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Managing noise from parked trains

UIC research project

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1 Summary

Noise from parked trains is an increasing problem. The urban development of sites in close proximity to train yards alongside the claiming of formerly unused sidings for the parking of trains is one reason for this problem. Another cause is that old trains are more and more being exchanged with modern multiple units (MU) that generally come with a far larger number of technical aggregates installed to grant maximum comfort and safety. The fact that this exchange may also raise the noise annoyance level of the parked trains has so far found too little concerns in preliminary assessments and subsequent procurement specifications.

Managing the noise from parked trains is complicated as different parties are involved like infrastructure managers, operators and fleet owners.

Parking noise issues have been included in the major revision of the TSI-Noise. The regulations however are not sufficient to solve parking noise problems.

The parking noise is determined by the parking modes of the trains, the aggregate conditions in the parking modes and the noise emission of the aggregates in their operating conditions.

Parking noise can be reduced by several measures and strategies.

A cost-benefit analysis of possible strategies shows that taking care of the noise emission within procurement specifications has a high noise effect and shows the highest benefit/cost ratio. Procurement contracts should clearly define parking modes and noise limit values for these parking modes.

Considering noise issues in the procurement requires a coordination of the train owners with train operators and infrastructure managers.

For existing fleets the retrofit of the trains (silent components, silencer, encapsulation, enhanced software modes), noise optimized parking positions, reduced operator's procedures on site, the relocation to other depots, sound barriers, a main supply or acoustic halls may be possible solutions.

2 Introduction

Beyond the immediate vicinity of parking locations, the noise issue from parked trains is not one the general public is much aware of. While noise from parked trains only makes for a fraction of the noise issues a modern society has to deal with, it may be highly annoying to those affected [6]. The vast increase in noise issues related to parked trains is largely a product of urbanization and modernization, which entail our ever-increasing demands on mobility, safety and comfort. In passenger transportation old fashioned composites of locomotives carrying passenger coaches are more and more being exchanged with modern multiple units (EMU/DMU), that generally come with a far larger number of technical aggregates installed to grant maximum comfort and safety. The fact that this exchange may also raise the noise annoyance level of the parked trains has so far found too little concerns in preliminary assessments and subsequent procurement specifications.

Another trend is the urban development of sites in close proximity to train yards alongside the claiming of formerly unused sidings for the parking of trains. Together with the development and reconstruction of railway networks, this inevitably raises the number of people affected by noise emissions from parked rolling stock. If overall development in the rail sector follows only scarcely the visions of ERRAC for the year of 2050 [7], the problem will further intensify as particular urban areas will be in need of additional parking capacities for their trains. The paper [7] also predicts (as a necessary assumption for rail transport to be competitive, accepted and compliant with legislations in 2050) that noise emitted from rolling stock will by then no longer cause much disturbance to the public, a goal that would still need to see fundamental improvements in the way noise is managed today.

A guideline to night-time noise published by the WHO in 2009 [6] presents studies that suggest a strong correlation between noise and health. The authors come to the conclusion that the by far most severe interaction is the disturbance of sleep that may have an impact on our personal wellbeing and overall health. As an indicator value they suggest $L_{night,outside}$ (night-time averaged sound level outside the bedroom as a mean value over one year) not to exceed some very low dB values, which in general and often also in a general sense are difficult to achieve within the current train parking situations. The same document also shows a survey done in the Netherlands in 2003 that shows that in the ranking of causes for noise related sleep disturbance the rail traffic is far less dominant than i.e. road traffic noise, which is partially due to the fact that the number of railway lines is smaller than the number of roads and rail noise is generally perceived as less annoying [11] [9]. The situation further changes for parked train noise. On the one side the percentage of the population disturbed by noise will be even smaller for parked trains than for rail traffic while on the other side the characteristics of the noise changes from intermittent to continuous. The noise emitted from parking sites stems only partially from moving trains (arriving, leaving and shunting) and else is largely emitted by technical aggregates on rolling stock such as engines, fans, pumps and compressors. These kinds of sources will in general not reach the high noise levels that i.e. train pass-by events may cause, but can have additional components to their noise pattern such as tonality that may further increase the annoyance level [10].

Many fleet operators, infrastructure managers and manufacturers have started to take on the task of reducing the parking noise of their rolling stock by implementing operational and technical countermeasures to noise emissions and immissions [2], [Appendix A] and by identifying potential conflict zones with the help of measurements and computational models [12]. However, no comprehensive summary of the problem exists in literature up to now, which is the very reason the UIC initiated the presented project as a basic compilation of current best working practices and guideline to managing noise from parked trains.

3 Defining the current state of managing noise from parked trains

Nowadays, parked railway units have to be short-term ready for operation. Thus, different aggregates as heating ventilation and air conditioning (HVAC) or compressors are often in operation during the parking of the vehicle and cause noise. Especially the blow-off via the exhaust valve of the air dryer within the air supplying device is very noisy. Fluctuations due to multiple compressors running at slightly different rotational speeds can further tension the problem. While the location of some of the aggregates on the roof of the vehicle makes countermeasures such as sound barriers far less effective. Particularly low-floor EMUs and DMUs encounter this problem, as most of their aggregates generating noise on the parked train are located on the roof.

The parking areas are often located in urban areas, so that the noise emission of parking vehicles leads to complaints from local residents. These complaints can lead to restrictions on railway operators, who often need to carry out essential preparation work (e.g. cleaning) and maintenance of rolling stock at night.

Managing the noise from parked trains is complicated as different parties are involved like infrastructure managers, operators and fleet owners. The problem has increased for Infrastructure Managers (IM) and Rolling Stock Undertakers (RU) as some European countries have adopted national legislation to control noise from parked trains at night. The current revision of the TSI Noise (version 1.1 as at the 23rd of July 2013) includes limit values within the stationary noise for the operation of the main air compressor (as the main intermittent noise source) and the exhaust valve of the air dryer (as the main impulsive noise source). This addresses two problems of parked rolling stock; it does not, however, cover all aspects of parked trains and it only applies for trains to be ordered in the future.

Due to the complexity of the problem, a comprehensive analysis of the problem is necessary, including the operation and parking schedule of the rolling stock as well as typical operating conditions of parked trains and the respective operating conditions of the aggregates.

The presented research project compiles a number of possible strategies to manage the noise from parked trains and intends to give guidance for infrastructure managers and rolling stock operators as well as fleet owners to deal with the problem.

Although freight trains contribute a lot to the overall noise pollution with their high rolling noise, their parking noise emissions will largely be limited to the locomotives. In addition, freight wagons will generally be parked further away from residential houses as local, regional or even long-distance passenger trains and often be underway during the night, when it is most crucial to keep parking noises as low as possible. In yards freight wagons will only significantly contribute noise when being shunted, and hence will not further be considered specifically in the following.

3.1 Establishing a data base

In order to obtain a representative picture of today's working practices and state-of-the-art methods to manage and deal with noise emitted by parked trains, a large number of infrastructure managers and fleet owners were questioned for specific noise issues regarding the parking of their trains. The ascertainment is based on a questionnaire developed by Müller-BBM and distributed by UIC. The participants were asked to give information on

- laws and standards applying to parked rolling stock in their country,
- particular specifications they make in procurement contracts regarding parking noise,
- some representative cases where noise emitted by parking their rolling stock has caused complaints by local residents,
- specifics on category and type of train that causes the noise issues such as: parking condition of the train, activity of noise relevant aggregates and parking schedules,
- measures that were taken to solve the situation and a quantification of their successes,
- ideas of improvement in their future noise management.

The questionnaire was launched in April 2014 and yielded a number of responses which may be found in Appendix A compiled to summarize the situation described and solutions tested by the participant. The data in Appendix A is presented in an anonymous form.

3.2 Literature review

Next to input information coming from the questionnaire a literature review has been performed. Documents and reports were supplied either by UIC or by participants to the research project. In the following a short overview shall be given on the most important studies and reports from the literature survey with regard to the noise issues caused by parked rolling stock.

1. Report study presented by TÜV Süd regarding the noise emissions from parked trains of the S-Bahn Munich [2]. The project was initiated by a noise action group to assess the development of an existing working process from DB to reduce parking noise of their light rail vehicles in the S-Bahn Munich. Listed are parking modes, acoustically relevant aggregates and technical/operational measures.
2. Research survey SoFa-R conducted by SBB towards the setting up of a noise emission data base for trains operated in Switzerland. The project aims to optimize standstill operation conditions and parking management [12]. The re-

port takes into account measurement data from [1] and presents a model for optimizing parking concepts. It as well lists a number of possible improvements to the parking situation (technical measures as well as operational measures).

3. SILENCE – a research project co-funded by the European Commission to study control mechanisms for noise caused by urban road and rail transport and formulate general guidance based on findings [8]. Subprojects contain details on state-of-the-art aggregate design such as for diesel engine cooling systems [13] or diesel engine encapsulation [14].
4. EMPA report on behalf of BAFU on classification and mitigation of parked train noise in Switzerland [1]. The report names typical acoustically relevant aggregates and defines parking modes. It also includes a series of measurements of most dominant noise contributors for typical trains operating in Switzerland.

Additional literature is listed in chapter 7. Results and conclusions of this project are all drawn from literature and the questionnaire responses compiled in Appendix A.

3.3 Identifying noise relevant sources on parked rolling stock

It is important to identify the loudest noise contributors (aggregates on rolling stock) before any kind of action is taken. This is vital due to two reasons: First, the sources (aggregates) are rather localized on a parking train; hence applying simple noise levels to distance relations (geometric spreading) may be the best way to start defining the problem and the easiest way to mitigate noise. Second, to decrease the annoyance impact of a parked train it may well be possible that measures to a few sources (often the noisiest aggregates) is the key, while measures to all other aggregates will only moderately change the situation, making them far less cost-efficient.

The following list of noise relevant aggregates is deduced from the responses given to the questionnaire [Appendix A] as well as from [1], [2] and [12].

HVAC: (heating ventilation and air conditioning)

The noise relevant components of the HVAC are the air-conditioning compressor, the cooling fan and the ventilation fan.

HVAC is used for regulation and conditioning of the inside temperature. Noise relevant components are fans, pumps and compressors. To be found on almost all modern EMUs, DMUs, locomotives and passenger cars; often located on the roof. They may function separately for driver’s stand and passenger area. Cooling is generally the noisiest activity due to air-conditioning compressor activity. The major noise sources are the air-conditioning compressor and the cooling fan.

Cooling fans/pumps: (for technical aggregates)

Supply of air (and liquid) cooling for engines, generators, traction motors, transformers, auxiliary converters, batteries. Fans are often located on the roof of the vehicle.

