UNION INTERNATIONALE
DES CHEMINS DE FER

INTERNATIONALER
EISENBAHNVERBAND

INTERNATIONAL UNION
OF RAILWAYS

Environmental Noise Directive
Development of Action Plans for Railways

April 2008

Paper prepared by Brian Hemsworth for UIC Noise Expert Network

CONTENTS

1 Environmental Noise Directive

1.1 Introduction

Directive 2002//49/EC “Relating to the Assessment and Management of Environmental Noise”, better known as The Environmental Noise Directive (END), came into force on 25 June 2002[1]. The overall aim of the Directive was to put in place a system which could be used to control the exposure of the EU’s population to environmental noise from roads, airports, railways and industry.

It implemented a two stage process which firstly, through noise maps, would determine the exposure of the EU population to environmental noise. This would be followed by the development of Action Plans to prevent and reduce environmental noise where necessary and preserve environmental quality where it is deemed to be good.

Mapping is intended to be carried out using common assessment methods for each of the sources identified above separately in terms of two noise indicators, the day-evening-night level L_{den} and the night level L_{night}. (These were defined by the Commission at an early stage in the preparation of END)

It is further intended that eventually common calculation methods will be used to derive the maps. This is not the case for the first round mapping in 2007 when either interim recommended methods or national methods can be used. No decision has been made to date on the methods to be used for the second round mapping in 2012. This situation will have to be monitored by the railway community

L_{den} is a 24 hour equivalent noise level using the following relationship:

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

where:

L_{day} is the 12 hour L_{eq} (default 0700 - 1900),

$L_{evening}$ is the 4 hour evening L_{eq} (default 1900 - 2300) and

L_{night} is the 8 hour night L_{eq} (default 2300 - 0700).

These are free field noise levels ie ignoring the presence of the façade of the building, calculated at a height of 4m above the ground.

The above relationship shows that evening noise levels are penalised by 5 dB(A) and night noise levels are penalised by 10 dB(A) reflecting a perceived increase in sensitivity to noise during those periods.

The 5 dB evening penalty means that every evening train is judged to make the same noise as more than 3 day trains with the same basic noise characteristics and every night train is judged to make the same noise as 10 day trains or more than 3 evening trains which have the same basic noise characteristics.

Depending on national circumstances the start of each period can vary.

The levels used for L_{night} mapping do not include the 10 dB(A) penalty.

END requires that the first round mapping, which for railways includes those railways in agglomerations with a population greater than 250 000 and railways outside agglomerations with more than 60 000 train passages a year, should have been completed by 30 June 2007. Action plans based on this round of mapping are required to be prepared by 18 July 2008. Second round mapping (agglomerations with a population greater than 100 000 and railways with more than 30 000 train passages a year) and the subsequent action plans are required to be completed by 30 June 2012 and 18 July 2013 respectively.

Where it has been possible to obtain information from Member State railways, the current progress on railway mapping and action planning is given in Appendix 1.

As stated above the Commission defined the noise indicators to be used for the maps and also the levels that were to be indicated on the maps.

The determination of where action is required will be the decision of the Member State as will be the involvement of individual railways in the whole process. The minimum involvement for railways in the mapping process is to provide the background data on train types, numbers and possibly speeds at

[1] Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise.

specific locations for use in the noise modelling. In some Member States, however, eg Italy and the Netherlands, railways have been responsible for producing the railway noise maps. The train speed information may vary for Member States and if specific site speeds are not provided by the railway it is likely that the modeller will use the lower of the line speed or the maximum speed of the rolling stock.

The important aspect will be that noise levels will have been determined either from national prediction models or the recommended interim model using input data either provided by or approved by national railways. The derivation of the maps should therefore not be a point of conflict between the regulatory body and the national railway, although the detail of involvement of railways varies for different Member States.

Action Planning will provide a more difficult political and technical situation for railways and although it is expected that action plans for railways will involve Member State Railway Companies, this is not guaranteed and lobbying of the responsible Government Department should be a high priority for each railway to ensure that action plans are only developed in consultation with those railways.

It is also assumed that some action plans may require noise reduction measures to be introduced. This paper, therefore, concentrates on the actions and options which, in the opinion of UIC’s Noise Expert Network, need to be considered by railways where noise reduction is an important element of the action plan. The procedure is defined in the flow chart of Figure 1 which also contains the section numbers of this paper which each element is discussed for cross reference.

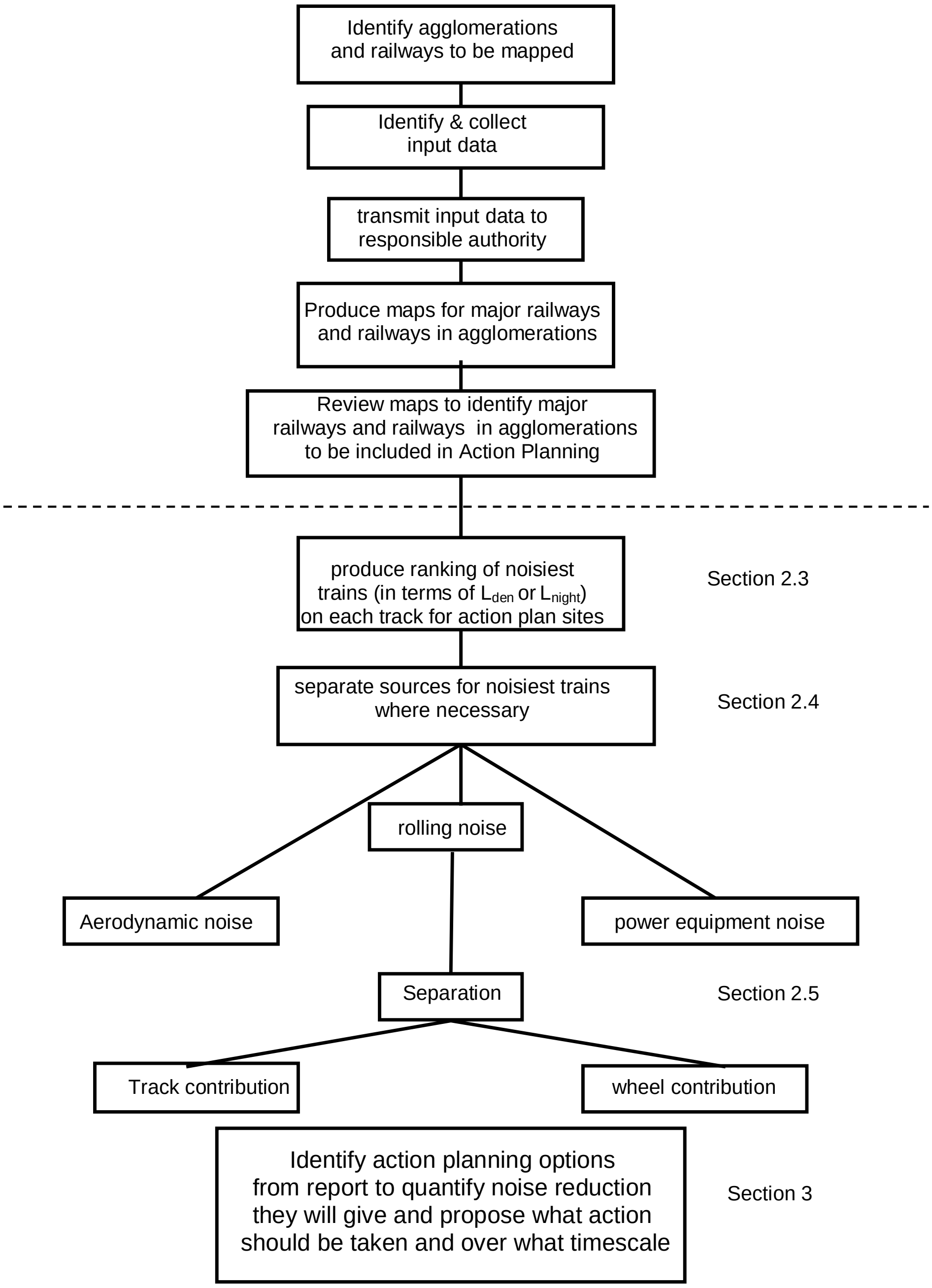


Figure 1 : Environmental Noise Directive Flow Chart

Details of the decisions and technical investigations associated with Figure 1 will be discussed in subsequent sections of this paper but four railway noise sources are identified:

- Rolling noise
- Power equipment noise
- Aerodynamic noise and
- “other noise sources”

Although it is not clear how each Member State will implement Action Plans it is likely that known technology for noise reduction would be implemented in the short to medium term. This will include noise control measures for rolling noise and some “other noise sources”. As will be described later, even these technologies will require detailed investigations to determine the most effective action.

Because of the complexity of source identification and the investigation of noise reduction options, reduction of power equipment noise and aerodynamic noise is unlikely in the short to medium term and would be considered only as a long term strategy. It follows that 2008 (and possibly 2013) action planning will concentrate on the reduction of rolling noise and "other noise sources". That will therefore be the focus of this paper.

Although the Directive requires maps to be produced for each individual source (aircraft, road, railway and industry) in terms of L_{den} and L_{night} in Annex 1.3 it also discusses the use of Supplementary Noise Indicators and amongst others identifies the use of L_{Amax} and SEL as being appropriate for night time protection. (it must be remembered that their use in this respect is not supported by noise survey data).

A number of Member States are producing maps of noise levels in noise metrics which are consistent with their existing national noise legislation. For this reason for example in England railways maps will be produced of L_{Aeq} for the day period 0600 – 2400 and night period 2400 – 0600. Sweden will produce additional railway noise maps in terms of 24 hour L_{Aeq} and L_{Amax}.

Annex 1.3 also mentions the production of maps which are a combination of noise from different sources, although no advice is given as to how the noise from different sources should be combined (adding noise levels or taking into account an annoyance differential). No advice is given on how these consolidated maps can be used in the action planning process, if at all. In fact it appears as if only the UK is producing consolidated maps.

What is clear is that railways should use the argument that railways are less annoying than aircraft and road traffic and that this should be taken into account when determining where action should be taken.

1.2 The Action Planning Process

The END states in Article 8.1 "The measures within the plans are at the discretion of the competent authorities, but should notably address priorities which may be identified by the exceeding of any relevant limit value or by other criteria chosen by the Member States and apply in particular to the most important areas as established by strategic noise mapping."

Annex V of the Directive also states that the actions which may be taken include:

- Traffic planning
- Land use planning
- Technical measures at noise sources
- Selection of quieter sources
- Reduction of sound transmission
- Regulatory or economic measures or incentives.

