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A Study of European Priorities and Strategies for Railway Noise Abatement

Final Report

EU Commission, Directorate-General for Energy and Transport
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Executive Summary

Nearly all EU member states and 5 non-member states have legislation concerning the maximum limit for railway noise reception levels. A few member states have legislation for the maximum emission level for vehicles, and another few states have published proposals for future maximum emission levels.

EU has for many years had legislation for the maximum emitted noise level from road vehicles and aircraft. Similar legislation for rail vehicles does not exist yet. Supplementary legislation covering all EU member states on the maximum noise emission level from rail vehicles is therefore needed. It is the purpose of this study to prepare the technical documentation, which makes it possible for the EU Community to fill this void. This Main Report with its two corresponding Annex I, describing the current legislation, and Annex II, describing a number of low-noise design cases, contains this documentation.

The retrieval of the current legislation described in Annex I has shown that there are large deviations in receptance levels from member state to member state, and only a few member states have legislation on emission levels. This situation necessitates a European legislation so interoperable vehicles can operate over the entire rail network. The proposed EU emission levels comply with the already existing national emission levels.

The low-noise system cases – described in Annex II - show that many technologies and products for noise reduction have been developed and are available on the market. Quiet vehicles and tracks already exist. Modern maintenance equipment, which can be applied to keep the railway systems quiet, is also commercially available.

Based on the demonstration of the current technical state-of-the-art in low-noise design, a set of figures for the future maximum noise emission from rail vehicles has been prepared. There is a set of figures for interoperable conventional rail vehicles and high speed trainsets (HST), and there is also a proposed set for non-interoperable vehicles. This means that all types of vehicles are covered, regardless of whether they are interoperable or not. The reason for this is that the Study Group has decided to recommend the EU Community to support the single market for rail vehicles by including vehicles that are not interoperable.

The Study Group recommends the EU Community to adopt a stepwise procedure consisting of as a first step a short-term set of noise emission levels, comprising the stationary condition and rolling at constant speed on tangent track. The second - longer term - step is proposed to be taken when sufficient experience with the administration of this limited type of operating conditions has been achieved. The EU Community is recommended – in the second step - to enlarge the legislation with other types of operative conditions than constant speed at tangent track and stationary. These types of additional operating conditions comprise curve driving, accelerating, braking, shunting, parking and similar well-known railway operations.

Due to the fact that rail vehicles have very long expected length of live, sometimes as much as 30-40 years, it is not sufficient to provide legislation on new rolling stock. In order to reach noticeable reductions of railway noise as soon as possible in-use rolling stock should be subject to noise requirements as well and either be scrapped or retrofitted to modern standards. Instruments that could be used are either voluntary agreements between the European Union or legislation in the form of a railway noise directive.

The Study Group has investigated various principles of enforcement in order to ensure that the vehicle conforms with the noise limits. It is recommended that the conformity check of each vehicle or trainset is done by the operator of the vehicle and that the relevant member state authority be responsible for monitoring that the operator's conformity check is done properly and results are available for future adjustments. According to the TSI the conformity checks should be done at regular intervals, but the Study Group proposes that it should also be possible for the operator as a voluntary alternative to use spot checks or continuous monitoring instead. This should be possible in case the operator can prove that these methods are more effective or feasible. An argument for employment of different methods for different railway systems is that the rail vehicles are very different in size, operating speed and design.

Furthermore, since it in nearly all cases is the change in wheel surface quality, which causes a change in the noise emission it should be possible for the operator to replace a noise conformity test with a – possibly easier - test of the wheel surface condition. Specifications for such a test and the limit values in each case could be prepared in the framework of the interoperability directives and presented in a TSI.

Prevention and removal of roughness on wheels (and rails) are closely linked to whether the vehicle conforms to the noise emission criteria or not. Of practical reasons – because the noise level type test takes place with wheels at their best possible surface condition - wheels should be allowed to have a level of roughness that causes a level a few dB's above conformity level. The report suggests this criteria for each type of vehicle.

1. Preface

This report has been prepared as part of the project performed under contract “PTREN E2 2000-6/SI2.300104” between the EU Commission and Ødegaard & Danneskiold-Samsøe A/S (ODS). The study has been performed by a group of companies shown in Section 12 of this report.

The project has been initiated by the Commission (DG TREN) by its “Invitation to tender No. TREN/E2/23-2000 concerning a study of European priorities and strategies for railway noise abatement”[1.1].

The background to the call for the tender is that the Commission is carrying out work to evaluate the possibilities for railway noise abatement and to prepare noise emission legislation. A working group (WG6) with representatives from Member States, railway industry, non-governmental Organisations and other stakeholders has been organised to work on the technical and economic aspects of noise reduction (by source) from rail transport. The objectives are to support the Commission with development of legislation/standards and to outline priorities for noise abatement. WG6 has discussed the different reports of this study in its regular meetings. The findings of the study are supposed to form an input to the drafting of a position paper by WG6 on strategies and priorities.

ODS proposed to carry out the study as described in the “Scope of Work”[1.2], which was submitted to the EU Commission as part of the ODS proposal.

ODS has been the leading company but has been supported by the following partner companies in the preparation of this report: psiA-Consult, STUVA, and akustik-data. Furthermore, FRAMA01 dB and Politecnico Torino have participated in the below-mentioned Annex I.

The project was performed during the period from early January 2001 to late August 2001.

Attached to this report are the following Annex I and Annex II, which have also been prepared under the same project.

Annex I: A Study of European Priorities and Strategies for Railway Noise Abatement. Report II. “Retrieval of Legislation” by Uffe Degn, Louise R. Villefrance, Christopher Maxon, Ulrik Danneskiold-Samsøe, Friedrich Krüger, Manfred Kalivoda, Bela Buna, and Marco Masoero. ODS Report 01.978. August 2001. ODS Reference No.: 00.2335, 63 pages.

Annex II: A Study of European Priorities and Strategies for Railway Noise Abatement. Report II. “Retrieval of System Cases” by Ulrik Danneskiold-Samsøe, Uffe Degn, Bernd Barsikow, Friedrich Krüger, and Manfred Kalivoda. ODS Report 01.979. August 2001. ODS Reference No.: 00.2335, approximately 150 pages.

Copenhagen 4 February 2002
Ulrik Danneskiold-Samsøe

2. Introduction

For many years most of the EU member states have had national reception levels for road, rail, and airport noise. Furthermore, the EU Community has had limits for noise emitted from road vehicles and has adapted international limits on noise emitted from aeroplanes.

An obvious void has therefore been present for years concerning limits for noise emitted from rail vehicles. The study documented in this report and its two Annex I and Annex II is one of the steps the EU Community has taken to fill this void.

The reason for the members states not have had noise emission limits may be the fact that the market typically has been dominated by one national rail carrier, which had their own environmental protection department. The governments may therefore have seen no need of pursuing specific legislation of rail vehicle emission levels, since this question – in theory – already was being handled by an organization controlled by the government themselves.

The report and the separate Annex I and Annex II have been prepared as background documentation for the position paper on railway noise abatement strategies that will be drafted within Working Group 6 (WG6) on railway noise. It will also serve as background to a position paper to be prepared by the WG6 concerning the future EU Community railway noise emission levels and corresponding timetable.

The purpose of the report is to propose the strategy that fulfils the following objectives of the EU Community:

- Enlarge the single market to the railway industry.
- Support the desire of upgrading the competitiveness of the railways by moving freight from the road to the railway and passengers from the aeroplane to the high-speed train as outlined in the recently published White Paper on European transport policy for 2010”[2.1].
- Elaborate a railway noise policy within the EU noise policy framework.
- Reduce the noise level along the railway lines.

3. National railway noise legislation

A survey of the noise legislation has been performed. The results of the survey are described in a separate report; Annex I to this report.

Annex I describes the railway noise legislation of the 15 EU member states as well as Norway, Switzerland, Hungary, Czech Republic, and Poland. Furthermore, the Annex I describes the method applied for retrieval of the legislation, and the results of a comparison between each set of legislation.

For each state a chapter is presented with comments to the legislation and regulations. References to the governing documents are given as well.

The noise limits set out in the different states are based on slightly different definitions. Consequently, it has been necessary to normalise the limits in order to compare the levels from the different states. In Figure 3-1 the noise reception limits are shown for the states having limits set out.

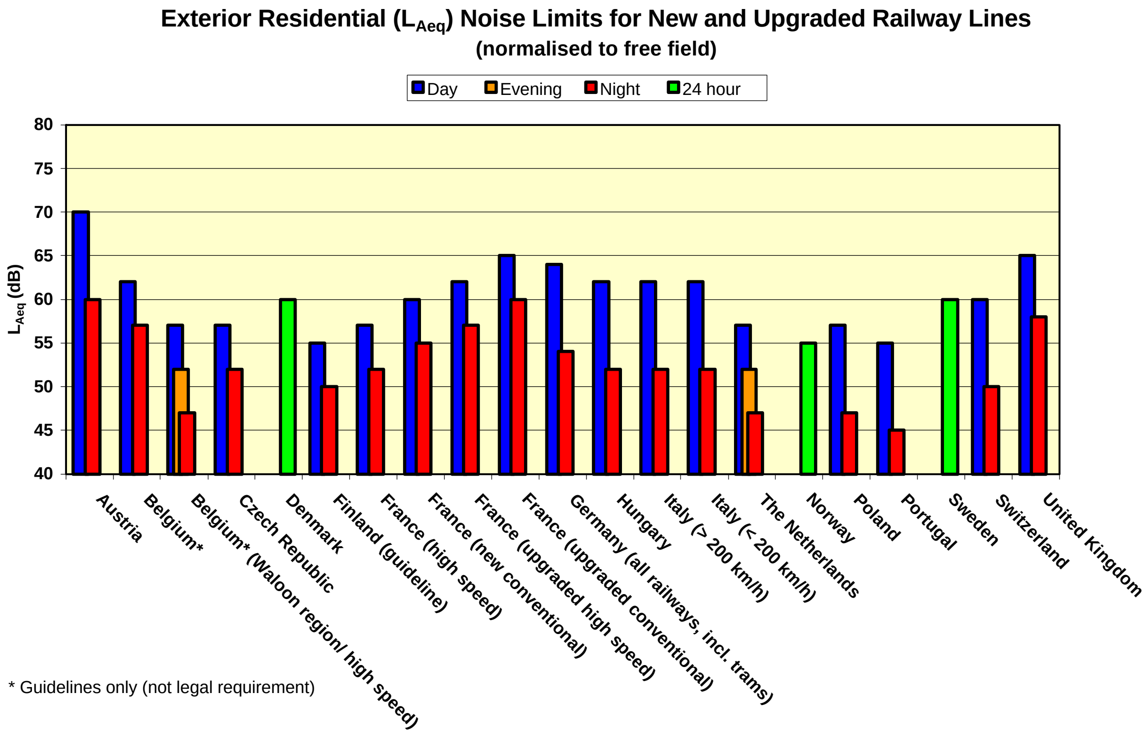

Figure 3–1. Noise limits for noise reception. Exterior residential (L_{pAeq}) noise limits for new and upgraded railway lines (normalised to free field). From Annex I.

For the noise reception limits the equivalent sound pressure level (L_{pAeq}) is used as the common noise parameter. Corrections regarding “free field” vs. “facade” and application of rail bonus have been necessary. The majority of states do have legislation on noise reception.

For the noise emission limits set out for vehicles the pass-by noise is used. The noise indicator used in the present legislation is the maximum pass-by noise level (L_{pAmax}) measured 7.5 metres or 25 metres from the track at a given speed. Only a few states do have legislation on noise emission.

3.1 Conclusion of the legislation study

Nearly all EU member states and 5 non-member states have legislation concerning the maximum permitted railway noise reception levels for new and upgraded lines. A smaller group has official noise limits for existing lines (CH, S, N, NL, I, DK) or has guidelines for the maximum noise level (CZ, SF, H, PL). Finally, a few member states have legislation for the maximum emission level from rolling stock, and another few states work on proposals for future maximum emission levels.

At the moment compliance tests are made locally or on a national level only. The legislation report has disclosed a need for more information on the acoustical properties of the source, which will provide better tools for compliance with the reception levels.

Common for all current legislation is that the legislation is valid for domestic use only, and this includes both emission level and receptance level.

The railways are, however, very international and rail vehicles travel through many member states. Each rail vehicle has to be designed and maintained in such a way that it complies with the current national legislation of the countries in which the vehicle runs. This means that each rail vehicle is subject to different requirements dependent on the country in which it is operated.

In order to ensure that a rail vehicle is ”legal” regardless of where it runs, a common EU railway noise legislation is needed.

3.2 Analysis of the national receptance level

There is a considerable spreading in the maximum noise level between the member states. This spreading is easily seen in Figure 3–1. Based the level illustrated in Figure 3–1 a comparison of the maximum receptance noise level some corresponding characteristic features of each member state has been tried.

As examples it has been investigated whether there was a correlation between the climates, or the population density, or the GNP per inhabitant, and the allowable maximum receptance noise level for the member states. The conclusion is that has not been possible to disclose such a correlation.

The Study Group has therefore concluded that there may be other reasons for how the member states originally has defined their individual maximum level.

3.3 Need for supplementary legislation to limit emission level

Therefore, a void exists for additional legislation common for the entire EU to limit emission levels on railway noise. When specifying such emission levels the following items have to be considered:

- The general EU legislation on environment, the polluter pay policy and the subsidiarity principle.
- The specific railway technical prerequisites (wheel and rail wear), that change the noise level and therefore have to be included.
- The specific railway prerequisites of operational nature, where one group of vehicles is interoperable and another group is purpose-built, and therefore not interoperable.
- The emission levels are maximum levels, which allow a local vehicle operator to specify even quieter “super low-noise” trains if desired.

Other key items, which have to be taken into consideration, are the following:

- The noise reducing potential of the EU strategy. The key content of this statement is, if an audible improvement shall be obtained, that it is absolutely necessary to reduce the noise originating from the largest noise sources. Otherwise it will not be possible to reduce the receptance level along the existing railway lines. The consequence of this is that the EU strategy must not be limited to new vehicles but also include in-use vehicles.

- Cost/benefit considerations. The strategy must include cost/benefit points of view, i.e. include the measures providing the largest noise reduction per unit EURO. The comparison items are here:

Vehicle/Track:	Investigations have shown that the best cost/benefit result is obtained if the investment is used for reduction of the vehicle noise. It is therefore clear that the EU legislation should give vehicles the highest priority.
Maintenance costs:	Improved maintenance has a reduced noise level as a side effect. For the same investment more than one advantage is obtained. The future EU legislation should therefore include requirements for the quality of the maintenance, so the vehicles remain quiet.
Preventive measures:	Preventive measures, performed either during the design phase or later during the operation, can reduce the generation of noise and therefore also reduce – or even eliminate – costly treatment. Preventive measures will reduce the maintenance costs and should therefore also be encouraged.

- Time considerations. Since noise reduction takes time, the time scale can also be used as part of the strategy. The industry needs time to perform additional R&D work including the tests, which are required for safety. Parameters, which are important in the time scale part of the strategy, are periods, which have to be included before stricter legislation comes into force.

4. European Union noise and transport policy

In 1996 the Community took the first step in the development of a new European noise policy when publishing The Green Paper on Future Noise Policy (COM (96) 540). Based on this document a programme has been established and actions have been taken in the meantime with the aim that no person in the European Union should be exposed to noise levels that endanger health and quality of life.

According to The Green Paper 1.7 % of the inhabitants of the EU corresponding to approximately 7 million persons are exposed to a railway noise level of 65 dB(A) during day time This level is normally regarded as above an acceptable level. Furthermore, an even larger amount of persons is exposed to a railway noise level of 55 – 65 dB(A), which is regarded very annoying.

Noise from rail traffic is one focus since rail traffic is the only transport mode for which noise emission is not limited yet. In the early eighties there were attempts to get rail noise regulated, unfortunately they failed. In 1993 Austria was the first country to introduce legally binding noise limits for domestic rolling stock, some other countries do have recommendations. However, a Europe-wide railway noise legislation is still missing.

