Railway Noise Research

Summary of Activities since 1990

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Summary of Railway Noise Research

1. Introduction

This paper describes the noise research carried out by ERRI and a number of European railways in the last decade. It evaluates the options available to aim for the UIC Board of Management's target of a 20 dB(A) noise reduction for freight vehicles compared with current levels. The paper concentrates on work that has, in the main, been funded by the UIC but also identifies certain national initiatives.

2. Current rolling noise levels

The combination of wheel and rail surface roughness has been shown to be the major parameter that determines the level of noise produced by railway vehicles as they run on a track. Thus, for example, since wheels with disc brakes are smoother than wheels with cast iron tread brakes, on uncorrugated track they are significantly quieter.

Conversely when track becomes corrugated, rail roughness dominates and the noise level increases and becomes independent of whether the wheel is disc braked or tread braked.

Disc brakes are now commonly used on newly built passenger rolling stock, but apart from in the UK, they are not widely used on freight vehicles in Europe where cast iron tread braked vehicles are in the vast majority. Thus, for today's railways freight and passenger services present different environmental noise problems to railway operators and infrastructure managers. For freight, the main issues relate to low speeds and the need to operate at night. Additionally, since there is no international agreement for the use of disc or composite material brake systems in their design, noise levels are higher than could be achieved with a minimum noise design. For passenger vehicles the commercial trend is for higher speeds which can lead to an increase in noise even when disc brakes are used.

For a receiver distance of 25m from the track, typical noise levels for these vehicles are:

(L_{max} noise levels refer to the maximum instantaneous noise level during the passage of a train past a receiver. This can be related to the perception of loudness of a noise event where a 10 dB(A) change approximates to a halving/doubling of loudness)

Four axled, disc braked passenger:

L_{max} = 79 dB(A) @ 100 km/h
= 88 dB(A) @ 200 km/h
= 93 dB(A) @ 300 km/h

[Articulated vehicles will give slightly lower noise levels due to the wider spacing of the wheels]

Four axled, cast iron tread braked passenger

L_{max} = 87 dB(A) @ 100 km/h
= 96 dB(A) @ 200 km/h
= 101 dB(A) @ 300 km/h

[These levels show that rolling noise is proportional to speed ratio and increases by about 9 dB(A) for a doubling of speed. Additionally they demonstrate the systematic difference of 8 dB(A) between vehicles which have wheels with cast iron tread brakes and smoother, disc braked, wheels]

Cast iron tread braked freight

$$L_{max} = 91 \text{ dB(A) @ 100 km/h}$$

Disc braked freight (UK Freightliner)

$$L_{max} = 79 \text{ dB(A) @ 100 km/h}$$

If the track is allowed to become seriously corrugated, the noise levels of cast iron braked vehicles will increase by about 10 dB(A) and for disc braked vehicles the increase will be about 20 dB(A).

3. Numerical Simulation of Rolling Noise, TWINS (Track and Wheel Interaction Noise Software)

The TWINS software was developed in the late 1980s through studies commissioned by ERRI C 163Committee. It has been validated using measurement data obtained for different vehicle designs running on a variety of tracks. Its development is probably the most significant input for the understanding of rolling noise and research into the generation mechanisms over the last 20 years.

TWINS shows that rolling noise results from the forced vibration of wheels, rails and sleepers. The noise propagates to the wayside. The software is used as an invaluable first filter in the design of quieter railway systems and it has been used, successfully, in the OFWHAT experiment to define the specification of wheel and track components for minimum noise.

TWINS only considers wheels and track as noise radiators on a railway vehicle. Measurements indicate that for present designs, noise from the vehicle superstructure is at least 10 dB(A) below the noise produced by wheel and track, confirming the TWINS approach. A confirmation study, for an empty tank wagon, is part of the Silent Freight project, and results are expected towards the end of 1998.

Consistent with measured data, TWINS shows that smooth running surfaces are necessary for minimum noise. Additionally, its formulation confirms that increasing the propagation losses is also an efficient noise reduction measure. Where the sum of these effects is insufficient to achieve target levels, design changes to wheel and track will be necessary. TWINS simulations can be used to assess the effect of such modifications. Investigations into optimum noise designs are part of the current Silent Track and Silent Freight projects.

A summary of noise reduction options is given below.

4. Noise Reduction Options

4.1 Smooth Wheels and Rails

In addition to the use of disc brakes, it has been known that composite tread brakes have the potential to provide smooth wheels. The development of composite tread brakes has been hindered by doubts about braking capability and the influence of high temperatures and residual stresses on the wheel integrity.

To overcome the residual stress problem S-shaped and bell shaped wheel designs are proposed and the combinations are to be tested as part of a UIC study. This is expected to lead to the development of RIV regulations allowing such vehicles to be used in international traffic. The expected noise reduction is of the order of 8 - 10 dB(A).

The current EU project, Eurosabot, has the objective of designing a brake block system that will give rise to smoother wheels and will not require a change in wheel design. Results from this study should be available at the end of 1998.

A study of ultra smooth wheel surfaces was carried out for ERRI C163 Committee on a 1/5 scale rig at London Underground. An important finding of this study was that there appeared to be a limiting roughness level in the rolling process and that it was unlikely that smoother surfaces were capable of being maintained in practice. The current smooth track, disc braked wheel combination appears to have reached that limit, therefore the levels in section 1 for disc braked vehicles are likely to be the lowest levels that can be achieved from the use of smooth surfaces alone.

The introduction of surface layers has been reviewed as part of the BASNOISE project, but their benefit appears to be limited to curve squeal and a delay in the growth of rail surface roughness. This study is currently under review.

4.2 Increase Propagation Losses

Recent national projects in the UK, Italy and Germany have demonstrated the potential of a bogie shroud and low trackside barrier combination as an alternative to the use of high trackside noise barriers.

Such a combination has been shown to give a reduction of up to 10 dB(A) in the most favourable circumstances. The study for British Rail, for example, indicated that by careful design of the shroud they would be able to achieve noise levels for disc braked passenger vehicles about 10 dB(A) lower than those shown in Section 2 above.

To achieve reduction of this magnitude, it is necessary for the bottom of the bogie shroud to be as close as possible to the head of the rail and to overlap the top of the barrier. This must be achieved whilst complying with gauging restrictions.

As the height of the bottom of the shroud above the rail head increases, a deterioration of the performance will result. This effect also occurs as the height of barrier reduces.

The critical factors for an acceptable design are:

- definition of a shroud envelope which allows passage on all infrastructure administrations
- upward movement of the shroud when the vehicle is unloaded
- difference in height of the shroud above the rail head for new and worn wheels
- the need to stay within gauge with a bottomed spring (full/excess loading)
- the need to stay within gauge with a broken spring

For body or bogie mounted shrouds, minimum gaps, hence maximum noise reduction, can only be achieved for a loaded vehicle with worn wheels. For all other conditions the performance will be reduced. It may be unwise to expect more than 5 dB(A) from practical designs that would be accepted for international traffic.

A working limit for the reduction deriving from the combination of smooth wheels, smooth rails, bogie shrouds and low barriers is likely to be 13 – 15 dB(A). Further investigation of the capabilities and modelling of the low barrier/shroud combination is taking place in the Silent Freight and Silent Track projects.

A preliminary investigation by ERRI C 163 Committee into the effects of changing ballast absorption properties indicated little gain from this technique where ballast stone size and ballast depth were varied. There are no current plans to investigate this further.

Thus it can be seen that further reduction of 5-7 dB(A) is likely to be required to achieve the long term UIC objective of 20 dB(A).

4.3 Vehicle Based Noise Reduction

The following options are being investigated as part of the Silent Freight project:

- Optimised wheel cross section
- Perforated wheel webs
- Additional damping to wheel (e.g. web damping, ring dampers, tuned absorbers)
- Smaller wheels.