Air compressor:

Compressor units supply the compressed air on the train. Used for brakes, sometimes doors and for maintaining contact pressure of the pantograph. Activity is mainly dependent on the sealing of the compressed air system and on its operating hysteresis (usually 8 to 10 bars).

Compressed air dryer:

Drying of compressed air, this inevitably leads to an impulsive blowing out of the condensate after each compressor cycle.

Power supply engines:

Used for technical aggregates in activity during parking. Power is generated by diesel engines, generators, batteries or taken by current collector (pantograph). This can require activity of transformers, converters, and cooling fans and pumps as well as compressors.

Supply aggregates: (on dinning cars and freight wagons)

Technical aggregates maintaining functionality (often cooling) on dining cars or freight wagons.

The noise annoyance is increased for tonal noise (compressors) or impulsive noise (exhaust valves of rolling over joints) [10].

A psychoacoustic study [11] looking at the annoyance levels for the above given noise generating instances (using ICBEN convention) came to the conclusion that the largest annoyance was caused by noise from compressors followed by the noise caused from rolling over joints and the noise generated by idling diesel engines. Fans (from the engine cooling system) were also regarded as rather annoying, while the pure rolling noise (in the parking area) and the decoupling and coupling of rolling stock was perceived as least disturbing. A surprise to the authors was the equally mild judgement of track squeal and braking noise, which they explained by the fact that these are typical noises occurring on train stations, hence the test persons were used to them and did not pay proper attention to sound levels.

3.4 Identifying typical parking modes for current rolling stock

Noise emission from parked rolling stock will severely depend on the state the train is left in over its parking duration. This ranges from trains being shut down entirely to trains standing by with all their technical aggregates in operation. The advantages and disadvantages from an operational perspective will strongly depend on schedules, weather conditions, maintenance duties/cleaning and the general availability of appropriate parking modes. The following list shall name the most frequently used parking modes. However, due to the large number of train types in operation and the numerous modifications made to them regarding technical aggregates and software control system an exact definition of the problem will only ever be possible for specific cases. For a large number of passenger trains (EMUs, DMUs, and locomotive and passenger cars) one or even several of the following parking modes may be applied:

Standstill

The train is fully operational. The pantograph is raised or the engine is running respectively and all noise-relevant technical aggregates are in operation. This is not a specific parking mode but it well reflects the situation of a stopping train i.e. waiting for a signal, during (un-) scheduled prolonged stops, for turning in terminus stations or sometimes while the train is being prepared for service after a longer parking duration. Staff will generally be required on the train. This mode needs to be avoided within noise sensitive vicinities in particular during night times.

Standstill – stopping train

This mode is similar to the standstill mode, yet has the activity of some of the aggregates tuned down to save energy and reduce noise emissions. The specifics strongly depend on software control; examples reported for this mode were: reduced fan speed for cooling of technical devices and one-engine-only operation for DMUs and reducing of HVAC activity as passengers may be on board. If not automated, staffs need to be trained to appropriately apply this stopping mode on any prolonged standstills and particularly in the night.

Parking

Most frequently used mode for parking trains that may be anything in between a standstill and a sleeping mode. In general some sort of power supply is sustained on the vehicle either by a raised pantograph, a running engine or generator, or by shore power supply. Activity of the different noise relevant aggregates will partially be tuned down to save energy. The mode is often a compromise between saving power and retaining fast operational availability. Therefore, HVAC will often be in operation (in particular on hot summer days or during the winter) to maintain a constant internal temperature (or keep it within a narrow range). This mode can be automated, but there are many cases (particular for older vehicles) where it needs to be set manually by the train operator and hence is easily subject to maladjustments. No staff are required and automated modes may include the preparation process with its safety tests, thus minimizing attendance durations for staff to save costs.

The vehicle will generally require some time to be prepared for standard service. During this preparation process some aggregates will see increased activity (such as the compressed air compressor) as all required aggregates are being brought back to standard operation. As well, safety tests such as brake tests need be performed, which will further increase noise.

Sleeping

A mode defined solely by its optimization of energy consumption and noise mitigation for the entire parking duration. It may be seen as the consequent answer of advanced train design and state-of-the-art technologies to modern sustainable emission policies. There are a number of facets to this mode as its actual implementation will vary on different trains depending mainly on hardware and software layout and whether it was retrofitted. In general, it is an automated mode where every unneeded aggregate is turned off by the software control system. It preliminarily requires defining the minimum aggregate activities required for retaining compliance with safety and transportation contracts (comfort). Within this research project sleeping mode was only reported for electric trains and requires them to have at least one pantograph raised. However, an optimization for energy consumption and noise management should be applicable on diesel driven units as well, in particular if an auxiliary generator or battery is used to supply power for the parking duration and part of the preparation service. Sleeping mode examples include ventilation and seldom internal heating and cooling (HVAC), retaining temperature within a manageable range for later preparation service (i.e. 10 to 28 °C), reducing fan speeds to a minimum of requirement and expanding air compression hysteresis from the standard 8 – 10 bars to 6 – 10 bars (or 6 – 8 bars), which may drastically reduce the number of compression cycles (as pressure losses are not only dependent on the quality of the sealing but also on excess pressure). No staff are required while the train is left in this mode, however, the operator may speed up the time required to reach the sleeping condition after arrival by manually switching off and tuning down aggregates beforehand. Wake-up of the vehicle and preparation for service may also be automated.

While preparing the train for service, the air pressure will have to be brought back to the standard 8 – 10 bars and brake tests need to be performed. Also inside heating or cooling may be required to meet passenger requirements (although part of this can be done in between departure at the depot and the first scheduled halt at a station). Preparation will inevitably lead to some increased noise emissions.

Battery

Generally used for malfunctioning and emergencies on trains. This is a mode where next to the control and communication system only vital components for sustaining minimum operation will be fed. Pantograph will be lowered but air compression sustained. Often, ventilation will run on emergency, while heating and cooling no longer function. The mode should not be used for parking and staffs needs to attend as this mode only has a limited period of time for operation, set by the state of charge of the battery.

Shut down

The train is shut down entirely. The pantograph is lowered and the engine switched off respectively and none of its technical aggregates is in operation. The mode is used for parking trains over a longer time period. It as well requires an extensive preparation process before the train may be put back to service. Particular for overnight parking it is important to consider the entire parking period from the arriving of the train to its departure, as especially the phase when the train is prepared for service can be rather noisy. Diesel driven trains will typically use this mode for any prolonged parking times.

While preparing the train for service, the air pressure will have to be brought to the standard 8 – 10 bars and brake tests need to be performed. Also inside heating or cooling may be required to meet passenger requirements (although part of this can be done in between departure at the depot and the first scheduled halt at a station). Since all necessary aggregates need to be started up, preparing a train for service that was shut down will generally require more time than preparing a vehicle that has been parked in any other mode. As the preparation time is often the most noise intensive part of the entire parking duration, shutting down trains for short time parking may not necessarily be the ideal solution to the noise problem, as it will severely depend on the noise emission from the preparation process. Diesel driven trains will generally be opted to shut down for reduced parking noise as their power package noise contributions are too large for justifying any other mode.

Additional to the noise caused by the operation modes of stationary vehicles that were listed above, there are several instances of potentially loud noise emissions during the parking procedure of a train. The most prominent are given below.

- **Braking** (mechanical brake) may cause brake squeal and is generally accompanied by a sudden release of air pressure (for pneumatic brakes) and consequently an increase in activity from the air compressor unit. Other ways of braking impose different noise emissions that will in general be perceived as less annoying (regenerative braking is used when possible but is less effective for low speeds, so is the use of eddy current brakes). Safety will generally demand brake tests whenever a vehicle goes into service from a parking state.
- **Starting** of a vehicle requires build-up of traction and hence comes with an increase in (diesel) engine turnings and/or current conversion.
- **Curve squeal** a high frequency noise (screeching/squealing) generated by slip stick friction at the train-track contact largely occurring in curves.
- **Rolling noise** from arriving or leaving trains or while shunting. Rolling noise generally becomes the dominant noise contributor somewhere in the range between 30 km/h and 80 km/h depending on track and wheel condition [15] and

on activity and types of aggregates. Joints and switches may have particular high impacts on noise.

- **Coupling** of rolling stock may cause impact noise and often requires compressor activity to supply compressed air to coupled units.
- **Decoupling** of rolling stock is often accompanied by release of air pressure from the decoupled unit.

3.5 Common noise issues caused by parking trains

The following chapter compiles a list of common noise issues as they were reported by participants in the UIC research project on managing noise from parked trains. A detailed summary of the responses may be found in Appendix A. The classification given here is by no means exact or complete, but shall rather be used as a basis for discussing noise mitigation methods in chapter 5.

Common parking situation:

A number of trains are parked in close proximity to residential houses. For night-time parking, trains will typically arrive (late) in the evening and depart (early) in the morning. Four potential noise generating processes may be identified for each train.

- **Arrival**

  The arriving train is brought into its parking position and a parking mode is set for it. This process may include some ***shunting*** for organizing trains dependent on their departure time. ***Rolling, curve squeal, decoupling*** and ***braking noises*** all may occur followed by a generally short follow-up time for the cooling of the technical components which, from an acoustical point of view, will mainly be associated with an increased in ***cooling fans*** activity. Arrivals generally cause issues when late in the evening and/or combined with shunting.

- **Parking**

  Covers the most crucial part of the night and will strongly depend on the used parking mode. If the train is not shut down entirely and no (external) main pressure supply is being used, there will be cycles of ***compressor*** activity for maintaining compressed air, as well as impulsive noises from the dryer's ***blow of valve.*** If no (external) main power is used, ***cooling fans/pumps*** will be in use for cooling ***diesel engines*** (less frequent as diesel units will typically shut down entirely), ***transformers*** and ***converters***. There are also a large number of complaints about ***HVAC*** activity during the parking (most often associated with cold or hot weather conditions). Heating will generally only generate additional ***fan noise*** while cooling adds cycled activity from the ***air conditioning compressor*** to the issue.

- **Cleaning/maintenance**

  Cleaning and basic maintenance is generally done during off-times of the vehicle, which will often be only the night time. In absence of (external) main supply the vehicle will need to generate the required power itself by ***diesel engine/generator*** or connected current collector/raised pantograph, hence

transformers, converters may be in use next to ***cooling fans/pumps*** for cooling of the technical devices. Lights and doors (of which ***closing doors*** will emit noise of themselves) need to work as well, which altogether often means the vehicle will be in an acoustically far less favourable mode compared to its intended parking mode.