On the other hand noise from railway lines is assumed to be of environmental relevance since it is included in the proposal for a European Parliament and Council Directive relating to the Assessment and Management of Environmental Noise.

There is a general political intention to shift short haul air transport to high-speed rail transport and heavy duty road transport to rail freight transport. Generally rail transport is assumed environmentally friendly. In some cases new railway lines do not get acceptance from the people living close to these new lines due to concern about unacceptable noise levels. Being unable to generate the necessary rail capacity will jeopardise the political objective of a modal shift.

The fact that noise from railways is generally less annoying than noise with the same equivalent level from road traffic has been reflected by national noise reception legislation by introducing a so-called rail bonus. However, this does not really help in the discussion with neighbours of a new railway line since noise generation from trains is said still to be too high.

There has been a progress in the past in railway noise reduction. The replacement of cast iron bloc brakes by disc brakes in most of the new-built coaches led to a significant reduction of noise generation from this vehicle type. Since cast iron bloc braked vehicles have rougher wheels than disc braked ones and contact roughness of the wheel rail interaction is the main driver for rolling noise, the focus has to be on the replacement of cast iron brake blocs.

Nevertheless, the progress was not primarily planned as a noise reduction measure but had its origin in non-acoustic requirements. Disc brakes had to be used in modern coaches to allow higher speeds than about 140 km/h. Since there was no non-acoustic technical need to replace the cast iron bloc brakes in freight wagons, noise generation from this sort of rolling stock did not change significantly the last decades. This lack of technical progress made noise from freight wagon’s the dominating railway noise problem in Europe, which is also reflected by the priorities of WG 6.

4.1 Interoperability of rolling stock

Rail traffic has always been “highly international” so also in the past issues of interoperability had to be managed and regulated. The UIC as a railway association and international agreements on vehicle exchange like RIC and RIV were the forums where international harmonisation took place. Regardless that UIC has not issued requirements on the noise generation from rolling stock the UIC has played a key role in managing the technical work to approve the new freight wagons with K-blocks, i.e. composite brake blocks. The K-blocks were homologated for a three years trial period in September 2000, following extensive tests. The final and permanent homologation could be expected when the three year period ends and conditioning that further tests confirm that the new brake blocks meet all requirements.

It was not possible on a national level to regulate the international traffic. National legislation like the Austrian SchLV [4.1] has always been limited to vehicles registered in the specific country and thus had no great effect on noise reception. Consequently the EU had to introduce noise as a criterion for interoperability. The Technical Specifications for Interoperability (TSI) for a Trans-European High-Speed Rail System [4.2] as well as for the Trans-European Conventional Rail System [4.3] are intended to limit noise emission from interoperable rolling stock.

4.2 Freedom of Trade

Due to the absence of a general European regulation there is a tendency to limit noise from rolling stock nationally. Such an approach will not really stimulate the freedom of trade and will build up administrative barriers thus making the rail market less competitive compared with other transport markets. In order to support a European Single Market also for non-interoperable rail vehicles, so noise emission will not be a barrier to the free trade of rail vehicles, the Study Group suggests that noise emission limits be prepared for the following types of rail vehicles:

Vehicle Type	**TSI-required, interoperability**	**Single market support**
Light Rail Transit (Trams and metros)	NO	YES
Conventional Multiple Units and Railcars	YES	YES
High Speed Trainsets	YES	YES
Locomotives, new	YES	YES
Passenger coaches, new	YES	YES
Passenger coaches, after brake retrofit	NO	YES
Freight wagons, new	YES	YES
Freight wagons, after brake retrofit	NO	YES

Table 4-1. Noise emission limits should be implemented for the rail vehicles shown above.

As shown in Table 4-1, the Study Group suggests that emission levels for all types of rail vehicles be implemented. This means that also non-interoperable vehicles will be included. The reasons for this are the following:

1. The testing costs for the manufacturers will be significantly reduced. Each new type of vehicle needs only to be tested once instead of once per member state or even once per operator. This means that the testing costs will be reduced, and that more means can be invested in providing the best testing conditions possible. Individual representatives of the rail vehicle manufacturing industry have stressed this fact to the representatives of the Study Group.

2. The same maximum noise emission limit covering the entire single market area for each type of vehicle means that the industry can increase the amount of identical vehicles, which are produced and thereby reduce the unit costs. This will provide a better competitive position for the railway industry and thereby be in line with the EU transport policy.

3. The same legal emission limit for each type or class of vehicle will support the "platform concept", which the leading vehicle manufacturers have adopted in recent years.

4. The same legal emission limit will eliminate the problem of purchasing, selling or renting railway vehicles across the member state borders and thereby support the single market for railway vehicles.

5. The same emission limit for each vehicle class will provide a more open market for the new vehicle leasing companies, which are emerging in these years as a consequence of the privatisation of the railway operating companies. In case individual emission levels survive for non-interoperable vehicles it will be more difficult to rent out vehicles.

6. EU will - by setting common emission limits also for non-interoperable vehicles - be copied by many other states or operators outside the EU. This will put the EU vehicle manufacturing industry in a competitive position, since the industry has already products, which comply with the EU emission limits.

4.3 Noise emission from other transport modes

Figure 4-1 shows the development of permitted noise emission limits for road vehicles from 1975 up to now. Noise emission from heavy duty vehicles has been reduced in the European Union by 11 dB(A) from 91 dB(A) down to 80 dB(A). Noise emission limits from passenger cars has been reduced 8 dB(A) from 82 dB(A) down to 74 dB(A). However, due to type-testing conditions developed when engine and exhaust system noise was the dominant source the actual noise reduction under everyday operation conditions has been lower than the reduction of the limits would indicate.

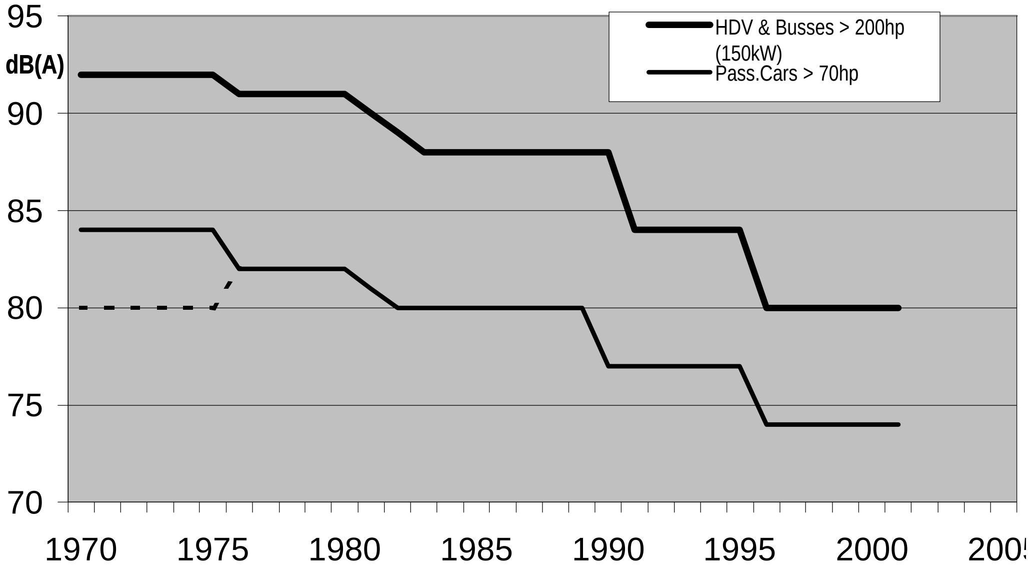

Figure 4–1. Time series for the noise emission limit for road vehicles.

A similar development took place in the civil aviation. In April 2002 the ban of noisy aircraft, which comply with Chapter 2, ICAO Annex 16, will be introduced in Europe so only quieter aircraft, according Chapter 3 of ICAO Annex 16, will remain in service in Europe.

4.4 Conclusion

The review of the political background to European railway noise policy shows that there is an urgent need to limit and reduce noise generated by railbound vehicles.

5. Case retrieval on railway noise reduction potentials

A case study has been prepared and the result is presented in Annex II “Case Study” to this report. The purpose of the case study has been to present successful low-noise design projects, which illustrate the current state-of-the-art and can be used as inspiration for preparation of the EU noise emission limits.

The Study Group has made some priorities in the selection of the cases.

a) Rolling noise has been given first priority. Noise emitted from the traction machinery, activation of brakes, curve squeal, shunting, and passage of rail joints and switches has been regarded secondary compared to rolling noise.

b) Vehicle emitted noise has been given first priority compared to track emitted noise. Regardless that the noise emitted from the wheels and the rails is often claimed to be of the same order. The reason for this is that vehicles must be allowed to run across Europe and produce their noise everywhere, but tracks produce noise only locally and their emission could consequently be regulated locally. The Study Group thus regards reduction of the noise emitted from the rails and other components of the track to be subject to the subsidiarity principle. Although the track, which shall be used by interoperable vehicles, is fulfilling the standards for interoperability it is the point of view of the Study Group that all types of track shall be subject to the subsidiarity principle. The acoustical properties of the track shall therefore purely be under national responsibility.

   The are at least two reasons why the Study Group regards the subsidiary principle to apply for the track. The first is that the Study Group regards the track to be equivalent to the road, which is also – as far as the Study Groups knows - subject to the subsidiarity principle. Each member state maintains its roads according to the national standards for roads. The second reason is that track maintenance like grinding should be regarded as a noise reduction measure equivalent to other types of noise reduction measures on the track. Such measures all are decided on a member state basis regardless of the fact that grinding is also done for other reasons than noise reduction.

c) The Study Group does not regard a low-noise design as a sufficient means to ensure conformity. Application of maintenance procedures, which are applied to keep the surfaces of the wheels and the rails sufficiently smooth, is also necessary. Cases on modern maintenance methods including preventive design, preventive maintenance procedures, noise or wheel/rail surface smoothness monitoring and treatment have therefore also been included.

5.1 Retrieval of cases on low-noise design of railway systems

In order to obtain as much information as possible about the presence of successful low-noise design cases a direct mail campaign was pursued at the beginning of the study. The amount of replies obtained from the operators, the manufacturing industry and various research and development institutions was poor. Approximately 5% of the addressees replied. An example is Germany, where more than 200 letters were submitted. Partly as a replacement of this poor response the Study Group has therefore used its own professional network to obtain information about the cases.

The cases presented predominantly comprise passenger vehicles. The operators and the industry have made a great effort to reduce the noise emitted from new passenger vehicles. Cases describing reduction of the noise from freight vehicles and the reduction of noise as a result of better maintenance methods are much more scarce. The Study Group would have been pleased to present more cases on these two subjects, if more cases had been made available to the Study Group.

5.2 Cases of low-noise design

The cases, which have been described in Annex II, are the following with the numbers for each corresponding to the actual chapter number in Annex II:

4. Design of track
5. Design of trams and light rails (Variobahn vehicle in Chemnitz)
6. Design of underground and similar vehicles (DT4 car in Hamburg)
7. Design of S-Train and suburban EMU's (DSB S- Train 4th generation train)
8. Design of high speed trains, HST (German ICE)
9. Design of passenger cars (ICE middle car)
10. Design of locomotives (LOK 2000 in Switzerland)
11. Design of freight cars (various brake replacement projects)

A summary and an A4 datasheet describing the main data for each case are shown in section 12.

Regardless of the fact that most noise measurements have been performed according to the existing measurement standard ISO 3095 the measured figures have been converted to the new figure for pass-by noise emission level, the TEL level specified by the new measurement standard prISO 3095:2001 [5.1].

The noise level of the vehicles described in Annex II has been compared with typical figures for vehicles of the same type or older vehicles used on the same network. A graph showing the emitted noise level per vehicle type together with the corresponding level for typical or older types of vehicles is presented in Figure 5.1.

The main conclusions are the following:

a) The TEL_{80} figure for the low-noise rail vehicles lies in the dynamic range: 74–83 dB(A). The HST is not included.

b) The difference between a typical “noisy” vehicle and a low-noise vehicle lies within the dynamic range: 15–20 dB.

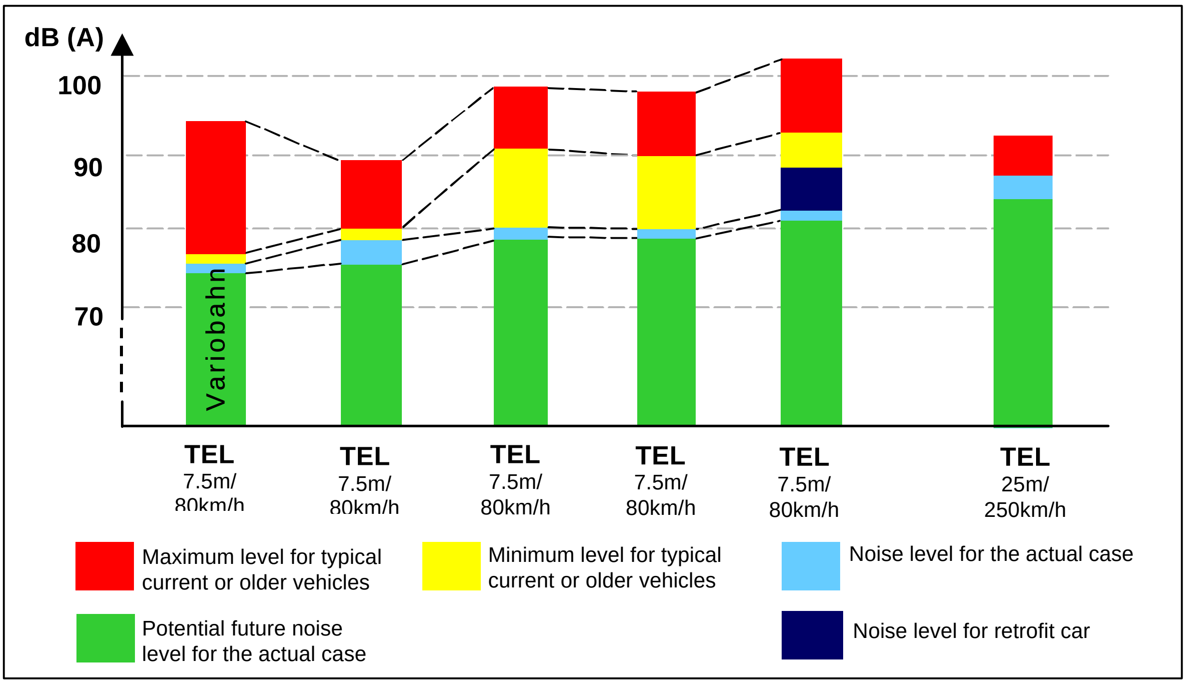

Figure 5–1. The emitted noise level measured as the TEL_{80} level in dB per vehicle type together with the corresponding level for typical or older types of vehicles.

With reference to the content of Annex II it has been proven that the following figures shown in Table 5-1 have been obtained in real projects:

	L_{Aeq}		TEL											
Speed km/h, 7.5 m	**Stat.**		**40**		**80**		**200**		**250**		**300**		**350**	
Case result/Proposed EU noise limit	**C**	**EU**	**C**	**EU**	**C**	**EU**	**C**	**EU**	**C**	**EU**	**C**	**EU**	**C**	**EU**
LRT's			68		76									
Conventional Multiple Units	58				80									
Locomotives, new					80		92							
Passenger coaches, new					75		87							
Passenger coaches, after brake retrofit					80									
Freight wagons, new					81									
Freight wagons, after brake retrofit					85									
High speed trainsets, 7.5 m							88		90		93		97	
High speed trainsets, 25 m							83		85		88		91	

Table 5-1. Figures "C" for the stationary and pass-by noise level obtained during the case study and documented in Annex II. The "EU" columns could be used for comparison with the proposed maximum noise level.

5.3 Cases of wheel/rail surface maintenance

Roughness of the surfaces of the wheels and the rails is the main contributor to an increase of the noise level. Several investigations have shown this relationship, and an increase in noise level of 10–15 dB caused by roughness has been seen. It is therefore important to keep the roughness at a moderate level.