All these have been shown to be effective in reducing the wheel component of noise, but their effect on total noise will depend on the balance of wheel/track contribution to total noise. Further, all studies to date on very small diameter wheels have been affected by a higher wheel surface roughness than compared with larger diameter wheels. It is not clear whether this is a consequence of wheel size.

4.4 Track Based Noise Reduction

The following options are being investigated as part of the Silent Track project.

- Optimised rail pad stiffness.
- Novel rail pad designs
- New rail fastening system
- Added damping to rail
- Optimised sleeper design.

Soft rail pads are preferable from a track damage point of view, but it was demonstrated in the OFWHAT experiment, that the use of harder rail pads resulted in a 4 to 5 dB(A) reduction in total noise. The potential conflict of designs for optimum environmental performance and other track considerations needs to be resolved.

The effect of a number of the Silent Freight and Silent Track options will be tested in May 1999. This includes the use of shrouds and barriers.

The benefits that accrue from changes in wheel and track design will be additional to the benefits from smooth surfaces and the bogie shroud/barrier combination.

The majority of the research activity carried out by the ERRI C 163 Committee has concentrated on rolling noise generation. Other studies have been carried out and these are summarised below.

5. Noise Barriers

The use of high lineside noise barriers can give reductions well in excess of 10 dB (A). The actual performance of the barrier depends on its design but the overriding parameter is the height of the top of the barrier above the source.

For vertical barriers close to the track, when sound reflective materials are used, performance is reduced due to sound waves reflected between the side of the barrier and the vehicle.

A survey of barrier design, supported by theoretical assessment, indicated that this reflection must be eliminated for maximum performance. This is best achieved by the use of acoustic absorptive materials on the side of the barrier facing the railway. This solution gave an enhancement of up to 5 dB(A).

Modern designs, claiming to use noise interference properties from the design of the barrier top, were shown to have minimal effect in practice.

An EU project Euroecran, with the objectives of developing barrier designs for reducing noise from mixed traffic at a lower cost than current is nearing completion. SNCF, FS and NS were members of the consortium and the final report is imminent.

6. Maintenance

It has long been known that when rails become corrugated there is a consequent increase in noise. The normal remedy is to grind the rail. The normal grinding strategy is based on track damage criteria rather than noise and significant increases in noise often occur before the track is ground. The process of rail roughness growth leading to the formation of corrugation still requires further study.

As part of the BASNOISE project, an investigation was initiated on the use of surface layers between wheel and rail to reduce noise. This has reached a stage where it is felt that the major benefit of such treatments may be to inhibit the growth of rail roughness rather than reduce noise directly. This could have an impact on grinding intervals if successful.

This study is currently under review.

7. Active Noise Control (ANC)

ANC is a technique that has been used with success in the aircraft and car industries. Studies began in 1995 and were continued as part of the BASNOISE project into the use of ANC in railway situations.

Theoretical assessments have shown that ANC is best suited for reducing locomotive fan noise and for enhancing barrier performance.

In 1998 tests will be carried out to demonstrate the effect of the technique in both these situations.

8. Cost Benefit Analysis

A number of a national models are available to allow planners to assess the most cost effective means of achieving railway noise reduction along certain lines or within national boundaries. These models normally include the effects of vehicle and track treatments, noise barriers, sound insulation to adjacent buildings, and changes to railway operations.

A current study, for Task Force Noise, has the objective of determining, on a European wide basis, the best cost effective options for the reduction of received noise. A number of routes will be taken to typify European operation and a modified version of the Dutch model will be used to carry out the assessment. Cost and acoustic benefit data from current projects will be added to the database as it becomes available.

9. Noise Legislation

It is expected that in the near future the European Union will start the process of preparing a directive on noise produced by railway vehicles.

ERRI C163 Committee, being aware of the implications to railways of such legislation, produced a document in 1994, as part of the Criterion project. This report outlined a plan of action of the key tasks the railways needed to carry out in order to be prepared for discussions with the EU on the subject.

Subsequently, the CER has developed a negotiating strategy on this and intends to maintain close links with the EU. Current negotiations with DG VII (Transport Directorate) and DG XI (Environment Directorate) are focussing on developing a voluntary agreement with EU where UIC/CER will agree to a substantial target reduction of noise from freight vehicles within a specified time period.

On a technical level, ERRI and member railways are represented on a CEN Committee defining the noise measurement procedure. A consensus view was reached in 1997 of railway members on C163 and the document forms an input to the discussion.

A European Union project, Metarail, looking at the same issue is also represented on the CEN Committee. Close co-operation is being maintained with all parties to ensure a consistent approach that is not detrimental to railway operation.

10. National Studies

10.1 Bridges

No co-operative studies have been carried out through ERRI C 163 Committee on noise from bridges.

A number of national studies have however been initiated in the last few years.

The availability of the results depends on local decisions whether to publish the results of the studies. It is known that claims have been made that the noise from trains on bridges, in dB(A), need be no higher then when the train is on an embankment.

A workshop on bridge noise was organised by NS in 1996.

10.2 Noise from High Speed Vehicles

Following the UIC strategy position to concentrate its efforts on freight vehicle noise reduction, there have been no recent ERRI co-ordinated studies into noise from high speed vehicles. The TWINS model is still valid in the speed range where rolling noise dominates and national studies indicate that up to 300 km/h, noise from aerodynamic sources is still less than rolling noise.

Noise barriers are more effective at reducing rolling noise, therefore their use in high speed situations may not give the same benefit as predicted by classical models.

As efforts to reduce rolling noise at source become more successful, aerodynamic noise will be more important at lower speeds. A watching brief on this element of train noise needs to be maintained.

10.3 Annoyance Studies

The last UIC funded investigations in this area consisted of a State of the Art review, carried out in the mid 1980s.

This reached the following conclusions:

- surveys indicate that at the same noise level, railways are less annoying than road traffic and aircraft
- interference with communications is the most annoying aspect of railway noise
- interference with sleep is the annoying aspect least mentioned by people responding to surveys

National legislation in different countries generally contains a differential between road traffic and railway noise. (This differential may not be maintained in future EU environmental noise legislation) Where night levels are included in legislation, the decision trigger levels are lower than the daytime levels.

Any studies which have been carried out recently have been the result of national initiatives with objectives of assessing the following:

- annoyance in mixed noise situations
- annoyance from high speed railways
- disturbance to sleep
- annoyance from new railways

- road/rail/aircraft differential

The three themes described above are those where it is known that research is being carried out at a national level. More information is needed from national activities to ensure greater effectiveness of collaborative research.

11. Residual Issues

11.1 Train Noise Reduction

The aim of work in this area is to provide railways with a comprehensive selection of alternative low noise solutions for use in the design of new systems, as retrofit and for use in situations of serious complaint. The UIC objective is to achieve the long term target of a 20 dB(A) reduction in noise from freight traffic compared with current cast iron tread braked vehicles.

The following key work areas have been identified:

- Develop low cost, high performance braking systems which give smooth wheels
- Investigate wheel running surface roughness as a function of wheel size
- Investigate the processes of rail surface roughness growth
- Develop low noise solutions for slab track, embedded rail and points and crossovers, if slab track is an issue at UIC level
- Optimise bogie shroud/low barrier configurations for international use

The following issues are part of current studies

- Develop acoustically optimum wheel for tread braking
- Confirm the effect of wheel and rail damping/tuned absorber treatments
- Define maximum allowable rail pad stiffness. If this is less than acoustically optimum, determine its effect on noise creation.
- Develop a cost benefit model to assess financial implications of different noise reduction strategies

11.2 Other Topics

Other potential areas of investigation which relate to railway noise include:

- Review the need for a single environmental noise calculation model
- Review the need for further noise annoyance studies in relation to
    - Mixed sources
    - High speed traffic
    - Sleep disturbance
    - New railway systems
- Noise in stations
- Noise in passenger vehicles

Although some of the outstanding questions may have been answered by national studies, there will need to be a review to prioritise all the above research items and determine funding taking into consideration the relevant commercial, legislative and socio-economic dimensions.