"Each action plan should contain estimates in terms of the reduction of the number of people affected (annoyed, sleep disturbed, or other)"

Not all Member States have noise limits applicable to existing railways and it remains to be seen how those Member States will identify railway locations where action planning is required. This should be another area of lobbying for railways to be in a position to influence this decision.

It should be pointed out that although the responsible authority in a Member State will use the noise maps to determine where action is required, the maps and the noise information they contain will be insufficient for developing action plans.

The maps will show composite L_{den} and L_{night} noise levels from all train operations whereas for effective action planning it will be necessary to identify and rank all railway noise sources at each location. This information can then be used to review the different options for noise control to develop cost effective action plans to successively reduce the noise from the sources giving the highest noise levels.

1.3 Railway Noise Sources

1.3.1 Rolling Noise

Noise, caused by the steel wheel rolling on the steel rail is always present. It increases with speed and is dependent on wheel and rail roughness levels. Cast iron tread braked wheels have a higher surface roughness than disc braked wheels or those braked using composite block brakes. Consequently they are noisier.

Rolling noise consists of noise radiated by the track and noise radiated by the wheel. Depending on the design of each and train speed the contribution of each to the total rolling noise level will vary with track noise generally dominating for track designs with soft rail pads and with train speeds typical of freight operation. The wheel contribution increases as rail pad stiffness and train speed increase. Therefore before developing an action plan aimed at reducing rolling noise it will be necessary to know whether the noise comes from wheel or track (or both).

1.3.2 Power Equipment Noise

Power equipment noise comes from a variety of sources including the engine, fans, exhaust outlets and traction motors.

This generally has little or no independency on train speed but can be significant in situations where full power is required, especially at low speed when rolling noise will be low. Power equipment noise is potentially a more serious problem for diesel traction compared to electric traction.

Although replacement low noise equipment, such as fans, may be available, it is probable that in the short to medium term, reduction of power equipment noise may only be possible where there is a replacement option with an existing quieter locomotive. For this to be feasible there has to be a quieter locomotive in use on the network and it has to be possible to transfer the duties of that locomotive from one routing to another. That will then mean that the effect of rerouting the noisier locomotive will need to be assessed.

The most likely scenario is that where locomotive noise is shown to be a significant contributor to the noise at an action planning site a longer term strategy of designing and introducing quieter locomotives will need to be followed.

1.3.3 Aerodynamic Noise

As train speed increases noise from the flow of air over the train surface can become significant in the area of pantographs, coach end connections, bogie areas etc where changes in cross section affect that air flow. The latest thinking is that this is not the dominant noise source below 300 km/h[2] but as train speeds increase and where it is shown that high speed trains are the major noise source, aerodynamic noise will need to be investigated in relation to other sources.

As with power equipment noise, the mitigation of aerodynamic noise may not be a short to medium term option but again will need to be reviewed as a longer term strategy in action planning at locations where it is shown to be a significant contributor to total noise.

Figure 2 shows the typical importance of each of these sources with speed, although the absolute and relative noise levels are only indicative and will vary with train design. It does show the potential for power equipment noise to be dominant at low train speeds, for rolling noise to be the main source at speeds from 50 km/h to 300 km/h and for aerodynamic noise to become significant at higher speeds.

The latest publications about the contribution of the rolling noise and the aerodynamic noise show that the contribution of the aerodynamic noise is not as high as previously assumed and that the reduction of the global pass-by noise must combine actions on the both sources.

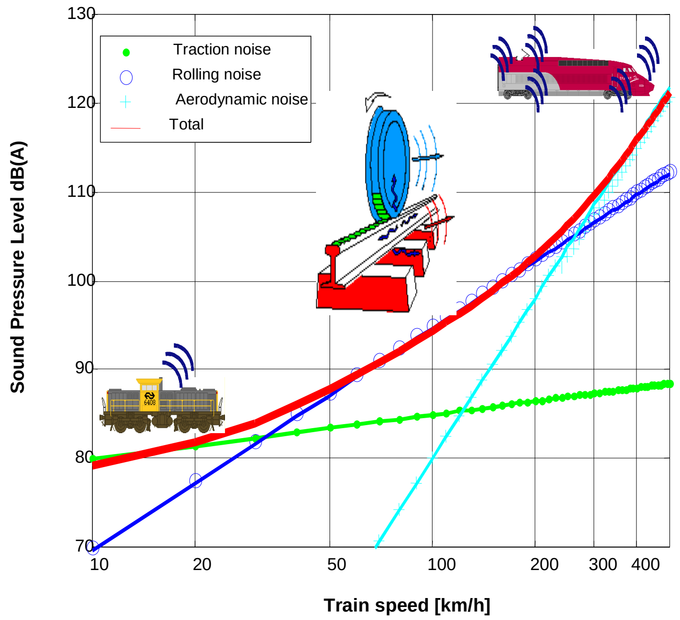


Figure 2. : Sound pressure level as a function of train speed

[2] Gautier, Poisson and Letourneaux: “Noise Sources for high speed trains: a review of results in the TGV case” Paper to 9IWRN Munich, September 2007

1.3.4 Other Noise Sources

In specific situations other noise sources can dominate. Examples are curve squeal, brake screech, broadband braking noise, elevated structure noise. Their importance at specific locations will need to be identified and noise reduction measures applied where appropriate.

It is possible, however that other sources such as curve squeal or additional noise from braking may not be part of the national noise prediction model. If, therefore, action planning is based only on noise levels in the map their presence will not have been included. It is possible that other information may be used for identifying where action is required and this could include the presence of other noise sources.

1.4 Options for Source Identification

END recommends that noise levels on maps are determined by prediction rather than measurement. This is likely to be the situation in the vast majority of cases.

In order for accurate maps to have been produced, information on train numbers train length and speeds for each train type and for each track will have been input by the modeller. (some models may combine traffic on different tracks for simplification but with loss of accuracy especially when shielding calculations are included) Although it is unlikely to be a direct output of the model, quantification of noise levels for each of the sources in Section 1.3 could be obtained as an intermediate output of the model and a ranking list obtained.

This option may not be directly available for the separation of rolling noise because most national models only predict total rolling noise and there are very few cases where the wheel and track contributions will have been separately identified in the modelling process.

It is thus more likely that supplementary measurements will be required at Action Plan locations to determine the ranking of the noise sources.

The input parameters for the prediction model used to produce the maps are important in the source identification process since predictions will have been made for the train types inherent in the model, the number of trains will have been input for each type, track and time period together with their assumed speeds. These parameters will need to be mirrored in the source identification process to produce the ranking.

The alternative methods for ranking railway noise sources will be the subject of the following sections of this paper, before the options for noise control are discussed.

2 Methodologies for Ranking Railway Noise Sources

2.1 Introduction

Using strategic noise maps produced for the first round mapping process, Member States are required to identify sites where action planning is necessary. The methodology they will use is not prescribed in the Directive which states that "Action plans should address priorities in those areas of interest and should be drawn up by the competent authorities in consultation with the public". In particular these action plans should be "based upon noise mapping results, with a view to preventing and reducing environmental noise where necessary and particularly where exposure levels can induce harmful effects on human life and so preserving environmental quality where it is good".

Irrespective of the methodology adopted by Member States for determining locations where action is required and any targets which may be set, it is assumed that there will be locations where noise action plans will require noise levels to be reduced. This will require a detailed knowledge of the noise sources involved and probable input from railway noise experts.

Such is the nature of acoustics that effective noise reduction can only be achieved (certainly where there is a future target noise level) when the noise from the sources making the highest contribution to the total noise is targeted.

The main thrust of this section of the paper is to identify the different options for ranking railway noise sources so that effective noise control strategies can be developed.

Measurements are likely to be most often used to derive a ranking. It must be noted, however, that any short term measurements, which will be discussed here, cannot be used currently for checking the accuracy of the maps.
The main reasons are:

(a) The mapping should have predicted the year average noise levels which will have included the effect of changing meteorology over the year with a consequent effect on noise propagation. For some sources (aircraft and road traffic) some changes of meteorology can affect the noise source terms, but this is unlikely to be a major issue for railway noise.

To date there are no widely accepted methods for converting the results of short term measurements into an annual average, although this was part of the EU FP6 project IMAGINE whose results were published during 2007.[3]

(b) For railway noise predictions, rail roughness is crucial in determining the level of rolling noise. Most prediction schemes are based on "national average" rail roughness levels and it is certain that at many sites rail roughness will be higher than the "national average". This will give higher measured levels of rolling noise than predicted. Procedures for identifying and dealing with situations where this is the case at "action plan" locations are discussed below.

Once it has been determined that the track roughness is in line with those assumed in the model used for mapping, the measurements described below can provide data that can be used to check the assumptions made regarding train operation and source noise levels. It should then be possible if changes are thought necessary to rerun the model with revised input terms to determine whether the site falls within those criteria used for action planning.

2.2 Validation of Rolling Noise Source Terms used in Prediction

Decisions regarding locations where action is required will have been made based on the noise levels in the map. Some assumptions regarding noise source terms used for carrying out the mapping predictions will need to be reviewed to determine whether they are valid at the site under investigation.

2.2.1 Rail Roughness

The rolling noise source levels in the noise prediction method are likely to have been based on empirical data obtained from the network using data from sites where the track is known to be in "average smooth" condition. It is necessary in the first instance at a site where action is planned to confirm the accuracy of this assumption.

[3] IMAGINE: Improved Methods for the Assessment of the Generic Impact of Noise in the Environment, Final Synthesis Report *Guidance on the IMAGINE methods*, DeltaRail bv November 2006.

Alternatives include:

a Direct measurement of rail roughness to compare with typical “smooth” rail roughness

b Indirect roughness measurement using microphones mounted on service or test trains to compare with noise measured at other sites.

c Comparison of measured passby noise levels with those from the prediction method.

For the analysis of data in (b) it will be necessary to carry out a widespread survey of the network to produce a distribution of noise levels. Where the noise at the site in question is at the lower end of the distribution it can be assumed that the track is in good condition. Where the noise level at the action plan site is towards the high end of the distribution it can be assumed that the track is in poor condition and its roughness is in excess of that assumed in the mapping prediction.

For comparison (c) it is important that only rolling noise is measured. This should be the case with trailing unpowered vehicles running at typical operating speeds though the site and which are not being braked. Higher noise levels than those assumed for that train type in the mapping prediction model will indicate that rail roughness levels are higher than the assumed level for mapping.

Where comparisons a, b and c indicate higher rail roughness levels than those assumed in the mapping prediction, rail grinding will be necessary before the detailed investigation of ranking of noise sources is undertaken.