It will be meaningless to design a low-noise vehicle without maintaining the wheels and the rails in such a way that the vehicle remains low-noise. Otherwise the investment in low-noise design is wasted and conformity will not be maintained.

As shown below, Annex II therefore contains a chapter describing methods for noise monitoring of the track, i.e. monitoring of the roughness of the rails and a chapter describing the integrated wheel monitoring and maintenance programme at the Copenhagen S-Train system:

- Rail surface monitoring and maintenance
- Wheel surface quality monitoring and maintenance

Maintenance can be pursued in many ways, and the conformity of the vehicles can be checked by means of a number of different methods, which obviously have to be relevant for each type of vehicle. Typically passenger vehicles are maintained more often than freight vehicles, and this fact stresses the necessity of good maintenance programmes for freight vehicles, so they conform.

Common for all vehicles is, however, the fact that a certain increase has to be allowed in roughness or noise level compared to the level measured at the type test. This allowed increase in roughness or noise level should be defined by the EU Community just as the Community publishes limits for the emission level measured during the type test. The noise increase should be caused by wheel roughness only. The Study Group regards the roughness of the rails to be covered by the subsidiarity principle.

Finally, the Study Group would like to stress that many kinds of maintenance technology are available on the market today. The cases have shown this very clearly. The planned future systems for identification of vehicles will be a very helpful tool in vehicle maintenance. As described in the cases better maintenance made for the purpose of noise reduction will also provide savings in other track and wheel maintenance costs.

5.4 Conclusion

The case study has shown:

- That it is possible – by means of known and commercially available technology - to build vehicles which are much quieter than rail vehicles built in the past,

- that the TEL_{80} figure for low-noise rail vehicles typically lies within the range of 74–83 dB(A) - all measured at an unknown rail and wheel roughness - and

- that much monitoring and maintenance technology, which can be used directly for check of the noise level and treatment of noisy wheels, is available on the market.

6. Legal, administrative, and economic measures

The most effective way of abating noise is to reduce and limit noise generation. Experience from a Swiss study [6.1] on the cost benefit ratio of different noise control strategies like reducing noise generation, building noise barriers or improving sound isolation of windows shows that impressively. The total costs of a certain level of protection could be reduced by 50% by introducing less noisy vehicles (including the existing ones) in combination with noise barriers and sound isolating windows instead of building noise barriers only.

The 5th framework R&D project STAIRRS prepares a Cost-Benefit-Analysis tool which will allow to assess different combinations of noise reduction measures. This study is in preparation at the moment and final results will be ready in one year. However, even now it can be expected that reducing and limiting railway noise generation will be an appropriate strategy on the European level as well.

The conclusion is that reduction and limitation of noise generation are the essential first step to improve the situation. However, a number of additional measures are necessary to stimulate development of quiet rolling stock and tracks and to stimulate the use of quiet railway technologies and operations. This chapter is going to summarise all measures and form a strategy.

6.1 Noise Emission Limits

The Study Group regards the stationary noise and the pass-by noise at constant speed on a straight track to be included in the short-term emission limits. It is clear that these conditions do not cover all the noise sources that could be relevant. The authors of this study are well aware that the proposal does not cover all the sources. However, in a first step it is essential to cover pass-by noise at constant speed. This noise has been dealt with for years and very good knowledge of the noise generation mechanism as well as the measurement methodologies is available which will lead to traceable and reproducible results.

Although other operational conditions like acceleration and braking are covered in the PrEN ISO 3095, the measurement methodology for those conditions appears not to elaborate enough to get reliable results with low standard deviations. The ISO standard is still in the review process and there is some national concern about these procedures. Also the Commission through DG Environment had the ISO reviewed with regard to its applicability to European legislation on railway noise generation (Dittrich [6.2]). This led the Study Group to the decision to exclude acceleration and braking at this stage of the discussion on emission limits for rolling stock and postpone regulation of this type of noise.

From the environmental effects it appears more beneficial to introduce noise limits which cover only 90% of the noise problem than to get a procedure that does not deliver reliable results or to wait some more years without any action and then cover about 92% of the problem.

There is another aspect still under discussion in the scientific community namely the influence of track and track conditions on vehicle pass-by noise. Research in this area which aims to separate noise contribution from track and vehicle is on the way but a practically tested method will not be ready before 2003. Rail roughness is well covered by prEN ISO 3095 but also other factors like pad stiffness can influence results in a range of 3 to 4 dB(A). The numbers in the tables below are based on a low-noise standard track as described in the annex of prEN ISO 3095. This track is concrete sleepers with UIC 60 rail profile and acoustically optimised pads (stiffness).

In a second step, i.e. longer term, also acceleration and braking should be included. In order to specify a sound methodology for these operation conditions and to be able to determine limit values for all listed operating conditions, it will be necessary to carry out further R&D work.

6.2 Voluntary agreements

Voluntary agreements between the European Community and the industry can be a powerful measure to retrofit existing rolling stock if existing vehicles cannot be included in a European legislation on railway noise generation. This will help to speed up the implementation of the noise reduction of the entire fleet and thus effectively lower the noise reception. The UIC action plan and several earlier proposals from the industry indicates that there might be possibilities to find a scope of such an agreement.

6.3 Emission based track access charges

Emission related track access charges are a tool, which should be used to stimulate the improvement of the fleet used and thus be an environmental incentive. Several approaches are possible from a cost-neutral track access charge including noise emission through a ban of very noisy vehicles. In the Netherlands different systems are discussed at the moment, Dittrich [6.3].

Introduction of noise related track access charges can be expected as a consequence of the liberalisation of the European railway market with different ownership of rolling stock and track and the main responsibility for the compliance of the railway network with noise reception limits put on the infrastructure owner. The recently published Directive 2001/14/ on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification [6.4] allows to modify the infrastructure charge to take account of the cost of the environmental effects caused by the operation of the train. Implementation certainly needs a vehicle identification system to allow to allocate the charge to the individual vehicles of a train in most cases owned or operated by different companies.

An automatic European train and vehicle detection system will help to simplify charging. However, even now when such an automatic identification system is still missing, allocation of track access charge to individual vehicles is possible. Most of the European railways already run a computer based train identification system which helps to follow a train from its origin to the destination and includes a list of the vehicles in the train with essential information such as length, number of axles and weight. Noise emission could easily be added to the existing system (Kalivoda & Kudrna [6.5]).

Nevertheless it must be clear that all future legislation on track access and access charging has to take the noise issue into account. At the moment there is a discussion of whether, in the future, there should not be any obligation for train operators to inform the infrastructure manager of which vehicles he is actually running in his train. It must be clear that such an approach would be counterproductive from the noise abatement point of view at least. The example of air traffic industry shows very well that even on a liberalised market it is still possible to transfer this kind of information from one partner to the other in the game. Airport and air traffic managers receive information on operator of a flight as well as on the aircraft identification and aircraft type used. On this information air traffic control fees, airport landing fees and noise fees are charged by the air traffic or airport manager. This procedure could be transferred to railways as well.

7. Strategy for check of conformity

Noise emission limits only have a meaning if conformity remains. Conformity remains when the vehicle complies with the maximum noise emission figures measured according to prISO 3095:2001 and added a few decibels (se Section 9.4) allowing creation of a certain degree of wheel surface roughness originating from use of the vehicle in service.

7.1 Background

It is stated in Article 14(2), which is included in the directive for conventional rail interoperability (01/16), that each member state shall check when they are put into service and at regular intervals thereafter that the subsystems (e.g. rolling stock) are operated and maintained in accordance with the essential requirements concerning them.

Until now noise specialists have agreed that lack of compliance with conformity predominantly is caused by the wheel surface condition. The noise level generated by the traction equipment and other types of machinery as well as aerodynamic noise does not change very much after the type testing has been done. The problem with the wheel surface condition is that it is not very well documented how quickly it changes with time. This lack of knowledge causes difficulties in defining the maximum duration of time between each conformity check.

As an example it is known – and shown in Annex II - that the wheel surface condition is influenced by the wheel steel quality, the axle load, the adhesion coefficient (which can vary very much), the possible surface treatment after reprofiling, and the braking principle (dynamic brake or disc brake or block brake). This means that the surface condition is dependent on the vehicle design and the operating conditions.

It should therefore be seriously considered whether periodic checks – like used for road traffic vehicles - are reasonable and sufficient to ensure conformity. This consideration should comprise pass-by noise only. Conformity check of the noise level at stationary condition is not regarded necessary unless replacement of major machinery takes place.

As previously described no international legislation on the noise emission from rail vehicles exists. Consequently prior international procedures for check of conformity do not exist either. Furthermore, regardless of the fact that many railway operators have had specifications for the maximum noise emission level measured at the commissioning stage, the level has seldom systematically been checked at a later stage during operation.

Instead the national operators have kept the noise level down by reprofiling the wheels regularly. The reason for reprofiling the wheels is typically different from vehicle to vehicle and from operator to operator, but noise is only one argument among a number of arguments for reprofiling the wheels.

The current situation is therefore that check of noise conformity is a new activity for the rail operators.

7.2 Technical considerations

In case the check of conformity of each rail vehicle should take place at regular intervals using the prISO 3095:2001 the check could be a significant economical burden for the railway industry. Both with respect to direct costs when moving the vehicle to a suitable testing site and with respect to indirect costs as the vehicle would not be available for traffic during the testing. It would therefore be very attractive to suggest a simpler and cheaper procedure, which will have the same final result.

7.2.1 Noise level and wheel surface quality relationship

It is well known that there is a close relationship between the wheel and rail surface roughness and the emitted noise level. Since the rail surface is suggested to be maintained according to the subsidiarity principle it would be obvious to check the quality of the wheel surface. In case the surface quality remains constant the emitted noise level remains constant as well. In case the surface quality deteriorates and the surface becomes rougher – or even gets defects – the noise level increases accordingly.

Unfortunately there is – at present - no internationally approved algorithm, which can be used to predict the noise emission from the wheel. The noise emission will depend on the geometry of the wheel, use of noise reducing measures like absorbers or resilient layers, and use of wheel mounted brake discs. A possible short-term solution for the operator will therefore be to prepare a vehicle specific empirical relationship between the wheel surface roughness and the emitted noise level.

7.2.2 Costs of check of the noise level or the roughness level or both

The costs of conformity checks will depend very much of the method applied and how often the check is being done. In case a noise or a roughness check has to be performed the following parameters, which influence the noise level, have to be observed:

<u>Noise conformity check (pass-by level at the track side):</u>

- Vehicle operating conditions (speed).
- Site conditions (topographic, weather, acoustic propagation, neighbouring track, and background noise).
- Track conditions (tangent track, documentation of roughness, ballast condition, rail mounting stiffness).
- Access to the test section in the track and availability of the vehicle.

<u>Wheel roughness check.</u>

- Checked indirectly by measurement of the rail vibration during vehicle pass-by (each wheel can easily be identified) or checked directly in the depot measured on the wheel above the pit.
- The check can be combined with other types of wheel condition checks (cracks, profile wear, surface defects) thus minimising unavailability costs.
- The actual noise level is checked by means of an empirical relationship between the wheel/rail noise level and the wheel roughness developed for the actual type of wheel.

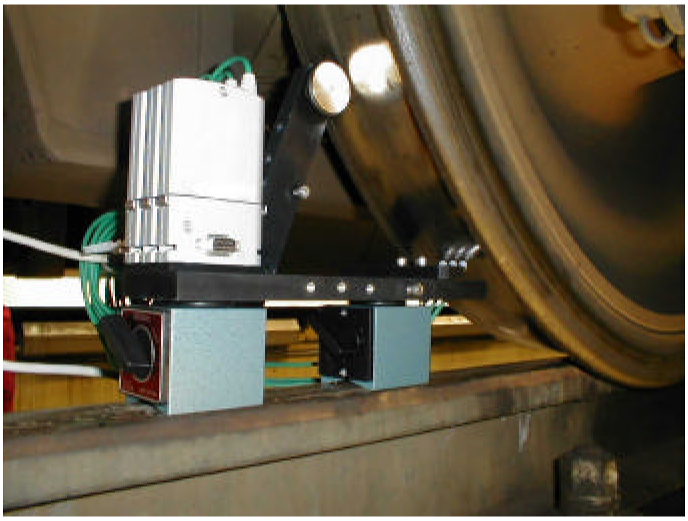

Figure 7–1. Recording frame of an instrument for measurement of the wheel surface roughness in the maintenance depot. The axle is elevated 1-2 mm above SO and turned. The signal from the transducers is transferred to a laptop computer for further processing and documentation.

The costs of the noise conformity checks can be considerable since it is often difficult to identify sites, which satisfy all site conditions. Measurement on both sides of the vehicle will often – for safety reasons – require that the neighbouring track has to be closed during the testing period. Furthermore, there may be considerable indirect costs originating from unavailability of the vehicles or the tracks or both.

These types of costs are minimised in case check of the surface roughness is used for conformity check. The operator can use either a portable depot system, which can be combined with other depot routines, or he can use a fixed track mounted system for permanent monitoring. Such a track mounted system will not require – in case it is permanently mounted – any traffic disruption, it will not be weather dependent, it will be insensitive to traffic on the neighbouring track and it will be insensitive to background noise.

So without doing detailed cost/benefit analysis it should be obvious that a conformity check of the wheel surface roughness is much more economical than a direct noise check.

The duration between each roughness check will depend on the operational experience for each vehicle type and the type of operating conditions for the actual vehicle. In order to ensure proper conformity the check – at the beginning before sufficient experience has been gained – should be done rather often.

7.2.3 Influence of the operational and environmental conditions on the wheel surface quality

Rail vehicles are operated under different conditions, and these conditions have a significant influence on the change of the wheel surface condition and therefore also on the noise level. Among the important parameters are the following:

Operational: Running distance per day, variation in axle load (for freight cars), braking activity (mountains), quality of track, speed, amount of curves.

Environmental: Temperature (ice), vegetation (adhesion coefficient).

All these non-wheel related parameters have – more or less – an influence on the development of the quality of the wheel surface. As an example a low adhesion coefficient caused by vegetation and a humid environment results in deterioration of the surface quality of the vehicle. This is illustrated in Annex II, Figure 13-13. This means that it will have no meaning to create a standard checking procedure. The checking procedure must be reasonable and adapted to the type of operation of each type of vehicle.

7.2.4 Prevention of wheel surface quality deterioration

A further argument for the applicability of using individual procedures for check of conformity is the fact that the operators can introduce measures, which reduce the speed of deterioration of the wheel surface quality.

The operator can invest in rolling stock, which has been designed in such a way that the wheels are less prone to get surface defects. An example is given in Annex II, Table 7-3. In addition to the content of Table 7-3 use of dynamic braking could be mentioned also. The well-known example of using disc brakes instead of block brakes does also apply. At present we, however, know less about the development rate of the roughness of disc braked wheels.

The operator can also invest in treatment of wheel surfaces, when the vehicle is put in operation. The operator can invest in sufficient wheel reprofiling capacity or buy such capacity at a maintenance contractor. In addition to that he can add wear resistant surface layers after reprofiling. This new type of technology has been described in Annex II, Figure 13-14.

Both the prevention and the types of treatment have a significant influence on the surface quality. The conformity checks should therefore take place more often on vehicles with wheels that are likely to get rough than on vehicles with wear resistant wheel surfaces. In Annex II the two sections, Section 7 and Section 13, which describe the DSB 4th generation train (design and wheel surface monitoring) give a practical example of the design and preventive measures, which have been applied to keep the surfaces smooth. In the table in Section 12.7 of this report a listing of such measures is shown below the headline “Design for minimum maintenance”.

