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# Action Plans for railway noise. Noise control options and their effectiveness.

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## ABSTRACT

The Environmental Noise Directive, 2002/49/EC, requires EC Member States to produce Action Plans to manage noise issues and effects, including noise reduction if necessary. They may include traffic planning, land-use planning, technical measures at source, selection of quieter sources, reduction of sound transmission and regulatory or economic measures or incentives. A number of technical and operational options are available to the railway industry in order to address the Action-Planning requirements of the Directive. This paper presents the available options and discusses their likely effectiveness and practicality within an operational railway environment. Reference is made to recent and historic developments in railway noise control, and to a new "noise trajectory" study carried out for the GB railway industry by the Rail Safety and Standards Board with DeltaRail's technical support. This study has tested the perception of historic trends in noise reduction and has modelled future scenarios, showing that increases in traffic volume and speed are largely balanced by projected vehicle noise reductions, leading to no significant increase in impact for the exposed population as rail usage grows.

## 1. INTRODUCTION

Following the first round of European noise mapping under the Environmental Noise Directive, 2002/49/EC, there is a requirement within the Directive to produce Action Plans "..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 health and to preserving environmental noise quality where it is good." The Directive states that these may include traffic planning, land-use planning, technical measures at source, selection of quieter sources, reduction of sound transmission and regulatory or economic measures or incentives. Railway environmental noise is a function of a large number of elements, each of which may be differently affected by operational parameters such as speed, load and traffic density. Therefore, an understanding of these elements is important in designing cost-effective approaches to the prevention and reduction of railway noise within the Action-Planning process.

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This paper describes the most significant noise-producing elements and indicates how these may be controlled within an Action Plan, but also indicates where mitigation may not be a cost-effective option. It goes on to describe a recent "noise trajectory" study carried out for the GB railway industry by the Rail Safety and Standards Board with DeltaRail's technical support. This study has tested the perception of historic trends in noise reduction and has modelled future scenarios in order to inform the process of Action Planning in Great Britain.

## 2. SOURCES OF RAILWAY ENVIRONMENTAL NOISE

### A. The main elements of railway environmental noise

Railway environmental noise arises from three main speed-related regimes (traction, wheel/rail interaction, aerodynamic effects). The noise contributions from traction and wheel/rail interaction are the main elements that are currently taken into account in railway noise mapping and are therefore the key factors that require attention under Action Planning, with aerodynamic noise also becoming of increasing relevance as train speeds increase. Other factors that can be major contributors to annoyance from railways at a local level are horn noise, curve squeal and announcements from public address systems, but these are not, at present, taken into account in noise maps, and they are therefore a lower priority in the Action Planning process.

### B. Traction

Traction noise can be present at all speeds, but tends to be dominant at around 50 km/h and below. Traction noise arises from the components associated with the motive power of trains. The main contributors are engine exhaust noise and carcass noise for diesel locomotives and diesel multiple units ("DMUs" – trains comprising coupled vehicles, some or all of which are powered), and cooling fan noise for all forms of train. Other elements include noise generated from electrical transformers and electrical traction control equipment, which tends to be tonal, noise from auxiliary equipment such as air compressors for brakes, and gear meshing effects, which again tend to be tonal, with frequencies dependent on speed.

### C. Wheel/Rail interaction

Wheel/rail interaction noise, or "rolling noise", is normally the major contributor to railway environmental noise from speeds between 50 km/h and 200 km/h and is therefore key to the Action-Planning process. It is a function of the combined surface roughness at the interface between the wheel and the rail, modified by a "contact filter", which excites vibration in train and track, leading to noise radiation. The vibration response of the various linked components and their radiation efficiency determines the nature and level of the sound emission, but in broad terms the contribution of the sound from the vehicle is of a similar order to that emitted by the track.

### D. Aerodynamic effects

At speeds above around 200 km/h aerodynamic noise becomes increasingly dominant. It is predominantly generated at discontinuities in the train structure, especially at the current-collecting "pantograph" on electric trains, at inter-vehicle gaps and at the "bogies" (ie the frames supporting the wheelsets, incorporating suspension and having the ability to rotate about a vertical axis).