- **Departure**

  Dependent on the mode the train has been parked in there will be a more or less extensive preparation process to ready the vehicle for operational service. This process will include generating the required ***air compression*** on the train, use of ***HVAC*** for preheating/-cooling and safety checks such as ***brake tests*** (and sometimes ***horns***). In absence of (external) main supply the required power needs to be generated on the train, hence ***diesel engines/generators*** and ***transformers*** and ***converters*** together with their associated ***cooling fans/pumps*** will be in use. Preparation processes are often the main cause for complaints regarding noise emitted by parked trains. In larger depots the departure of the first train may be early in the morning, while staggering of departure schedules will have other train follow in short succession thus making it a semi-continuous process. The preparation process is hence often the dominant noise contribution in the later part of the night.

- **Stopping trains**

  Stopping trains are another cause of complaints. Prolonged stopping durations may be met at stations and terminus stations and will generally have the train being operated in no particular noise reduced mode.

- **Shunting**

  Shunting or generally the movements of trains in the yard as well as arrivals and departures are closely linked to parking since it can affect the same people that are already prone to the parking noise. Typical noise contributions contain the noise components listed in 3.3 for moving trains in addition to the noise emitted from the train’s aggregates. Shunting is reported as a major problem nowadays.

The above described situations may further intensify due to several reasons, one being the fact that many (historical) rail yards have grown in size and capacity usages while the areas surrounding them became (otherwise well situated) residential dwelling areas. Secondly, modern train designs incorporate a larger number of technical aggregates such as HVAC that will often operate automated to save power and reduce staff attendance (save costs) while still meeting comfort requirements.

4 Legislations on parked train noise

A generalized debate about parked train noise is often difficult as the groups involved may bring up a variety of different legitimate reasons, such as to historically justified states or to the applying of certain limits defined in laws or standards, on which legislation has not yet conclusively settled.

There are many cases were the rail yards existed and the surrounding areas were increasingly urbanized. Some larger depots, formerly settled at the outskirts of a city, have built housings within their close proximity which were meant for the working staff. Nowadays, the city engulfs the former outskirts and the working class housings became attractive living areas. The rail yards thus became a nuisance.

On the other side, many of the complaining people feel that the situation only gets worse, which may even be true due to the fact that the number of trains in larger cities generally increases, schedules are being expanded into night times and today's rolling stock being equipped with multiple noise emitting aggregates that simply did not exist in the old days.

It therefore is vital to find a consensus which both sides feel they can live with. The legislative authorities may try to do so by defining emission/immission limits that apply to parked train noise. However, those can easily be too harsh, meaning that there will be many violations, or too soft, such that their enforcement will not change the effective annoyance level.

In most countries legal restraints will only apply to new trains and railways or if substantial changes are made to either of them. Given the long duration trains will typically stay in service, newly introduced limits can only slowly take an effect. Therein, emission limits on the sources (trains) are in general solely covered by TSI regulations, while immission limits are generally defined for railway lines and are subject to national legislations.

4.1 Noise restrictions on parked rolling stock according to the technical specifications for interoperability (TSI NOISE)

The European Railway Agency (ERA) publishes technical specifications for interoperability (TSI) to enforce European Commission legislations on railways. The TSI must be transferred into national legislations of the European Union (EU) member states. In Switzerland the TSI guidelines and limits are incorporated into legislation by acceptance of the TSI as part of the codes of practice to be met by all operators and manufacturers.

The intention of the TSI (as an extension of Directive 2008/57/EC) is to create interoperability within the European Union’s rail system. The TSI therefore formulates conditions to be met by all rolling stock in the EU when applying for authorization. If a vehicle is found to be conform within the current TSI limits and is authorized by one member state of the EU, the authorization shall be valid in all other EU member states. In the course of defining boundary conditions for interoperability of European railways, noise control regulations were included in the TSI.

The current TSI:2011 regarding noise emissions from conventional rail [18] contains the following regulations and limits for stationary rolling stock. The (energy) average of the sound pressure level ($L_{pAeq,T}$) taken at equally distributed measurement points at a distance 7.5 m from the centre of the track and 1.2 m above the top of the rail must comply with the limit values for

- Locomotives 75 dB
- EMUs 68 dB
- DMUs 73 dB
- Coaches 65 dB

All aggregates that operate continuously when the unit is stationary are operated at normal load (assuming outside temperature to be 20 degrees and one passenger per seat and keeping interior at constant 20 ° Celsius) during acceptance tests. For units with internal combustion engines, the engine runs on idle.

Intermittent noise sources (compressors) and impulsive noise sources (blow-off valves) are not considered.

This kind of regulation is ill suited to ensure low parking noise as the acceptance procedure according to TSI does not check the actual mode intended and used for the parked train. Instead, the situation mimicked will more likely represent the standstill scenario met at stations and terminus stations. However, as the questionnaire has revealed, the most critical situations for trains in a standstill mode are being met under hot weather conditions, where the HVAC fans and compressors are the dominant noise contributors, or when brake tests are being performed for safety reasons (entailed by compressor activity and impulsive blow-off noise). Parked train noise will only be positively affected by TSI limits if the requirements lead to the use of more silent aggregates and not just to an optimization of the noise emissions of the stationary mode being used during acceptance tests.

A revision [19] of the current NOISE TSI[1] partially addresses these problems by introducing limit values for intermittent noise and impulsive noise. For intermittent noise the air compressor has been identified as the main source and its impact is evaluated from the nearest measured position within the current measurement procedure. Future authorization of rolling stock will therefore require the A-weighted equivalent continuous sound pressure level at nearest measured position to the main air-compressor ($L^{i}_{pAeq,T}$) to not exceed for the time of its operation

- Electric locomotives 75 dB
- Diesel locomotives 78 dB
- EMUs 68 dB
- DMUs 76 dB
- Coaches 68 dB

[1] Expected to enter into force in 2015.

The blow-off valves have been identified as the main peak noise source and therefore the AF-weighted sound pressure level at the nearest measured position considering impulsive noise sources ($L^{i}_{pAF,max}$) have been assigned a limit value of 85 dB.

In addition, the existing limit values for continuous noise emitted from stationary rolling stock has been tightened to the following values:

- Electric locomotives 70 dB
- Diesel locomotives 71 dB
- EMUs 65 dB
- DMUs 72 dB
- Coaches 64 dB
- Wagons 65 dB

The introduction of further regulations and limits within the TSI, which properly account for the parked train scenario, is a delicate issue, as some EU member states are less affected by the parked train problem as others and hence the feeling may arise that such regulations would inappropriately raise costs while not being overall beneficial. An attempt within the ERA working group to introduce significantly reduced 2nd step limit values for stationary vehicles, that should enter into force in the future, was abandoned due to uncertainties arising from possible future revisions of the TSI before their entering into force, which would make 2nd step limits in the current revision redundant and from the availability of technical advances needed to be compliant with future requirements [19]. Part of the problem may be that so far there is no distinction being made in the TSI between a stationary and a parked vehicle, hence the development of silent parking modes is unnecessarily being hampered by the technical challenge to reduce noise in standstill mode. However, this puts a lot of pressure on those countries that suffer the most from parked train noise to introduce national laws and limits that will more likely find the public's approval.

Considering the long service durations of rolling stock, the main problem with respect to legislative limit setting is the existing fleet. The absence of a parked train definition within the TSI makes it even less an appropriate tool to combat today's noise emissions from stationary vehicles in yards and on sidings.

4.2 National laws and standards regarding parked rolling stock

There is no general practise on how to treat noise from parked rolling stock within national legislations around Europe. In general noise emission limits for railway vehicles are set by the TSI (in 2006 only Austria, Finland and Italy had emission limit values in their national legislations [24]).

Most EU member states in addition have laws applicable to the noise reception (immission) at working and living areas as well as other noise sensitive vicinities [20]. However, for railway noise this legislations generally only apply to new lines or if substantial changes are made to them.

A compilation on European railway noise legislations may be found in a survey from 2002 [21] carried out on behalf of the Working Group Railway Noise of the European Commission and in a review report from 2010 [22] studying the state of implementation of the European Noise Directives (END) in national legislations. Standard noise indicators for comparison with noise reception limits are L_{den}, L_{day} (usually 06-22) and L_{night} (usually 22-06). Some countries additionally use $L_{evening}$. Their definition stems from directive 2002/49/EC [23], in which L_r stands for the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the day periods r of a year. Few countries such as Sweden also apply L_{max} (maximum sound level at any time – generally weighted and calculated for a specific time constant). Considering average noise reception limits from all listed legislations in [21] and [22] for rail traffic and industrial noise, one obtains the following average noise limit values listed in Table 1.

Table 1: Average noise reception limits for residential areas deduced from the compilation of national noise legislations and guidelines in the EU presented in [21] and [22]. Range of limit values are given in brackets.

	Rail traffic noise	
L_{day} [dB]	**L_{night} [dB]**	**L_{den} [dB]**
61 (55 – 70)	52 (40 – 65)	62 (55 – 73)
	Industrial noise	
L_{day} [dB]	**L_{night} [dB]**	**L_{den} [dB]**
57 (50 – 70)	48 (40 – 70)	60 (46 – 76)

Notably industrial noise limits are generally lower than those for rail traffic. Countries that use the same legislative regulations for rail traffic and road traffic often have a rail bonus applying to railway noise (such as Germany (until 2015)), France, Sweden, Switzerland and Austria). This bonus has not been considered in the above average. It must also be noted that long-term average reception values are not easily measured and hence most often mathematical models are used. Therefore the actual restrictions a national legislation will have on the noise emitters (trains) will also depend on the prediction model used to calculate L_r. Noise transmission models are not harmonized within the European Union neither are reception limits. Harmonization of European railway legislations remains to be the designated goal.

In most European countries noise reception limits are defined as free-field values; in some countries, however, it is defined on the facade, which requires a 3 dB correction term to compare to free-field values [21]. A few countries such as Germany, Czech Republic, Belgium, Netherlands, Italy and Sweden also have indoor noise limit values defined in legislations [21] [Appendix A]. Finally, only some countries have regulations regarding existing lines (Czech Republic, Denmark, Italy, Netherlands, Norway, Sweden and Switzerland), that on average have 5 dB to 10 dB higher limits than new or substantially upgraded lines [21]. In most European countries neither existing lines nor existing trains are subject to noise regulations unless parts of them are significantly changed.

Parked train noise will generally be regarded as either railway noise (rail traffic noise) or industrial noise. In some countries (i.e. Germany[2]) legislation is not yet conclusive on how noise emitted from parked trains should be judged. The assessment of parked train noise according to industrial noise legislations will on average be stricter than assessment according to rail traffic legislations (see Table 1).