7.3 Principles of conformity check procedures

As included in the TSI and Article 14(2) the interoperable vehicles should be regularly checked for conformity. As shown above periodic check will only in some cases be feasible, and the Study Group suggests that also spot check and continuous monitoring is considered as options although these alternative procedures are not required by the TSI. For some operators spot check or continuous monitoring might be cheaper to pursue and ensure a higher likelihood of conformity. A description is given below:

7.3.1 Periodic checks

The likelihood of periodic checks ensuring conformity will depend very much on the duration of time between each check, and typically the time of the check will be known beforehand by both the checking organization and the operator of the vehicles, which are going to be checked. An unwanted scenario is that the operator does not care about the roughness of the surface of the wheels except shortly before the check, where the wheels are being reprofiled in order to pass the check. In such a situation there is a risk that the vehicle will not conform to its noise emission specifications most of its operating time.

The only way this problem could be solved is by making the checks very often. This type of conformity check will, however, not encourage development of low-noise technology, as the incentive for the operators may be doubtful. Furthermore, periodic check of the wheel surface is in reality identical to the procedure, which the railway operators have used for decades, except from the fact that the noise level or the roughness or both have not been measured previously. Instead the condition of the wheel surface has been checked by visual inspection.

Concerning the duration of time between the conformity checks and the methodology applied it is suggested that each operator prepares a procedure, which he is convinced will prove that the vehicles comply with conformity. The reason for this is that the vehicles are so different in design that, at the moment, it is impossible to prescribe a procedure, which will both ensure conformity and be practical. This means that a conformity check may be included in the normal maintenance cycle of the vehicle.

Furthermore, in case a noise test is selected for proof of conformity, type test conditions are suggested not to be required. The actual check conditions should, however, be documented according to the requirements of prEN ISO 3095. Furthermore, the difference in the noise level caused by the different types of track design between the actual test conditions and the type test conditions should also be included in the report.

Check reports, regardless of whether they are based upon noise tests or wheel roughness tests, should be prepared regularly and submitted to the regulatory body, which also reviews type test reports, for review and approval.

7.3.2 Spot checks

Spot checks may be a significantly better tool for checking conformity than check at periodic intervals. The reason is that a spot check will make it possible to check the real noise condition of the vehicle, and not check the "polished" vehicle at periodic intervals shortly after reprofiling.

Spot checks have the advantage that this type of procedure encourages development of low-noise wheel technology, where the surface of the wheel remains smooth. By having continuous smooth surfaces the operator's risk of "getting caught" is much smaller, and the operator will therefore have an incentive to invest in low-noise wheel technology.

7.3.3 Continuous monitoring

Continuous monitoring is use of equipment for monitoring of the noise level or/and the surface condition each time the vehicle passes an installation site, where the equipment is permanently mounted in the track. A practical example of continuous monitoring of the surface condition is shown in Annex II, Section 12.7. Track mounted equipment may be replaced by vehicle mounted equipment, but this option is not included in this description.

Continuous monitoring provides the same incentives for the operator to invest in low-noise technology as the spot checks do. Furthermore, since the installations most often will be permanent on the same site, it may be attractive to combine the sound measurement equipment and the wheel surface monitoring equipment. This option means that the installation also will include an identification of the wheels, which are causing a possible, high noise level and thereby be a valuable tool for rectifying the problem.

The noise level or/and the indirectly measured roughness level should be measured at certain monitoring sites, and should preferably be applied for both individual vehicles and for complete trains. It would be obvious that the interoperable trains are monitored, where most trains pass, which may be equivalent to the procedures developed in the airline industry, where the airports, which have the largest traffic, are the ones having the monitoring installations.

Because of the variations in speed, track condition, acoustical conditions on the site, background noise problems (traffic on parallel tracks), and meteorological conditions it must be foreseen that a monitoring site will be different in instrumental design compared to the instrumental design of a type test section. The figures obtained at the monitoring site should, however, correspond to the figures obtained during type test. This relationship has to be established by proper signal processing and normalisation for the influence of the speed.

Monitoring of the noise level may be pursued by means of microphones mounted close to the track or by means of vibration sensors mounted on the rail or a combination of both. The sensor-based system can of course only be used for trains where the wheel/rail noise is the dominating noise source. Since the acoustical conditions close to a railway track are often complicated because of background noise from other tracks or reflections from nearby surfaces, monitoring of the wheel surface condition by means of vibration sensors may be most practical.

Use of accelerometers as vibration sensors mounted on the rail is described by a case in Annex II, Section 13. Accelerometers are independent of the acoustical conditions on the site, of the background noise problems, and of the meteorological conditions. Furthermore, the condition of the surface of each individual wheel can easily be identified, which is important in case the cars in a train have different owners. This will typically be the case for freight trains.

The relationship between the noise level and the acceleration or velocity level measured by the accelerometers has not been disclosed although the acceleration level measured on rail provides an indirect figure of the degree of the wheel surface roughness and amount of surface imperfections.

7.4 Continuous monitoring of noise from various transport modes

The noise emission of road vehicles and aeroplanes does not change (much) with time. Consequently there is no need to check the noise emission unless they are modified technically. The noise from roads and airports does, however, change very much with the type of operation. For railways it is the maintenance condition – and typically not the mode of operation – which causes the noise receptance level to change. Therefore the noise level caused by the aeroplane traffic at major airports is monitored intensively.

Compared to airport noise and automotive noise the noise receptance level from railway traffic changes in a different way. For the aeroplane – and to some degree for the car - the operational settings and the path change have a substantial influence on the receptance noise level, whereas the noise source strength changes less. For the rail vehicle the situation is opposite. The operational settings and the path remain the same from passage to passage at a given location, but the noise source strength changes significantly because of the change of the surface quality of the wheels.

To push it to the extremes the pilot from the airline, which does not regard the noise exposure of the airport neighbours as important as other airlines do, may be replaced with the rail vehicle maintenance organisation, which cares less about the surface quality of their wheels.

According to the September 2001 UNIFE and UIC Research departments, UITP, CER, CCFE, GEB proposed joint strategy for European rail research for the interoperable railway system in Europe [7.1] by the year 2020 a 50% reduction in the generation of pollutants and increase of the productivity is expected as shown in the table below:

EU rail transport	**1970**	**1998**	**2020**
1000 Mio. pass-km	217	290	676
1000 Mio. tkm	283	241	784

In order to accomplish the significant increase in productivity and the reduction in pollution as predicted by the above-mentioned organisations, it may therefore be reasonable to learn from the airline industry, which within the last 20 years has expanded significantly.

The lesson from the airline industry may prevent that future conflicts with railway traffic restrictions and investment in costly noise screens and building insulation are avoided as much as possible. Around airports, where the traffic is particularly intensive, monitoring activities are pursued. Based on these experiences, it is recommended that a policy for rail vehicle noise level and/or wheel surface quality check be pursued on member state level.

7.5 Recommendations

As a consequence of the fact that the TSI states that the vehicles must conform to the noise legislation and the Study Group's aim of recommending a procedure, which is individually adapted and thereby should have a reasonably low cost, the following actions are recommended:

7.5.1 Legal actions on European level

In order to ensure conformity the following actions are recommended:

- All interoperable vehicles should have their noise level and/or wheel surface condition checked. The method applied should correspond to the actual need so conformity during the whole operational period is ensured.

- The conformity check must – as a minimum - be performed so intensively that development of roughness and surface defects does not take place to such a degree that the vehicle does not conform during the period – or part of the period - between each noise or wheel surface check. This means that the noise level originating from the wheel surface excitation only is allowed to increase with a certain number of dB's as described in Section 9.4.

- The conformity check of each vehicle or trainset shall be done by the operator of the vehicle, but the relevant member state authority is responsible for ensuring that the operator's conformity check is done properly and the results are available for future adjustments. The conformity checks should be done at regular intervals, or by spot checks or by continuous monitoring according to what is most effective or feasible for the operator.

- The requirements should be changed and possibly expanded according to the technical and economical development in the railway industry.

7.5.2 Other actions on European level

The following non-legal actions on a European level are recommended:

- All interoperable vehicles must be fitted with an identification tag - or equivalent method of identification - for remote identification of the vehicle.

- Research in wheel roughness development and wheel roughness prevention should be encouraged and possibly supported by the EU research programs.

Vehicle identification is an important prerequisite for realising continuous monitoring, noise dependent track access charges, and some types of voluntary agreements on reduction of the noise level.

In case a continuous monitoring procedure is chosen by a operator the lack of an electronic identification system makes the conformity check difficult but not impossible, since the railways already have other systems, which are used for identifying the vehicles.

7.5.3 Actions on member state level

The member states are – as a voluntary activity – recommended:

- To implement noise or wheel surface quality check for non-interoperable vehicles corresponding to the checks for interoperable vehicles.

- To maintain the coefficient of friction of the rail head above a certain minimum level in order to prevent creation of sliding defects on the wheel surfaces.

- To grind the rails to such a level that the smooth surface condition of the wheels of the interoperable vehicles is used to its optimum extent.

The recommended action of implementing wheel surface quality checks for non-interoperable vehicles will generate a larger European market for equipment and systems for noise and roughness check. As a consequence of the assumed market increase a more competitive market for this type of equipment may appear. This development may therefore also – on a more long-term basis - support the improvement of the methods for conformity check of the interoperable vehicles.

8. Cost/benefit analysis

An attempt has been made to perform an analysis of the cost/benefit of the investment in noise reduction. The conclusion was that a detailed cost/benefit analysis of the noise reduction costs is difficult to pursue for the selected cases shown in Annex II. The main reasons why a cost benefit analysis may seem meaningless are the following:

a) The low-noise design is integrated with other design goals like weight reduction, the design for minimised maintenance costs, or energy consumption. Isolation of the pure noise reduction costs is difficult. Even for bogie shrouds, the isolation is difficult, since the primary reason for applying bogie shrouds (at least on HSTs) is reduction of the aerodynamic drag and thereby saving of energy.

b) The cost/benefit analysis should be done on an LCC basis. The LCC for the shown cases are difficult to achieve unless a detailed investigation is undertaken together with the manufacturer/operator. The size of the present project performed by the Study Group did not allow such a time-consuming activity, which may nevertheless be eligible for a separate project.

c) It is assumed that the costs of the component primarily responsible for the noise level (in its standard and "low-noise" version for comparison) would be extremely difficult to obtain. The manufacturers would be very reluctant to release any such figures.

In general, however, ODS assumes that the noise reduction costs lie in the 2 - 4% interval of the total costs of a complete system.

8.1 Low-noise design

Low-noise design comprises the various components, which are either applied in a low-noise version or have been reduced by additional noise reducing means like enclosures or adding of vibration absorbing materials. The costs of low-noise design measures are paid at the installation time, and in principle such type of design causes no extra costs except for general maintenance like other components of the vehicle.

Low-noise traction equipment, low-noise air-conditioning equipment and low-noise auxiliary machinery are all included in this category. Concerning the wheels, which is the most important component of reduction of rolling noise the following types of noise reduction measures apply:

- Vibration absorbing wheels
- Acoustically optimised wheels
- Resilient wheels
- Bogie shrouds
- Wheel mounted brake disc

8.2 Measures for preventing generation of wheel/rail noise

Measures for preventing generation of wheel/rail noise caused by roughness generation and generation of surface defects are another group of noise reducing measures. This group is characterised by the fact that both installation costs and costs caused by the operation of the vehicle contribute to the total LCC costs. The below-shown types of measures are contributing to keeping the surface of the wheel smooth and an increase of the noise level is therefore – to some degree – prevented.

- High axle load
- Tread friction control
- Steel alloys with high wear resistance
- Sinter brake blocks
- Composite brake blocks
- Flange lubrication
- Laser treatment of the tread after reprofiling

Some of the above-shown measures like laser treatment or use of alternative steel alloys have not attracted so much attention in the past, and common for all the measures is that they have a potential for savings of other types of costs – typically maintenance – of operating both the vehicle and the track. A complete cost/benefit analysis, which includes all the possible measures and benefits will therefore be very complicated.

8.3 Maintenance measures for reduction of wheel roughness and surface defects

Finally, it is not enough to prevent the surfaces to get rough. Regardless of the different prevention measures, which are applied, wheels sooner or later get rough and must be reprofiled. The methods and tools for this purpose are:

- Wheel surface defect and roughness monitoring systems (A case is shown in Annex II)
- Wheel reprofiling machinery (different types of machinery are available on the market)

In Annex II (the section describing the wheel surface monitoring) a so-called “Savings List” illustrates all the potential benefits, which have to be evaluated and investigated – case by case – in order to perform a complete cost/benefit analysis. The costs of a monitoring installation are typically much lower than the costs of the reprofiling machinery. Included in the costs of

“Wheel surface defect and roughness monitoring systems” could also be the costs of operating equipment for voluntary conformity check.

8.4 Survey of LCC calculation

In order to provide a survey of the items, which have to be included in a complete cost/benefit calculation – dependent of the type of measure – the below-shown table has been prepared:

	Vehicle in general	Wheel surface roughness and defects	
	Low-noise design	Preventing measures	Maintenance measures
Investment during vehicle construction	YES	YES	YES
Costs during vehicle operation	N/A	YES	YES
Potential savings in other costs *)	N/A	YES	YES
Prediction of total LCC costs	Construction phase only	Complicated	Complicated

*) A detailed listing is presented in Annex II.

8.5 Cost-benefit figures from past and current investigations

For some reason a comprehensive analysis of railway noise abatement costs is nearly impossible. The main reason for this is the fact that a proper low-noise design does not necessarily mean an increase of production or life cycle costs. At the same time changes in the vehicle design can be due to some non-acoustic requirements with a positive impact on noise emission. To be able to separate in such a case between the costs due to acoustic and to non-acoustic requirements is very difficult.

Prototypes are another obstacle for a proper cost assessment. Many of the low-noise solutions published have been produced in a very limited number only. Thus prices and costs are not representative of a broad application in a competitive market. Finally, investment costs are what we talk about. However, LCC are the relevant figures for each enterprise but these numbers are impossible to get for new cases and solutions. For the reasons explained, the numbers summarised in Table 8-3 thru Table 8-4 are cases published and a rough estimate of what the investment costs could be for each case listed. The spread of costs estimated for a retrofit of cast iron block braked wagon with k-blocks between “cost neutral” (reference Silent Train and Silent Track project [8-1], [8-2]) and EUR 732 per wagon (reference [8-3] based on DB-AG figures) clearly shows these uncertainties.

The amount of EUR 732 is the extra costs for a k-block retrofit compared to a renewal with cast iron brake blocks. The total costs for a brake block change are approximately EUR 5,000, but this amount include replacement of four wheelsets, which had to be done in both cases regardless it is a cast iron replacement or a k-block replacement.

It is far easier to summarise the effects and benefits of the different solutions by showing the noise reduction level in relation to the baseline. The estimation also includes a qualitative assessment of the impact on the environment, if there is a local or individual effect only or if there is a positive effect all over the network.

Parameter, brake blocks	Costs per 4-axle vehicle, EUR	Reference	Effect, whole network
Cast iron	88 ..136	[8-3]	Baseline
k-blocks	232	[8-3]	-5 .. -8 dB(A)

Table 8-1. Investment cost and effect estimation for replacement of cast iron brake blocks with k-blocks.

Parameter, brake type or wheel dampers	Costs per 4-axle vehicle, EUR	Reference	Effect, whole network
8 ORE 920 wheels	4,480	[8-1], [8-2]	-
Block brake, conventional	12,500	[8-3]	Baseline
Drum brake	16,500	[8-3]	-10 .. -12 dB(A)
Disc brake	26,000	[8-3]	-10 .. -12 dB(A)
Wheel disc brake	20,000	[8-3]	-10 .. -12 dB(A)
Composite brake blocks	Cost neutral *)	[8-1],[8-2]	-5 .. -8 dB(A)
k-block retrofit incl. Braking system change	732	[8-3]	-5 .. -8 dB(A)
Retrofit with k-blocks and BA004 wheel sets	9,000	[8-4]	-5 .. -8 dB(A)
Wheel damping ring	800 .. 2,200	[8-3]	about -1 dB(A)
Wheel damper (ICE 1 type)	3,200 .. 4,000	[8-3]	-2 .. -4 dB(A)

*) Requires additional maintenance costs for rail grinding according to reference.