## 3. CONTROL OPTIONS AND THEIR PRACTICALITY

### A. Physical Control at Source

**Traction noise** is amenable to control by means of good acoustic practice, which often mirrors approaches taken in the automotive industry, albeit on a different scale. Exhaust noise can be controlled via the use of silencers which can be absorptive, reactive, or a combination of the two; air-management noise can be reduced by considering fans that are larger and slower-running where possible, or choosing radial fans, and ensuring that fans are working at an efficient point in their characteristic; air ducts can be designed for low noise by avoiding discontinuities that generate turbulence, but ducts can also be designed to act as silencers for fan noise and air turbulence noise by incorporating bends, labyrinths and plenum chambers, combined where practical with an acoustically absorbent lining. All of these considerations can be achieved cost-effectively, provided they are designed in to the vehicles rather than retro-fitted.

The use of on-board acoustic shielding and encapsulation, especially for engine carcass noise, has more practical implications however, despite potentially useful noise reductions, as there is very limited space available on railway vehicles to provide such treatments and also there can be problems with visual inspection, access for maintenance, and the build-up of heat. Electrical equipment can be difficult to design without a tendency to generate some magnetostrictive vibration, but the level of sound radiation from structures coupled to this equipment can be reduced in a practical manner by resilient mounting, provided the mounts are chosen to isolate the relevant frequencies when the mass of the equipment is taken into account. Lower noise gear arrangements may also be a practical possibility.

**Wheel/rail interaction noise** is best controlled by ensuring that the combined surface roughness at their interface is kept at the lowest possible level. Fortunately, there are practical measures that can be taken to achieve this, providing useful options for Action Planning.

Smooth wheels are obtained by using braking arrangements that do not rely on the traditional approach of cast-iron blocks bearing on the running surface (tread brakes). Modern trains will tend to be disc-braked, or be fitted with tread brakes made from resin-based materials (composite blocks). Both of these approaches lead to smooth wheels and hence running noise that is around 8 dB(A) lower than the equivalent cast-iron tread-braked vehicle when running on smoother track. Although it is preferable to install braking arrangements that lead to smooth wheels at the design stage, there is the possibility of replacing cast-iron tread brakes with composite tread brakes as a retro-fit. There is a strong move within Europe at present to carry out this retrofit to the very large fleet of cast-iron tread-braked freight vehicles. One drawback of this approach is that, currently, there is not a safety-approved composite block that provides similar friction characteristics to the traditional cast-iron brake, and therefore the replacement of blocks also requires costly modifications to the braking mechanism. However, the use of composite tread brakes for new vehicles tends to be cost-neutral. Alternative non-friction braking techniques, such as dynamic braking using the traction motors, are available, but are not suitable for low speed braking.

Rail roughness tends to increase with time and traffic, although sometimes the opposite occurs. Therefore roughness growth with time, of both general "broad band" roughness and of the specific periodic wear phenomenon of "corrugation", needs to be understood, monitored and, where possible, controlled. High levels of corrugation, typically with a pitch of 30mm – 80mm, and with a potential depth of 120 microns or greater, can increase rolling noise by 20 dB(A) or more. Control of the growth of roughness and corrugation remains difficult to achieve, as the phenomenon is complex and, as yet, not fully understood or predictable.

If rail roughness/corrugation has grown to a point where it has a significant adverse effect on rolling noise, this situation can be identified in a number of ways. Ideally, the mapping process will have taken true local rail head roughness into account in modelling rolling noise. In the UK, processes were developed for Defra[1] to do this by using data obtained from on-board measurement of rolling noise ("NoiseMon") and feeding it into a modified version of the "Calculation of Railway Noise 1995"[2] (CRN) algorithms. If such an approach is taken, the noise maps will immediately identify "hot spots" that merit attention. Alternatively, the on-board rolling noise data alone (or vibration data from the wheel bearing "Axle Box") can be used to identify high levels of roughness, as can complaints about, or measurements of, elevated levels of trackside noise at specific locations, and visual inspection. Action can be taken to control roughness by grinding the track. Standard techniques of grinding are, however, designed primarily to restore the rail's cross section geometry and despite providing a useful acoustic benefit in most instances, especially when grinding marks have "rolled out", a finer grinding technique, known as "Acoustic Grinding" is required if optimum roughness reduction is required. This latter technique tends not to be appropriate for wide-scale grinding, but is more often used for setting up test tracks for the measurement of pass-by noise.

There is some opportunity to reduce rolling noise by optimising the wheel shape and reducing its diameter, which controls its vibration response and radiation efficiency. This can lead to reductions in the wheel component of rolling noise of around 6 dB(A), but the influence of such optimisation on overall rolling noise will be significantly less, typically around 1 dB(A), unless the track is also treated.