Reception limits generally only apply to new (or substantially upgraded) railway lines (yards) and not to the trains and are required to be met by long-term average energy equivalent noise levels, which means the more noise is emitted from a train, the less time it may spend on the track. Secondary measures to reduce noise on its transmission path may be used to assist the problem. However, to prevent future issues on new or upgraded lines, the rolling stock itself should be sufficiently silent, which for some countries means that TSI requirements are not strict enough (generally countries with low reception limits and a dense population). Consequently, additional specifications are being made in the procurement contract. In the absence of a parked train noise definition within the TSI and national noise reception regulations only being applicable to new lines, noise specifications in procurements are often the only limit setting tool to reliably reduce the noise annoyance for affected residents.

[2] In Germany, railway noise including noise from parked trains is up to now generally assessed according to the Traffic Noise Protection Ordinance (Verkehrslärmschutzverordnung, 16. BImSchV). A current revision of the legislation plans to have noise generated by aggregates on stationary trains assessed according to the Technical Instruction on Noise Abetment (Technische Anleitung zum Schutz gegen Lärm (TA Lärm)) that is generally consulted to assess industrial noise immissions.

5 Ways to mitigate noise from parked trains

The following chapter will look at ways to mitigate noise emissions from parked trains. The measures that will be listed are a summary of the measures reported in the questionnaire [Appendix A] together with the operational and technical solutions presented in the literature [1] [2] [3] [4] [8] [12]. It must be noted beforehand that there is no global solution to the noise problem due to the boundary conditions being different in each individual case. It will strongly depend on parameters that cannot be taken into account entirely in a generalized approach such as ground levels, building forms and types, train types and their specific parking modes, but also on sensitivity of local residents as well as their (sleeping) habits.

Possible measures may be divided into three categories:

- **operational measures** that focus on optimizing the management for the existing rolling stock,
- **technical measures** which are optimizations of the rolling stock (sources) itself thus changing the emission and
- **infrastructural measures** that will try to mitigate sound propagation in the parking train's surroundings thus changing immission characteristics. Which measures should be taken will depend on specific boundary conditions but will also have to consider costs and benefits.

Furthermore, it must be noted that often complaints will be directed at infrastructure managers who manage the depots, yards or sidings (as they are generally the ones legally responsible for the parking sites). This creates an imbalanced situation where the public (and legal) pressure will be met more often by infrastructural and operational measures than by technical measures which act directly on the sources (trains) as fleet owners and manufactures will be far less involved.

5.1 Technical measures and solutions

Technical measures try to reduce the noise at its source, the train. They largely contain optimization of the software control for noise emitting aggregates but may also include hardware measures such as selecting silent components with state-of-the-art equipment or the installation of silencers and encapsulation. This may apply for new rolling stock as well as for redesigning of existing trains. It must be noted that almost all of these measures will be subject to approvals from the responsible railway authorities.

Noise optimised operating condition

(Selection of a less noisy parking mode (3.4) or noise optimization of the parking mode in use.)

The manufacturer may try to minimize noise emissions from a vehicle by implementing quiet modes for the parked train. Often this is synonymous to optimizing power consumption. If software control is not fully automated, implementing silent modes for the individual aggregates will also work if they will be set manually by the train driver on arriving at the parking site. Ventilation of the interior with outside air (i.e. switching the air conditioning compressor in the HVAC off) and cooling only if inside temperatures exceed certain values while in parking mode could help to diminish the cause of complaints in hot summer nights (days). Also the hysteresis of the compressed air cycle could be changed from the usual 8 – 10 bars to 6 – 10 bars (or 6 – 8 bars) to have less leakage of compressed air and fewer compression events.

COST/BENEFIT: Costs will mainly depend on whether software modification must be done by the manufacturer and if the change is subject to approval from rail authorities. Benefits may be gained if previously to the software optimization there were no or only acoustically unfavourable parking modes available on the train. Optimizations may also help to reduce power consumption of the train while in parking mode.

Encapsulation

Encapsulating particular noisy aggregates such as compressors or engines may drastically reduce the noise emitted from them. Encapsulation is often limited due to restricted spatial containments.

COST/BENEFIT: Costs are medium if the changes are not subject to approvals from rail authorities. This may be the case if some existing encasement of a compressor or engine is only redesigned into an acoustic encapsulation. Often proper encapsulation of noisy aggregates is not only limited by costs but also by available space to apply the measure. This is not the case if the encapsulation was considered in the design phase prior to the purchase of the train. Benefits will be limited to the aggregates receiving an encapsulation, but if those aggregates are the most dominant or most annoying noise sources the actual benefit may be huge. In case of low frequency noise such as from idling diesel engines, encapsulation will often be the only way to drastically lower the noise levels, as many of the secondary measures are less effective for low frequencies.

Silencer

Specifically the blow-off valve of the compressed air dryer should be fitted with a silencer, as the impact of it on the overall annoyance level can be large, while the costs are generally moderate compared to other measures. Also, if the compressor is being encapsulated, there will be the need to use silencers on all openings (for air intake/cooling). It should however be noted that this may also cause a pressure drop, which in return needs to be compensated by higher fan speeds, thus changing (increasing) noise emission.

Dampers on the quick-acting valve of the braking system can reduce the impulsive noise components from the sudden air pressure release for braking trains. This may be a viable option if the trains are moved around the depot a lot (which in general should be avoided).

COST/BENEFIT: Silencers on the blow-off valve from the compressed air dryer are cheap in comparison with other hardware modifications and will in general not be subject to costly approvals from rail authorities. Their benefit is limited to the impulsive noise from the blow-off event, but as this is one of the loudest and most annoying noise generating processes on a parked train, the benefit will be large relative to the costs. The costs of silencers for fans in the HVAC system are medium to high dependent on how easily it can be fitted. Costs will be lower if silencers are considered in the initial design phase for the train prior to purchase. Benefit of silencers will be medium, dependent on what the fans contributions were to the total noise annoyance.

Retrofitting hardware components

Vehicles that are particular noisy due to some noisy aggregates may often see huge improvements when retrofitted with state-of-the-art components. The replacement of larger aggregate components (i.e. HVAC fans) can be rather costly for a greater number of affected trains; hence these measures will often only be seen as a last option. When it is consequently used to optimize the aggregates' noise emission by optimizing hardware components and software control, retrofitting can be one of the most successful solutions to the parking noise problem.

COST/BENEFIT: Costs for retrofitting hardware components will generally be medium to high as the changes will in general require approval from rail authorities. Benefits will depend on the noise contribution of the replaced component relative to the rest of the noise sources (if the new silent component will no longer be a dominant noise contributor) or relative to the noise contribution from the new silent component (if it is still the dominant noise source). Considering silent components in the design phase of the train prior to purchase may help to significantly lower the overall lifetime costs spend for noise mitigation for a train.

Maintenance

Regular maintenance cycles for all noise relevant aggregates will help to prevent unnecessary noise from malfunctioning components. This should also expend the overall life expectancy. Feedback systems from staffs and local residents may be used to help early detecting functional flaws.

Monitoring can be simplified by an automatic noise monitoring system.

COST/BENEFIT: Maintenance costs are fixed and will need to be expanded to cover acoustic checks. If acoustic surveillance requires the replacement of minor components such as mountings that under other circumstances could still be used, the costs may rise. Benefit will be low to medium. In general, if acoustic tests suggest a component to be cleaned or exchanged it should also be favourable from an operational point of view as it helps to prevent malfunctioning of that component.

Working groups for managing noise from parked trains should at some point involve acoustic engineers (alongside support from the manufacturer) to estimate the potential gains and costs for technical solutions on particular noisy trains.

5.2 Operational measures and solutions

Operational measures will attempt to minimize noise immissions for a given situation by optimizing operational procedures and repositioning noise sources (trains).

Noise optimized parking positioning

Attempt to minimize noise immissions by parking noisier vehicles in spots that are less sensitive to noise. This firstly requires a formulation of the problem, i.e. by naming the dominant noise contributors and their locations with respect to housings. Sound propagation is often calculated with software tools to optimize the situation for immission values [12] [17]. When in doubt, measurements should be done to validate results from such calculations, as they often assume simplified terrain layouts and worst case scenarios for noise emissions. As well power level spectra should be known for each relevant source.

COST/BENEFIT: Costs should be rather low. In situations where only parts of the rail yard or sidings are in close proximity to residential housings the benefit from parking the noisiest trains as far away and shielded as best as possible from dwelling zones may be medium to high. However, the noise emissions will still be the same hence if the rail yard is small the benefits will be from rearranging will be low.

Shielding with noise neutral rolling stock

Attempt to additionally shield loud noise sources in depots by parking less noisy or even noise neutral rolling stock such that direct lines of sight to residential housings are blocked. The effect will be less noticeable for aggregates on top of the vehicle or if the surrounding terrain is sloped upwards or there are tall buildings around the depot.

COST/BENEFIT: Costs are low; however it will in general also be difficult to have noise neutral trains parked in-between noisy trains and housing all of the time. Benefit will be low as the shielding effect is very low for aggregates on the roof and since there is a gap between train and railway line and the shielding train reflects the sound wave without absorbing much.

Reduced operator’s procedures on site

Training of operating staff to minimize noisy procedures performed on site i.e. by manually tuning down or switching off noise relevant aggregates ***before*** the train’s arrival or by only activating what is really needed until the train has left its parking site. Some safety tests (i.e. brakes) could also be performed later on in the day, as often they are only required to be taken once in a certain time interval and not necessarily in the morning before the train’s departure. This needs to be legally evaluated beforehand.

COST/BENEFIT: The costs for training staff will be low. If the parking process is automated or well planned and the awareness level of staff regarding noise is sufficiently high the potential to further mitigate noise will be low.

Relocation to other depots

For particular noisy trains it may be the most efficient measure to relocate them to depots in less noise sensitive vicinities. This noise mitigation method is limited by the availability of free parking slots on close by yards or sidings.

COST/BENEFIT: The costs for parking noisy trains in other depots will mainly be determined by the additional time investment of the train drivers (running costs) and the track access charges for the additional journey. The benefit can be medium to large for small yards or siding if the dominant noise source is removed altogether. However, if the noise emissions from the individual trains is not too different (similar train types/series) or if many trains are parked in a yard the benefit will start to vanish.

Feedback system

Installing feedback systems that involve staffs as well as local residents could help to quickly detect malfunctioning aggregates and the use of unintended noisy parking modes and may increase the acceptance for necessary noise emissions from rail yards.

The monitoring can be simplified by an automatic noise monitoring system.

COST/BENEFIT: Costs for installing a feedback system are low. Benefit will be low as if all was working as intended there could be no actual improvement. Apart from the acoustic benefit there is also a benefit to be gained from stirring awareness of the working processes in a yard and on a train alongside the associated noise emissions. The noise issue may partially viewed as being solved if the acceptance of the noise emission means there will be no complaints.