NB: For the assessment of roughness from noise measurements (b and c) it is important that disc braked vehicles are used as the noise source.

2.3 The Freight Traffic Noise Reduction Action Programme

The International Union of Railways (UIC), the Community of European Railways and Infrastructure Companies (CER) and the International Union of Private Car Owners (UIP) initiated the “Freight Traffic Noise Reduction Action Programme” in 1998. The objective of this programme is to implement a sustainable railway noise reduction by introducing low noise technology in freight traffic, this traffic being the main railway noise source. The reduction in noise is achievable by replacing cast iron brake shoes on freight vehicles by synthetic brake shoes. This will lead to lower surface roughness on the wheels and thus reduce the noise they generate.

To equip new wagons with synthetic brake shoes is cost neutral; therefore the railways already decided to use this technology for new rolling stock in 2002. Currently some 8500 wagons equipped with synthetic braking shoes are in operation or are ordered.

Funding and technical issues mean that the introduction of lower noise freight vehicles will be phased over a number of years. Since it is however part of every railway’s plans, retrofitting presents a special case for action planning.

Current tests are indicating that the rolling noise from cast iron tread braked freight vehicles is reduced by about 8 dB(A) when those brakes are replaced by brake with blocks made from composite materials, it therefore seems worthwhile investigating the impact of this replacement as a first step when an action plan site is identified.

The most convenient way of carrying this out will be by calculation by reviewing the source noise levels used as input to the calculation method reducing the rolling noise element of cast iron tread braked freight vehicles by 8 dB(A)[4]. From this an effective noise source level in terms of L_{den} can be derived or the full prediction can be carried out including propagation effects. The reduction in L_{den} will indicate, for each site, how effective implementation of the action programme will be. It should be remembered that this is global action and quieter vehicles will impact on many locations.

At locations where rolling noise from freight trains is dominant, this action will be very effective but for mixed traffic routes this may not be universally the case.

The information obtained can be used in a number of ways. Firstly for locations where the Action Programme is effective a priority for retrofitting specific vehicles to give the greatest impact can be derived and at locations where the Action Programme does not provide sufficient noise reduction to achieve any objectives which may have been set for action planning, the options described in the later sections can be reviewed to define the appropriate to be taken.

[4] : UIC/CER: Rail Noise Abatement Status Report 2008. To be published 2008

2.4 Identification of the noisiest trains

The general case will be a multi track railway on which run a number of different types of train, at various speeds and a variety of power settings for the motive power. All these will have been known or assumed input parameters for the prediction model. Therefore those input parameters for the location under investigation should be reviewed. This will give the following information for each time period (day, evening and night):

- Defined train types (and default train length) used in the prediction model on each track
- Train speeds
- Numbers of trains

The prediction model will have assumed that at any particular site, the noise from trains on each track will be a series of repeated events since, for example, all through mainline passenger trains of a particular design on a particular track will be travelling at approximately the same speed. The same will have been assumed for local trains and freight trains. Thus when groups of trains of a specific design operate consistently at a different speed to other groups of the same design at that location because, of say, the proximity of a station, the groups will have to be designated as different train types.

A train type can be defined as a group of trains each with the *same noise characteristics*, each on the *same track* and each travelling at the *same speed*. When any of these parameters change, a new "train type" needs to be defined.

The calculation of L_{den} is such that either the noise from all the trains operating during each of the time periods can be summed to give a total L_{day}, $L_{evening}$ and L_{night}, or these quantities can be derived for each train type and to give partial values and then summed to give L_{den} for each train type. It is this second method that will be used where comparison of L_{den} for each train type will provide the ranking.

As first steps, simple measurements can be carried out and because of the repeated nature of train passbys the requirement is to provide an average noise level for a single train passby, in terms of a noise energy unit such as Sound Exposure Level (SEL) or hour averaged L_{eq}. The choice will depend on national preferences and the noise consultant carrying out the assessment.

For repeated events $L_{Aeq,T}$ is derived from the following expression:

$$L_{Aeq,T} = SEL + 10 \log N - 10 \log T_s \quad (2)$$

Where $L_{Aeq,T}$ = L_{Aeq} over time period T_s

SEL = average SEL for a single train passby

N = number of trains in time period T

T_s = time period (day, evening or night) in seconds

Where the base energy average is in terms of hourly L_{eq} for a single train passby the expression is:

$$L_{Aeq,T} = L_{Aeq,1hour} + 10 \log N - 10 \log T_h \quad (3)$$

Where $L_{Aeq,1hour}$ = average hourly L_{Aeq} for one train passby

T_h = time period (day, evening or night) in hours

The duration of measurements will depend on the length of time required to obtain a reliable average level for each train type operating at the site. Since night time noise levels are penalised by 10 dB(A) and this could be the only time when certain freight trains are operating it is probable that noise from night time trains will dominate the calculation of L_{den}. Some night time noise measurements may be inevitable. A review of the train timetable and the input data for the prediction model will identify the times at which different trains operate so that a plan can be developed to obtain all the necessary data.

It is recommended that the measurement procedures in ISO 3095[5] are followed as closely as possible particularly with respect to meteorological conditions ie wind direction from track to microphone with a speed < 5m/s and no falling rain or snow. Microphone positions should be set where it is most convenient to achieve uninterrupted noise propagation from all tracks, but distance corrections should be made for propagation to make the data relevant for the nearest affected development especially for a multi track railway. It is recommended that in order to minimise meteorological effects, these measurements are carried out closer than 50m to the railway.

[5] ISO 3095:2005:Railway applications -- Acoustics -- Measurement of noise emitted by railbound vehicles

Since the predicted noise levels will have been based on vehicles in good condition, any measurements which include the effect of wheel flats should be disregarded in producing the average noise level but their presence noted for remedial action to be taken.

The number of measurements of each train type will depend on the consistency of the noise they produce but a minimum of three passbys per train type will be required. Where it is necessary to remain on site to obtain data from certain trains, measurements from all trains passing the site should be made.

At the end of this process the average SEL (or other energy related quantity) for each train type on each track will have been obtained giving a series of noise levels:

$$SEL_{i,tt}$$

Where i refers to a particular track and

tt refers to a particular train type

Using equation 2 the noise levels for each time period are:

$$L_{day,i,tt} = SEL_{day,i,tt} + 10 \log N_{day,i,tt} - 46.4$$

$$L_{evening,i,tt} = SEL_{evening,i,tt} + 10 \log N_{evening,i,tt} - 41.6$$

$$L_{night,i,tt} = SEL_{night,i,tt} + 10 \log N_{night,i,tt} - 44.6$$

The above equations are for the general case but it is likely that for a particular train type, train speeds will not vary throughout the 24 hour period and the SEL (hourly averaged L_{eq}) will be the same for each period of assessment.

The partial contribution to the total L_{den} from that train type ($L_{den,i,tt}$) is given by:

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

Comparison of values for $L_{den,i,tt}$ will give a ranking for all the train types thus identifying those where reducing the noise will reduce the total L_{den}.

Total L_{den} is derived from partial L_{den} using the following equation

$$L_{den} = 10\lg\sum\left(10^{\frac{L_{den,i,tt}}{10}}\right) \qquad (5)$$

where $\sum$ is the summation of all train types i,tt

Revision of the equations 4 and 5 after calculating the effect of implementing noise mitigation identified in Section 3 will determine the benefit accruing from the noise mitigation options.

2.5 Separation of Sources

Once the “noisiest trains” have been identified it is necessary to determine which sources in those train/track combinations are the largest contributors to total noise.

2.5.1 Rolling Noise and Power Equipment Noise

Initially trains at conventional speeds will be considered where there will be no possibility of aerodynamic noise. Figure 3 shows the simulation of the noise level time history for a train hauled by a diesel locomotive which is on power.

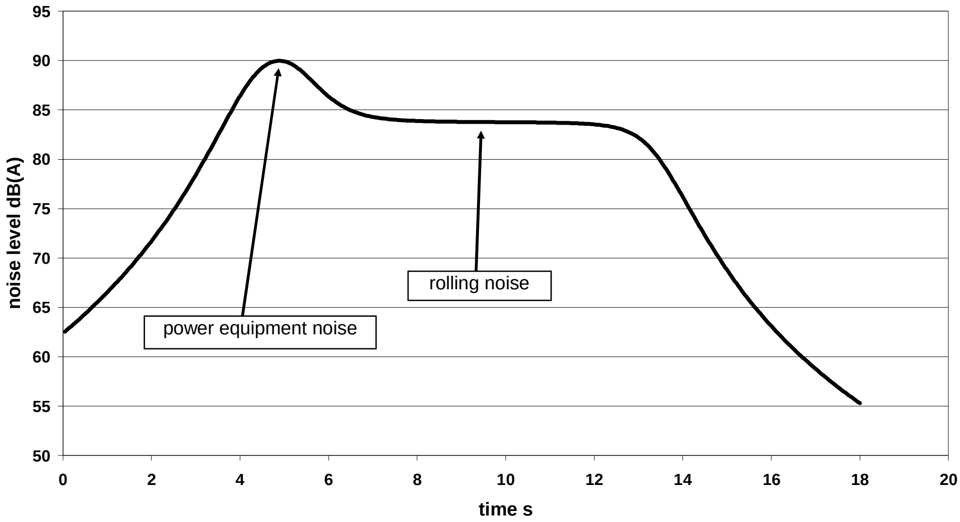


Figure 3 : noise level time history for diesel hauled train (80km/h, d = 25m)

Two distinct phases are apparent: a peak caused by the locomotive at the head of the train and a level portion for the remainder of the train caused by rolling noise of the trailing vehicles. The noise levels are typical for diesel locomotives on full power hauling vehicles with cast iron tread brakes running at 80km/h for a measurement position of 25m from the track.

The analysis of other passbys may not be as obvious as this. For instance power equipment noise tends to be independent of speed whereas rolling noise levels will increase by about 9 dB(A) for each doubling of train speed. Thus at 160km/h the rolling noise will be in excess of the power equipment noise (in terms of dB(A)) even though power equipment noise is likely to be distinctly audible because of its low frequency character. In non full power situations the power equipment noise will be less but may still contribute.

In situations where power equipment noise can be readily identified, as in Figure 3, separation of rolling noise and power equipment noise, manually with analysis equipment is straightforward in order to then quantify the noise energy in the passby associated with each source.

Where such a separation is not readily achievable, further testing may be required in which the train type under consideration is run through the site under test conditions of minimal or no power to give the rolling noise characteristics of the train. Subtraction of the rolling noise element from the total noise will give the power equipment noise.