A track-based option that is proving increasingly of interest, and which can reliably produce useful reductions in rolling noise, is the use of tuned vibration absorbers on the rail. These devices are attached to the rail either by adhesive or by clips, and comprise steel masses and elastomers, with rail vibration energy absorbed within the elastomer material as they vibrate. By choosing appropriate resonant frequencies and damping characteristics it is possible to increase the vibration decay rate in the track at the relevant frequencies (typically 800 Hz – 5 kHz) by more than a factor of 10, significantly reducing the length of track that is radiating sound. This can result in a reduction of rolling noise to the trackside environment of 3-5 dB.

Curving noise, or 'squeal', is often a cause for complaint. It is caused by an incompatibility between vehicle suspension characteristics and track geometry leading to the wheels failing to roll tangentially and hence being excited into high frequency vibration. As an interaction issue, it requires consideration of the vehicle and track as a system, preferably at the design stage. A reduced bogie yaw stiffness, or "steering" bogies, which allow the individual wheelsets to rotate relatively to each other in yaw, are features that can be designed-in. For the track, the design considerations can include an optimum degree of "cant" for the track, or of the "gauge" dimension between rails, and the possibly use of asymmetric cross-sections for the rails. Squeal can sometimes be controlled retrospectively through the application of lubrication to the track or wheel “flange root”, and/or by the use of “friction modifier” material, which provides consistent friction characteristics at the wheel/rail interface around the curve. Tuned absorbers or constrained layer damping on wheels can also be beneficial, and are potentially amenable to retrofit. As squeal is not currently modelled in the noise maps under the Directive, it may therefore not be considered a priority in the Action-Planning process if the maps alone are to be used to identify “hot spots” and to gauge the effectiveness of mitigation.

**Aerodynamic noise** is best controlled at the design stage by avoiding discontinuities in vehicle external surfaces, especially in the region of the pantograph and the bogies, and by the use of fairings on these components, the latter also being an option for retrofit.

## B. Propagation Control

One Action-Planning option that is widely used within Europe is the installation of trackside noise barriers, which have a performance that is reliable and predictable, with guaranteed insertion losses of 10 dB(A) or more depending on path difference. Rolling noise emanating from the wheel/rail interface is more amenable to control by barriers than elevated sources such as engines, exhausts and pantographs. Tall trackside barriers, either reflective or absorbent, are the main application of this approach, but have the disadvantages of visual intrusion, cost, a need for substantial foundations to cater for wind load, graffiti, and potential safety issues for staff working on the track. Low, close, barriers can also be beneficial, provided they create an adequate acoustic shadow and do not impinge into the kinematic envelope of passing trains. Shields around noise-producing elements such as the bogies, especially when combined with low close trackside barriers, can be acoustically effective, but are often not very practical for reasons of maintenance, inspection and heat build-up.

## C. Operational Control

Intuitively it could be considered that a reduction in train numbers passing a given location within a given period, or speed reductions, might provide a useful means for the reduction of noise to the environment. Even if such approaches were acceptable within the context of the environmental desirability of encouraging modal shift from road and aviation to rail, with a consequent growth in railways, the comparative insensitivity of the trackside noise exposure in $L_{eq}$-based indices to flow (3 dB/halving) and speed (6 dB/halving) renders such an approach impractical. One possibility that arises because of the 5 dB evening weighting and the 10 dB night-time weighting imposed on the $L_{den}$ indicator for mapping under Directive 2002/49/EC is to move evening and night-time traffic to the day. This is extremely unlikely to be practical, however, because it is often necessary in a mixed railway, such as in GB, to move slow freight services at night rather than to attempt to fit them between fast daytime passenger services.

Idling diesel trains in depots or standing at stop signals are often annoying to the public. Shutting down such trains if the idling period exceeds a certain defined time can be helpful, but it is not always easy to restart such stock quickly and quietly, and therefore the net benefit may not be sufficient to justify the practice.

As previously indicated, there are two noise sources associated with railways that might logically be considered within Action Planning as they are often a cause of complaint but, as with squeal, they are not currently modelled for inclusion within noise maps. These are warning horns and public address systems at stations. As horn noise level tends to be defined by safety-related standards specific to railway administrations, or issued by international bodies, further level reductions will often not be permissible. However, operational methods for reducing the duration and frequency of sounding may be considered, as has recently been the case in GB. Public address system noise can be controlled by a combination of sensible design and operational measures (eg a large number of speakers of low sound energy, directional arrays, proximity detectors, automatic gain control based on background noise, making announcements only when necessary and relying wherever possible on visual displays for passenger information).