It should be kept in mind that while in theory perfect operational solutions may exist, the measures implemented will still need to be practicable. Minor improvements in immission values from a repositioning of parked trains in the yard will not likely justify a large increase in train movements (shunting). As well staff availability will need to be considered.

5.3 Infrastructure measures

Infrastructure measures generally are measures to alter sound propagation, hence taking an effect only at certain immission locations.

Sound barriers

Sound barriers will reflect and absorb noise, thus reducing sound levels behind them. They are a frequently debated option for noise mitigation for parked trains as their cost is moderate compared to other solutions. Building sound barriers typically incurs significant costs while only reducing noise exposure for a defined region, with no improvement elsewhere. As well sound barriers will have an effect

- only within a limited area behind the screen (tall buildings or hilly terrain will make them redundant),

- if the height of the noise barrier is higher than the location of the sound sources (it therefore is less effective for sound sources on top of the railway car),
- if the rail is close to the noise barrier. Noise barriers at yards with several rails have a reduced effect for the rails further away from the noise barrier.

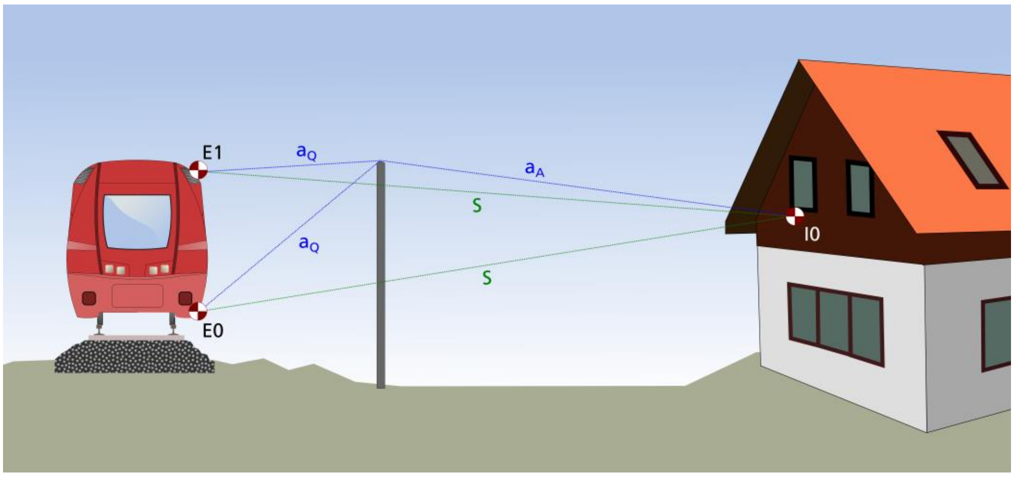

Figure 1. Geometrical distance for calculating the so-called screening value z of a noise propagation barrier: $z = a_Q + a_a - s\ [m]$ EO = emission point; IO = immission point

Concerns are sometimes raised about the reflected sound resulting in higher noise exposure on the opposite side of the site, however experience suggests this effect is negligible (at less than 1 dB). In addition sound has the tendency to bend around objects; hence there benefit in the area behind the sound barrier is dependent on distance and the surrounding ground levels. The shielding effect can in a simplified way be calculated from:

$$\Delta L = 10 \cdot \lg(3 + 60 \cdot z) \qquad (1)$$

Sound barriers will also often be rejected by the public since they block sight (generally being a 5 m tall wall close to their homes) and because they seldom benefit the townscape.

COST/BENEFIT: Costs for sound barriers are medium to high. Medium to high benefit is limited to the case where noise emission is close to the sound barrier, the barrier is much taller than the emission points (mainly aggregates not on the roof of the train) and if the immission points (buildings) are not tall themselves and do not lie on a higher ground level as the railway lines. Large railway yards would have to have sound barriers in between the various railway tracks to effectively reduce the noise at some distance. This is very expensive and often not applicable due to missing space between the lines.

Main supply

Supply of external pressure and power from stationary shielded compressors and generators at the parking sites. This requires that parking sides and a large part of the parked vehicles are fitted for shore supply and that technical staff is available whenever a train needs to connect or disconnect.

COST/BENEFIT: Costs for installing shore power and compressed air (which is acoustically shielded) is medium to high dependent on the fact whether the parked trains need to be retrofitted with connectors or not. The benefit of not having compressors running or no idling diesel engines or transformers can be huge. Local train services with always the same vehicles being parked at specific sites will most likely benefit the easiest.

Acoustic halls

Housing of the trains will mitigate sound propagation in every direction very effective. However, they are generally an expensive solution while likely not benefitting the townscape. If also used for maintenance and services they become a viable option. Only a limited number of rail yards will be shielded in this way, while it is almost impossible to apply this measure to large depots.

COST/BENEFIT: Large costs and large benefits. If the reasons for parking the trains indoor are not solemnly acoustics this can become a viable option (as i.e. to prevent vandalism, freezing and for maintenance).

Further infrastructure options

- Research studies on **low height sound barriers** installed directly on the tracks to mitigate the train's braking noise were reported as successful in trials. However, these will only help the shunting problem that is but a smaller part of the overall noise problem from parking trains.
- Installation of **lubrication equipment** to apply greasing on the rail could be used to counteract curves squeal.

It should be noted that all secondary measures such as sound barriers will have a certain frequency dependency. Noise reduction is generally less for lower frequencies and the typical dimensions of a sound barrier will often do not perform well for frequencies below 500 Hz. Due to the fact that many objects in the path of the sound wave will be small compared to the wavelength for low-frequency noise, the sound wave will be diffracted rather than scattered and reflected. In addition sound isolation for typical housings is also more useful for higher frequencies. Typical sources for low frequency noise on parked trains are idling diesel engines. However, noise from compressors and fans can have dominant low frequency components to it as well.

While dealing with low frequency noise it is important to look for appropriate measures at the sources. Care should be taken that sources are decoupled by appropriate isolating treatments to not transmit structure-borne noise to the outer chassis of the train that will then emit airborne noise. Combining this with an encapsulation of the sources may then often be the only viable solution to the low frequency noise problem.

5.4 Assessment of noise mitigation methods regarding costs and benefit

Following the initial questionnaire and literature survey conducted in the first phase of this research study an assessment of the identified mitigation methods was aimed for. For this purpose a number of parked train noise experts were asked to give their judgement regarding costs and benefit of the individual noise abatement methods.

Participants were mainly respondents from the initial questionnaire raising. The final data set is based on six responses and is presented in a graphical form in Figure 2.

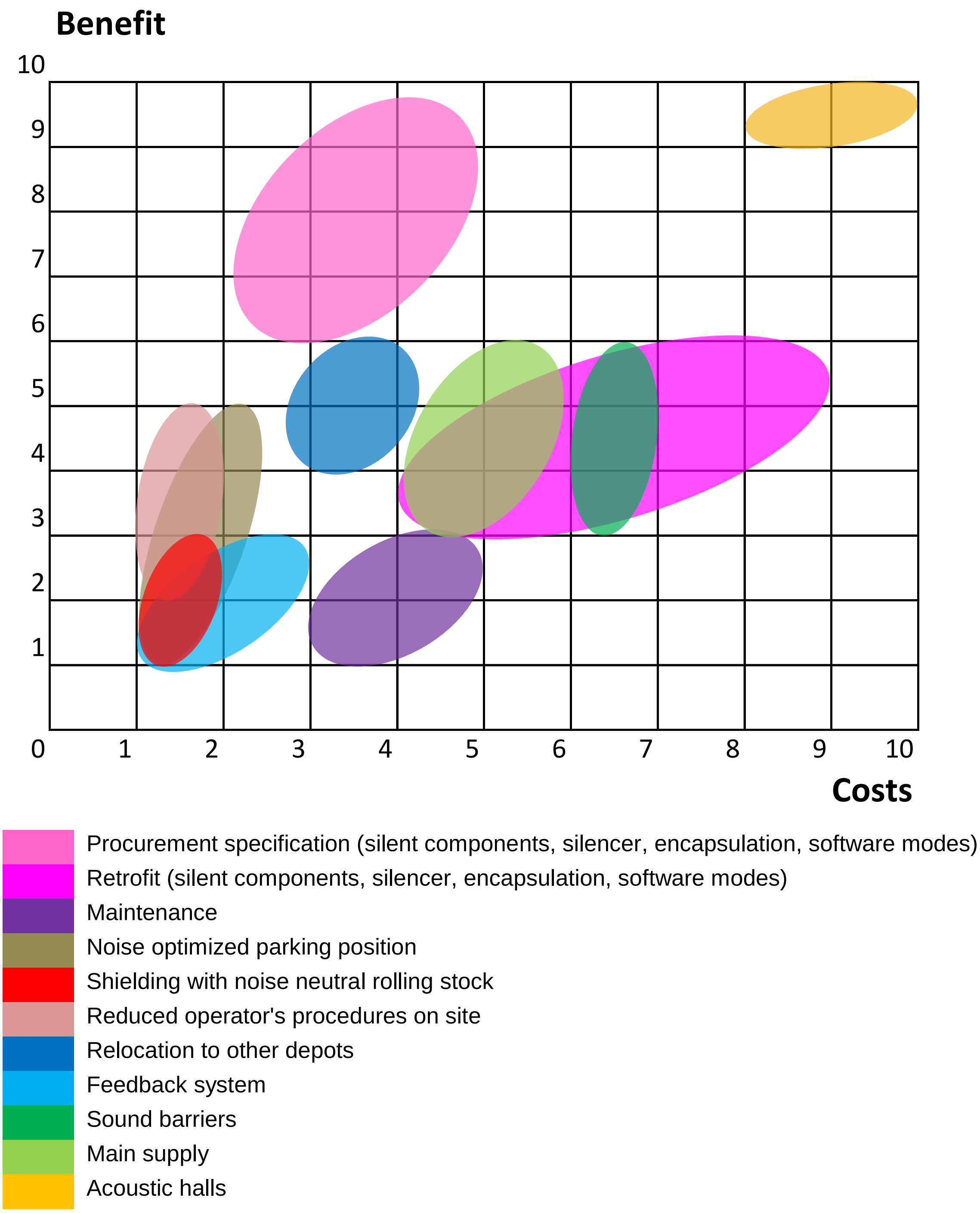

Figure 2. Costs plotted versus benefit for the noise mitigation methods described in the previous chapters. Data is based on the ratings given by six parked train noise experts asked to judge the mitigation methods regarding costs and benefits. The findings suggest that the by far most beneficial noise mitigation or prevention method is to have parked train noise accounted for in procurements. This should not only help to prevent future noise issues but also saves overall costs.