12. Conclusion

This summary indicates that a great deal work has been carried out and a high level of knowledge has been accumulated to find effective solutions to reduce railway noise in its creation and reception.

There are still areas of research where work can be identified to further reduce railway noise (whether for rolling noise or other noise sources – aerodynamic noise, noise nuisance from depots, squeal) but these need to be prioritised to meet strategic aims. However it is evident that social and legislative pressures will continue to determine that railways will need to concentrate further efforts on noise reduction techniques

Individual Project Summaries

Project Summary 1

TWINS
Numerical Simulation of Rolling Noise Generation

Project Objective
To develop a software simulation for the generation of rolling noise taking into account the dynamic features of wheels and track.
The software to be capable of defining the specification of material properties for optimising vehicle and track components, for minimum noise.

Duration and Costs
1987 – 1998 @ 1.67 million ecu.

Method
- Use linear frequency regime model, SPRINGBOARD, developed by BR Research.
- With input from internationally recognised experts update SPRINGBOARD with new modules to increase accuracy and include effect of additional variables.
- Validate model by measurements on operational railway.

Results and Residual Questions
TWINS software developed with contributions from Prof. Heckl (TU Berlin), Dr Remington (Bolt Beranek & Newman), Dr Heckl (Keele University), M Vincent (Vibratec) and Dr Thompson (TNO-TPD).
Basic structure of original software remains but changes made to 75% of algorithms, allowing effects of wheel, track parameters to be assessed.
Major change is that the noise radiation of sleeper is considered in addition to noise from rail.

General conclusions
- Sleeper noise controls low frequencies
- Rail noise controls middle frequencies
- Wheel noise controls high frequencies

Validation investigations indicated that TWINS can be used to assess the effect on noise of changing wheel and track designs. Absolute predictions of noise levels are less accurate.
Further development of track models, particularly with respect to the inclusion of rail cross sectional deformation is required.

Additional Studies
Following validation of the initial model in 1994 the following capabilities have been added:
- Inclusion of rail cross sectional deformation,
- Improved ballast modelling,
- Improved sleeper modelling,
- Inclusion of slab track modelling.

Further improvements will result from the jointly funded Silent Freight and Silent Track projects.

Project Summary 2

TWINS – Wheel Optimisation Studies

Project Objective
To predict the effect on wheel noise arising from changes in wheel design.

Duration and Cost
1991 – 1994
28 570 ecu

Method
Carry out parametric studies using TWINS software.

Results and Residual Questions
Wheel shape

Symmetrical cross-section
+ 18% reduction in wheel diameter,
+ increase in web thickness from 25 mm to 37 mm
= reduction in wheel noise above 1000 Hz of 10 dB.

Symmetrical wheel (straight web) is not compatible with tread braking.
Reduction in wheel diameter is not compatible with retrofit of wheelsets onto existing vehicles.
Taking account of these restrictions, little benefit is predicted from changes in wheel shape as a retrofit solution to existing tread braked vehicles. There is potentially significant benefit for new designs, where smaller wheels would be acceptable.
The thicker web, in isolation, is beneficial because of added mass, but heavier wheelsets are unlikely to be acceptable.

Additional wheel damping:

Reduction of about 6 dB from wheel is predicted but practical problems with high wheel temperatures during braking must be overcome. The mass of the wheelset will also increase.

Tuned Absorbers:

A 9 dB(A) reduction in wheel sound power is predicted for absorbers tuned to the first axial and radial wheel modes. Again the wheelset mass will increase.

Overall, significant reduction in wheel noise is predicted through optimisation of wheel cross-section, reduction in diameter and increase in damping. The remaining question is to make them effective within any constraints of a practical retrofit solution.
A practical assessment of these options will be carried out in the OFWHAT investigation where design changes will be assessed through measurement.

Project Summary 3

TWINS – Track Optimisation Studies

Project Objectives
To predict the effect on track noise arising from changes to track design.
Duration:
1991 – 1994
38 090 ecu

Method
Carry out parametric studies using TWINS software with special reference to SBB track with bibloc sleepers and DB track with concrete monobloc sleepers.

Results and Residual Questions
Rail pad stiffness:

Optimum vertical dynamic stiffness, where noise from rail and sleeper are roughly equal is in the range 1.3 – 1.8 x 10^{9} N/m for 100 km/h. This increases with train speed.
SBB track is close to optimum, therefore little benefit is predicted from changes of rail pad stiffness.
DB track uses softer rail pads (2.5 x 10^{8} N/m) and a reduction of 3 dB for track noise is predicted at optimum rail pad stiffness.

Rail pad damping:

A doubling of present values was considered practicable, giving further reduction in track noise of 2 dB(A) when used in conjunction with optimum stiffness rail pads.

Dynamic Absorbers:

More effective with soft rail pads, where rail vibration is increased. In general similar reductions to those achieved with optimum stiffness, high damping pads is predicted.

A practical assessment of these options will be carried out in the OFWHAT experiment where TWINS simulations will be used to determine track component specification, followed by full scale track testing.

Project Summary 4

TWINS – Control of Rolling Noise by Contact Zone Modifications

Project Objective
To investigate the relationship between rolling noise and wheel/rail transverse profiles.

Duration and Costs
1996 – 1997
54760 ecu

Background
Earlier theoretical studies in the development of TWINS had indicated that a wheel transverse profile which conformed to the rail head profile would give a 5 to 10 dB reduction in the interaction force and hence would produce less noise.
Measurements of NS vehicles with sinter brake blocks indicated smoother wheels than those with disc brakes, but produced more noise. These wheels had a higher degree of hollow wear and should be more conforming.
Using noise, roughness and profile measurements from these trains and more detailed TWINS assessments an explanation of this conflict was carried out.

Results
It is predicted that the use of conforming profiles does not provide significant noise and vibration reduction. In the case investigated with sinter brake blocks, wheel roughness increased towards the edges of the contract zone, thus increasing the effective force.
A number of residual questions remain which will be addressed in the Silent Freight project. These include

- Quantification of the effects of roughness filtering
- Quantification of the effect of moment excitation including statistical analysis for the distribution of the contact point
- Improvements to TWINS to include the effect of the above

Project Summary 5

Optimised Freight Wheel and Track
OFWHAT Project

Summary of investigation to assess wheel and track designs optimised for noise

Project Objective

The OFWHAT project was initiated, by ERRI Committee C163 (Railway Noise), in 1995, with the objective of designing and testing, at full scale, low noise wheel and track components for freight vehicles. The components tested were:

Wheels with optimised cross section (860mm diameter)
Dynamic wheel absorber
Rail pads with optimised stiffness ($k > 5 \times 10^8$ N/m at 100 Hz)
Rail pads with increased damping ($\eta > 0.4$)
Dynamic rail absorber

Duration and Cost

1994 – 1996
642 850 ecus

Method

- The specification of the components, to minimise noise, was determined using TWINS software.

- Suppliers were invited to tender for the manufacture and supply of components to the specifications.

- The chosen wheel and track designs were tested at the Velim Test Centre near Prague.

- The effectiveness of individual components and combinations was determined by comparing passby noise at 60km/h and 100km/h with the noise from a reference vehicle (with UIC 920mm diameter freight wheel) running on a track consisting of UIC 60 rail on bi-bloc sleepers with standard SNCF rail pads ($k \approx 1 \times 10^8$ N/m).

Results and residual questions

NB
Results are normalised to a common total wheel and rail roughness and are presented as changes to wheel or track component of noise. The effect on total noise will depend on the comparative levels of those components which will vary with speed, vehicle and track design.