2.5.2 Aerodynamic Noise

Similar testing will be required in situations where high speed trains are contributing most to total noise. In order to determine how much aerodynamic noise is present it will be necessary to estimate the rolling noise content of total noise at high speeds.

This can be carried out by running the train in question through at site at a number of speeds, say 100 km/h, 150 km/h and 200km/h (or as high as possible where aerodynamic noise is believed not to be present) and obtaining a relationship for rolling noise ($L_{Amax,rolling}$) as a function of speed.

This is likely to be of the form:

$$L_{Amax,rolling} = k * \log(\text{train speed}) + \text{constant} \qquad (6)$$

This will produce a line similar to that attributed to rolling noise in Figure 2.

At the speed of high speed trains through the site subtraction of the estimated rolling noise from the measured total noise will give an estimate for aerodynamic noise, but will not identify which aerodynamic noise process is responsible. If this simple analysis shows aerodynamic noise to be a significant contributor to total noise and its reduction would be beneficial to the action plan, further studies will be necessary to identify how aerodynamic noise might be reduced.

2.6 Separation of track and wheel noise

As a steel wheel rolls on the steel track, forces in the contact zone cause the wheel and track (rail and sleepers) to vibrate and hence radiate noise. The force generated in the contact zone is dependent on train speed and also on the surface roughness levels of wheel and rail. Thus rolling noise increases as a particular train goes faster and vehicles with high roughness wheels (eg cast iron tread braked vehicles) will generate more noise than vehicles with low roughness wheels (eg disc braked wheels). Also when either train runs on a high roughness level track (eg corrugated track) the noise level will be higher than for that train on smooth track. This level difference is more noticeable for trains with smooth wheels where for the same condition of wheel the noise level can increase by up to 20 dB(A).

The relationship between wheel radiated noise and track radiated noise is given by:

$$L_{total} = 10 \log (10^{L_{wheel}/10} + 10^{L_{track}/10}) \quad (7)$$

Where

L_{total} = total rolling noise

L_{wheel} = wheel radiated noise

L_{track} = track radiated noise

This relationship is important for assessing the effectiveness of any mitigation action applied to either wheel or track.

If $L_{track} – L_{wheel}$ > 10 dB(A), the track contribution dominates the total rolling noise and wheel treatments in isolation will be ineffective.

For tracks with softer rail pads (the more normal situation in Europe) and at lower speeds, the track noise will usually dominate over wheel noise. In these situations low noise wheel components in isolation will be ineffective and quieter railways will only result when measures are first applied to the track. This was demonstrated in the Silent Track project[6].

Conversely if $L_{wheel} – L_{track}$ > 10 dB(A), wheel noise dominates and track treatments in isolation will be ineffective.

In situations where there is no clear dominance of either L_{wheel} or L_{track} it may be necessary to mitigate both the wheel and track noise to reduce total noise.

A number of options are available for determining the wheel and track contributions. The choice will be dependent on the expertise and facilities of the railway/consultant carrying out the action plan.

2.6.1 Approximate Separation from Frequency Analysis

The general results from studies carried out over a number of years has indicated that low frequency rolling noise is generated by vibration of the sleeper, mid frequency rolling noise is generated by vibration of the rail and high frequency rolling noise is generated by vibration of the wheel. Thus frequency analysis of the rolling noise can be used to give and approximate quantification of the wheel and track contributions. An example of this is shown in Figure 4.

[6] Hemsworth, Gautier & Jones "Silent Freight and Silent Track Projects" Proceedings of InterNoise 2000, Nice August 2000

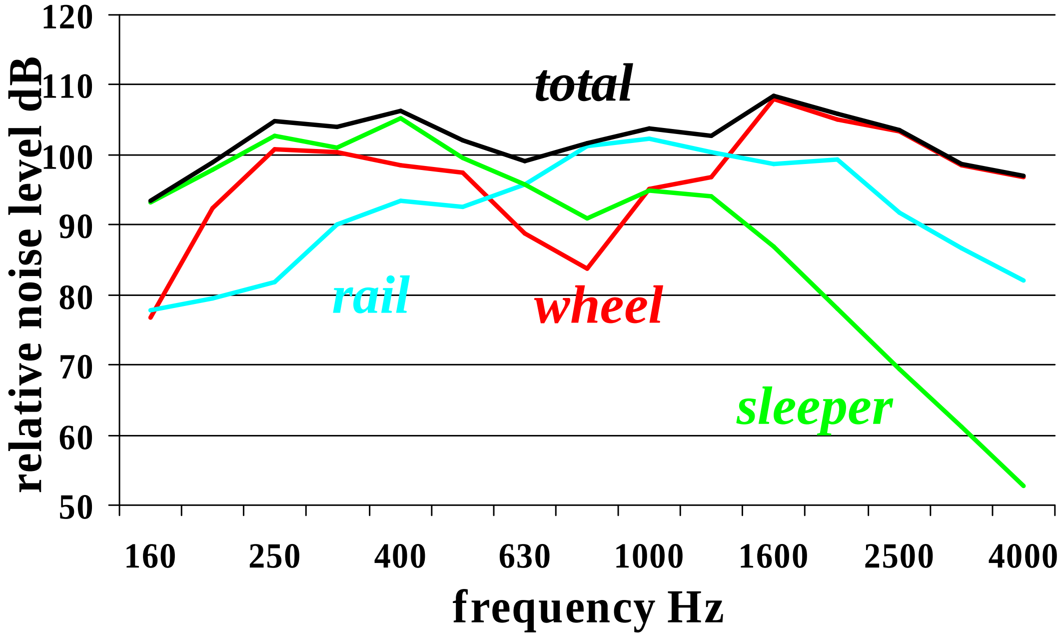


Figure 4 : Relative Contributions to Rolling Noise

To a first approximation it can be assumed that track noise dominates at frequencies below the 1250 Hz or 1600 Hz third octave bands. The steps in this analysis are:

1. determine total A-weighted rolling noise level (L_{total})
2. determine A-weighted level for spectrum in frequency range 100 Hz – 1250 (1600) Hz

   this is designated track contribution to rolling noise L_{track}
3. $L_{wheel} = 10 \log (10^{Ltotal/10} - 10^{Ltrack/10})$

It must be noted that this is very much an approximation and should only be used when no other alternatives are available.

This technique was used in the analysis of data for EU FP4 Projects Silent Freight and Silent Track.[7][8]

2.6.2 Separation by Measurement

Over recent years a number of techniques have been developed to separate the wheel and track contributions to rolling noise by measurement.

The Vibro-acoustic Track Noise method (VTN) and the Multiple Input Single Output method (MISO) were developed by AEA Technology Rail bv (now DeltaRail bv) and SNCF respectively as part of the EU FP5 Project STAIRRS. They are described in detail in the final report of STAIRRS Work Package 2 as reports STR23TR130902AEA1 (VTN) and STR23TR261102SNCF1 (MISO) and summarized at the World Congress on Railway Research 2003.[9][10].

[7] Silent Freight Project: Final Report Ref 5E0U15T1.DB December 2000

[8] Silent Track Project: Final Report Reference 00615/7/ERRI/T/A December 2000

[9] Verheijen et al: "VTN: A validated method to separate track and vehicle noise and to assess noise reduction measures" WCRR Edinburgh September 2003

[10] Letourneaux et al, "MISO: A measurement method to separate noise emission of railway vehicles and track" WCRR Edinburgh September 2003

The basic principles for each method are:

The Vibro-acoustic Track Noise method

measure the total rolling noise (L_{total}) at the side of the track and

measure the vibration of rail and sleeper.

The vibration levels are used as input to simple noise radiation models for those track components to predict track radiated noise (L_{track}).

Vehicle radiated noise (L_{wheel}) is derived from the equation

$$L_{wheel} = 10 \log (10^{Ltotal/10} - 10^{Ltrack/10})$$

The Multiple Input Single Output Method

measure the total rolling noise (L_{total}) at the side of the track

measure the track transfer function between track vibration and noise for the portion of the passby not affected by wheels (ie for cross section between bogies, total noise = track noise) This analysis requires microphones to be located close to the track where parts of the noise level time history which have no input from wheel radiation can be identified.

compute the track radiated noise (L_{track}) for those slices of the time history, where wheel and track combine, from the track transfer function and track vibration

Derive vehicle radiated noise (L_{wheel}) from the equation

$$L_{wheel} = 10 \log (10^{Ltotal/10} - 10^{Ltrack/10})$$

As can be seen the principles of both methods are simple in that the track contribution to rolling noise is determined by either modelling of sound radiation from vibration measurements (VTN) or by determining radiation transfer functions from measurement and signal processing techniques (MISO). The vehicle contribution is derived by subtracting the track contribution from the measured total rolling noise.

2.6.3 Separation by Modelling

A number of models have been developed to describe and quantify the rolling noise process. The most widespread in use today is TWINS which was developed by UIC through the work of Committee C163 (Railway Noise)[11][12].

Noise is predicted from the assumption that rolling noise derives from the forced vibration of wheels and tracks through their contact patch. Wheel and rail roughness are important parameters in determining the level of the force.

The model requires Finite Element models to be developed for wheel and track components and the noise from each can be determined as separate outputs. It is thus possible to develop a TWINS model for the wheel/track combination under investigation to determine the vehicle and track contributions to rolling noise.

Use of TWINS requires specialist knowledge and this method is only recommended where the Member State Railway has staff (or access to consultants) with experience in FE modelling and TWINS software.

2.7 Identify other noise sources

It is possible that other sources may be present at the site under investigation. The influence of these sources may have been included in the model used for mapping, in which case it may have been the cause for developing an action plan or it may be an additional source which was not included in the mapping process.

In each case it will need to be quantified and where necessary plans put into place for its reduction.

Examples of these additional sources are:

- Curve squeal (high frequency pure tone as train traverses as sharp curve)
- Brake screech (high frequency pure tone during braking)
- Broadband braking noise (broadband noise during braking)
- Elevated structure noise (enhancement of rolling noise through noise radiation of support structure)

[11] Thompson, Hemsworth & Vincent “Experimental Validation of the TWINS Prediction Program for Rolling Noise, Part 1: Description of the Model and Method” Journal of Sound and Vibration Vol 293 May 1996.

[12] Thompson, Fodiman & Mahe “Experimental Validation of the TWINS Prediction Program for Rolling Noise, Part 2: Results” Journal of Sound and Vibration Vol 293 May 1996

3 Action Plan options to reduce railway noise.

3.1 Introduction

In order to develop the new EU noise policy, the EU Commission created technical working groups to assist in the preparation of the policy in 1998. Working Group 5 (Noise Abatement) was given the task of evaluating noise mitigation methods. In its final report (Inventory of Noise Mitigation Methods, 18 July 2002) it discussed a number of options for reducing the effects of noise from road, rail and aircraft.