The data presented shows a clear priority of noise abatement in the procurement of the train. It is the by far most beneficial way to prevent parked train noise situations while at the same time saving overall costs. This measure should be prior to all other measures.

Acoustic halls provide also a very high benefit, are however more expensive.

For existing fleets the retrofit of the trains (silent components, silencer, encapsulation, software modes), noise optimized parking positions, reduced operator's procedures on site, the relocation to other depots, sound barriers or a main supply may improve existing parking noise problems.

All other measures are limited in their effect, even if a considerable amount of money is invested.

6 Guideline for managing noise from parked trains

Issues with parked rolling stock have intensified with the installation of additional noise emitting aggregates that help to meet the ever increasing comfort, cost and safety requirements on modern trains. In the absence of appropriate harmonised noise emission control mechanisms for parked trains (as i.e. supplied by TSI for stationary vehicles and train pass-by events) and the general tendency of legislations to only affect new trains and railway lines (and substantially upgraded ones) the necessity of proper noise management and noise abatement has grown significantly. The following chapter therefore shall summarize the most important noise abatement strategies and measures from the previous sections to help fleet operators and infrastructure managers manage the noise from their parked trains.

6.1 Guidelines for infrastructure managers

In general infrastructure managers will be the ones any kind of noise-related complaints for i.e. parked rolling stock will be directed against. After identifying hot spots they may apply noise abatement strategies or secondary measures to reduce noise immission values. They are generally not in the position to apply direct measures to the trains (sources); however, they should consult with fleet operators, owners and manufacturers as to where technical measures should be given preference to maintain or achieve well managed parking sites. Infrastructure managers should also consult with planning authorities for the development of neighbouring areas that will directly be influenced by the noise emitted from nearby yards or sidings.

Taking into account all possible sound sources at a given parking site, the following measures are possible (in no particular order):

- Minimize train movements to prevent unnecessary rolling, braking and accelerating noise.

- Have trains stay in noise reduced (parking) modes for as long as possible. Parking modes need to be made available by the manufacturer, hence if it does not exist or if noise emissions are not acceptable retrofitting of software control systems needs to be evaluated together with train owner, operator and manufacturer.
- Instruct train drivers to reduce noise at parking sites by accelerating and braking gradually and keeping train speeds slow and by tuning down noise sources before the train's arrival and only activate necessary components for departure. Signs may be used as a reminder for train drivers to reduce noisy operations when entering parking sites and feedback systems (residents or automated) may be used in combination to ensure that the intended optimized parking modes are being used.
- Instruct maintenance and cleaning staff to minimize noise emissions by working only on a few trains at a time and immediately restoring a noise reduced (parking) mode on the train when done.
- Noisy trains can be shielded (by barriers close to the rail and acoustic halls) or assigned to yards / sidings in less noise sensitive vicinities.
- Parking positioning of trains should correlate with time staggering of their arrivals and departures in such a way that night time noises are emitted furthest away from residential housings.
- Involve local residents (by informing them and letting them give feedback).
- To avoid future conflicts it is crucial to have infrastructure managers (or acoustic experts from the railway companies) consult with planning authorities as far as development of sites close to depots and railways are concerned. A general guideline for preferable building shapes and interior room layouts is given in [8]. It needs to be kept in mind that calculated noise immission values may not represent actual noise values, nor may they coincide with the subjective sensation of the noise by local residents.

As the effect of possible measures for reasonable costs are limited, it is crucial to pay special attention that new trains are parking noise optimised. Because the infrastructure management is responsible for the noise emitted from their rail yards and sidings it could be helpful to give them a handle on noisy trains. A possible measure could be a system giving a bonus to parking noise optimised trains.

6.2 Guidelines for train operators

Train operators are generally the ones responsible for appropriate and intended operation of service of the trains regarding schedules, comfort, cost and safety as well as maintenance and correct handling of the vehicles. The later takes them into responsibility to ensure that trains are operated and maintained in a way that relates to the current codes of practice. This includes abatement of noise pollution from parked trains. Wherever noise issues arise for parked trains that cannot be come by with simple infrastructural measures, it is advisable to consult with train operators as they will likely have a good grasp of the technical necessity the noise generating processes may have. This should go along with a consultation of the manufacturer if the evaluation of the overall situation comprises technical measures for solving the parking noise issues (i.e. by retrofitting of hardware or software components). Often train operators will be involved in negotiations preceding procurement specifications and hence have the unique possibility to limit future noise annoyance by defining appropriate parking noise limits.

For fleet operators the following points should be kept in mind when confronted with parking noise problems.

- Procurement contracts should clearly define parking modes that limit the noise emissions from the parked trains. A special attention shall be paid to keep noise emission in the parking modes small. The noise emission values in the parking modes should be coordinated with train owners/infrastructure managers.
- Fleet operators should consult with manufacturers to estimate benefits and costs for technical measures (i.e. retrofitting) on existing rolling stock. This process will involve the fleet owner.
- Maintenance cycles should not only be used to counteract attrition but also minimize occurrences of unnecessary noise.
- Instruction manuals and training for train drivers should include regulations on how the noise emitted from the train may be limited to a necessary minimum. This should also be given as feedback information to infrastructure managers such that it allows them to find the right proportion of operation and infrastructural measures for noise mitigation. Minimum noise operation may not be ideal from a cost and comfort oriented point of view.
- Train operators should also be able to best evaluate if transportation contracts (schedules, comfort and cost) may still be maintained if a noisy vehicle is redirected to a less noise sensitive parking yard/siding.

6.3 Guidelines for train owners

Essentially, the train owner will be the one legally responsible for the train. However, if he is not the operator of the train, some of these responsibilities may be shifted from him. In this case the important issues are:

- The highest attention should be paid to the procurement of new trains. It is vital to define appropriate noise related parking modes in procurement contracts as current noise related legislations in Europe generally do not specify parking noise limits. Procurements could also contain requirements for preinstalled technical noise mitigation measures such as silencers for the dryer's blow-off valve or shielding/encapsulation on engines and compressors.
- The noise emission values in the parking modes should be coordinated with train operators/infrastructure managers.
- For existing rolling stock the individual situations where noise emitted from parked trains causes issues, need to be properly evaluated and analysed. Retrofitting of hardware and/or software components may be the overall best solution to a given parked train noise situation. However, it should be noted that for this to work, the technical measures applied (retrofitting) must be measures

to the dominant noise sources (or at least severely reduce the annoyance level from them by i.e. removing tonal components); else the benefits may not justify the costs. Noise reduction measures in the retrofitting process are in general more expensive and less effective than taking care of them in the construction phase.

6.4 Guidelines for noise specifications in procurement contracts

To account for parked train noise in procurement it is important to be able to give realistic approximates for the required maximum noise levels that the new trains may add to the noise levels from the existing trains. The limits requested in procurements must be technically feasible or else the specification is at risk not to be tackled with although agreed on.

To prevent parked train noise issues one needs to consider the maximum noise contributions a new train may add at the most critical rail yards and sidings. If no tools are available to calculate the maximum added noise contributions the following simplified model may be used to obtain a rough estimate.

Different assumptions are made:

- The reception point (i.e. residential housing) lies within 15 - 100 m from the rail yard so that a train can be modelled as a line source.
- It is assumed that new trains are parked on the tracks close to the reception points.
- The length of the trains is assumed to be at least 50 m.
- The ground level is assumed to be flat
- Noise barriers are not considered can however be included in the calculation.
- The emission noise level from all new trains to be added to the yard is derived from the condition that the sum level of the existing noise plus the noise added from the new trains is at each reception point smaller than the most critical noise indicator value.

Modelling the yard as a line source is a rather conservative assumption as well as the fact that shielding effects from the new trains are not taken into account. The topographical parameters can go either direction, wherein raising ground levels around the yard will generally intensify the noise problem (as well as tall buildings).

The noise indicator value for a given area is defined in national legislations either regarding rail traffic noise or industrial noise immissions (see section 4.2). In general the most critical indicator value is L_{night}. For residential areas the average value of L_{night} is 52 dB(A) for rail traffic noise legislations (Europe) and 48 dB(A) for industrial noise legislations (see Table 1). The indicator value changes for different types of areas that were assigned different degrees of noise sensitivity; it also may differ from country to country.

To make an approximation of the maximum emission levels for a parked new train a number of parameters needs to be known:

1. $L_{p,\mathrm{old}}$ = current sound pressure level at reception point.
   This can i.e. be approximated from a measurement of $L_{\mathrm{pA,night}}$ (no extreme weather conditions) at the reception point, if the critical noise indicator is L_{night}.
2. D = shortest distance from reception point to railway tracks.
3. N = number of new trains to be added to the rail yard at the track close to the reception point.
4. $L_{p,\mathrm{crit}}$ = critical noise indicator value (reception limit).

To estimate the maximum average sound pressure level $\overline{L}_{pA,train}(7.5m)$ the new train may have in a distance 7.5 m from centre of track the following formula may be used:

$$\overline{L}_{pA,train}(7.5m) \leq 10 \cdot \log\left[\frac{D}{N \cdot 7.5m} \cdot \left(10^{L_{p,crit}/10} - 10^{L_{p,old}/10}\right)\right] \qquad (2)$$

$\overline{L}_{pA,train}(7.5m)$ is the energetically averaged sound pressure level of a train in a distance of 7,5 m from the center of the rail. $\overline{L}_{pA,train}(7.5m)$ is averaged energetically over the length of the train and over the relevant time span of $L_{p,\mathrm{crit}}$ (including all noise emissions of the different parking conditions of the train in that time span)

Example:

As an example we will assume to have a rail yard with EMUs parking overnight. The critical noise indicator value be L_{night} = 52 dB. Closest housings are assumed to be in 30 m distance from centre of nearest track. The total sound level from the existing trains adds up to about 51 dB at the reception point. Two additional trains (EMUs) shall be parked in the yard at the rails close to the reception point. Equation (2) estimates the maximum average sound pressure level for one additional train in 7.5 m from centre of track to be $L_{\mathrm{pA,eq}}$ = 48 dB. This value can now be transferred to the procurements.

If the yard has still more capacity the calculation could be done for the number of vacant slots rather than the number of added trains to prevent future noise issues. To further account for unfavourable circumstances or conditions the values should be tightened a little.

A comparison of the calculated values with existing train noise emissions is obtained by adding $L_{\mathrm{W'A,train}} = L_{\mathrm{pA,eq}}$ +14 dB and comparing to the sound power level per unit length given in Table 3 of appendix B. The above results in $L_{\mathrm{W'A,train}}$ = 62 dB which is well within the boundaries for trains with noise-optimised parking or sleeping modes. This also means that the demanded values should be technically feasible for EMUs.