Wheel with optimised cross section (860mm diameter)

Reduction of 1 dB(A) in wheel component of noise, although a reduction of 4 dB(A) was predicted. This discrepancy was probably due to uncertainties in roughness levels on the wheel. Identifying which roughness level to use for prediction is a matter for further study.
There is also a conflict between a symmetrical wheel, required for noise optimisation and a curved web, required to overcome residual stress problems with tread braked wheels. This balance should be addressed in future studies.

Dynamic wheel absorber

Reduction of 4 dB(A) in wheel component of noise. This was less than predicted but the supplied absorber did not meet the initial specification. Further optimisation should be achievable and engineering development is required.

Rail pads with optimised stiffness (k >5 x 10^8 N/m at 100 Hz)

Reduction of 4 to 5 dB(A) in track noise. This result followed the prediction of TWINS. Results also showed that optimisation of pad stiffness is speed dependent, therefore train operation needs to be identified before optimisation is carried out. The above reduction was considered to be the most that could be expected from adjustment of rail pad stiffness alone.

There is a potential conflict between the requirements of high pad stiffness for low noise and softer pads to reduce track damage.

It was also noted that suppliers do not have the facilities to control the stiffness of their products at the frequencies required for acoustic optimisation. If this optimisation is taken further, the suppliers will need to develop that capability.

Rail pads with increased damping (η > 0.4)

The required doubling of rail pad damping was not achieved in the samples supplied for testing. The effect of a highly damped rail pad has still to be tested.

Dynamic rail absorber

No noise measurements were available but it was deduced from rail vibration measurements that a 2 dB(A) reduction in track noise could be achieved. The acoustic benefit has still to be measured and it is felt that the current unit costs of rail absorbers is high for the noise reduction that might be achieved.

Additional tests with 640mm diameter wheels

Although not part of the original test protocol, some wagons with 640mm diameter wheels were made available for testing. A reduced wheel noise component meant that the noise was track dominated and it was only possible to infer a wheel noise component. This suggested a predicted benefit of 18 dB(A) for wheel noise.

Unfortunately, the small wheels also had a higher surface roughness and it is not known whether this increase in roughness is a consequence of wheel size. This should be investigated further.

Future Studies

With the exception of whether there is a link between wheel roughness and very small diameter wheels, all the other outstanding issues will receive attention in the Silent Freight and Silent Track projects. These investigations will gain from the experience of OFWHAT, which clearly demonstrated the benefit of carrying out simulations using TWINS to determine the specification of low noise designs for wheels and track components, prior to manufacture and testing.

Project Summary 6

Reduction of received noise by increasing the acoustic absorption of ballast

Project Objective

To design acoustically optimal ballast by the theoretical assessment of sound propagation over a porous material.

Duration and Cost

1997 – 1998
23 800 ecu.

Background

Porous asphalt is becoming used widely for the surface layer of motor ways. Through reduced force into road vehicle tyres and increase in the propagation losses, the noise from vehicles on these surfaces is significantly reduced when compared to the same vehicles on more conventional roads.

Initial theoretical studies, carried out under the Noise Propagation Project for Committee C 163, indicated that this technique could provide a means of reducing rolling noise radiated to the wayside when applied to the design of the ballast layer.

Method

Carry out numerical simulation of noise propagation over an absorbing surface to assess the effect of changing ballast properties. In particular the use of smaller sized ballast stones was investigated.

Results

The effect of smaller (by a factor of 5), more uniformly sized, ballast compared with normal ballast of between 30 mm and 63 mm gave only a small benefit. Additionally the effect of increasing the ballast depth was predicted to be minimal.

Conclusion

The technique does not appear to give the same reductions in noise which are apparent from the use of porous asphalt for road surfaces, probably because the input force to wheels and rails is unaffected.

Consequently, further investigations, which would have included field testing are not proposed at this time.

Project Summary 7

Railway Noise Barriers in Europe

Project Objective

To produce an inventory of barrier designs used by railway companies in Europe.

Duration and Cost

1993 – 1994
71425 ecu.

Method

Information from European railways was obtained by questionnaire and interview as part of the Noise Propagation Project of ERRI Committee C 163. The results were collected into a report by external consultants and summarised in ERRI Report RP 20 “Railway Noise Barriers – State-of-the-art of railway noise barriers in Europe”. July 1997.

Results

The survey indicated that there is no commonly used design for railway noise barriers in Europe. Barriers of different designs are available from a variety of suppliers and a particular suppler/design will be chosen following a tendering process. The important elements will include cost and performance. The options used for barriers where high noise reductions are required are to (a) increase its height relative to the rail and (b) use absorbent materials in its manufacture to eliminate reflections between the side of the barrier and the vehicle.

The survey also provided indicative costs for barriers.

The study of barriers was not taken further because information was expected to be forthcoming from the EUROECRAN project, aimed at increasing the performance and reducing the cost of noise barriers for railway application. SNCF, NS and FS are partners in this project, which was completed in 1998.

Project Summary 8

Prediction Models for Railway Noise Barriers

Project objective

To produce an inventory of calculation models used to determine the performance of noise barriers used on railways.

Duration and Cost

1993/94
19050 ecu.

Method

Information was obtained by questionnaire, interview and literature search on models used for the calculation of railway noise barrier performance as part of the Noise Propagation Project of ERRI Committee C 163. The results were collated into a report by external consultants and summarised in ERRI Report RP 20 “Railway Noise Barriers – State-of-the-art of railway noise barriers in Europe” July 1997.

Results

Details were given of 14 different prediction models; of these 13 were used by European countries and 1 from Japan. All were empirical or semi-empirical in that algorithms were derived from measurement data.

A common feature of the models is that predicted performance is based on the difference in path length between a propagation path drawn between source and receiver via the top of the barrier and the direct path between source and receiver. To calculate this, it is necessary to assume a source location. For rolling noise, a variety of source locations, relative to the near railhead are used in the different models, but since the prediction is based on measurement, if the measured performance is constant with geometry, the predicted performance should be consistent even allowing for different assumed source locations. Comparison of predictions for a reference situation of a 2 m high barrier, however, showed a 6 dB spread across the different models. The implication is that the barrier performance measured by different investigators also varied for the same barrier/track/receiver geometry. This was considered significant and could not be explained by changes in source spectrum.

The results indicate that barriers with an absorptive surface on the side facing the railway can be about 5 dB(A) more effective than a reflective faced barrier, for the same geometry.

Although the difference in predicted performance is worrying, it will be difficult to change some of the models because they are part of national noise legislation eg. In Germany, Holland, etc. The need for a common prediction methodology may, however, be identified during the current discussion on Future EU Noise Policy.

Project Summary 9

Possibility of Improving Noise Barrier Performance

Project objective
To review design modifications to noise barriers in order to enhance their performance and use numerical methods to predict the effect of these changes.

Duration and Cost
1993/4
119 050 ecu.

Method
A survey was made of special barrier designs, usually proposed for use on motorways. A numerical assessment was made of these designs using source locations, source frequency content and geometrical considerations relevant to the railway situation.
The results are presented in a report by external consultants and summarised in ERRI Report RP 20 "Railway Noise Barriers – State-of-the-art of railways noise barriers in Europe" July 1997**.**

Results
The most commonly used noise barrier is a vertical structure at the side of the track. The most important aspect of the design that affects performance is the height of the top of the barrier relative to the source.
If reflective materials are used it is possible to reduce rolling noise by about 15 dB(A) for barriers with a height in excess of 3 m. This represents an approximate upper limit and is a result of reflections which occur between the inner force of the barrier and the side of the vehicle.
A number of options are considered to enhance barrier performance including the use of absorptive materials, sloping barriers, multiple barriers, modification to the top of the barrier by T-bars and cylinders and the addition of interference boxes to the top of the barriers.
The numerical simulations, supported by limited measurement data, indicated that the most effective means of enhancing the performance of a reflective barrier is to use absorbent material on the side of the barrier facing the railway. Sloping barriers eliminate the reflection without the need for absorptive materials.