For railways it only considered roiling noise reduction at source and maintenance although it implied in a table that there might be some benefit from the application of speed restrictions without discussing it in the text of the report. No advice was given regarding mitigation of motive power noise or aerodynamic noise.

It did, however, consider traffic planning, traffic management and land use planning for road traffic although it is difficult to see how a number of these options could be used in action planning.

Nonetheless Annex V (Minimum Requirements for Action Plans) of the Environmental Noise Directive contained a list of potential action planning options without identifying to which traffic mode these may be applicable. In noting that public consultation (and public participation) is an integral part of the action plan process, there is no doubt that all of these actions will be raised by outside bodies at some time and the purpose of the following sections is to give an indication as to the effectiveness of each and the benefit/risk for the railway..

The options given in Annex V of the Directive are repeated below.

- Traffic planning
- Land use planning
- Technical measures at noise sources
- Selection of quieter sources
- Reduction of sound transmission
- Regulatory or economic measures or incentives.

In considering technical measures at sources and the use of quieter sources a distinction has to be drawn between local and global measures to reduce noise. Any action taken on the track or at trackside is a local action and will not impact on other sites on the network. Action taken on vehicles, however, is a global action because benefit will occur wherever that vehicle operates (although the benefit may not be the same at all sites). It therefore appears that in order to develop a cost effective action plan for a network, that network should be assessed in its totality rather than a series of local plans. For example where it is shown that one particular train type is identified in section 2.3 to be significant contributor to the total noise at a number of sites, global remedies should be reviewed to determine the benefit for the noise on the whole network following their implementation.

This will be particularly important where it is shown that noise from cast iron tread braked freight vehicles are the dominant source at a number of sites. Assessing the benefit of retrofitting composite brake blocks will be the first step to determine whether that action alone will be sufficient to meet the targets set for the action plan. If the answer is no, further mitigation will need to be implemented. It is of course possible that action planning will be required at sites with little or no freight traffic. In these situations the implementation of alternative mitigation from the options discussed below will be necessary.

Unless otherwise stated the noise reduction quoted below is for the maximum level associated with the train passby and the effect on partial L_{den} and total L_{den} has to be assessed using the equations in Sections 2.3 and 2.5.

3.2 Selection of Quieter Sources

3.2.1 Vehicle Braking Systems

As discussed in Section 2.3 one of the most important influences of rolling noise is rail/wheel roughness. Increases in wheel and rail roughness cause more noise. Wheel roughness is controlled by the method of braking the wheel with high roughness levels being a consequence of using cast iron tread brakes. This has historically been the system used for freight vehicles although this discussion applies to any vehicle with cast iron tread brakes.

As passenger train speeds increased cast iron tread braking was phased out in favour of disc brakes which gave a more compatible braking characteristic for those higher speeds. Figure 5 shows the difference in rolling noise level, as a function of speed, between cast iron tread braked vehicles and disc braked vehicles for a measurement distance of 25m.[13]

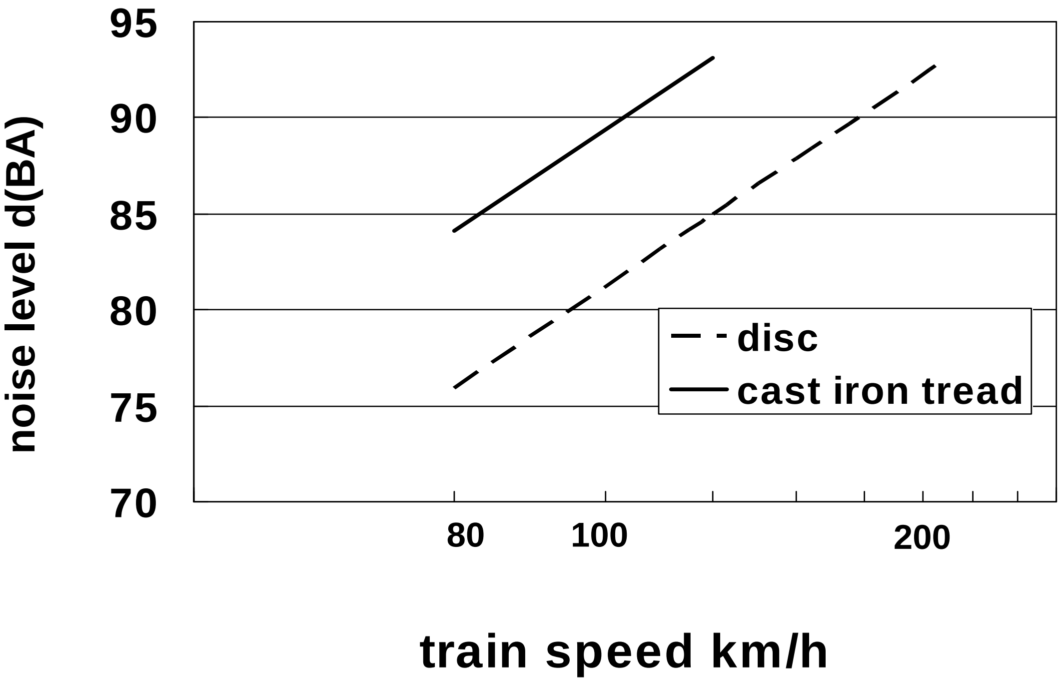


Figure 5 Effect of Train Speed and braking system

This shows the well known relationship that because disc braked wheels are smoother than cast iron tread braked wheels they cause about 10 dB(A) less noise at the same train speed. For new passenger trains, the use of cast iron tread brakes is being phased out to comply with recent TSI noise levels but replacing cast iron tread brakes by disc brakes is unlikely to be a short term action plan option.

The current initiative by UIC to retrofit Europe's cast iron tread braked freight fleet with composite brake blocks is aimed at achieving the same noise result for freight vehicles. Early noise data suggests that noise reductions of about 8 dB(A)[14] at the same train speed can be achieved.

Questions of funding and priority setting for this action are still under discussion but where it can be demonstrated that the retrofitting of specific vehicles would have a large impact on a Member State's action planning (and for International traffic be beneficial for another Member State's Action Plans) that would increase the priority level for retrofitting being applied to those vehicles.

It should be noted that the 10 dB(A) or so benefit discussed above will be the limit of noise reduction from using alternative forms of braking because rail roughness will then dominate total roughness and even smoother wheels will not give further noise reduction.

3.2.2 Rail Dampers

EU project Silent Track and more recent investigations have shown that tuned absorbers attached to the rail can reduce the track contribution to rolling noise by up to 7 dB(A)[15] Later studies (SNCF internal research, SILENCE and Dutch IPG project) confirm these values and also indicate that it can be assumed that a reduction of total rolling noise of about 3 dB(A) can be achieved with rail dampers.[16, 17]

Where the investigations described in Section 2.4 show that track generated noise is significant the effectiveness of rail tuned absorbers should be assessed. This will however be classed as local action and may not provide the same noise reduction for all trains and tracks. Certainly it is likely that for higher speed trains the vehicle contribution will increase and track treatments will be less effective.

[13] Hemsworth "Rail System Environmental Noise Prediction, Assessment and Control" Handbook of Noise and Vibration Control, Chapter 121 2007.
[14] See ref 4
[15] Hemsworth, Gautier & Jones "Silent Freight and Silent Track Projects" Proceedings of InterNoise 2000, Nice August 2000
[16] van der Dool "Rail Dampers, rail infrastructure gets quiet" Proceedings of InterNoise 2007
[17] Benton et al "Track Absorbers: Concept, Measurements, Simultaion SILENCE Seminar, Paris January 2008

3.2.3 Wheel Damping

EU project Silent Freight and more recent investigations have shown that tuned absorbers attached to the wheel can reduce the wheel contribution to rolling noise by up to 7 dB(A).[18] Later studies (SNCF internal research, SILENCE and Dutch IPG project) confirm these values and also indicate that it can be assumed that a reduction of total rolling noise of about 2 dB(A) can be achieved with wheel dampers.[19]

Where the investigations described in Section 2.4 show that wheel generated noise for one or more vehicle design is significant the effectiveness of wheel tuned absorbers should be assessed. This will be classed as global action and may impact other sites but the effect will only be effective where the wheel contributions from those trains are significant.

3.2.4 Bogie Shrouds and Low height barriers

Bogie shrouds and trackside barriers are most effective when the lower edge of the shroud overlaps the upper edge of the barrier. To stay within an envelope of European gauge limits, this was not possible in the Silent Freight/Silent Track projects where a gap above rail head level was required.

In combination with wheel and rail tuned absorbers a noise reduction of about 10 dB(A) was achieved in these projects.

National studies in the UK and Germany have indicated that where an overlap can be achieved substantial acoustic benefit can result. In these studies, the bogie shroud/low barrier combination gave an acoustic benefit of between 8 and 10 dB(A)[20][21].

Cost and effectiveness studies will need to be carried out to optimise the mitigation options where a reduction in rolling noise is required.

3.2.5 Quieter Locomotive

Where it has been demonstrated that locomotive noise dominates one possible option is to replace the locomotive in question with a quieter design, if one exists.

The low cost, potentially short term option is to use a quieter locomotive that is currently operated on other parts of the network. Questions to be answered include:

- Is there a current quieter locomotive in use?
- Are there enough locomotives available to provide the service?
- Is the locomotive suitable for the service in terms of power and speed?
- What are the noise implications for the routes on which these locomotives operated?

If positive answers are provided these questions an action plan could be drawn up.

In the situation where it is known that quieter locomotives exist but either not in use on the network or where the answer to all or some of the questions above is negative, the solution could be to replace the existing noisy fleet with the quieter locomotives specifically purchased for their noise characteristics. Because of the cost implications this could only be considered as a long term solution and would need to be included in an overall future planning strategy for the railway.

3.3 Train Speed

Rolling noise energy, $L_{eq,}$ is proportional to the ratio of train speed with the relationship

$$L_{eq} = 20 \log (\text{train speed}) + \text{constant}$$

This is shown in Figure 6

[18] Bouvet et al "Rolling Noise from Freight Railway Traffic: Reduction of Wheel Radiation by means of Tuned Absorbers" Proceedings of InterNoise 2000

[19] see Reference 16

[20] Jones "Railway Noise Control using Combined Vehicle and Track Treatments" World Congress on Railway Noise Research, Paris 1994.

