aerodynamic noise, generation, propagation and control - Improved prediction methods and design solutions for aero acoustics of high speed trains				
R&D	Target annoying noise, tonal noise - Further reduction for traction noise / equipment noise / screech / squeal				
R&D	Indicators beyond the dB (A) level				
R&D	A system approach for noise reduction				
Demo / I	Demonstrator: Green Silent European Train & Track - Real train and track where green solutions are implemented and tested in operation				➔ ongoing
R&D	**Improvement of interior acoustic comfort for passengers**				
R&D&I		**Ground borne vibration and vibration induced noise: From better understanding of the phenomena to efficient vibration control**			
R&D	Better understanding of the generation mechanisms				
R&D		Modelling			
R&D&I			Innovative vibration mitigation technologies		
D		Standards for the assessment of vibration			
D		Clear responsibilities			

D	Improved communication strategy **Short-term** • Communication management/ strategies including complain management • Best practice exchange within existing technology **Mid-term** (Action to be taken within 5 years) • Noise and vibration annoyance (systematic studied of cost for noise reduction versus reduced annoyance). • Psychoacoustics (Exterior and interior noise) • Perception of combined impact when noise and vibration **Long-term** (Action long-term perspective (>5 years)) • The proximity issue/the social aspect • Soundscape • Socially acceptable noise mitigation measures

ANNEX 1 – LIST OF ABREVIATIONS

CEN	European Committee for Standardization or Comité Européen de Normalisation (CEN)
Db	Decibel
DG ENV	Directorate-General Environment
DG MOVE	Directorate-General for Mobility and Transport
EC	European Commission
END	Environmental Noise Directive
ERA	European Railway Agency
ERRAC	European Rail Research Advisory Council
ERRI	European Rail Research Institute
ERS	Euro rolling silently
EU	European Union
FP	Framework Programme
LCC	Life cycle cost
NDTAC	Noise Differentiated Track Access Charges for Rail Infrastructure
OFWHAT	Optimised Freight Wheel and Track
SBB	Schweizerische Bundesbahnen
SNCF	Société nationale des chemins de fer français
STAIRRS	Strategies and Tools to Assess and Implement Noise Reducing Measures for Railway Systems
TSI	Technical Specification for Interoperability
TWINS	Track-Wheel Interaction Noise Software
UIC	Union Internationale des Chemins de fer
UNIFE	Union des Industries Ferroviaires Européennes
WP	Work Package
y	Year