NB

> This increase in performance is only evident when the receiver is below the line drawn from the source through the top of the barrier, i.e. the receiver should not be able to see the source. With passive devices the area of effectiveness (shadow zone) can only be increased by increasing the height of the barrier.

Further enhancement to performance can be achieved by using a T top to an absorptive barrier.
A number of interference designs are marketed in Europe and are used extensively in Japan. Simulations, and field measurements, indicate that apart from the gain due to the increase in height of the barrier to accommodate the device there is little enhancement to barrier performance.
Active noise control techniques were identified as possible means of enhancing barrier performance and these are being considered in the BASNOISE project.

Project Summary 10

Effectiveness of low barriers, close to the track

Project objective

To derive, by numerical simulation, the effectiveness of low, close trackside noise barriers to reduce track radiated noise.

Duration and Cost

1993/94
100 000 ecu.

Method

Boundary Element calculations have been used to predict the effectiveness of barriers between 150 mm and 375 mm away from the rail and extending 55 mm above the rail head. The geometry chosen was consistent with the structure gauge and UIC 54 rail. The only sound sources considered were the rail (vertical vibration, lateral vibration and foot distortion) and vertical vibration of the sleeper. Thus no accent was taken of noise from the wheel.

The work was carried out as part of Noise Propagation Project of ERRI Committee C 163 and the results are summarised in ERRI Report RP 20 “Railway Noise Barriers – State-of-the-art of railway noise barriers in Europe”. July 1997.

Results

For the configurations assessed, reasonable reductions in the track component of rolling noise can only be achieved when absorptive materials are used in the manufacture of the barrier.

The most effective combination consisted of barriers displaced 150 mm to each side of both rails (i.e. 4 barriers) with their upper edges 55 mm above the head of the rail. The predicted reduction in track noise was about 8 dB(A). In the calculation it was assumed that, although the barrier would be mounted on a sleeper, vibration of the barrier was negligible and air turbulence effects were ignored.

A similar configuration is being assessed as part of the Silent Track project in combination with shrouds mounted to a vehicle bogie as part of the Silent Freight project.

Project Summary 11

Rolling Noise from Wheels with Ultra Smooth running surfaces

Project objective

To investigate whether wheel and rail vibration remains a linear function of wheel and rail surface roughness in conditions of extremely low levels of roughness.

Duration and cost

1994 - 1996
11 550 ecu.

Method

The 1/5 scale test rig at LUL was used to measure wheel and rail vibration for five conditions of combined wheel/rail surface roughness. An ultra smooth condition, on both wheel and rail, was achieved by hand polishing to a mirror finish. These surfaces naturally roughened during the test, automatically providing other test conditions. For the final test conditions, wheel and rail had to be artificially roughened.
This investigation represents part of a series of studies carried out for ERRI Committee C 163 to assess the suitability of investigating rolling noise using TWINS simulations and the 1/5 scale rig.
Due to data becoming corrupted it remains the only investigation for which results were reported fully.

NB:
Due to the acoustic environment of the test area containing the rig, implications on generated noise are inferred from vibration of the wheel and rail.

Results

Taking into account the scaling of the rig, the initial roughness of wheel and rail was well below that which obtains on a full size railway.
Roughness increased naturally as the tests progressed until an equilibrium condition was reached. When scaled it was noted that this equilibrium state corresponded to levels found on full-scale wheels and rails in good condition.
The final two test cases could only be achieved by artificially increasing the roughness.
It was found that vibration remained a linear function of roughness to a roughness level lower than the equilibrium condition. At very low roughness levels some non-linearly was noted with vibration moving towards an apparent limiting value. Thus although the mechanisms could not be identified, it appeared that for ultra smooth conditions, the vibration generation could possibly be independent of the roughness of the rolling surfaces.
In practical terms, however, it is unlikely that without any other controlling mechanism, the ultra smooth rolling conditions could be maintained and an equilibrium condition would be reached where roughness related vibration is dominant

Project Summary 12

CRITERION
Comments on CER Draft Railway Noise Directive 1993

Background
In 1983 a draft directive was produced by the EU which set noise creation limits for rail bound vehicles. For various political and technical reasons the draft directive failed to be accepted. In 1993 CER in discussion with EU DG XII agreed to review the original draft and propose a new directive. This work was carried out by the UIC Ad-hoc Group "Noise" who then asked the ERRI C 163 Committee for comment.

Duration and cost
1994
…… ecu

Method
The draft document was distributed to members of ERRI Committee C 163 who were asked a number of specific questions regarding:

- Desirability and necessity of a directive.
- Existing data on which future limits may be based.
- Measurement method.

The response was coordinated by NSTO on behalf of ERRI Committee C 163 and a report, with conclusions produced.

Conclusions
The consensus view was that a common European directive on railway noise creation limits was considered useful and could even be in the railways' interest.
Before the directive could be drawn up three activities would need to be completed:

- Formulation of a common European railway strategy towards noise control.
- Definition of a standard measurement method, preferably in cooperation with CEN and ISO.
- Production of an inventory of measured noise levels from existing rolling stock using the above method.

Links with other Projects
These conclusions are consistent with the proposed negotiating strategy of UIC/CER and were still valid when papers were presented at the 1997 Conference on the EU Green Paper, in the Hague.
Work on noise measurement standards (see Summary 12) was carried out as part of the BASENOISE project in 1996, with its results being used in the current discussions with CEN and by the EU project Metarail.
It was expected that plans for the directive would have been given at an EU Conference in Copenhagen in May 1998, but that conference was cancelled. It is expected, however, that a statement will be issued by the EU towards the end of 1998, although there appears to be confusion over its current plans for such a directive.

Project Summary 13

Active Noise Control: State-of-the-art

Background

Active noise control is a well known, successful, technique where received noise is reduced by introducing equal, but out of phase, noise near the source.
To date it appears to have had little, if any application in the field of railway noise, yet is becoming increasingly used for aircraft and road traffic noise.
This study, carried out by SNCF on behalf of the ERRI C 163 Committee, reviewed the current status of active noise control, presenting the scientific background to its successful use. A number of important applications were identified and particular attention was drawn to those which have been or could be applied to a railway noise situation.

Duration and Costs

1995
23810 ecu.

Results

For successful application a. number of problems have to be overcome:

- location of detector(s),
- control algorithm for minimising time delay in changing the output of the secondary source,
- development of effective hardware.

The scientific background giving the principles for the design of active noise control system was presented and a number of successful applications identified:

- ear defenders,
- noise in ducts (20 dB, 200 – 600 Hz)
- noise from fans (16 dB at duct outlet),
- internal road vehicle noise,
- internal aircraft noise,
- power transformers,
- structural sound,
- noise barriers (6 dB).

A number of railway applications were found but none of the cases gave information relating to field experience.
A number of the reported uses seemed applicable to a railway situation, particularly those associated with fan noise (locomotives) and barriers (general external noise). It was also felt that further investigation was necessary to see whether the techniques could be applied to the control of rolling noise at source.
Subsequent preliminary investigations identified that currently investigations into the control of rolling noise by active noise techniques should not be continued.

Project Summary 14

Active Noise Control – Locomotive Fan Noise

Background

The noise from locomotive fans, particularly for stationary locomotives or for trains at low speeds, is a cause of annoyance for people living near railway lines.
The character of fan noise is such that it can be controlled, in certain circumstances by active noise control techniques.
The study carried out by SNCF, on behalf of ERRI C 163Committee, was intended to investigate options for controlling the noise from locomotive fans by active noise control and to recommend future action.

Duration and Cost

1995
47620 ecu.