## 4. THE NOISE TRAJECTORY STUDY

### A. Background to the study

In order to inform the process of formulating Railway Noise Action Plans within Great Britain, the Rail Safety and Standards Board has carried out a study of past and potential future trends in railway environmental noise. The project steering group included the Association of Train Operating Companies and the Department for Transport, with DeltaRail providing technical support.

One key element in considering future trends in railway environmental noise is the potential influence of European Commission mandatory “Technical Specifications for Interoperability” (TSIs). The noise-related TSIs define environmental noise limits for new coaches, “multiple units” (self-powered coupled sets of vehicles) and locomotives, and also for new and “renewed” or “upgraded” freight wagons. Of particular relevance to this project is the “Conventional Rail Noise TSI” (CR-N-TSI), which came into force in June 2006. This TSI includes mandatory limits for pass-by (predominantly rolling noise), stationary and accelerating noise, all at 7.5m from the track centre line and 1.2m above the rail head. These are quantified, respectively, in terms of the energy-averaged A-weighted sound level during the pass-by time of the vehicle/unit ($L_{pAeqTp}$) at 80 km/h, the energy averaged A-weighted level measured at a series of locations around the vehicle/unit ($L_{pAeqT}$), and the maximum A-weighted level measured using a “Fast” response ($L_{pAFmax}$). The levels are designed to be challenging but achievable and, for pass-by noise, are required to be assessed on a test track of defined low rail head roughness and comparatively high vibration decay rate, to minimise the influence of the track on the measured level. The pass-by levels are set sufficiently low to ensure that cast-iron tread brakes will no longer be allowable for new trains.

The study therefore aimed to track the change in noise emission over time for individual vehicle categories from the 1960s up to the present day, and then to predict for the future when the influence of the CR-N-TSI will increase as fleets are renewed. As the current issue of the CR-N-TSI recommends that a future revision, applicable to stock to be put into service 12 years after the coming into force of the current issue (ie in 2018), should include a further reduction in mandatory pass-by limit levels, the noise trajectories for individual vehicle categories have been taken up to this date. Pass-by, stationary and accelerating noise, in terms of the indices defined within the CR-N-TSI, have all been considered.

## B. Data and scenarios

The vehicle/unit categories taken into account were (i) passenger coaches, (ii) diesel multiple units, (iii) electric multiple units, (iv) diesel locomotives, (v) electric locomotives, (vi) freight wagons.

The data used for this study was predominantly from the DeltaRail database of measurements, which extends back to the 1960s, combined with their experience in formulating source terms, such as those provided to Defra for the recent noise mapping exercise. As the decision had been taken to standardise the data for this study in terms of the indices specified in the CR-N-TSI, it was necessary to convert this historic data into the same indices. For accelerating noise and stationary noise, this was straightforward as the relevant indices ($L_{pAFmax}$ and $L_{pAeqT}$ respectively) had tended to be used as a matter of course. For pass-by noise, historically the information had been stored in the form of the source terms used within CRN, which are based on Sound Exposure Level (SEL) per vehicle, at 25m from the track, for rails that are in good, but not highly smooth, condition.

In addition to tracking the noise trajectory of individual vehicle categories, an approach more relevant to the assessment of the noise impact of the railway system as a whole was taken, by considering a set of four generic railway traffic scenarios, modelling, for each scenario, (i) the present day, ie 2009, (ii) 20 years in the past, ie 1989 and (iii) 20 years into the future, ie 2029. $L_{den}$ and $L_{night}$ values, as required under the Environmental Noise Directive, were modelled.

The generic traffic scenarios, based on true flows and speeds at specific locations, combined with DfT advice on the growth of traffic from 1989 to present, and on forecast growth from the present to 2029 were (i) a high speed main line, currently non-electrified but electrified by 2029, (ii) London suburban, (iii) a lower speed non-electrified main line, (iv) a high speed electrified main line.

## C. Conversion of CRN pass-by source terms to $L_{AeqTp}$ on TSI track

A methodology was developed for the analysis of pass-by data to convert SEL-based values at 25m from the track for the whole pass-by event (including rise and decay), as used in CRN, to the $L_{eq}$ at 7.5m from the track centre line measured during the pass-by of individual vehicles/multiple units at 80 km/h as required within the TSI ($L_{AeqTp}$).