Table 8-2. Investment cost and effect estimation for noise reducing measures on rolling stock.

Parameter, measures on the track	Costs per track metre, EUR	Reference	Effect, local
UIC 60 track	635	[8-1]	Baseline
Tuned rail absorber	188	[8-1]	
Rail grinding, per year	4.6	[8-1]	Up to 14 dB(A)

Table 8-3. Investment cost and effect estimation for noise reducing measures on the track.

Parameter, barriers and windows	Costs, EUR	Reference	Effect
2 m noise barrier, per m length	810	[8-1], [8-4]	Local
3 m noise barrier, per m length	1,080	[8-1], [8-4]	Local
4 m noise barrier, per m length	1,350	[8-1], [8-4]	Local
Isolated window, per window	2,000	[8-1]	Individual

Table 8-4. Investment cost and effect estimation for noise transmission reducing measures.

An overall Cost-Benefit-Analysis for different noise reducing measures has been carried out by the UIC for two European freight corridors [8-4]. The basic question was how to reach a given noise reception limit with a minimum of costs. This study showed that a freight rolling stock improvement by reducing then emitted noise by 10 dB had the best cost-benefit ratio while a track improvement of – 5 dB by tuned absorbers and optimised pads had the worst cost-benefit ratio [8-5].

9. Implementation of railway noise emission limits

Establishing limits for emission levels generated by rail traffic will be an important step towards abating wayside-noise levels. The following items should be taken into consideration when establishing such limits.

1. Whether or not limits for sound levels should be stepwise reduced according to a given timetable. This procedure will give the industry the chance to react in time.

2. Different time periods of implementation for the different vehicle categories.

3. Notified bodies have to be introduced to check the compliance with the limits.

4. Interface with government agencies, industries, research institutes, and operating companies relating to questions like: What is possible? What is necessary? What is desirable? And what are the long-term goals?

9.1 Scope

Both new vehicles and in-use vehicles should be covered by the noise emission limits, where the distinction should be made between:

- Newly-ordered vehicles.

- Retrofit of vehicles that have been in service for many years but will remain operational for some time in the future (more than 5 to 10 years).

The number of vehicles, which should be tested, must be limited. It is recommended to make a type test for a whole series of vehicles with up to three vehicles. In addition the conformity of production can be checked with one vehicle out of fifty produced.

Periodic re-check of the noise emission as well as monitoring of the noise emission during daily operation are not foreseen to be commenced immediately due to unsolved methodological problems but should be considered after implementation of a European vehicle identification system.

According to the noise characteristics and practical reasons the classification of the rolling stock is used and shown in Table 9-1. It is the opinion of the Study Group shown that it is technically not reasonable to have different limits at a speed of 80 km/h for diesel and electrically powered rolling stock.

	Vehicle class - electric vehicles	Vehicle class - Diesel vehicles
Vehicle type	Type of vehicle family for illustration (examples)	Type of vehicle family for illustration (examples)
Light Rail Transit (i.e. Trams, Metros)	Combino, Sirio, Citadis, Incentro,Variobahn, Vagn 2000, DT4	
Locomotives	SBB Lok2000	
Conventional Multiple Units and Railcars	IR4, Signatur, TER, LINT, Talent, DSB S-Train, BR423,	IC3, BR612, Virgin CC, BR641, LINT, Talent, Desiro, ITINO
Passenger coaches	DB AG ICE1 coach	
High speed train sets (HST)	ICE 3, Thalys, ETR 500, TGV, AGV, WCML, TALGO 350, ICN	ICE-TD

Table 9-1. Classification of vehicles for determination of sound level limits.

The suggested emission levels comprise pass-by noise level in free-field conditions and stationary condition at open track in stations.

Accelerating from platform, decelerating when entering platform, and standing at platform are seldom an environmental problem (except for door whistles and similar). But it may be a comfort problem for the passengers. Reduction of the noise level at the platform is therefore to be regarded as market driven in the competition between the future different rail operators. Measurement at platform is therefore excluded from the suggested types of noise emission tests.

Table 9-2 shows the types of noise emission having an environmental consequence and the types having an influence on the passenger comfort and therefore may be assumed to be reduced as a result of the market.

Acceleration and deceleration in the main track often cause an increased noise level. It is therefore regarded as an environmental noise problem.

Type of operation	**Environmental reasons**	**Comfort for passengers**	**Illustrating example**
Pass-by	Yes	No	All types
Stationary	Yes	No	Diesel loco idling
Standing at platform	No (normally)	Yes *)	DMU waiting at platform
Accelerating from platform	No (normally)	Yes *)	DMU accelerating from platform
Accelerating in marshalling yard	Yes	No	Freight train accelerating
Parked	Yes	No	EMU parked during night at end station
Accelerating during driving	Yes	No	Diesel loco in main track
Decelerating during driving	Yes	Yes	Dynamic braking in all places
Friction braking	Yes	Yes	EMU at platform or in main track

*) Passengers waiting on the platform

Table 9-2. Table showing the types of noise emission having an environmental consequence and the types having an influence on the passenger comfort.

9.2 Measurement Methodology and Procedure

An absolutely necessary prerequisite for establishing sound level limits is an exact description of the conditions for certifying a vehicle. One possibility for this is provided by the guidelines given in prEN ISO 3095. There are many omissions in these guidelines, however, and questions such as how to establish unique conditions for certifying a vehicle are not covered, i.e., neither the conditions for the vehicle nor the track are discussed. In the final version of the standard, these and other such conditions will have to be clearly defined. Though national standards committees have already submitted objections and suggestions for improvements in the standard the majority has given a positive vote. It is still too early to tell what the final version of this draft will contain. However, the specifications for a type testing procedure have been worked out by TNO in their recent report for the Commission [6.2].

Track influence on measured total noise emitted can be reasonable. All limits refer to a test track in optimum condition, which includes a rail roughness even lower than proposed by prEN ISO 3095 [5.1]. As long as simple vehicle/track noise separation methodologies are not available or elaborate enough it is recommended to use an acoustically optimised track with very low rail roughness. Figure 9-1 shows an example of three tracks (Bi, K1a, RS2) with rail roughness reasonably below the proposed ISO 3095 limit. However, if measured total noise generated on a track, which does not comply with the optimum conditions, stays within the limits this measurement will be accepted.

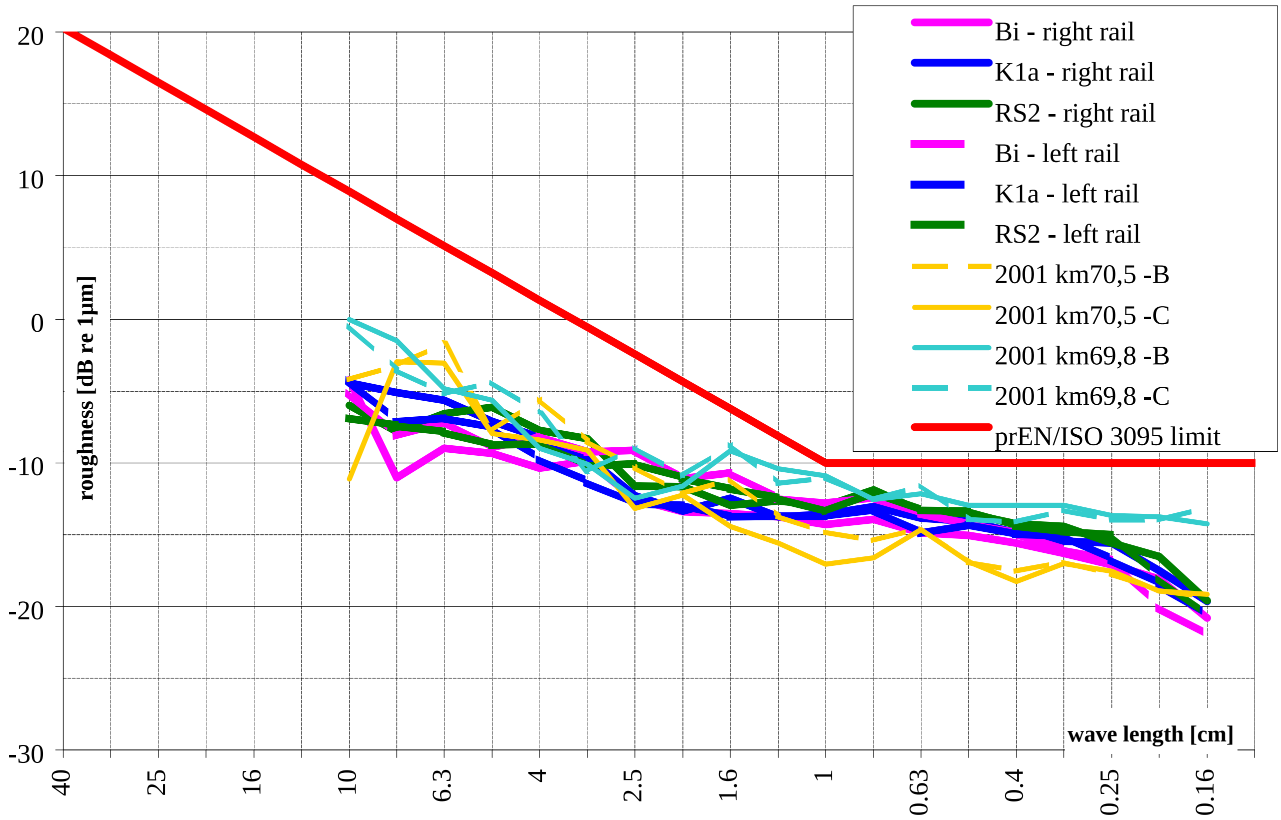

Figure 9–1. Roughness levels for the 3 track types with rail ground in longitudinal direction about half a year before the roughness measurement took place: bi-bloc sleeper (Bi), concrete mono-bloc sleeper (K1a), double H-shaped sleeper (RS2); ref [9.1].

In addition to the definitions in the prEN ISO 3095 [5.1] there is a number of further specifications listed below which are essential to type testing purposes but not included in the draft standard:

- For trainsets the measurement time T for TEL the time is elapsed during pass-by of the entire train plus a time span of 2 seconds before and after the train pass-by.

- The $L_{A,eq}$ is the level to be measured during pass-by of a group of vehicles, and the TEL_A is the level to be measured during pass-by of a locomotive or a trainset with a fixed configuration. Both criteria are taken in a 7.5 metres distance from the centre line of the track in two heights above the rail surface. The microphone position MP1 is 1.2 metre above the rail surface and microphone position MP 2 is 3.5 metres above rail surface.

- For HST the 7.5 metres distance is also recommended from a technical point of view. However, the recent draft for the High Speed TSI contains a proposal for 25 metres distance and 3.5 metres height above rail. If this is not changed for HST the microphone position can be used with the limits given for 25 metres.

- Vehicles have to be tested at 80 km/h and at maximum speed. A vehicle/train is accepted if the arithmetic average of the $L_{A,eq}/TEL_A$ from at least 3 pass-bys at one speed is less or equal to the numbers in Tables 9-1 through 9-3. Both the limit at 80 km/h and the limit at maximum speed have to be kept. If the limit is exceeded for maximum speed only the vehicle/train will be accepted to run at a lower maximum speed Vred if it stays within the limits when tested at Vred.

9.3 Noise emission limits

The vehicle categories used here for limiting railway noise generation are based on the results of the case study and cover those technical aspects only, which are relevant from the acoustic point of view. Since rolling noise is mainly the consequence of wheel roughness on the vehicle’s side, only this aspect is taken into account. Thus it does not matter which technology is used to keep the wheels smooth and therefore no reference is made to disc, drum or block braked wheels. As long as the limit is kept all braking technologies can be used.

Limits have been derived from the cases listed in Annex II of this study sometimes combining effects and measures. For freight wagons for example results from MetaRail were used and an estimation of the effect of a surface roughness lower than MetaRail rail has been added. For coaches results from ICE 1 coaches which had the lowest emission level had been used.

This approach is different from the classification made within the STAIRRS Project. STAIRRS needs its classification to describe the actual noise emission from existing rolling stock without type testing results available. In this case technological features which today correlate with noise emission can be used. For the exercise in limiting noise generation this approach is not necessary.

The limits are given for specific speeds. For LRT and HST the numbers for the pass-by noise cover the speed range from the minimum to the maximum speed of this category. Limits for a maximum speed in between can be derived by linear interpolation.

For the Conventional Rail System only one level for 80 km/h L(80) is given. The limit for maximum speeds, Vmax higher than 80 km/h L(Vmax), can be derived using the following formula based on a cubic speed dependency:

$$L(Vmax) = L(80) + 30 \lg (Vmax/80)$$

In the following the noise limits proposed by the Study Group are shown in Table 9-3, and Table 9-4. Reference should be made to the content of Figure 5–1 and Table 5-1.

	Light Rail Transit (LRT)	Pass-by at const. speed, TEL	Stationary, $L_{A,.eq}$ *)
		7.5 m	7.5 m
Short term new	40 km/h	72	60
	80 km/h	80	
Long term new	40 km/h	69	57
	80 km/h	77	

*) Without air-conditioning 5 dB(A) less.

Table 9-3. Light Rail Transit (i.e. trams, metros).

	High speed railway systems	Pass-by at const. speed, TEL ***)		Stationary, $L_{A,.eq}$
	Distance, m:	7.5 m	25 m	7.5 m
Short term New	250 km/h	93	87	78
	300 km/h	96	91	
	350 km/h	n/a	n/a	
Long term New	250 km/h	90	85	72
	300 km/h	93	88	
	350 km/h	97	91	

Table 9-4. Noise emission limits for High Speed Trains. The proposed figures are identical for both loco hauled trainsets and for trainsets with distributed power. The figures do not apply for retrofit trainsets.

	Conventional railway systems Type of vehicle	Stationary, $L_{A,.eq}$ 7.5 m	Pass-by at const. speed, TEL ,7.5 m, 80 km/h ***)
Short term New	Diesel locomotives *)	75	80
	Electric locomotives *)	75	80
	EMU's **)	70	80
	DMU's **)	73	80
	Passenger coaches incl. parcels vans	70	80
	Freight wagons **)	60	81
Short term Existing (retrofit)	Diesel locomotives *)	N/A	N/A
	Electric locomotives *)	N/A	N/A
	EMU's **)	N/A	N/A
	DMU's **)	N/A	N/A
	Passenger coaches incl. parcels vans	N/A	83
	Freight wagons **)	N/A	85
Long term New	Diesel locomotives *)	75	78
	Electric locomotives *)	75	78
	EMU's **)	70	79
	DMU's **)	73	79
	Passenger coaches incl. parcels vans	70	79
	Freight wagons **)	60	77

*) Measured without loading from connected cars.

**) Includes refrigerated cars and other vehicles with noise generating machinery operating in the stationary condition. Noise generation from the load, i.e. cooling containers is assumed to be included in a separate legislation.

***) Must be corrected according to the actual maximum speed by the following correction formula: L(Vmax) = L(80) + 30 log (Vmax/80)

Table 9-5. Noise emission limits for Conventional Railway systems.

9.4 Allowed noise level increase during operation

As mentioned in Section 7 the noise level will inevitably increase during operation. The question is how much the noise level should be allowed to increase – compared to the lowest possible level with completely reprofiled and smooth wheels - in order to maintain conformity? This question has to be answered before implementation of monitoring systems.

Passenger trains are typically maintained better than freight vehicles. Without any scientific proof but only the professional estimate of the Study Group the following figures for the allowed increase are proposed:

HST and locomotives:	+ 3 dB
Conventional multiple units and railcars:	+ 4 dB
Freight vehicles:	+5 dB

It is clear that more documentation must be provided. The above-shown figures are therefore only shown in order to make the Commission aware that there is a question that has to be answered.