Results

Various locations for the active noise control sensors were considered:

- in the ventilation duct,
- in the roof of the locomotive,
- external to the locomotive to improve the low frequency performance of a trackside noise barrier.

Preliminary studies indicated that reductions in excess of 6 dB could be obtained but it was recommended that further, detailed information was required of the internal environment of the ducting and locomotive before recommendations regarding locomotive based control systems could be made.
Experiments related to the enhancement of noise barrier performance had shown a benefit of 6 dB in certain situations, but it was too soon to be definitive about the likely benefit for a barrier/locomotive combination.

Studies are continuing in this area.

Project Summary 15

Rail Surface Coatings for Noise (RASCON)
Literature Search and Preliminary Theoretical Studies

Background

The majority of studies aimed at reducing the noise caused by railway vehicles rolling on a track have concentrated on investigating changes to the design of wheel/track components or the use of barriers.

Little work has been carried out on controlling or even reducing the excitation force between wheel and rail, yet less noise is caused when the wheel and rail surfaces are smoother as the examples of the use of disc braked wheels and the presence of railhead corrugation clearly demonstrate.

Surface coatings have been used to control curve squeal and a more general question was raised as to whether the introduction of a coating material could control the generation of rail roughness or affect the roughness generated forces.

This study intended to provide some preliminary answers to those questions and give more specific information regarding the control of curve squeal. The specification of appropriate materials would also be specified.

Duration and cost

1995/6

71 425 ecu.

Method

Literature searches were undertaken to identify previous work on coatings and their effect on noise.

Additionally, theoretical studies were commissioned to develop models for the behaviour of a surface coating in the wheel/rail contact zone. These models were used to specify the necessary material properties required for noise reduction.

The work coordinated by LUL, on behalf of the ERRI C 163 Committee.

Results

Literature Searches

Little appeared to have been published on the use of surface coatings for controlling friction and noise in the railway environment.

Theoretical Studies

One model showed the need for high viscosity layers to prevent metal to metal contact, thereby reducing the interaction force and consequently the noise. This was not consistent with braking and traction requirements.

A survey also indicated that materials with the appropriate properties would be difficult to find.

Another model suggested that reduction in noise and wear could be possible by the use of layers, which improved wheel/rail adhesion. It was likely that this would have to be a solid or powder layer.

Recommendations

- Appoint technical panel of experts from within the railways to review the results of this phase and define future experimental studies.
- Develop models to predict the effect of layers on curve squeal and roughness growth.

- Carry out initial tests on commercially available materials in the laboratory to determine likely effects on noise and rail wear.
- Investigate methods for applying the surface coatings in practice.

Links to other projects

The recommendations were accepted and the study continues as part of the BASNOISE project.
Rail roughness growth modelling is an element of the Silent Track project to provide a tool which can assess the rate of roughness growth when changes are made to the track dynamic properties. The study of surface coatings is not part of the that project.

Project Summary 16

Noise Measurement Standards

Project objectives
To review current standards for type testing of railway rolling stock. To obtain consensus of railway noise experts on ERRI Committee C 163 for changes to be put forward for inclusion in the next draft standard from CEN 256 Working Group 3.

Duration and Costs
1996 – 97
23 800 ecu.

Method
ISO 3095 and the 1993 draft CEN standard are two documents that could be used for measuring the noise from a passing train as part of a vehicle type testing procedure.
As part of the BASNOISE study of ERRI Committee C 163 a working group from BR, SNCF, DB and NS held a two-day workshop to review the above standards, identify weakness and propose changes.

The recommendations concentrated on:

- measured quanties,
- specification of test track,
- requirements to produce results that are meaningful to the legislator and layman.

Results and recommendations

- Where the noise from a whole train is required a quantity "Transit Exposure Level" (TEL) should be used.

Mathematically this is defined as

$$TEL = SEL + 10 \log t$$

Where: SEL = sound exposure level (dB(A))
t = pass by time in seconds

TEL is the quantity used by DB and SNCF but is called "passby L_{eq}". The new identification was felt necessary since the quantity is not an L_{eq}.

- Where the noise from some of the vehicles in the train is required, the measured quantity should be L_{eq} measured over the passage of a specific number of identical vehicles.
- Rail roughness needs to be more precisely defined. Following a review of European track identified as "good quality" a roughness range acceptable for carrying out type testing was defined.
- It was recommended that precise measurement of the track dynamic parameters is carried out, although a balance between accuracy and practicality is required.
- The results of a survey of noise measurements from different European trains was included in an appendix (not passed to third parties). This was a first step in obtaining a database of train noise levels to assess the effect of any proposed legislature limits on railway operation.

The recommendations will be used by the CEN Working Group finalising the standard for carrying out type testing of railway vehicles.

The EU project METARAIL which is developing type testing, monitoring and diagnostic measurements methods is also in receipt of the results of this study.

Prepared by ERRI Noise and Vibration Unit

Project Summary 17

Active Noise Control – Results of Experiments

Background

Earlier studies had indicated the potential benefit of using active noise control for the enhancement of barrier performance and to reduce the noise from fans on locomotives.
In the case of barriers a position had been reached where experimental assessment of the benefit of active noise control was required. For locomotive noise further investigations of the source characteristics were required before a system design could be proposed.
This study presented the results of investigations carried out for this purpose.
The work was the responsibility of SNCF, for ERRI Committee C 163 and was part of the first phase of the BASNOISE investigation.

Duration and cost

1996
33 333 ecu.

Method

Barrier Enhancement

The enhancement for pure tones (200, 400, 600 and 800 Hz) and for broad band noise (0 – 2 500 Hz) was measured for a barrier 10 m long and 1.9 m high, for a source 5 m from the barrier.
The positions of secondary sources and feed back transducers were varied to optimise the performance of the active noise system in a control zone behind the barrier.
Numerical simulation of this experimental set up was also performed to compare prediction with measurement.

Locomotive Fan Noise.

Before a design for an active noise control system can be made, further information about the spatial and frequency characteristics of the noise was required.
Background information was obtained by mapping the noise sources of BB 26000 locomotive with just fans operating. Two conditions were investigated, namely with a supply frequency of 30 Hz representing a train standing at a station and with a supply frequency of 60 Hz representing a train arriving at a station.

Results

Barrier Enhancement

With an optimum configuration of two secondary sources located on top of the barrier and two error sensors located behind the barrier a semi-elliptical attenuation zone was obtained. In the region of the error sensor an increase of noise occurred but an area giving additional noise reduction of between 10 and 15 dB was measured.
The computational simulation showed good agreement with measurement.

Locomotive Fan Nose

Fan noise was identified as being concentrated in the frequency range below 350 Hz positioned by the inlet/outlet of the central block and transformer block fans.
Thus from a source location and frequency content point of view it was considered that active noise control was a suitable option for reducing the fan noise from this locomotive, with the active system located on the top of the central block.

Proposals for further studies included:

- Development of an audio system to simulate active noise control efficiency,
- computational simulation for a large noise source, such as stationary locomotive,
- experimental assessment of active noise control on a stationary (and slowly moving) locomotive with and without a lineside noise barrier.

These are planned for the next phase of the BASNOISE project

Project Summary 18

Active Noise Control

Subjective Assessment of Locomotive Fan Noise Application

Background

Previous studies for ERRI have indicated that active noise control should be capable of reducing the noise from fans on locomotive.

In this study, prior to carrying out detailed experiments with a locomotive, an assessment was made of the potential benefit of its use by simulating results for a Eurostar power car.

Duration and cost

1997

23810 ecu.

Method

From previous SNCF measurements, which were used in this study, it is known that the noise from the power car of an Eurostar consists of pure tones superimposed on a broad band background. This is a typical fan noise spectrum. Active noise control is capable of reducing low frequency pure tones and for this simulation the levels of the pure tones were reduced to the level of the broad band background noise at the corresponding frequency.