[21] Hugo & Saabel "Implementation of the Noise Abatement Program of the DBAG" 2nd International Workshop – Abatement of Railway Noise Emissions – Freight Transport, Berlin 1998

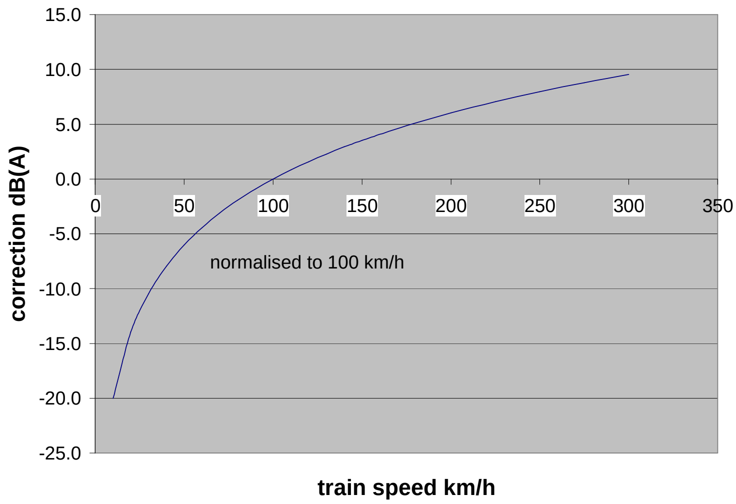


Figure 6 : Rolling Noise Speed Correction

The table below (derived from Figure 6) shows the changes to train speed required to give specific reductions in noise level.

Train speed ratio	Change in noise level (dB(A) L_{eq})
.89	-1
.80	-2
.71	-3
.63	-4
.56	-5
.32	-10
.10	-20

It can be readily seen that useful reductions in noise level can only be achieved by large reductions in train speed. Such changes are not compatible with the operation of a commercially competitive railway.

It should also be noted that in a situation where there is a significant amount of diesel engine noise, at low speeds the maximum noise level from the whole train is fairly independent of train speed and in fact for full power situations reducing the train speed can increase the noise energy level by a small amount.

Train speed reduction is therefore not seen as an effective action plan option.

3.4 Redirection of Traffic

This reduces the number of trains passing a given point within a prescribed time period.

L_{eq} is proportional to the ratio of numbers of trains with the relationship

$$L_{eq} = 10 \log (\text{No of trains}) + \text{constant}$$

(The same ratio applies to changes in train length)

This relationship is shown in Figure 7.

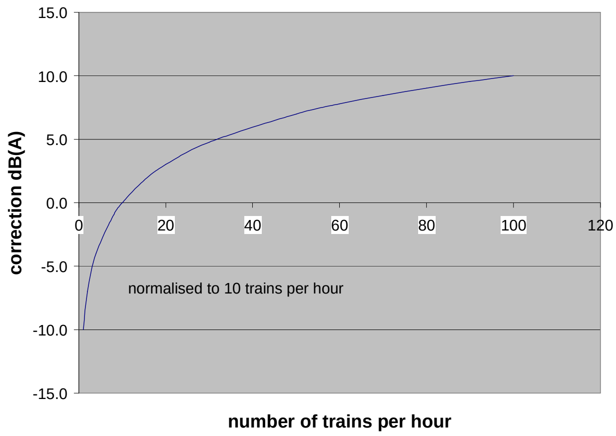


Figure 7 : correction for number of trains per hour

The table below (derived from Figure 7) shows the reduction in traffic density required to give specific reductions in noise level.

Number of trains ratio	Change in noise level (dB(A) L_{eq})
.80	-1
.63	-2
.50	-3
.40	-4
.32	-5
.10	-10
.01	-20

The table demonstrates that noise level is insensitive to small changes in train numbers. Where a passenger or freight service is justified commercially by the operation of a prescribed number of wagons in a particular time period, a reduction in that number is not an effective option for action planning.

3.5 Traffic planning (timing of operations)

Received noise will be assessed in terms of the day, evening, night level L_{den} where:

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

The 5 dB penalty for evening trains means that each evening train has the same effect on L_{den} as 3 identical daytime trains.

The 10 dB penalty for night trains means that each night train has the same effect on L_{den} as 3 identical evening trains or 10 identical daytime trains.

Thus, transferring trains from sensitive noise periods (night and evening) to less sensitive time periods (evening and day) will reduce the received noise in terms of L_{den}.

It is possible to carry out simulations with actual train operations to test the sensitivity of L_{den} to such changes but it is not possible to assess at this stage whether this option is practicable for the operation of a national railway network where timetables have to be met and rolling stock have to be at specified locations at specific times to meet the demand of freight clients and passengers. Leaving them “parked” during the night period may not be a viable option, particularly for freight trains.

3.6 Land Use Planning

This was identified in Annex V of the Directive as an action planning option and indeed the use of separation between the railway and sensitive receivers is a design option when considering the introduction of new infrastructure into a residential area or the development of housing near an existing railway. It is unlikely, however, that movement of the railway tracks or the relocation of noise sensitive development near the railway will be an effective option for action planning as part of END.

For completeness, however, Figure 8 shows the effect of distance on the noise level from a railway track derived from the following expression:

$$L_{Aeq} = \text{constant} -(13\log(d/dref)+.008d -.2)$$

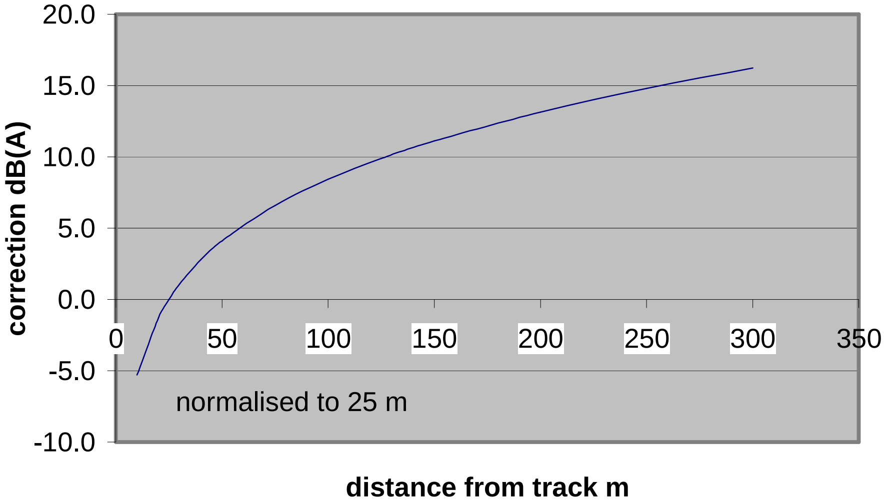


Figure 8 : reduction of train noise energy with distance

The table below gives the changes of noise level with distance relative to a reference of 25m.

Distance from track m	Reduction in noise level (dB(A) Leq)
10	-5,3
20	-1,3
25	0,0
30	1,1
40	2,8
50	4,1
75	6,6
100	8,4
125	9,9
150	11,1
200	13,1
250	14,8
300	16,2

It can be seen that noise level is sensitive to distance changes of 10m for distances closer than 50m, but for larger distances noise level is insensitive to even medium changes in distance.

3.7 Maintenance

Noise level is function of rail and wheel surface roughness. Figure 9 shows the distribution of noise level for a particular route, normalised to a train speed of 100 mile/h[22]. Although there will be small changes in noise

[22] RRK Jones, AEA Technology Rail "Remote monitoring systems for rail corrugation and curve squeal" Paper to Railtex 2000, Birmingham November 2000

level due to slight differences in track parameters throughout the route, as a first approximation it can be assumed that the distribution is a function of rail surface roughness.

The range of noise levels is in excess of 20 dB(A) and it is likely that the places where the higher noise levels occur would be considered ones where the track is corrugated. The noise levels around the mode of

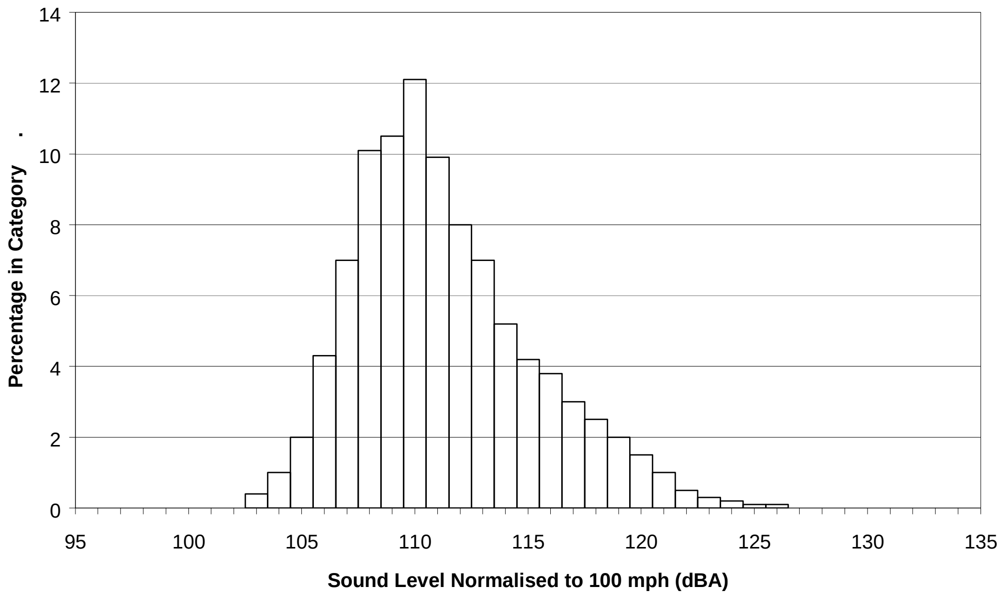


Figure 9: Distribution of Underfloor A weighted Sound Pressure Level Normalised to 100 mph

the data will however be taken as normal service track and noise reductions will accrue from maintaining rail roughness at levels where the lower noise levels in the distribution occur by adopting a grinding strategy.

The range of the distribution is dependent on wheel roughness and lower benefits from rail grinding will occur for vehicles with cast iron tread brakes.

A strategy that states that rail grinding will be used to control rail roughness, hence rolling noise and that wheel flats will be removed as part of a vehicle maintenance programme are valid statements within an action plan.

Consideration could also be given to following the experience of DB and their Specially Monitored Track where "Acoustic Grinding" follows regular monitoring of track roughness with a test vehicle. Such smooth rails are particularly effective at reducing noise from smooth wheeled vehicles.

3.8 Lineside Noise Barriers

Noise barriers have been used in the past to reduce noise from land transport systems and are widely used for mitigating railway noise in mainland Europe.