9.5 Noise emission from other sources than wheel/rail contact

As shown in Table 9-2. The following operating conditions, which also have an influence on the noise emission, have not been subject to any proposed noise limit:

- Accelerating in marshalling yard
- Parked
- Accelerating during driving
- Decelerating during driving
- Friction braking

The sources contributing to the noise level are the traction machinery, auxiliary machinery, air-condition machinery, brakes, track curves, and rail joints and switches. These sources are all important to the noise level in well-known conditions where noise is a problem, but the Study Group suggests that noise emission levels for the above-shown conditions are postponed to a final third step as mentioned in Section 9.7.

9.6 The role of different bodies

According to the interoperability directives notified bodies will be responsible for the 'EC' verification of subsystem, e.g. a new rolling, and the technical file with all relevant documentation, including evidence that a rolling stock meets the noise limit values. It is important that the notified body acquire the necessary competence in this area and that member state take this requirement into account before granting notification of a body.

The authorities that will be responsible in the member states for carrying out the checks that the subsystems conform with the noise limits should also have sufficient competence in noise measurement techniques. They should normally restrict themselves to systems inspection, i.e. to check that compliance monitoring by internal means of railway undertakings and infrastructure managers and the notified bodies are carried out according to the rules. The notified bodies should as far as possible be made responsible for organisation of field tests for limit value compliance.

9.7 Priorities and schedule for implementation

A three-step procedure appears very appropriate to introduce for the implementation of noise limits for rolling stock in Europe. It seems inevitable to include existing rolling stock as well in this strategy. Only retrofit of existing vehicles, mainly freight wagons, will guarantee a noticeable reduction of noise perception within a reasonable time period.

- First step is to publish noise emission limits for the different rolling stock classes with different numbers for new and existing in-use vehicles.
- After a certain time period, which can be different for new and existing vehicles, the published limits come into force as a second step.
- In a final third step noise limits for new vehicles can be adjusted according to the technical progress as well as taking into account progress in noise measurement methodology like track/wheel separation or additional operational conditions.

10. Timetable

As outlined above maximum emission levels for rail vehicles will lead to a sustainable reduction of the noise impact in the vicinity of railway lines. This policy should be started soon and then be followed uncompromisingly.

As shown in Figure 10–1, the consequential enforcement of limiting emission levels will lead to a medium-term lowering of the noise impact. This principle applies for new rolling stock as well as the acoustical improvement of existing rolling stock (retrofit) or the phase-out of very noisy vehicles. Different time periods can be used for different vehicle categories or new and existing vehicles to reach the final goal at a certain time.

However, it must be clear that different legal acts are necessary to implement this strategy. Noise generation from new high speed trains will be covered by the HST-TSI and noise from interoperable conventional rolling stock will be dealt with by the TSI on conventional rail systems. Both TSIs are on their way. For the rest, the non-interoperable rolling stock such as light rail transit and the existing rolling stock additional legislation is required.

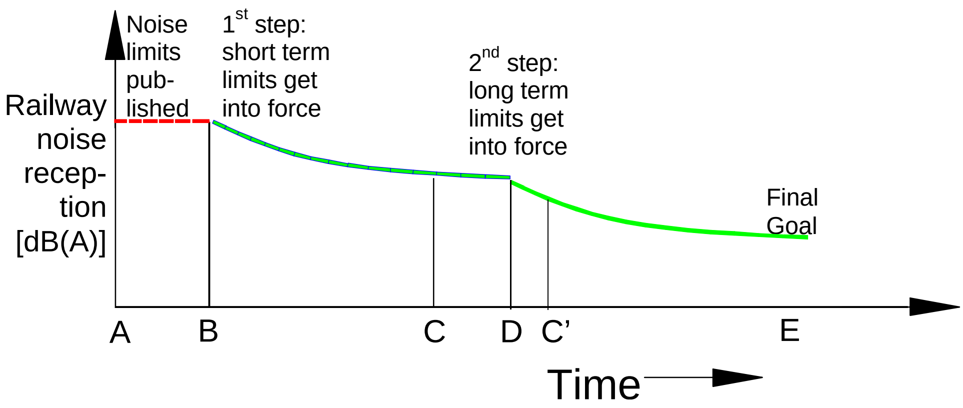

Figure 10–1. Medium-term effect of noise emission limits on the noise impact beside railway lines.

A: Time of publication of the future EU noise legislation on railway noise generation.

B: Time when the maximum emission levels come in force. Can be the same time as (A) if immediately applicable or a time span greater than 0 to allow further technology development or for completion of vehicle contracts, which have already been signed. From this point the overall noise emission of the fleet starts to fall.

C: Time when the fleet has completely changed and all vehicles comply with the limits of step 1. Can be before (D) or after (D) if it is a virtual point C' (the fleet has not totally been renewed when tighter limits were introduced).

D: Time when long-term emission limits come in force. The minimum duration of time between C and D must be included in the TSI or in the directive for the industry to prepare.

E: Final reduction goal has been reached.

Figure 10-2 shows the timetable for implementation as well as which European regulation is going to cover each specific vehicle category. TSI/CRS means that this type of noise generation will be covered by the TSI for conventional rail systems. Noise emission from TSI/HST marked vehicles will be covered by the TSI for High Speed Trains. Both TSIs are on the way. Finally for those categories, which at the moment are not covered at all, an additional Railway Noise Legislation (RlyNLeg) is required.

Retrofitting of existing vehicles is here included in the legislative process as an option. Normally legislation should not be needed if a voluntary agreement between the EU and the relevant industry bodies is reached, in order to cover noise reduction measures on the existing fleet.

For retrofit of both passenger coaches and freight wagons and for new freight wagons, technologies for low-noise products, which comply with the short term limits, are available and thus should be applied as soon as possible. For these categories the limit will be in force from the day of publication of the regulation. This approach is also very reasonable from the environmental point of view since rail freight transport causes the main pass-by noise problem.

For the other categories a two-year introduction phase appears necessary to give the industry a chance to further improve their product and commonly introduce low-noise technologies and products. This two-year duration does not mean that technology is not available in all the fields. However, this period should give all the industrial companies the opportunity to develop their own product that complies with the noise standards.

Long-term limits should then come in force in seven years. Again, this time period appears necessary for the stimulation of technological research and the development of the improved products.

Prior to the time, when the legislation comes into force, there will be a certain period for preparation and presentation for the industry. During this period the industry will have the possibility to prepare for the new legislation.

The abbreviations cover the following:

TSI/CRS: TSI for Conventional Railway Systems

TSI/HST: TSI for High Speed Trains

RlyNLeg: an additional Railway Noise Legislation is required

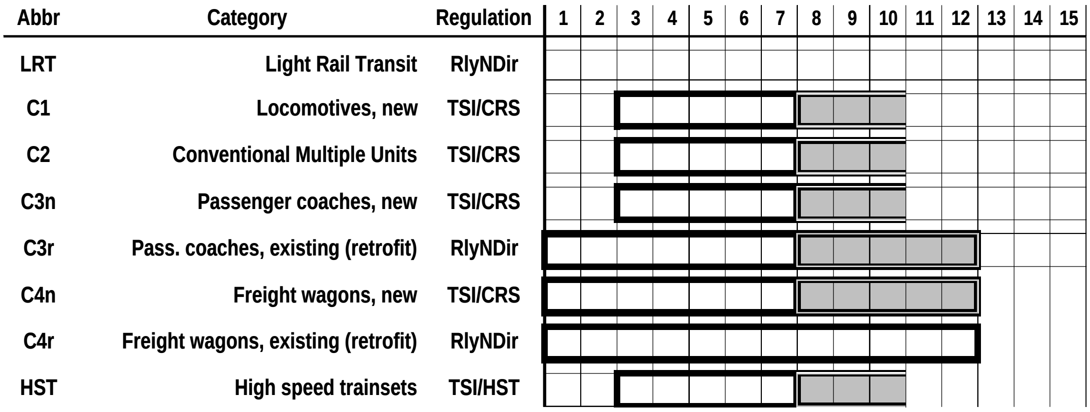

Figure 10–2. Timetable in years for implementation of noise emission limits for the different categories. The white bars indicate the minimum implementation time starting at the time when EU regulations become applicable. The grey bar indicates an additional time period to which the implementation could be extended if there are good (economic) reasons.

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12. Main data from the case study

Annex II comprises a description of various European rail low-noise design projects, which have been performed with success. The projects have been spread between different types of vehicles ranging from transit cars to locomotives and high speed cars. Particularly cars, which are interoperable, i.e. run on track owned by different companies in different member states of the EU, have been given first priority. This means that freight cars have been given a high priority, since they are also among the noisiest cars.

Urban rail vehicles have, however, also been included, since a general EU maximum noise emission level for these cars will support the single market for transit vehicles. It is the intention that the realized noise emission level for each type of car should form the basis for future EU noise emission level legislation.

Almost within each type of vehicle the cases have shown that it is possible to design very quiet vehicles. Common for all the cases is that the low-noise design has been applied almost from the conceptual design phase of the vehicle. Possibilities of "additional low-noise design" have also been suggested. These possibilities should be understood in broad terms that are in general applicable on the type of vehicles, but not necessarily on the actual vehicle.

What has not been shown so clearly is that it is also possible to "slow down" the roughness and surface defects generation process. This has – as an example – been the experience at the new Copenhagen S-Trains, which have more hard wheels than normal, a very good wheel slide prevention system, and a high axle load, which prevents gliding.

Finally, it is well known that the noise level from a rail vehicle is dependent on the surface quality of the wheel. A case describing a successful monitoring of the wheel surfaces has therefore also been included.

12.1 Tram and light rail

The first case comprises trams and light rail vehicles, which both typically have a maximum speed of 80 km/h. The case is from the German city of Chemnitz, which has a particularly quiet system including also very smooth rails. Conventional tramways mostly travel along "road dependent" tracks embedded in the road surface. The separation of the road and the track is increasingly ensuring better trip quality, with higher operating speeds and greater reliability. The following factors will affect the noise level:

- As a rule, rougher rail running surfaces than if tracks were laid separately,
- Narrow track curves (track follows the road layout),
- Short distances between stations imply frequent acceleration and speed reduction,
- Small distances to the buildings (reflections),
- Crossing traffic with other lines, many turn-outs and insulated rail joints,
- Grooved rails laid in the road surface,
- Interaction with road traffic and pedestrians (influence on the required brakes and signalling).

Light rail systems are electric railways used for local transport, developed from tramways. Light rail system offers transport capacity in between the range of tramways and metros. Often a separate track is built alongside the lanes for ordinary road traffic, especially in the suburbs. The tracks of a light rail system, in contrast to a regular tramway system, have non-grooved rails (e.g., the S49 rail type) and smoother rail running surfaces. Light rail vehicles are also wider than trams.

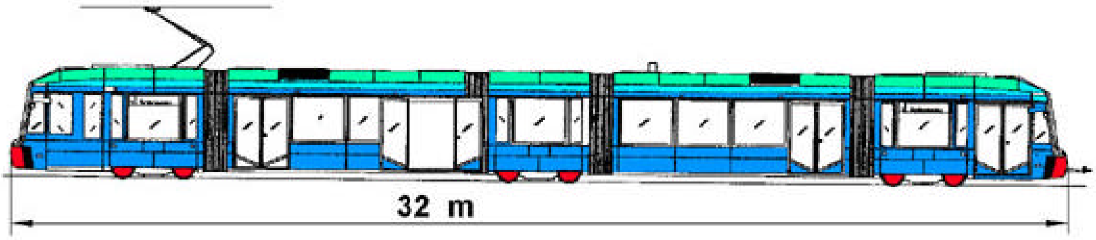
According to the above definitions, the system in Chemnitz, Germany is a "Light Rail System". Most of the lines run on a dedicated, separate ballast track with wooden or concrete sleepers. The acoustic sources of a LRV can be grouped as follows:

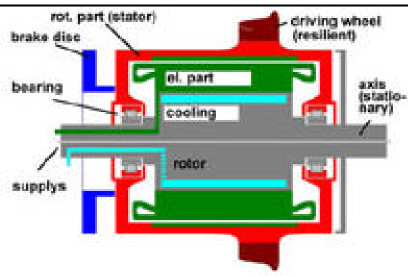
- Audio communication equipment (horn, loudspeaker),
- Driving safety devices and wear-reducing parts (wheel-flange lubrication, sand distributor),
- Auxiliaries (ventilator, compressor, air-conditioner),
- Drive (motor, transmission),
- Wheel-rail noise.

For the sound emission only the latter two noise sources are important (at speeds above approx. 30 km/h to 40 km/h, as a rule, the wheel/rail noise dominates the total noise level).

Quiet Rail Vehicle Data

Variobahn 6NGT-LDE/LDZ Tram





Wheel hub motor

Category	Tram; low-floor 100%	
Operator/owner	Chemnitzer Verkehrs-AG CVAG	
Manufacturer	Adtranz	
Production year	1993-2000	
Maximum speed	70 km/h	
Type of track	Concrete sleeper, S49	
Website for information 1	www.cvag.de	
Website for information 2	www.adtranz.com	
Current noise level at 80 km/h		
L_{pAFmax}, 25 m, ISO 3095	68-70 dB(A)	
TEL, 7.5 m	76 dB(A)	
Potential noise reduction at 80 km/h		
L_{pAFmax}, 25 m, ISO 3095	-2 dB(A) (quieter track)	
TEL, 7.5 m	-2 dB(A) (quieter track)	
Main noise sources	**Current low-noise design**	**Additional low-noise design**
Wheels	Resilient wheels (SAB-V60)	
Wheels	Damping rings	May be possible but needs R&D
Wheels	Absorber	Not possible (not enough space)
Wheels	No wheel discs	Not possible
Traction motor	Wheel hub motor, without gear (gear ratio 1:1), (water-cooled) low revolution: about 600 rpm at 70 km/h	
Traction converter	Three-phase (water-cooled)	
Magnetic construction elements	e.g. self-induction coil: with sound damping	
Data sheet prepared 2001-05-31	F. Krüger	STUVA e.V.

12.2 Metro Cars

The second case comprises metro vehicles, which typically have a maximum speed of 120 km/h. The case is from the German city of Hamburg, where the vehicles also run at grade and on elevated structures. More than 400 vehicles have been delivered to the operator, in replacement of the older DT3 and DT2 types.

Hamburg Public Transport Authority (HVV) was set up in 1964 as the world's first fully integrated public transport system. All Greater Hamburg's public transport services are now linked in this closely woven and attractive network, with 300 km of underground and suburban rail lines, 1,703 km of bus routes and various ferry lines. In 1994 HVV carried some 613.8 million passengers. Hamburg has about 1.86 million inhabitants.

The metro in Hamburg has a line length of about 100 km with 89 stations. At times, there are approx. 800 cars in use, of these approx. 330 are of the DT 4 type. Almost the entire Hamburg suburban rail fleet will be replaced by the ultra modern, three-phased induction-motor DT4 trains within the next few years.

On all lines, outside the tunnels, ballast tracks with wooden sleepers are used as a matter of standard. For new or upgraded lines, concrete sleepers will be used in the future.

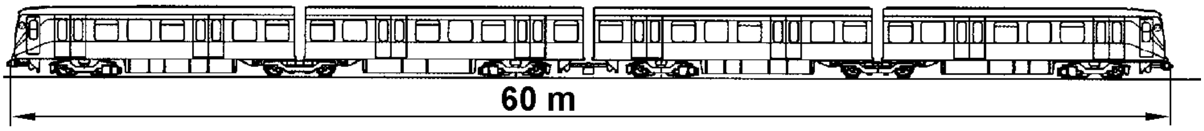
One of the reasons for the low-noise emission of this metro car is the measures applied in the design of the bogie. These measures comprise the following items:

- Liquid-cooled drive motor.
- Screening of the wheels by outer bearing of the axles.
- Double-ribbed disc-wheel.
- Absorption mats over the wheels (underneath the floor).
- Compressor: fully encapsulated.
- Tuned absorbers.

Other reasons for low-noise emission figures for the DT4 car are the following:

- Totally separated track (no connection with automobile traffic flow),
- Regular maintenance of the tread of the wheel running surfaces,
- Track in good condition (fairly new),
- Regular rail grinding.