The simple model for a rough estimation is unable to account for the complex situations. Existing noise mitigation methods such as sound barriers and optimised train parking procedures as well as topographical layouts need to be considered.

7 Literature

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Appendix A

Comprehensive summary of questionnaire responses

Early morning preparation noise **Train staggering** **Sound barriers** **Annoyance from continuous parking noise**	***Situation:*** Night-time parking of regional trains, electric locomotives plus railway cars with no air-conditioning. Use of existing sites with no recent modifications and therefore no legal obligations. Verifying possible measures within a state founded noise remediation program. Main noise sources are on locomotives: converter motor [L_W *= 91 dB – running constantly while pantograph is raised*], air compressor [L_W *= 93 dB – running 2 – 3 times per hour for 40 s*] and exhaust valve of the air dryer [L_W *= 109 dB – running 30 s per compression cycle*]. Closest residential housings within less than 50 m. Pantographs are lowered in parking mode. Noise annoyance mainly in the late evening while bringing trains into parking mode and in the early morning while preparing trains for standard service. Last train arriving after midnight while starting first preparation cycle at 03:00 in the morning. ***Solutions***: Attempt to shield noise sources (Locomotives) with noise neutral railway cars and have noise sources positioned the furthest away from residential houses. Did not help much due to trains parking mainly inline and alongside a populated area. Considering sound barriers. Final improvements were gained from exchanging noisy vehicles with new trains. ***General conclusions:*** Operational measures cannot always solve the problem. While the contributions from parking noise may be small compared to the pass-by noise from close railway tracks (in a night time average), they may still be perceived as much more annoying.

TSI procurement specifications **Local trains cause most issues** **Early morning preparation** **Train staggering** **Infrastructural and operational measures**	***Procurements:*** Often contain no specifications apart from TSI when there is competition in tendering procedures, noise being generally a far less determining factor in the assessment of a proposal than cost. ***Situation:*** Increasing comfort and safety requirements cause an increase in noise emissions from parked vehicles. The largest number of complaints in urban areas are for local trains. The main problem is the early morning where preparing vehicles for standard operation (air compression/heating/brake tests). For larger parking sites this process becomes more or less continuous while starting as early as 03:00 o'clock am due to the time staggering in service schedules for the vehicles. DMUs and diesel locomotives are far less frequently used than EMUs and electric locomotives but their power package (engine unit) is often a large noise contributor. On the other hand: EMUs are often parked with their pantograph raised hence air compression (compressor activity and blowing off of condensate) needs to be sustained over the entire parking time. Long distance trains cause fewer problems, as their parking sites are often further away from residential areas. ***Solutions:*** Have vehicles that will be run up earlier stationed the furthest away from residential housing. Installation of sound barriers where possible, though tall buildings and large parking sites in addition to aggregates on top of the vehicles makes for limited use. Have vehicles parked in the least noise emitting mode that still allows fulfilling transportation contracts regarding schedules, cost and comfort. In some cases feedback systems including local residents will help to ensure conventional processes by fast detecting unnecessary noisy vehicles (malfunctioning aggregates or wrong parking modes).

Freight trains **Halting noise**	***Situation:*** Freight traffic on railways is far less concerned with parking issues than with its rolling noise. Freight wagons in some countries no longer have active aggregate systems (such as cooling) of their own, limiting the noise problem to locomotives. Locomotives will be removed when rolling stock is in parking position. Additional issues are reported for stopping trains (source = locomotive), while waiting for signals. ***Solutions:*** Solutions were generally to move the affected signal post further away from noise sensitive areas.

Procurement specifications for noise optimized parking **Preparation of trains for service cause most noise issues** **Retrofitting** **Silencers and encapsulation**	***Procurements:*** Operator has introduced a sleeping mode for all rolling stock installed after 2007/2008. Sleeping mode optimizes the power consumption of the parking operation while at the same time tries to minimize noise emissions. Procurement contracts take this into account. To be conform to legislations immission values are specified in contracts, which poses a problem for manufacturers as they can't know for certain where the vehicles will be parked and hence have to design carefully. Acceptance tests typically include noise measurements done in *7.5 m* distance from trains and immission values are then calculated for specific sites. ***Situation:*** Operation in densely populated areas requires many parking sites to be close to residential housings (approx. 90 percent of all depots). Night time parking is managed by infrastructure managers. Issues typically occur during preparation services for standard operation that start early in the morning. Main sources of annoyance are compressors and HVAC fans in addition to the safety tests (brake tests). ***Solutions:*** Noisy vehicles are stationed further away from residential housings. Retrofitting older rolling stock for sleeping mode is used where applicable. This includes: Optimization of compressed air supply to work in a *6 – 10 bar* hysteresis instead of *8 – 10 bar*. All unneeded aggregates need to be able to switch off in sleeping mode. Improvement of sealing of air compression to reduce compressor activity. Electric multiple units can have the minimum of only two operator stand activated on start up to reduce aggregate activity in the early morning (all others operator stands are put to operation later in the day). Software optimizations (as well as hardware optimizations) often require permission procedures which makes them lengthy and costly. Shore supply of pressure and power has been debated, yet it requires appropriate connectors on rolling stock as well as increased staff availability. All vehicles are equipped with sound absorbers on blow-off valve. Encapsulation of all aggregates is implemented if possible. To predict hot spots for noise immissions the sound propagation is calculated numerically, but those results may strongly diverge from the personal sensations of affected residents.

Daytime parking problem from HVAC noise **Retrofitting** **Strict new legislations** **Sound barriers** **Shunting**	***Situation:*** Issues with electric multiple units (operating since 2000) emitting loud noise from air conditioning aggregates (source = axial fans emitting largely in upward direction) on the roof top of the vehicle. The units (3 units with each 3 carriages) are deposited for 2 to 8 hours during daytime. Air conditioning needs to be active in summer / winter times to keep the interior at temperature. No particular parking mode is implemented for the HVAC system, thus the train continuously emits noise while parked (unless staff is available to manually switch it off). Hot spot is a small parking site located in the city centre with closest housings lying approximately *40 m* away from tracks. Measurements for the worst case scenario of all air conditioning systems of at all units active at a time, as is the case in summer times, exceed legal restriction values at the housing positions by more than *9 dB* (average over noisiest 8 hour during day time). An additional fourth unit is planned to be deposited in the parking site in the near future. ***Solutions:*** Sound barriers are inefficient as sources are on top of the vehicle and buildings in close proximity are tall. Still in progress is the search for a less noise sensitive parking area; however this could come at the price of not being able to sustain current operation schedules. A technical solution tested is the retrofitting of the axial fan unit with a unit composed of two modern intake fans, which would reduce the noise by more than *11 dB*. ***Situation:*** Shunting – specifically the brakeing noise steers complaints. ***Solutions:*** In discussion: low height noise barriers close to tracks.
Night time cleaning **Air conditioning in summer**	***Situation:*** Increased aggregate activity for trains during night times due to cleaning. Frequent and noisy activity of air conditioning during summer times. Safety tests are an annoyance in particular in the early morning. Additional complaints regard the sound emission of closing train doors. ***Solutions:*** Changing procedure for cleaning hours away from night times or move parking vehicles to less noise sensitive locations. Generally, noise is not perceived as a big issue by the public.

No specifications for night noise **Compressor and fan noise annoyance** **New trains**	***Situation:*** Current limit values for existing external noise sources take the $L_{Aeq,24h}$ – thus (night time) parking noise has no large impact on level of daily equivalent. In highly populated areas parking trains cause complaints mostly during summer times, largely due to the fact that people prefer to sleep with opened windows, while bedrooms traditionally face backyard and railway lines. Most annoying noise sources are compressors and fans. ***Solutions:*** Stepwise phasing in of modern trains that will replace old ones also gradually improves the noise problem. Trains are already equipped with sound absorbers on blow-off valve for compressed air dryer.

Night time cleaning and maintenance **Horn testing** **Halting trains** **No stringent use of parking modes**	***Situation:*** Night-time maintenance and cleaning while engines are running for power supply within very close proximity to residential housings. ***Solutions:*** Shore (main) power supply not possible. Have only a few engines generate the needed power. Sound barriers were installed. Positioning of vehicles has been optimized to block direct line of sight to noise sources. Use of a “door to door” feedback system incorporating residents to be able to take swift action when depot operation as intended. ***Situation:*** Horn testing (safety tests) and depot movements during night times ***Solutions:*** Use of baffle boxes or indoor testing (at closed shed doors) for signal horns or to test them outside the depot and far away from dwelling zones. Sound emitted during depot movements may be reduced by the use of greasing equipment to reduce flange squeal for heavily used tracks in depot or in turning area. Better track maintenance (i.e. avoidance of larger extension gaps, differences in rail height, track-bed compaction) and moderate driving speeds will help as well. ***Situation:*** Turning areas: prolonged waiting times for onward signals has stationary vehicles be in an acoustically unfavourable mode (standard operation mode). ***Solutions:*** Applying a “one engine only” operation for standstills and moving signal posts such that there is no direct line of sight to close housings. Additionally use of other locations for turning trains. ***General conclusions:*** Improvements may already be gained from a stringent use of parking modes which is often not done yet and by taking a noise-focused maintenance approach (trains and tracks). To avoid future conflicts it is crucial to have railway companies consult with planning authorities as far as development of sites close to depots and railways are concerned. A “best practice” guide to noise management in rail should be produced centrally.

HVAC and air compressor	***Situation:*** Complaints about electric multiple units and locomotives. Main noise contributors are HVAC unit of passenger area and air compressor.
Noisy DMU engines **Curfew on noisy activities** **New vehicles**	***Situation:*** Overnight activities of DMUs and diesel locomotives cause annoyance in local residents. Noise emitted largely from locomotive engines both while moving around the depot and during maintenance activities. ***Solutions:*** Generators were installed to provide hotel power for maintenance. Operational instructions were given to working staff to limit high speed engine running. A curfew was partially agreed on for noisy activities. Phasing out noisy old vehicles for newer trains should help the situation. There is the consideration of setting up an acoustic tent. ***General conclusions:*** Improvements may also be gained from an electrification of the affected railway network, as this would allow replacing the diesel locomotives with acoustically favourable EMUs.