Two comparisons were made of the resulting spectra (with and without pure tones):

- Determination of overall noise level,
- Subjective assessment by a jury of 22 people.

For the subjective tests an audio listening system was set up so that individuals could listen to the different noises through head phones. For a particular comparison they were asked to score:

- **1** if the controlled spectrum was more annoying
- **0** if there was no difference
- **-1** if the controlled spectrum was more pleasant.

This work was carried out by SNCF on behalf of ERRI Committee C 163 and was part of Phase 2 of the BASNOISE project.

Results

Removal of significant peaks in the spectra gave no change to the resulting computed overall level.

The listening jury noted a change in the character of the noise, yet again the removal of the significant pure tones from the signal gave virtually no change in listener perception of annoyance.

Both of these results are surprising.

It was concluded that just removal of pure tones is insufficient to obtain reduction in overall noise level (to achieve an objective target) or annoyance (subjective reaction).

For significant improvements it will be necessary to reduce, additionally, the broad band component of the noise.

Project Summary 19

Rail Surface Coatings for Noise (RASCON)
Review and Recommendations of Technical Panel

Background
Following an initial literature search and theoretical modelling, a recommendation was made that a panel of experts from within the railways should be set up to provide a critical review of the results obtained to date. This review would either confirm or redefine the proposed work programme.

Duration and costs
1997 – 98
23.8 kecu.

Method
A technical panel consisting of experts in wheel/rail contact dynamics from LUL, SNCF, NSTO, AEAT and Vibratec was set up. This panel reviewed the work carried out in the preliminary phase of the project, the recommendations of the study and the work programme proposed for the next phase.
Their recommendations were made in the form of a report.
This work was coordinated by LUL on behalf of ERRI Committee C 163 and represented the initial stage of the second phase of the RASCON project funded as part of the BASNOISE studies.

Recommendations of the Panel
- Contrary to initial recommendations, no further theoretical studies should be undertaken at the present time.
- Carefully planned, laboratory tests should be carried out to evaluate the properties of a selection of prospective materials (this would obviate the need for the initial laboratory tests originally proposed.)
- Wheel/rail separation using a full fluid layer is unlikely to give useful results through its conflict with signalling and traction requirements.
- Investigations should concentrate on assessing the effect of materials on roughness growth and slick/slip behaviour.
- Use laboratory tests to define the measurements to be carried out on an operational railway or test track.

A broad description of the necessary laboratory testing was presented together with a list of facilities where the tests could be carried out. Additionally a number of potential test materials was identified.

Observations
The objectives of the investigation have changed following the assessment by the Technical panel. They see the major benefits from the use of surface coatings in the control of curve squeal and the growth of rail roughness. This latter effect, if shown to be successful, would have an important impact on rail grinding strategies in that newly ground rails, once worn smooth, would retain that smooth surface for a longer period of time with the consequent effect on noise levels and track damage.
A review of this project is planned for 27 August 1998.
The original proposal for completion of the project in 1998 now cannot be met, unless no further work is carried out and should continuation be recommended an extension of funding into 1999, but without an increase in value, will be requested.

Project Summary 20

SILENT FREIGHT Work Activity
Improvement of Noise Simulation Models

Objective

To produce an extended version of TWINS capable of dealing with a wide range of relevant design variables for rolling stock, by improving existing modules or adding new modules as appropriate. Where incorporation into TWINS is not directly appropriate (e.g. for boundary element BEM or finite element modelling FEM), to specify complementary modelling required to feed in or extract appropriate data with respect to TWINS.

Duration and Costs

Silent Freight Project: 1996 – 1999

Total project	3.2 million ecu	UIC Funding: 22% (629 kecus)
This activity:	210 kecu	UIC Funding: 9 % (8 kecu)

Participating organisations

ABB, Chalmers, ERRI, ISVR, TNO

Method

- Develop a series of enhancements to TWINS and other software which can be associated with TWINS to more accurately predict noise creation characteristics of rolling stock**.**

Specific modules are:

- WDM (Wheel Damping Module): to model the effect of additional damping to a given wheel shape
- SPM (Wheel Sound Power Module): A BEM model has been developed to calculate the sound power radiated by an axi-symmetric body with non axi-symmetric mode shapes. This was assessed against a series of measurements taken on a wheelset and enabled changes to be made to the existing TWINS module.
- SPLM (Sound Pressure Level Module): This translates the sound power output of TWINS into sound pressure information to determine near-field propagation, environmental impact etc. It also facilitates calculation of the effect of mixed technologies applied to a given train.
- ShM (Shielding Module) This is being developed in conjunction with the shielding work activity to assist in the prediction of optimised shielding and application of absorbent layers.
- ASCM (Acoustic Short Circuiting module) This is a database allowing TWINS users to calculate the affect of short circuiting on perforated wheel designs.
- RCWM (Resilient and Composite Wheel Module) The module was planned to be used to carry out TWINS calculations on resilient and composite wheel designs per the LTAS wheels.
- Integration: the above modules and associated software will be incorporated as appropriate into TWINS and a user manual and reference documents will be produced.

Results and Residual Questions

- WDM: The module was produced at an early stage of the project and has been particularly useful in the MTSOD wheel development work
- SPM: Changes have been made to the TWINS sound power module to improve the prediction of radiation caused by the radial motion of the tyre.
- SPLM: originally produced in FORTRAN, this module is being converted so that it can be incorporated into TWINS.
- ShM: this is currently being used to assist in the shielding design work activity

- ASCM has been used in particular in conjunction with the development of the LCST perforated wheel design.
- RCWM: Although originally anticipated to be a calculation module the budget from this task has been used to define and validate procedures to enable TWINS to be used for resilient wheels. A FEM model of a resilient wheel has been developed as a basis for determining recommendations including a reference report.

Additional Studies

The modules produced in Silent Freight will be combined with those developed in the Silent Track project resulting in an enhanced version of TWINS (TWINS 3) which is expected to be completed during 1998.

Project Summary 21

SILENT FREIGHT Work Activity
Transverse Profile Investigations

Objective
Determine whether wheel transverse profile can be optimised to reduce rolling noise creation.
Improve TWINS to take proper account of the effect of wheel-rail transverse profile on the excitation of wheel and rail vibrations.

Duration and Costs
Silent Freight Project: 1996 – 1999
Total project 3.2 million ecu UIC Funding: 22% (629 kecus)
This activity: 135 kecu UIC Funding: 26% (35 kecu)

Participating organisations
ERRI, ISVR, TNO

Method
- Carry out evaluation of TWINS against measured data to determine the ability of TWINS to take into account different transverse profiles
- Identify missing parameters and additional data required then collect relevant data
- Produce improved model incorporating the effect of transverse profiles on wheel/rail vibration then implement in TWINS
- Carry out parametric study of the effects of transverse profile on noise with the aim of producing an optimised profile, assessing the implications of this profile on dynamic properties.

Background
This study included in SF following earlier NS investigations which showed that for units of the same type with differing braking systems the smoothest wheels using sinter blocks were noisier than other rougher wheels. This raised the question of the effect of the profile on noise generation and whether the dynamic characteristics of the wheel had any effect on noise creation. The SF work was linked with a parallel study for ERRI C163 Committee on contact zone stiffness (see summary 5).

Results and Residual Questions
Analysis of a field test campaign revealed that hollow profiles cause wheels to ride at stable positions on the outer parts of the running surface whereas normal conical profiles allow displacement of the contact point around a central patch. Change in contact position could not explain the differences observed for the braking systems. Other parameters have been examined such as the effect of contact receptance and change in roughness filtering on sound power level. The conclusion of these studies show that the average roughness on a large area balances the effects of contact stiffness and that there is little impact of developing a wheel with a conforming profile to reduce noise levels. The effects of creep forces, contact stiffness and moment excitation (of a conforming profile) have been examined but they seem to have small effect on noise.