Noise levels can be reduced if the upper edge of noise barrier is imposed between or above the line of sight between a noise source and a receiver. The higher the noise barrier, the greater will be its effect. Although the benefit will reach an asymptotic value.

For railways benefit can also occur when the surface of the barrier facing the railway is acoustically absorptive and may give up to a 5 dB(A) benefit relative to an acoustically reflective barrier.[23]

In the general case of trying to protect people in low rise dwellings next to railways, a 10 dB(A) reduction in rolling noise can be achieved by a reflective barrier approximately 2m high relative to railhead level. For higher barriers the upper limit for the effectiveness of a reflective barrier is approximately 15 dB(A). Absorptive barriers are more effective.

It is more difficult to protect people in high rise situations since it is more difficult to obstruct the line of sight for a high receiver with a barrier of acceptable geometry.

It should also be noted that noise barriers are less effective at reducing diesel locomotive noise because the source is generally taken to be at the exhaust and could be in excess of 4m above the rail head. Consequently the barrier needs to higher before the line of sight is interrupted.

Adverse impact from visual intrusion to neighbours is one of the negative effects of barriers together with their potential to block the view of passengers inside the train when high noise barriers are used.

[23] Her Majesty's Stationery Office: Calculation of Railway Noise, UK Department of Transport 1995

3.9 Reduction of Sound Transmission

Reduction of sound transmission by installation of secondary glazing to properties is already an option that is used when new railways are introduced near existing development or where new development is planned near an existing railway.

Where it is considered that the noise inside the property is critical and no other options are effective, introduction of secondary glazing will need to be considered.

3.10 Elimination of Curve Squeal

Where it is shown that curve squeal is the dominant noise source at location identified for an action plan, the objective should be to eliminate that squeal, not just reduce it.

As the train traverses a curve it can emit a high frequency pure tone (or combination of pure tones) which derive from the resonance frequencies of the wheel. Solutions tend to either reduce the excitation using some form of lubrication or reduce the response of the wheel through added damping.

UIC has sponsored a number of studies in recent years. Phase 1I, completed in 2003 published a report "Toolbox of Existing Measures" which identified a number of potential solutions to control curve squeal[24].

These included:

- Wheel treatments (ring dampers, constrained layer damping, tuned absorbers etc)
- Resilient wheels
- Steerable axles
- Lubrication (water spray, rail lubrication, friction modifiers)

It was shown that there is no single means of control that works universally and that different options have to be reviewed to ascertain which is most likely to work in a particular situation based on past experience of a similar application.

The second phase intended to increase confidence in selected mitigation measures.[25]

UIC background literature should be used to determine which might be the most appropriate means of controlling curve squeal at the site in question.

3.11 Elevated Structure Noise

As a train runs on a track vibration is transmitted through the wheel rail contact into the track and its supporting structure. For normal ballasted track this vibration causes either audible rolling noise or feelable low frequency vibration or (normally for trains in tunnels) an audible low frequency rumble.

For a train on an elevated structure that vibration is transmitted into the structure which can then radiate noise. This will be additional to the rolling noise caused by vibration of wheels and tracks.

Steel structures tend to be "noisier" than concrete structures and those where the track is fastened directly to the bridge structure are "noisier" than those where there is a ballast layer between the track and and bridge deck.

Elevated structure noise is most often controlled by vibration isolating layers (proprietary rail fasteners) between the track and the bridge decking or less often by damping of the vibrating bridge elements. When the design allows the addition of a ballast layer, which adds damping and mass, can be beneficial for direct fastened track structures.

The choice of the most appropriate solution can only follow a comprehensive assessment of the noise radiating elements of the train/track/bridge combination.

The use of noise specialists with a proven track record of controlling elevated structure noise is recommended.

3.12 Trains in Tunnels

It is possible that suggestions will be made to consider placing the railway in tunnel. In this situation, the noise created cannot reach a receiver by a direct airborne noise path. For the design of a new railway in noise sensitive areas the use of tunnels if often considered and implemented. However, as in the case of a surface railway, the movement of the train causes vibration to be transmitted into the ground via the track support structure and the tunnel elements. This vibration propagates away from the tunnel and can be

[24] Muller et al "Curve Squeal WP3: Toolbox of Existing Measures" February 2003

[25] Oertli "Combating Curve Squeal Phase II: Final Report" August 2005

perceived by people in adjacent buildings as either whole body low frequency vibration or audible groundborne noise.

The most likely disturbance will be from groundborne noise radiated into a room space by the vibration of walls, floors and ceilings. This is characterised as a low frequency (50 Hz – 200 Hz) rumble each time a train passes and personal disturbance can be caused at such low levels that inaudibility is almost the design criterion.

In terms of control there is no proven equivalent to the airborne noise mitigation measures of noise barriers or sound insulation, although success has been achieved in particular situations by applying vibration isolation to the foundations of buildings. This can, however, be expensive.

The known control techniques are to apply vibration isolation into the track design and alternatives such as ballast mats, resiliently supported sleepers and floating slab track have been used with varying degrees of success.

The most cost effective way of controlling groundborne noise is to include appropriate vibration control into the initial design. Retrofit action will be detrimental to the railway service since the line will be closed for the period of the works and may not always be possible since there will be cases where the size of the tunnel cross section is insufficient to cater for an increase in construction depth to include the added resilience.

To carry out actions at the design stage of tunnel construction requires accurate predictions of groundborne noise inside adjacent buildings as a function of frequency so that potential problem situations can be identified and the characteristics of the required resilience can be defined. Because of the number of rolling stock, track, intervening ground and building dynamic parameter values required to carry out such a prediction, the state of the art for such predictions is not as advanced as for airborne noise. The ability to define where mitigation is needed and its specification is less precise.

It is therefore possible that putting the track in tunnel will transfer a potential airborne noise problem into a potential vibration problem which may be more difficult to mitigate against.

Notwithstanding these technical considerations the costs associated with tunnelling are likely to dismiss this as an option for action planning.

4 Cost of Mitigation Measures

The table below gives indicative costs that were used in the cost effectiveness analysis of the STAIRRS project updated with information from the SILENCE, IPG projects and the UIC review.

mitigation	Indicative Cost
2m barrier	1000 €/m
3m barrier	1350 €/m
4m barrier	1700 €/m
Insulated windows	2200 – 8000 € (4 windows per house)
K blocks (retrofit)	4000-10000 € per wagon
LL blocks (retrofit)	500 – 2000 € per wagon
Rail tuned absorbers	300 - 400 € per track m (2 rails)
Wheel tuned absorbers	3000 - 8000 € per wheel inc fitting

5 Summary of Effectiveness of Action Plan Options

Annex V of the Environmental Noise Directive lists a number of examples of actions which could be taken. These have been discussed in Section 3 and the results are summarised below using the order of action in the Directive.

5.1 Global versus Local Actions

Actions taken to reduce wheel roughness and other vehicle noise related measures will impact at all locations where those trains are operated. These are termed Global Actions.

Actions taken to reduce the track contribution to rolling noise, use of noise barriers and additional sound insulation at the receiver will only impact at the location where the noise reduction measure is taken. These are termed Local Actions.

In order to integrate Global and Local actions in Action Planning it is recommended that a network wide plan is developed to firstly determine the effect of any potential global actions at all the sites under investigation before the need for local action is assessed. This will ensure the most cost effective plan, for the whole network, is implemented.

5.2 Traffic Planning

It is assumed that "traffic planning" includes all elements of train operation which impact on the noise level L_{den}. It therefore includes speed restrictions, rerouting of trains and retiming of trains. (These methods were included as examples in the reports of the EU's Working Group 5 "Noise Abatement" for road traffic control.)

5.2.1 Application of speed restrictions

Small changes in train speed have little effect on the noise. Application of speed restrictions, which would need to be high to give worthwhile reductions in noise, is not consistent with the operation of a commercially competitive railway.

5.2.2 Rerouting of Trains

Could be achieved as a national plan but large changes in train numbers would be required to give noticeable changes in noise levels at specific sites. Naturally where trains were diverted to another route, the noise would increase at sites along that route.

5.2.3 Retiming of Trains

The nature of the L_{den} calculation means that at a specific site L_{den} could be reduced in situations where trains operating in the evening period were transferred to the day time period or trains operating during the night period were transferred to either the evening period or the day period.

The implication of this would need to be investigated as a complete national network strategy to judge whether it could be considered as an effective option. This only reduces noise levels when expressed as L_{den} and calculated using the formula in this paper.

5.3 Land Use Planning

The moving of tracks or relocation of noise sensitive development at action plan sites are not considered to be realistic action plan options.

5.4 Technical Measures at Source

5.4.1 Use of Vehicles with Smooth Wheels

Past studies have shown that phasing out of cast iron tread braked vehicles in favour of those with disc brakes (passenger vehicles) or composite tread braked vehicles reduces the noise from those vehicles. This could be an effective action plan where the rolling noise from cast iron tread braked vehicles is shown to be the dominant source. Their use will reduce both the track contribution to rolling noise and the vehicle contribution.

5.4.2 Rail Tuned Absorbers

Correctly designed rail tuned absorbers can reduce the track contribution to rolling noise by up to 7 dB(A) and total rolling noise in general by about 3 dB(A). Their use as the only means of noise control will only provide more reduction to total rolling noise in situations where the track is the major contributor to rolling noise.

5.4.3 Wheel Tuned Absorbers

Correctly designed wheel tuned absorbers can reduce the wheel contribution to rolling noise by up to 7 dB(A) and total rolling noise in general by about 2 dB(A). Their use as the only means of noise control will only provide more reduction to total rolling noise in situations where the wheel is the major contributor to rolling noise.

Combined use of wheel and rail absorbers may need to be assessed in situations where neither wheel not track is dominant in rolling noise generation.

5.4.4 Low Noise Locomotives

In special circumstances the replacement of "noisy" locomotives by quieter locomotives may be possible. Unless however those locomotives can be transferred from one part of the railway network to the problem site this is likely to only be a future planning strategy for noise control where new quieter locomotives would be purchased.

5.5 Noise Barriers

Noise barriers do reduce noise and reductions in excess of 10 dB(A) are achievable with barriers with an absorbent inner face at heights of 2m above rail level.

Barriers are not likely to be as effective in the reduction of locomotive noise due to its low frequency content and its high position above the railhead.

Cost effectiveness studies in the EU FP5 project STAIRRS demonstrated that high noise barriers alone were not cost effective and noise reduction at source should be investigated before including noise barriers in a noise control strategy.