Procurement specifications stricter than TSI **Parking is optimized for noise** **Annoyance ranking** **Silencers and encapsulation** **Dampers on brake valve**	***Procurements:*** Future procurement contracts will incorporate TSI requirements but set stricter limits on starting noise ($L_{pAF,max}$) and standstill ($L_{pAeq,T}$). In addition limit values on squeal noise in yards ($L_{A,max}$), braking noise ($L_{A,max}$) from *30 – 0 km/h* and source power level ($L_{Wr,tb}$) given as an energetic sum of all sources and corrected for activity time and ($L_{Wr,max}$) for the operational modes sleeping and ready are defined. ***Situation:*** Most rail yards (especially the ones for passenger trains) are located in urban areas in close proximity of housing districts. The train capacity ranges from a few up to 200 carriages in a single yard. In a research report from 2003 [5] it was found that the distribution of noise in noise-affected houses were roughly given by shunting (30.5 %), parking during extreme winter or summer weather conditions (27.5 %), parking during cleaning (10.8 %), preheating and preparing for departure (9.3 %). Main issues are caused by HVAC, compressors and converter units. When parked, the trains are always in sleeping mode except for the maintenance, cleaning, pre-heating/ cooling situations and in extreme weather conditions. In sleeping mode all heating/ cooling, ventilation and lights are switched off. ***Solutions:*** Smart stabling (parking as much as possible in sleeping mode). When ordering new rolling stock, setting strict noise limits in specifications. Observing energy consumption of aggregates as an indicator for malfunctioning. Diagnosis systems are being used to check which aggregates are active. Parking management is already optimized for noise reduction. Trains are generally equipped with sound absorbers on blow-off valve of compressed air dryer and (some with) an encapsulation for the air compressors. To partially combat shunting noise a large train series was equipped with dampers on the quick-acting valve for the braking system.

Night time parking noise issues **Standby noise during day** **Aggregates on roof (HVAC) and blow-off valve** **Night time cleaning and maintenance** **Solution shut down of trains**	***Situation:*** Complaints received for parked trains in stations during night, or waiting in standby mode for longer time during the day in terminus stations, parked trains on ending tracks, parked trains in workshops. Main noise sources are aggregates on the roof (HVAC) and blow-off valves. Trains are staying all night in a parking mode that has the pantograph raised (and most aggregates active) to quickly be operational in the early morning. So far no use of encapsulations of compressors or sound absorber on blow of valve of compressed air dryer. Cleaning and maintenance will always require some activity of aggregates. ***Solutions:*** Trains are now being shut down entirely unless weather conditions require continues cooling/heating (when wake up time is too short to otherwise fulfil comfort passenger requirements for interior). Use of other trains as screens for nearest residential housings. Possible future solutions could be the use of stronger / additional batteries to feed HVAC without pantograph raised in all weather conditions. Switching of parking sites and retrofitting (ventilation/control system) are too cost intensive to be worthwhile at the moment.
Noise from large yard (EMUs) **Affected housing were built for yard workers** **Night time noise (summer)** **Sound barrier**	***Situation:*** Night time noise from large rail yard. Neighboring houses on higher ground level. Problems relate mainly to EMUs being cleaned and under maintenance. There is also some degree of necessary shunting to get the trains to the cleaning facilities. Housing was formerly build for workers in the yard; have no become well situated single family housings close to the city center. The problems are biggest during summertime when there is the need for cooling of the train interior while people stay in their gardens or sleep with open windows. Problem intensified with introduction of modern trains due to more standby time and more aggregates. ***Solutions:*** Large parts of the yard will be shielded with a sound barrier. Due to higher ground level of housing this sound barrier needs to be tall.

Appendix B

Compilation of reported measurement data

Assessment of measurement data

The data presented in the following was drawn mainly from [12] and supplemental information from respondents to the questionnaire. The measurement data thus obtained was compared to results from Müller-BBM projects and where possible the compilation of measurement data was supplemented by these results. To compare data from different sources it had to be converted to a single noise indicator which here was chosen to be L_{WA} (A-weighted sound power level) complemented by $L_{W'A}$ (A-weighted sound power level per unit length [1 m]).

Comparison of sound power levels from typical noise generating aggregates on trains in different stationary modes

Sound pressure levels for aggregates were always converted assuming a single measurement value to be representative for the surface time-averaged sound pressure level $\overline{L}_{pA}$ on a hemisphere of radius *r* with the source at its centre. In general the distance *r* at which aggregate sound pressure levels were measured was 1 m.

$$L_{WA} = \overline{L}_{pA} + 10 \cdot \log\left(2 \cdot \pi \cdot r^2\right) \quad (3)$$

The results obtained in this way are presented in Table 2 as a range of A-weighted dB- values for the individual aggregates (column 1) in particular parking modes. Note that the informational gain from Table 2 is in no way representative for the entire fleet of rolling stock being operated around Europe. Statistics vary from 0 to 10 measurement reports for the individual aggregate types in each mode.

From Table 2 it can be seen that there is a wide range of noise emission levels for a single aggregate being operated in a specific mode. The noise emission will depend on specific design and installation of the aggregate (including encapsulation), software control and size (as i.e. the noise from an HVAC unit will inevitably scale with the interior volume assigned to it). Largely the range in sound power levels may be attributed to the range of acoustic optimization measures applied (primary measures from the aggregates manufacturer and secondary measures incorporated into train operation and design). The variance of noise emission levels for a given aggregate in a specific mode may therefore reflect potential gain in acoustic optimizations (including retrofitting).

There is a clear gain from applying software control systems that optimize energy consumption and noise emissions as represented by sleeping mode (column 4) over the unfavourable standstill mode (column 2) or the general parking mode (column 3). It should be noted that from an acoustic point of view, parking mode is ill defined as it may be more or less optimized for noise emission. Preparation (column 5) hints towards the increased activity levels and hence noise emissions during the preparation of the train for standard service. The preparation levels will generally apply only for a short period of time. Typical durations of activity for the individual aggregates for an 8 hour night are indicated in column 6.

Table 2 Range of sound power levels L_{WA} deduced from measurements of $L_{pA,eq}$ in 1 m distance from aggregates [dB(A)]. Duration refers to the approximate time of activity for night time parking of the train given in percent and assuming 8 hours parking duration.

	Standstill	Parked	Sleeping	Preparation	Duration of activity [%]
Air compressor	80 – 93	69 – 93	69 – 78	-	5 – 10
Converter	91	74	72	-	100
Transformer	-	-	70 – 76	-	100
Exhaust valve (no silencer)	-	109	-	-	2
HVAC	74 – 88	62 – 88	52 – 73	81	100
Cooling system fans	72 – 79	61 – 79	60 – 72	78	100
Brake test	-	-	-	77 – 109	2
Cooling system pumps	-	76 – 81	66 – 75	-	100
Air conditioning passenger area	-	67 – 78	65 – 76	-	90

Comparison of sound power levels from trains in different stationary modes

To obtain sound power levels for the entire train one of two methods was applied. If the number of the individual noise emitting aggregates *N* on a train was known alongside their sound power levels, the sound power level of the entire train could be computed by summing up of levels. To be representative for the parking duration of the train the individual sources were weighted by their average time of activity *p* (in percent/100).

$$L_{WA} = 10 \cdot \log\left[\sum_{i}^{N} p_i \cdot 10^{0,1 \cdot L_{WA,i}}\right] \quad (4)$$

This method was generally used to obtain the sound power levels for trains in parking mode as listed in Table 3 (column 2). The same method could be applied for standstill mode if measurement data was available. However, to have a larger number of measurements for a train and a better relation to current legislation limits the sound power level of a train was also calculated from results of TSI acceptance tests. The calculation was done assuming the sound pressure indicator value measured according to TSI [18] on stationary trains to be representative for the surface time-averaged sound pressure level $\overline{L}_{pA}$ on a half space cylinder with radius r = 7.5 m wrapping the entire train (the train is viewed as a line source).

$$L_{WA} = \overline{L}_{pA} + 10 \cdot \log(\pi \cdot r \cdot l) \qquad (5)$$

To further be able to compare different train types (as longer trains will generally have higher total sound power levels) the sound power level per unit length [1 m] $L_{W'A}$ was calculated from equation (6)

$$L_{W'A} = L_{WA} - 10 \cdot \log(l) \qquad (6)$$

where l is the length of the vehicle in meter. In the above estimation the areas (quarter spheres) at the ends of the train were neglected.

Note that the compressor of the compressed air supply is generally inactive during TSI acceptance tests, thus the values obtained will generally underestimate actual noise emissions of the halting train. It should as well be noted that different acceptance tests on the same type of train (but with some modifications made due to different customer requirements) resulted in a certain range of values for the total sound power level of the trains in standstill mode. Where possible the value listed is chosen for the exact same type of train that was used to obtain power levels for the parked mode.

The entries for the categories of trains (EMU, DMU, diesel/electric locomotive, passenger coaches) were calculated by combining equation (5) and (6)and using the average measured TSI noise levels for the stationary noise of the train categories reported in [25] (statistics ranging from 7 to 33). For standard measurement positions in a distance of 7.5 m from the middle of the track the sound power level per unit length is obtained from:

$$L_{W'A} = \overline{L}_{pA} + 14 \text{ dB} \qquad (7)$$

The last entry (TSI) revers to the allowed range within the limit settings of the current TSI [18], obtained by replacing $\overline{L}_{pA}$ in the above equation with the actual TSI limit.

Comparison of the values for $L_{W'A}$ in Table 3 shows that noise emissions may be reduced by 10 dB or even more by consequent appliance of a noise optimized parking mode. In general parking noise levels are far below what is requested by TSI for stationary trains (the largest difference being 28 dB). This indicates that the TSI is not an appropriate tool to control parked train noise and parked train noise issues will not be solved by simply requesting TSI conform vehicles in procurements.

Table 3 Total sound power levels for a number of trains in parking mode calculated from summation of sound power levels L_{WA} of the individual noise emitting aggregates (column 2) compared to sound power levels of the same type of vehicle in standstill mode calculated from TSI acceptance tests (column 4). The same power levels are also expressed per unit length (1 m) in column 3 and 5 respectively. One * indicates an acoustically optimized parking mode, while two ** indicate sleeping mode in column 2. In column 4 the ° stands for measurements with a higher aggregate activity level compared to requirements from TSI.

Train type	**Parked** L_{WA}	**Parked** $L_{W'A}$	**Standstill** L_{WA}	**Standstill** $L_{W'A}$
Flirt 75	74*	58	83	68
Flirt 100	78*	58	86	66
GTW 55	74*	57	87	70
TGV	92	69		
RV-Dosto	83*	63		
DTZ	85*	65	94°	74
ICN	87	64		
DPZ+	77*	57	101°	81
Domino 75	89	71		
Domino 100	89	69		
RV-Dosto 150	73**	54	97	78
RV-Dosto 100	73**	55	95	77
ICE1/ETR610	92	69		
Re460+EW4	91*	66		
EMU				69
DMU				81
Diesel locomotive				82
Electric locomotive				76
Passenger coaches				74
TSI				82 – 89