The approach taken was:

- Convert SEL values at 25m to 7.5m from track and 80 km/h.
- Analyse a set of data from previously-recorded pass-by events to establish the mean relationship between SEL and $L_{AeqTp}$ at 7.5m for each vehicle/unit category.
- Consider 10 pass-by events of Mk III disc-braked passenger coaches (in spectral terms) at a specific site in GB where the rail-head roughness had been measured. Assemble an assumed combined roughness (dB re 1 micron vs wavelength) at the wheel/rail interface for these events from measured rail roughness and a typical wheel roughness.
- Compare the measured SEL values for these Mk III coaches with those predicted using CRN to establish the A-weighted difference in level at the site, a value known as “Acoustic

Track Quality" (ATQ), which had a mean value of +1.7 dB(A), ie somewhat higher than the roughness implicit in CRN.

- Establish the difference between the combined roughness that applied for these events and the combined roughness that would arise for the same vehicles passing on track with a roughness as specified for testing in the TSI, which had a mean value, at 80 km/h, of 3.1 dB(A), ie these disc-braked passenger vehicles would have been 3.1 dB(A) quieter on TSI track than on the track actually used.
- Use this information to establish the difference in level that would arise between these vehicles passing on CRN track and on TSI track: 3.1 dB(A) – 1.7 dB(A) = 1.4 dB(A), ie for a Mk III disc-braked passenger coach TSI track produces rolling noise that is 1.4 dB(A) quieter than the same coach passing on track of roughness implicit in CRN.
- Use the derived ATQ value for TSI track of -1.4 dB(A) within algorithms developed for Defra for noise mapping to correct pass-by levels for individual vehicle types predicted from CRN into those that would arise on TSI track, and then convert these, as above, into $L_{AeqTp}$ values for a wide range of types and ages of stock.
- This approach was also used in reverse to establish the equivalent rolling noise source term from CR-N-TSI limit values, to enable the generic scenarios to be modelled using both established CRN source terms and potential future values on CRN track based on these CR-N-TSI limits.

## D. Results of trajectory study

The full set of results is available on the Rail Safety and Standards Board website[3]. Example results are shown in Figures 1 and 2 for individual vehicle trajectories, and in Figures 3 and 4 for scenario trajectories.