DT4 Underground Trainset



Quiet Rail Vehicle Data

Category	Subway
Operator/owner	Hamburger Hochbahn AG
Manufacturer	ALSTOM / LHB GmbH
Production year	1989 –2005
Maximum speed	80 km/h
Type of track	Wooden/concrete sleeper, S49
Website for information 1	www.Hochbahn.de
Website for information 2	www.transport.alstom.com

Tuned Absorber

Current noise level at 80 km/h	
L_{pAFmax}, 25 m, ISO 3095 (on a test track)	70 dB(A)
TEL, 7.5 m (on a test track)	77 dB(A)
Potential noise reduction at 80 km/h	
L_{pAFmax}, 25 m, ISO 3095	2
TEL, 7.5 m	2

Water-cooled Drive Motor

Main noise sources	**Current low-noise design**	**Additional low-noise design**
Wheels	Tuned Absorbers	Low-noise wheel design? (R&D)
Wheel	Screening of the wheels by outer bearing of the axles	Wheel disc brakes? (R&D) Damped wheels (wheel disc)? (R&D)
Wheel	Double ribbed disc-wheel	Sound optimized wheel (e.g. holes, spikes, optimized geometry etc.)
Car body (underside)	Absorption mats over the wheels	
Traction motor (Three-Phase AC)	Water-cooled, fully encapsulated	Damped motor and transmission bearing? (R&D)
Traction inverter	GTO converter, el. equipment: water cooled, encapsulated	
Compressor	Fully encapsulated	
Data sheet prepared 2001-05-28	F. Krüger	STUVA e.V.

12.3 Suburban EMU'S

The Copenhagen 4th generation S-Train trainset is among the quietest European EMUs. The trainset was designed in the mid-nineties, and the first trainset was delivered by ALSTOM LHB/Siemens Consortium to DSB S-Train in 1995. The first year of service of eight trainsets was so successful that DSB decided to order 112 optional trainsets, which will bring the total number up to 120 trainsets by 2005. By this date DSB S-Train expects that all existing older 2nd and 3rd generation trainsets will have been removed and scrapped. The consortium has committed itself to very strict noise specifications, and therefore a noise management plan was adopted right from the beginning of the project. The main items of this plan were the following:

a) Preparation of specifications of the acoustical properties of each component, i.e. the acoustical requirements of the components were specified either as internal consortium technical requirements or requirements outlined in sub-supplier contracts.
b) Testing of the acoustical properties of each component at various stages during design, production and assembly.
c) Prediction of the exterior (and interior) noise levels at various stages during the design, production and assembly phases.
d) Pursuing periodic design reviews with consortium and sub-supplier design engineering teams.
e) Testing of acoustical properties of the vehicle during various stages at the assembly and during driving along the test track.

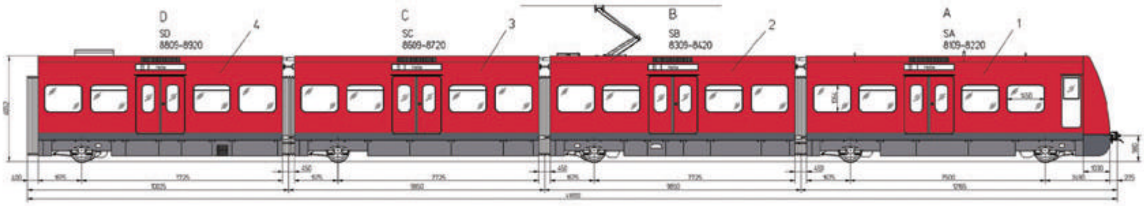
By adopting this procedure the consortium and ODS, who served as acoustical consultant, were successful in complying with the contract specifications.

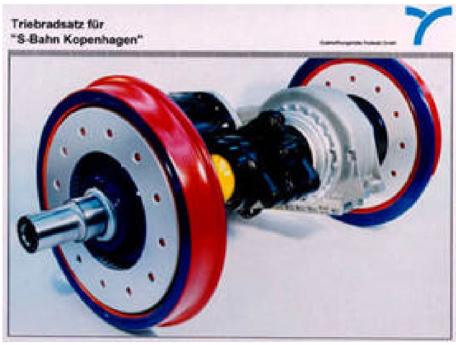
Compared to the current 2nd and 3rd generation trainsets, which are very traditional in their designs, the 4th generation is notably different. The most remarkable new features of the 4th generation trainsets are the following:

- Single axle steerable bogies resulting in minimum flange (and rail) wear and reduction of weight. Instead of 32 axles on the old trainsets (max. length) the new trainset has 20 axles.
- Hollow axles and wheel mounted brake discs consisting of aluminium to reduce weight.
- Increased bodyshell width and reduced car length enabling installation of 3 seats in each side.
- Use of aluminium throughout the car and selection of low-weight components whenever possible.

Quiet Rail Vehicle Data

DSB 4th Generation S-Train





Category	Regional EMU		
Operator/owner	DSB S-Train A/S		
Manufacturer *) Consortium	ALSTOM LHB/Siemens *)		
Production year	1995 –2005		
Maximum speed	120 km/h		
Type of track	UIC 60 rail in ballast		
Website for information 1	www.s-tog.dk		
Website for information 2	www.transport.alstom.com		
Website for information 3	www.siemens.com/ts		
Current noise level, speed, km/h	80	100	120
L_{pASMax}, 25 m, ISO 3095, dB	73	76	78
TEL, 7.5 m	80	83	85
Potential noise reduction			
L_{pASMax}, 25 m, ISO 3095	- 2	- 2	- 2
TEL, 7.5 m	- 2	- 2	- 2
	Quieter track		

Main noise sources	**Current low-noise design**	**Additional low-noise design**
Wheels	Reduced number	Not applicable
Wheels	Wheel mounted brake discs	May be possible but needs R&D
Wheels	Damping rings	May be possible but needs R&D
Traction motor	Fan silencer	Will not provide a lower noise level
Traction inverter	Fan silencer	Will not provide a lower noise level
Data sheet prepared 2001-05-28	Ulrik Danneskiold-Samsøe	Ødegaard & Danneskiold-Samsøe A/S

12.4 High speed trains

Present plans in Europe are for high-speed trains running at speeds significantly higher than 200 km/h to form the backbone of the inner-European railway network. The forerunner of high-speed-train technology in Europe was the French SNCF, which started commercial service with the first generation of TGV trains (the TGV *South/East*) in 1981. In subsequent years, the SNCF began operations on other lines with the TGV *Atlantique*, the TGV *Réseau*, and the double-decker TGV *Duplex*. In 1989, the TGV *Atlantique* already initiated scheduled service at a top speed of 300 km/h. In future, a not yet designed generation of TGV trains will operate within France at a top speed of 320 km/h.

In Germany, the DB AG started high-speed train service in 1991 with the ICE 1 and, somewhat later, the ICE 2 with both train types running at a top speed of 280 km/h. The newest member of the ICE family is the ICE 3, which will begin operations at a top speed of 300 km/h on the newly-built rail line between Cologne and Rhein/Main in 2002. Other high-speed DB AG trains that have recently entered service are the ICE-T, with tilt technology, and the ICE-TD, a similar train with diesel propulsion.

The Spanish RENFE began scheduled service with the AVE high-speed train (a modified version of the TGV) at 300 km/h, initially on an isolated network of standard gauge rails. On an expanded rail network, an already planned new generation of trains will operate at speeds up to 350 km/h. In 1988, viz., before the introduction of the AVE and ICE trains, the Italian FS broke into the high-speed club by operating the ETR 450 *Pendolino* at 250 km/h. In addition, the ETR 500 has been running at speeds up to 300 km/h on newly-built rail lines since 1992. Other high-speed trains operating in Europe are the cross-border trains *Eurostar* and *Thalys* (both trains are modifications of the TGV) as well as the Swedish *X2000*, which, however, only reaches speeds slightly above 200 km/h in normal service.

From a global perspective, the first high-speed train was introduced into service in 1964 in Japan at 210 km/h. Since then, many types of Shinkansen trains have been developed and operated by JR-Central, JR-East, and JR-West. Train speeds have been increased stepwise and today they lie at a top speed of 300 km/h, with a future maximum of 350 km/h already planned for. This speed range is also the long-term goal in Korea and Taiwan. In the USA, scheduled service has just recently begun on up-graded track linking Boston, New York, and Washington with the *Acela* train reaching speeds up to 240 km/h.

Quiet Rail Vehicle Data

ICE 1 / ICE 2

Category	High-speed train
Operator / owner	DB AG
Manufacturer	German railway industry
Production year	Since 1991
Maximum speed	280 km/h
Type of track	UIC 60 rails, stone ballast
Website for information 1	www.bahn.de
Website for information 2	-

Current noise level, speed, km/h	200	250	280
L_{pAFmax}, 25 m, dB(A)	85.5	89.5	92.0
TEL, 25 m, dB(A)	83.5	87.0	89.0
Potential noise reduction (for TEL)	-	4.0	4.0
L_{pAFMax}, 25 m, dB(A)	-	85.0	87.0
TEL, 25 m, dB(A)	-	83.0	85.0

DSA 380D Pantograph with foot-region covering on the ICE 3.

Main noise sources	**Current low-noise design**	**Additional low-noise design**
Traction motors	-	Acoustical treatment
Oil-cooling fans	-	Use of silencers
Traction-motor fans	-	Use of silencers
Wheels on power cars	Disc brakes	Use of bogie skirts
Wheels on middle coaches	Noise absorbers	More efficient absorbers / bogie skirts
Pantographs	-	Aeroacoustical treatment
Aerodynamic noise from bogies	-	Use of bogie skirts
Outer contour of train	Aerodynamical optimisation	-

Data sheet prepared 2001-06-22	B. Barsikow, akustik-data Engineering

12.5 Locomotives

Low-noise design of locomotives is more scarce compared to the efforts allocated to other rail vehicles like the DMUs or the EMUs. The magnitude of locomotives is also smaller compared to the number of cars, and wheel/rail noise emitted from a complete train is thus often dominated by the contribution from the cars. This may be another reason why locomotive noise has received less attention. At low speeds, however, the locomotive noise is often a dominating source. Examples are the noise from diesel locomotives during acceleration and fan noise from electric locomotives during braking.

A famous example of low-noise design of locomotives is the Lok 2000 made by SLM in Switzerland (now part of Bombardier Transportation). The Lok 2000 was developed and built in the early nineties, but has now gone out of production. The Lok 2000 is able to operate at speeds of up to 200 km/h.

As is the case for other rail vehicles, wheel/rail noise dominates the sound emission of a locomotive at intermediate and maximum speeds. All wheels of the Lok 2000 are fitted with damping rings, but there are significant differences between the two wheels of each wheelset, originating from the drive mechanism attachment. The directly driven wheel is less noisy because of better damping by rubber pads. Furthermore, the wheels are equipped with tread brakes supplied with sinter brake pads. This reduces roughness on the wheel treads significantly as compared with the conventional cast iron type.

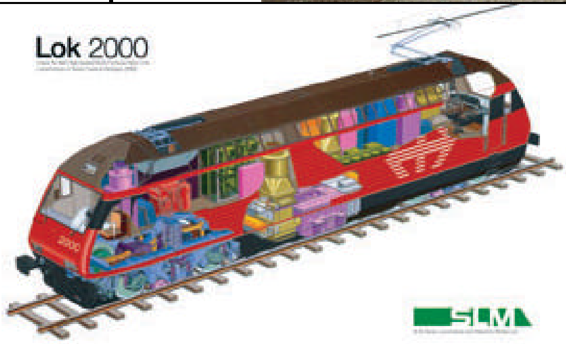
Another noise-reduction measure was applied to the gearbox and its related components. The reduction of the gearbox noise is important, since the noise originating from the tooth mesh propagates through the structure and is not only radiated from the gearbox itself, but also from the associated wheel and even the rail.

A further noise-reducing measure for low and intermediate speeds comprises the cooling fans for the traction motors and the cooling fans for the power inverters. At the speed of 80 km/h, the noise from these fans dominated the total sound emission of the Lok 2000.

Fitting the fans with silencers both on the suction and pressure sides reduced the noise from these fans. The application of these air ducts to the traction-motor and inverter fans resulted in an overall reduction of the sound emission of the treated components of approximately 12 dB(A). The air duct principle shown is a well-known technology. Today, however, most traction motors are self-ventilated, i.e. each of them has a fan mounted on the motor axle, and this design provides less opportunity for a sufficiently low noise level.

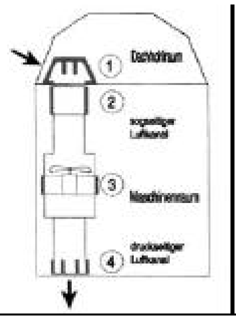
Quiet Rail Vehicle Data

Lok 2000



Category	Locomotive
Operator / owner	SBB, BLS, and KCRC
Manufacturer	SLM (now Bombardier)
Production year	Since 1991
Maximum speed	200 km/h
Type of track	UIC 60 rails, stone ballast
Website for information 1	www.sbb.ch
Website for information 2	-

Current noise level, speed, km/h	80	120	200
L_{pAFmax}, 7.5 m, dB(A)	79.0	84.5	91.0
TEL, 7.5 m, dB(A)	80.0	85.0	92.0
Potential noise reduction (for TEL)	2.5	2.5	2.5
L_{pAFMax}, 7.5 m, dB(A)	-	-	-
TEL, 7.5 m, dB(A)	77.0	82.0	89.5



Main noise sources	**Current low-noise design**	**Additional low-noise design**
Wheels	Vibration absorbers	More efficient absorbers
Wheels	Sinter brake pads	-
Wheels	Skirts	-
Traction-motor fans	Silencers on suction side	-
Inverter fans	Silencers on each side	May be unnecessary (GTO to IGBT)
Gearboxes	Optimised tooth mesh	-
Traction motors	-	Acoustical treatment
Pantograph head	-	Aeroacoustical treatment
Data sheet prepared 2001-06-22	B. Barsikow, akustik-data Eng. and U. Danneskiold-Samsøe, ØDS	

12.6 Freight cars

Rolling noise is the dominating noise source for most of the existing freight rolling stock. Cast iron block brakes create a very rough wheel, which has a noise emission level that is about 10 through 13 dB(A) higher than that of a smooth wheel. The retrofit strategy for existing freight cars is to replace the cast iron block by materials, which avoid roughening the wheel. As an additional measure it is necessary to change the wheel set and replace it with thermal-resistant wheels and to adjust braking pressure according to the friction characteristics of the brake block material.

Within the MetaRail project replacing the cast iron blocks with sinter metal blocks on flat wagons led to a 6 - 7 dB(A) noise reduction compared with the standard block braked vehicles. For composite brake blocks (k-block) the results appear even better. A further reduction requires a reasonable change of the bogie construction and braking system and will induce quite high costs of a retrofit although the additional noise reduction is rather low compared with the costs.

As a first step to reduce rolling noise from new freight wagons, k-blocks should be applied generally. Recently, UIC has homologated k-block brake for new and reasonably altered freight wagons. The homologation is limited for 3 years at present and wagons with a maximum speed of 120 km/h and 22.5 tons axle load are covered.

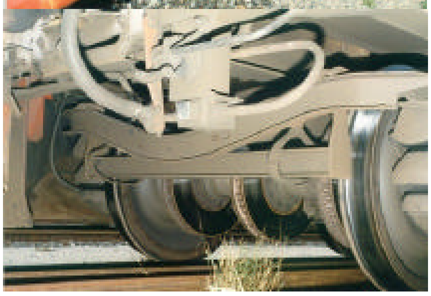
Examples of results from three major demonstration projects on low-noise freight car solutions are the following:

The first project is the German “Komponententräger” (Component train) in 1995 when a number of freight vehicles had been equipped with disc and drum brakes and bogie shrouds by DB-AG. The second project is the EU supported Brite-Euram project “Silent Freight”. Finally, in 1999 some flat wagons had been equipped with composite brake blocks, magnetic brake, wheel dampers and wheel skirts.