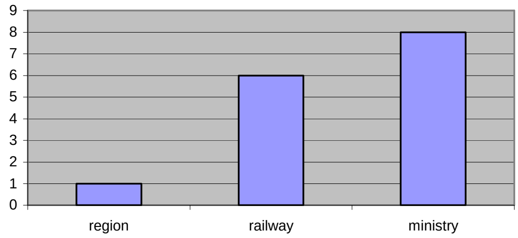
5.6 Maintenance

The inclusion of track maintenance (rail grinding) and wheel maintenance (turning to remove wheel flats) as a noise control strategy will probably be seen by outside bodies as a necessary requirement of action planning.

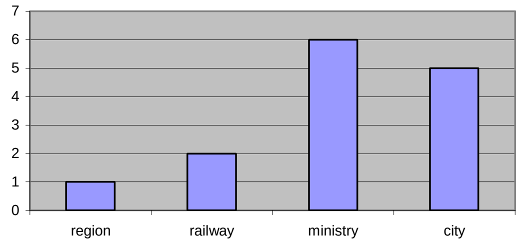
Appendix 1 : Implementation of END

A questionnaire was sent to members of the Noise Expert Group and other EU railways with representation on the Environment Group to obtain progress on the implementation of the Environmental Directive in different Member States. 15 railways responded (some not providing answers to all questions) and the charts below summarise the replies.
They indicate a wide range of responsibilities for railways and varying involvement with the implementation process.
The replies show that the majority of railway maps have been completed and that few decisions have been made on action planning. There is still doubt in a number of Member States as to how the process will be taken forward and it is not clear who will pay for it. The trend is, however, for an extra cost burden being placed on the railways.

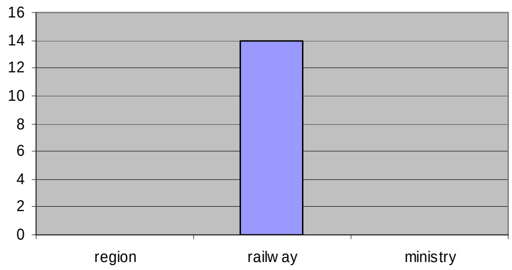
Q1: Who is responsible for maps of major railways?



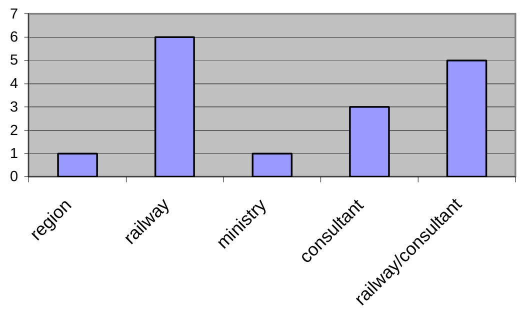
Q2: Who is responsible for railway maps in agglomerations?



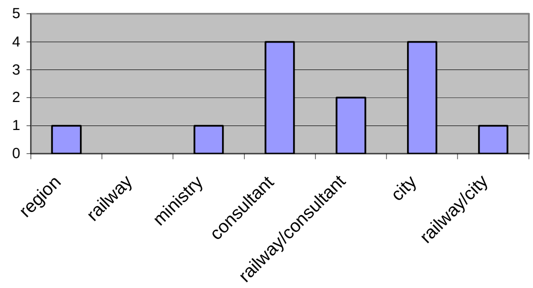
Q3: Who provided operational input data for mapping?



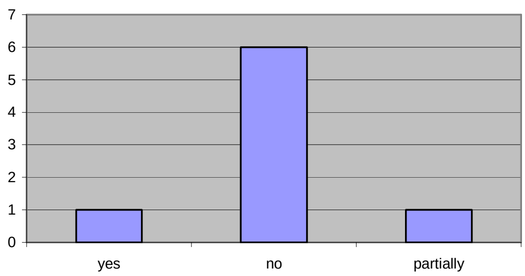
Q4: Who produced the maps for major railways?



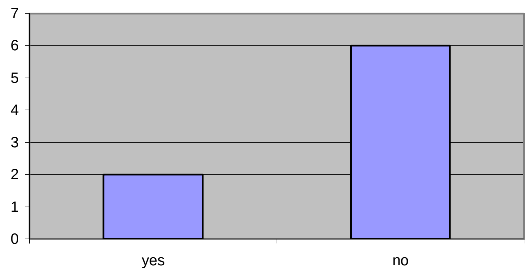
Q5:Who produced the maps for railways in agglomerations?



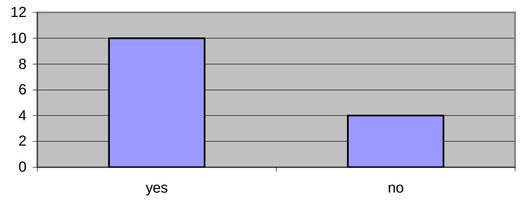
Q6:Have the maps been validated?



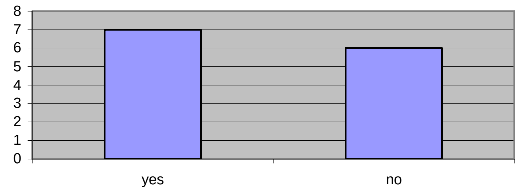
Q7: Will there be a map showing combined noise from road, rail and air?



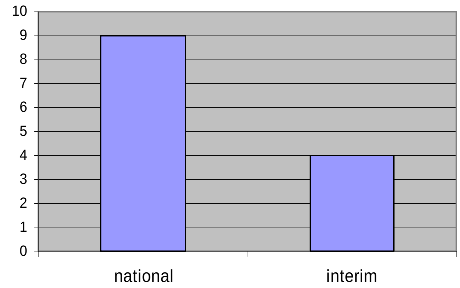
Q8: Have the maps for major railways been completed?



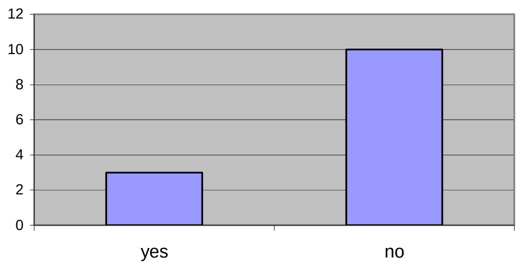
Q9: Have the maps for arailways in agglomerations been completed?



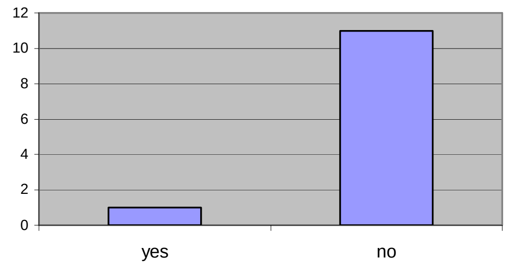
Q10: Which calculation method was used?



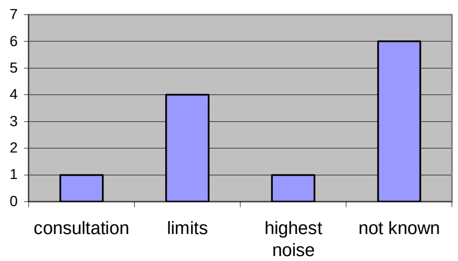
Q11: Have action plan locations been identified for major railways?



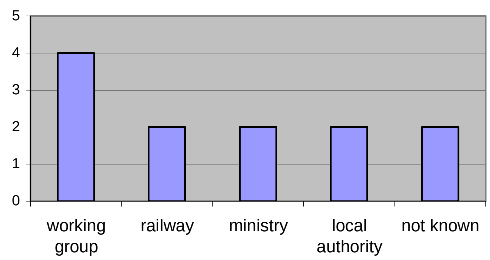
Q12: Have action plan locations been identified for railways in agglomerations?



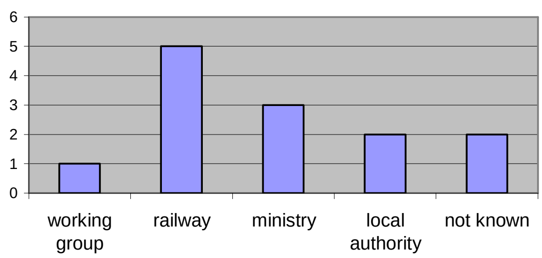
Q13: What process will be used to identify action plan sites?



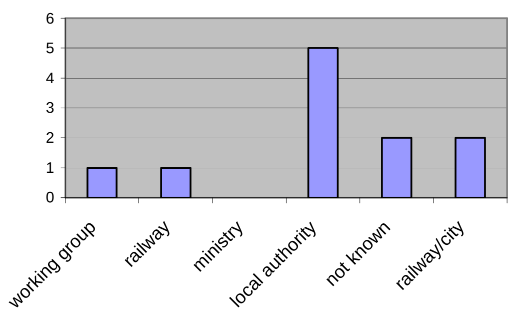
Q14: Who will do this?

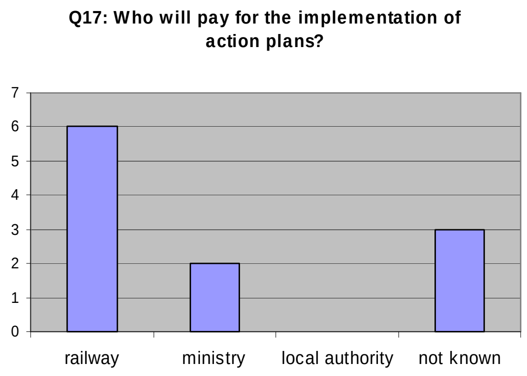


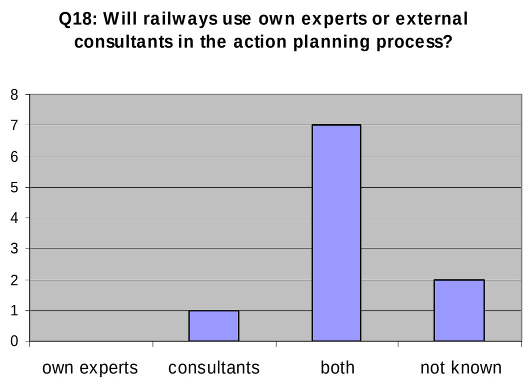
Q15: Who will produce action plans for major railways?



Q16: Who will produce action plans for railways in agglomerations




Q17: Who will pay for the implementation of action plans?
7
6
5
4
3
2
1
0
railway
ministry
local authority
not known


Q18: Will railways use own experts or external consultants in the action planning process?
8
7
6
5
4
3
2
1
0
own experts
consultants
both
not known