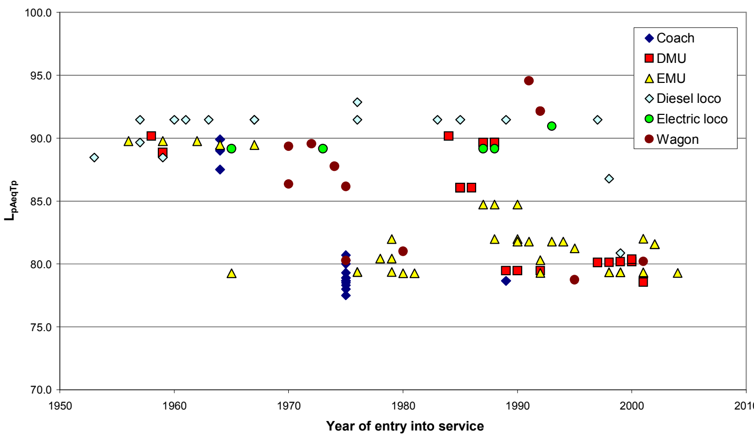



**Figure 1**: Pass-by values at 7.5m, 80 km/h, for existing stock, vs specific year of entry into service

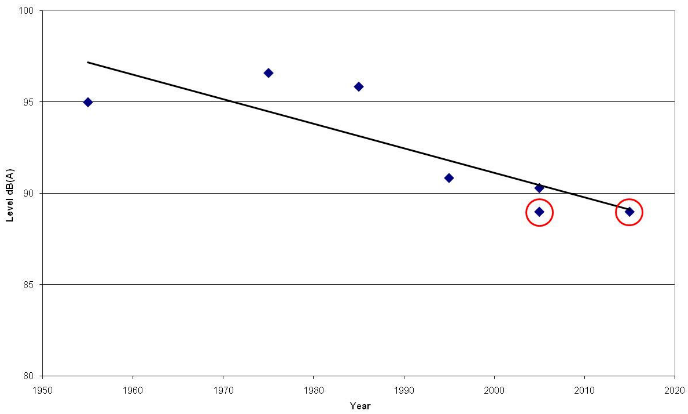
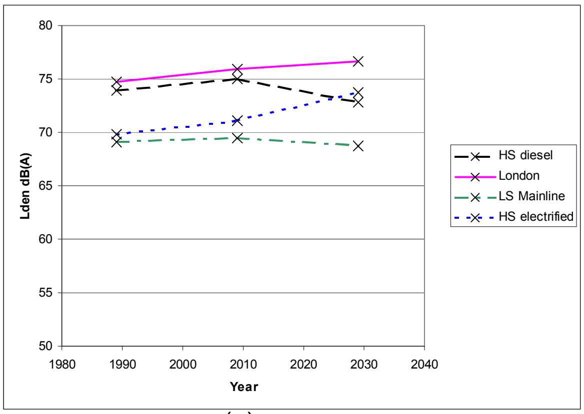
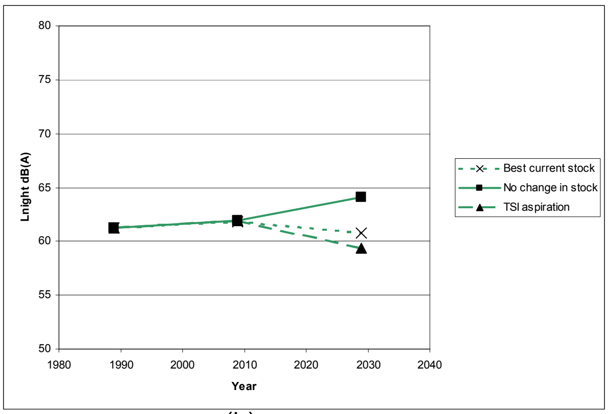



**Figure 2**: Accelerating noise values at 7.5m for diesel locomotives vs year of entry into service, averaged per decade, including TSI limit values (ringed), with linear trend line




(a)




(b)

**Figure 3a**: $L_{den}$ vs time for the generic scenarios, assuming that the current "best in class" is used in the future

**Figure 3b**: $L_{night}$ vs time for the Lower Speed Main Line, showing the effect of not changing stock, of using the current "best in class", or of all stock meeting the TSI limits

## E. Findings of the trajectory study

The study showed a clear trend for noise levels from individual vehicle or multiple units to have reduced over time in most cases. Noise reductions can be expected to continue into the future, resulting from implementation of existing and emerging technical improvements, driven partially by the need to comply with CR-N-TSI requirements.

Although the past trajectories could be quantified via trend lines, it is not advisable simply to base future projections directly on these trends, as the potential for acoustic improvement would have been greater in earlier years than is now the case. This is predominantly due to the fact that rolling (pass-by) noise is reduced by up to 10 dB when cast-iron tread brakes are replaced by disc brakes or composite tread brakes, and because early diesel stock had little, or no, exhaust silencing. The majority of current GB stock now has disc brakes or composite tread brakes, and diesel engines will now always have reasonably efficient exhaust silencing, and therefore further potential improvement in these areas will be somewhat limited. Projections into the future will therefore require not only reference to past trends but also an understanding of what remains possible within practical and financial constraints. The traffic modelling showed that levels measured in terms of $L_{den}$ and $L_{night}$ have increased from the past to the present day, but only marginally because of acoustic improvements in stock despite increased speeds and flows. When the model was used to project to the year 2029, it could be seen that $L_{den}$ and $L_{night}$ did not tend to increase significantly and may even decrease in the more optimistic scenarios where stock is widely compliant with the CR-N-TSI.

## 5. CONCLUSIONS

Railway environmental noise emission is a function of a wide range of factors, all of which can be significant under particular operational conditions, and which therefore need to be well understood if efficient and cost-effective control is to be carried out. Although Action Plans are a legislative necessity, it is important that they are formulated through careful consideration both of the practical realities and the financial implications. The railway industry in Europe will be obliged through the TSI process to address noise emission from new trains, but there will remain a significant proportion of the rail fleet that produces higher noise levels. When possible Action-Planning approaches that might be taken for treating older vehicles are considered, as outlined in this paper, cost-effectiveness is likely, in many cases, to be low. For this reason it is probable, in the shorter term, that governments and railway administrations will focus on local infrastructure treatments (eg barriers) at identified "hot spots" rather than vehicle-based retro-solutions, despite the latter being more advantageous network-wide.

In the longer term, the effect of the current CR-N-TSI limits, and the likely future reduction in these limits, will lead to an increasingly quiet railway, although the rate of change will not be as great as that which has occurred in previous decades. Because of these diminishing returns it is essential that research and development should focus on identifying areas where the greatest cost-effective returns are possible, and it may be considered that such investment is a potentially valid element of Action Planning.

## ACKNOWLEDGEMENTS

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