Another project that is currently underway is called “Low Noise Train”. A consortium of finally three European railway companies, FS, SBB, ÖBB (DB-AG left the consortium in May 2001) will support and stimulate industry to develop a number of prototype wagons. The requirements for the vehicles are clear. The project commenced in 2000 hence results cannot be expected before 2002.

Quiet Rail Vehicle Data

Low-noise freight vehicle

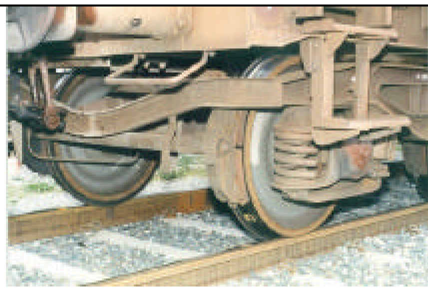


Category	Sgss Y 703		
Operator/owner	DB-AG		
Manufacturer	Bombardier-Talbot		
Production year			
Maximum speed	140 km/h		
Type of track	Mono-bloc concrete, UIC 60 rail profile		
Website for information 1			
Website for information 2			
Current noise level, speed, km/h	80		
L_{pAFmax}, 25 m, ISO 3095, dB(A)	73		
TEL, 7.5 m, dB(A)	79		
Potential noise reduction			
L_{pAFMax}, 25 m, ISO 3095, dB(A)	72		
TEL, 7.5 m, dB(A)	78		

Main noise sources	**Current low-noise design**	**Additional low-noise design**
Rolling noise	Disc brakes	
	Bogie shrouds	
Data sheet prepared 2001-06-24	M. Kalivoda	psiA-Consult

Quiet Rail Vehicle Data

Freight vehicle retrofit



Category	Rkqss / Sgjss		
Operator/owner	ÖBB		
Manufacturer			
Production year	1997		
Maximum speed	140 / 100 km/h		
Type of track	K1 monobloc sleeper, UIC 60 rail		
Website for information 1			
Website for information 2			
Current noise level, speed, km/h	80		
L_{pAFmax}, 25 m, ISO 3095, dB(A)	79		
TEL, 7.5 m, dB(A)	85		
Potential noise reduction			
L_{pAFMax}, 25 m, ISO 3095, dB(A)			
TEL, 7.5 m, dB(A)			

Main noise sources	**Current low-noise design**	**Additional low-noise design**
Rolling noise	Sinter metal brake blocs or k-bloc	
	Thermal resistant wheel	
	Wheel damping ring	
Data sheet prepared 2001-06-24	M. Kalivoda	psiA-Consult

12.7 Wheel surface quality monitoring and maintenance

Monitoring and maintenance procedures start as soon as the vehicle has been commissioned. In spite of the investments spent on low-noise design, the noise level of the vehicle increases when the vehicle is put into service. It is therefore necessary to make a continuous maintenance effort at keeping noise levels below an acceptable limit.

The case describes the system and procedures adopted at the DSB S-Train system in Copenhagen. The main goal of the S-Train monitoring and maintenance procedures is to minimize the wheel and track maintenance costs. An important spin-off, however, has been a significantly lower noise level.

A complete wheel monitoring system (WMS) - comprising monitoring of surface defects and profile wear – has operated in combination with an automatic vehicle identification (AVI) system at DSB S-Train since January 2000. This combined system has replaced a former, similar type of system that has run since the late eighties.

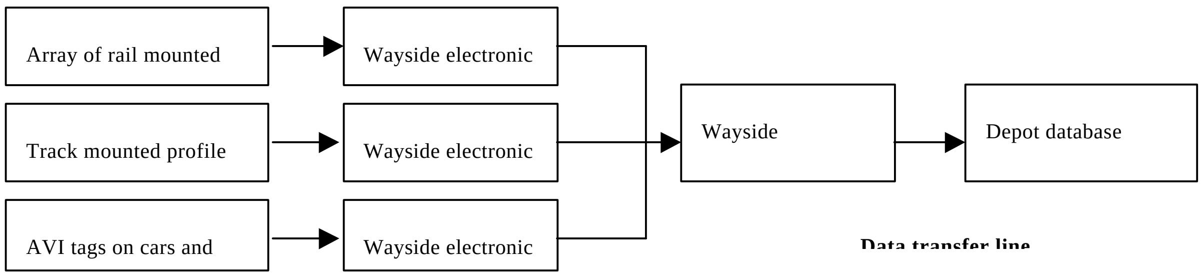
Wheel surface defects are detected by means of the 3rd generation Caltronic system using an array of accelerometers. The wheel profile wear is measured by means of laser scanners and CCD cameras manufactured by another company. The operating experience of the first generation WMS system achieved through a whole decade has made it possible to implement many new features in the new system, e.g., algorithms for diagnosis of the type of the defect like wheel flat, out-of-round wheel, and corrugated wheel. As a result, significant savings and quality improvements have been obtained in car availability, wheel maintenance costs, wheel inspection costs, track maintenance costs, car component damage costs, and costs for noise and vibration reduction.

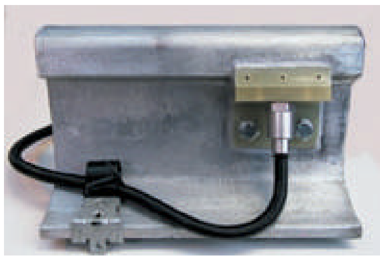
DSB started using the new 3rd generation wheel-defect detection system in the winter of 2000. The experience from the first generation system has been very positive. Therefore, there were never any doubts that a new, extended system should be installed as part of the maintenance system and monitoring equipment for DSB’s S-train cars.

Both the old system and the new system detect wheel flats, but, compared to the first generation system, the new system has been improved concerning the detection of out-of-round wheels, polygonised wheels, and wheels with corrugation.

Quiet Rail Vehicle Data

Wheel maintenance program



Category	Wheel maintenance	 
Operator/owner	DSB S-Train Copenhagen	
Manufacturer	Honeywell/ØDS-Caltronic	
Production year	1999	
Maximum speed	70 km/h at actual site	
Type of track	UIC 60, ballasted	
Website for information 1	www.s-tog.dk	
Website for information 2	www.honeywell.dk	
Website for information 3	www.odegaard.dk	
Design for minimum maintenance		
High axle load	Prevents gliding	
Small wheel diameter (high w/r force)	Prevents gliding	
Fast wheel slide prevention system	Prevents gliding	
Hard wear resistant tread steel alloy	Prevents deformation	
Dynamic braking	Less defects than friction	
	braking	
Preventive maintenance		
Rail washing	Prevents gliding	**Maintenance method improvement**
Maintenance of WSP (If applicable)	Prevents WSP malfunction	Laser treatment after reprofiling
		Friction modifier?
		Rail adhesion monitoring
Wheel defect and surface quality monitoring and reprofiling		
Track mounted detection system	Better than human detection	
Wheel condition database	Ensures quick follow-up	
Large capacity underfloor lathe	Ensures optimized reprofiling	
Data sheet prepared 2001-08-20	Ulrik Danneskiold-Samsøe	Ødegaard & Danneskiold-Samsøe A/S

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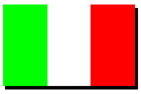

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14. Glossary

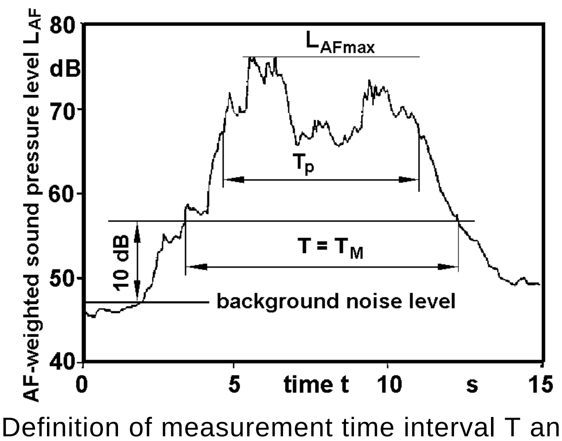
Notion	Alternative Notion	Description	Reference
AF-weighted sound pressure level L_{AF} in dB	AF sound pressure level in dB(A) or dBA	The A-weighted sound pressure level L_A is the sound pressure level with the frequency weighting function A. For sound emission measurements on railways the time constant F (τ = 125 ms) is used.	EN 60651 VDI 2716
Absorber, Wheel		Tuned or wide band absorber: • Tuned absorbers have an effect to reduce the curve squeal (tuned to the first natural frequency of the wheel rim). • Wide band absorber reduces the radiated sound in a wide frequency range (reducing of rolling noise, e.g. ICE 1)	
Absorber, Rail		Absorber mounted on the rail (below the foot of the rail or on one side of the web of the rail)	
Background noise		The general composite non-recognisable noise from all distant sources, not including the source of interest. Generally background noise consists of a large number of distant noise sources.	
Conformity of production		To check whether each single specimen of a series of products is in conformity with the sample unit, which has been type approved.	
Continuous monitoring		Monitoring of airborne sound and/or structure-borne noise close to a railway line of every pass-by. Herewith changes in the running surface conditions of rail and wheel can be observed. Together with an automatic vehicle identification system (AVI-System) vehicles with bad running surface conditions can be detected and subsequently for inspected.	
Damped ring		Steel rings build in the wheel rim (pressed). The effect of these rings consists of friction due to the relative movement between the ring and a the vibrating surface of the wheel.	
Day-evening-night level L_{den} in decibels (dB)	(or LDEN)	$L_{den} = 10 \cdot \lg \frac{1}{24}\left(12 \cdot 10^{\frac{L_{day}}{10}} + 4 \cdot 10^{\frac{L_{evening}+5}{10}} + 8 \cdot 10^{\frac{L_{night}+10}{10}}\right)$ in which: • L_{day} is the A-weighted long-term average sound level, determined over all the day periods of a year; • $L_{evening}$ is the A-weighted long-term average sound level, determined over all the evening periods of a year; • L_{night} is the A- weighted long-term average sound level, determined over all night periods of a year; in which	ISO 1996-2: 1987 And see next page

Notion	Alternative Notion	Description	Reference

		• the day is 12 hour, the evening 4 hour and the night 8 hour; Member States may consider a general resting period in the afternoon as a part of the 'evening' and shorten the real evening period accordingly (such a choice shall be identical for noise from all types of sources);
		• the start of the day (and consequently the start of the evening and the night) shall be chosen by the Member State (this choice shall be identical for noise from sources); the default values are 07.00 – 19.00 hours, 19.00 – 23.00 hours and 23.00 – 07.00 hours local time;
		• a year is the relevant year regarding the emission of sound and an average year regarding the meteorological circumstances an average meteorological year be defined as a year having the average meteorological conditions over 10 or more recent years;
		
		and in which
		
		• the incident sound is considered, which means that the sound that is reflected at the façade of a dwelling or another building under consideration is neglected.
		
		The height of the assessment point of L_{den} is dependent on the application:
		
		• for the purpose of strategic noise mapping in relation to noise exposure in and near buildings, the assessment points are at a height 4.0 ± 0.2 m (3.8 – 4.2 m) above the ground, at 2.0 ± 0.2 m in front of the most exposed façade; for the purpose of noise mapping as defined in Article 7 of this Directive, the most exposed façade will be the external wall facing onto and nearest to the specific noise source; for other purposes other choices may be made;
		• for the purpose of strategic noise mapping of public parks and relatively quiet areas in the open country the assessment points are at 4.0 ± 0.2 m above the ground;
		• it is recommended to base zone contours on the value of L_{den} at 4 m height, if appropriate;
		• for other purposes other heights may be chosen, but they shall never be below 1.5 m above the ground; examples are the following:
		    • the design of local measures meant to reduce the noise impact of specific dwellings;
		    • detailed noise map of a limited area, showing the noise exposure of individual dwellings.
			ISO 1996-2: 1987
			
			Proposal for a DIRECTIVE OF THE EUROPEAN PARLAMENT AND OF THE COUNCIL relating to the Assess-ment and Manage-ment of Environmental Noise

Notion	Alternative Notion	Description	Reference
Decibel dB		The decibel is a measure on a logarithmic scale of the magnitude of a particular quantity (such as sound pressure, sound power, sound intensity) with respect to a standardised reference quantity.	
Discrete monitoring		Regularly and /or sporadically monitoring of airborne and/or structure-borne noise (see continuous monitoring, too)	
Free Field		An area in which the effect of the boundaries upon the sound field are irrelevant	ELSEVIER's Dictionary of Noise and Noise Control
Eigenfrequency f_0 in Hz	Natural frequency	The frequency at which a system oscillates freely after suitable excitation.	
Emission	Creation Generation	Sending of noise (source, e.g. at a point of 7.5 m away from the track centre line and 1.2 m above the rail surface).	
Existing Line		A line which is in operation	
Immission	Reception	Reception of noise at a receiver (e.g. the facade of a building)	
Composition brake block	K-Block	Brake blocks made of synthetic material to minimise creation of roughness on the running surfaces of the wheels.	
Maximum AF-weighted sound pressure level L_{AFmax}		L_{AFmax} : see Figure 1 (used only for braking and acceleration)	prEN ISO 3095
Rail bonus	• Annoyance rail bonus • Annoyance differen-tial • Railway correction factor	The "Rail Bonus" describes the less annoyance of rail traffic noise compared with car traffic noise. In most EU countries the rail bonus is 5 dB(A). The rail bonus is only relevant to noise immission (reception). There is no connection to the noise emission (creation) and to the determination of noise emission limits.	e.g. Austria, Germany (16. BImSchV; Schall, 03); France; Switzerland
Rating level L_r		The rating level L_r is the time-averaged level for specified evaluation times and may include additions and deductions.	VDI 2716
Significantly altered lines (tracks)	Upgraded lines	Rebuilt or expanded lines (tracks) with the result of changed (increased or reduced) sound emission levels	

Notion	Alternative Notion	Description	Refe-rence
Sound pressure level L_p		$L_p = 10 \cdot \lg \frac{p^2}{p_0^2}$ dB where: p is the root mean square value of the sound pressure in N/m^2; $p_0 = 2 \cdot 10^{-5}$ N/m^2 is the reference sound pressure.	
Structure-borne noise or sound	Solid-borne noise or sound	Sound energy transmitted through the solid media of a structure (e.g. wheel, rail).	

Notion	Alternative Notion	Description	Refe-rence
Transit exposure level, TEL	$L_{pA,transit}$	"A-weighted sound level, in decibels, of a single train passage, measured for a time interval T and normalised to the pass-by time T_p. The time interval T must be long enough to collect all the acoustic energy related to the event. TEL is given by the following equation: $$TEL = 10 \cdot \lg\left(\frac{1}{T_p}\int_0^T \frac{p_A^2(t)}{p_0^2}dt\right)\ \text{dB}$$ where: T_p is the pass-by time of the train, in seconds, which is the total length of the train (buffer to buffer or coupling to coupling) divided by the train speed; T is the measured time interval; $p_A(t)$ is the A-weighted instantaneous sound pressure; p_0 = 20 ìPa is the reference sound pressure. The measurement time interval T is not exactly defined in prEN ISO 3095. Therefore the definition of VDI 2716 is used: T (= T_M in VDI 2716) is the time interval during which the AF-weighted sound pressure level L_{AF} exceeds the background noise level (environmental noise) by at least 10 dB. In order to estimate the TEL from the earlier used L_{pAFmax}-values (Figures for this are available for many trains), the following Eq. can be used: $TEL_{long} = L_{pAF\max} - 1$ dB(A) or $TEL_{short} = L_{pAF\max} + (0.5 \pm 0.5)$ dB(A) "Long" means train-sets with l > 30 m to 50 m,. "Short" has to be used for locomotives, short trams etc.  Fig 1: Definition of measurement time interval T and the level L_{AFmax} (see also Figure 1 in VDI 2716)	prEN ISO 3095 VDI 2716
Type testing		Test of a new type of rolling stock (HSR, freight wagon, passenger car, tram, mass rapid transit car, underground etc.). The tests have to be carried out under strict conditions according to a standard.	prEN 3095