Moment excitation will be investigated further. In parallel a multi-body model will be developed giving the statistic distribution of the location and shape of the contact point.

The following modules will be implemented in TWINS:
- Modified offset of the wheel/rail position

- Non circular profiles
- Moment excitation (if relevant)

Additional Studies
Further work is unlikely to be carried out given the result that changes in profile do not have an appreciable effect on rolling noise creation.

Project Summary 22

SILENT FREIGHT Work Activity
Development of Low Noise Wheel solutions

Objective
To determine principles for low noise wheel designs, produce prototypes and carry out laboratory and field tests.

Duration and Costs
Silent Freight Project: 1996 – 1999

Total project	3.2 million ecu	UIC Funding: 22% (629 kecus)
This activity:	1.1 million ecu	UIC Funding: 3.7% (41 kecu)

Participating organisations
ABB, CAF, CEIT, Chalmers, ERRI, ISVR, Valdunes, Vibratec

Method

- Use models specifically developed in another work activity within Silent Freight which are integrated or linked to TWINS to optimise wheel designs for specific families of solutions
- Low cost short term solutions developed using ring dampers and perforations (acoustic short circuiting). Individual solutions and combined solution to be tested. The ring damper was designed for use with a standard UIC 920mm wheelset and the perforated design applied to an 860mm forged version of a wheelset used in iron ore trains.
- Mid Term Shape Optimised Design. Using TWINS calculations an optimised wheelset is developed. Two treatments: constrained layer damping and tuned absorbers are applied to the design following optimisation of their application using the modelling techniques developed earlier in Silent Freight
- Long term advanced solutions. A series of “radical” wheel set designs are investigated to determine their validity both in terms of their acoustic properties and practical exploitation. The solutions consider wheels which are not tread-braked (unlike the LCST and MTSOD solutions)

Results and Residual Questions

Computer simulation and tests on the ring damper and perforated wheels have been promising. Their noise reduction capabilities are complementary (the damper more effective for axial modes below 1000 Hz and perforations above 1000 Hz). This result prompted the decision to develop a combined solution using both dampers and perforations.

The shape optimised wheel was designed to meet the thermal stress criteria as laid down by the B169 draft wheelset specification to be adopted by CEN TC256 WG 11. This was to ensure that any solution derived in this work activity could be readily applied to operating traffic. It had originally been proposed to use the shape optimised wheel developed in the OFWHAT proposal but this did not meet the thermal specification.

Long term solutions have examined the use of composite materials (found not to be effective), resilient wheels, close proximity wheel shields. Of these the resilient wheels are considered to be the most promising. If the results of initial design and tests are encouraging then the wheel will be tested at Vélim during the validation exercise.

Prepared by ERRI Noise and Vibration Unit

Project Summary 23

SILENT FREIGHT Work Activity
Superstructure Noise

Objective
To develop tools to investigate noise creation from wagon superstructure and use them to collate data which could be used to design low noise solutions. In addition to develop a methodology which could be extended to a wider range of wagon types.

Duration and Costs
Silent Freight Project: 1996 – 1999
Total project 3.2 million ecu UIC Funding: 22% (629 kecus)
This activity: 317 kecu UIC Funding: 26 % (81 kecu)

Participating organisations
ERRI, ISVR, TNO (Talbot withdrew from project)

Method
- Define requirements for array techniques to analyse structure borne noise
- Assess computer simulation techniques to determine their suitability for modelling superstructure noise generation
- Develop a model which could have possible links to TWINS using collated data to determine superstructure noise creation
- Carry out static tests to determine magnitude of superstructure noise and validate simulation model
- Based on the results of the tests and computer simulation, design and manufacture low noise superstructure for testing in validation trials in Vélim

Results and Residual Questions
Measurements
The State of the Art report did not produce as much information as had originally been anticipated. As a result an initial dynamic test campaign was arranged in France using Tombereau wagons which were reputed to generate loud superstructure noise.
The results of these dynamic and additional static tests on the Tombereau wagons revealed that superstructure noise was at least 10 dB(A) quieter than rolling noise and at present levels was not perceived to have any contributory effect to existing noise levels. Should rolling noise be drastically reduced, superstructure noise may in turn dominate the noise created. The researchers were keen to ensure that conclusions derived from the Tombereau wagons were not generalised without another set of tests on a different wagon type. Tank wagons are considered also to have high superstructure noise creation levels. A series of static tests is planned to be carried out on a bogie tank wagon in September 1998. Should these tests also reveal a low comparative noise level versus rolling noise, then no further work will be carried out on this activity, with the conclusion that, at present, the effect of superstructure noise is not significant. It has been agreed that no low noise superstructure solutions will be developed for the field tests in Vélim.
The dynamic testing campaign provided the opportunity for a new measurement technique to be developed which coupled microphone array techniques with on-board measurements to provide valuable information on source location.
Modelling
Appropriate techniques have been sought to best deal with superstructure noise. Impedance techniques were found to be unsuitable for low frequency applications. A finite element model of a Y25 bogie has been produced, investigated and modified. An SEA model is being developed of both the wagon body and bogie configurations. Both sets of models will be validated against available test data.
It appears that there may be scope to reduce superstructure noise by taking remedial action on bogies

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Prepared by ERRI Noise and Vibration Unit

Additional Studies

Further work is only anticipated at such time that rolling noise creation is reduced to such levels that superstructure noise has a significant contribution.

Project Summary 24

SILENT FREIGHT Work Activity
Shielding Investigations

Objective
To determine the efficiency in reducing the level of noise propagated from wheel/rail systems by developing body mounted and bogie mounted shielding systems to be used in conjunction with, or separately from, low trackside barriers (developed in Silent Track)

Duration and Costs
Silent Freight Project: 1996 – 1999

Total project	3.2 million ecu	UIC Funding: 22% (629 kecus)
This activity:	193 kecu	UIC Funding: 30% (58 kecu)

Participating organisations
ERRI, ISVR, TNO, Integral (Talbot, originally a member of this task, withdrew from project)

Method
- Validate BEM and SEA models to study propagation near wheels with shielding devices
- Investigate the feasibility of body and bogie mounted shielding systems to operate throughout the European railway given the constraints of national gauging restrictions:
    - Determine kinematic envelopes suitable for body and bogie mounted solutions to produce space frame appropriate for shields
    - Carry out analysis of space frame to determine acoustically optimised layout for shields making use of sound absorbent material
    - From results of analysis produce robust design appropriate for operational use
- Validate designs and models by testing prototypes

Container wagons (initially R type but subsequently Sgs type) with Y25 bogies were selected for investigation given their widespread and continued use.

Results and Residual Questions

Theoretical analysis showed that use of BEM was inappropriate and SEA only was used for acoustic optimisation.

Initial gauging investigations on R type wagons indicated that body mounted shields were not feasible given the dynamic criteria established for body/bogie performance in UIC fiches. Decision taken not to continue work on body mounted shields.

Investigations carried out by Integral, confirmed by ERRI and RB Haarlem, indicate that there would be a gap between the lower edge of the bogie mounted wagon shields and upper edge of the close proximity barriers. This would reduce the efficiency of the solution. The gap width varies between 235mm for an unloaded vehicle and 185mm for a loaded vehicle. It has subsequently been agreed that testing should take place for a specific case of fully loaded vehicle with a half worn wheel, without consideration of possibility of broken springs. This test would indicate the validity of a solution of this type.

The track contributions in the bogie area, in the space between two bogies and the wagon outer end have been calculated using SEA. Total sound power reduction is estimated to be 2.9 dB(A).

Progress in this activity has been impeded initially, by the withdrawal of Talbot and subsequently by the withdrawal by WB Amersfoort (Talbot's replacement) who were responsible for the design and

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construction of the shielding devices and provision of a test site. This work has been taken over by RB Haarlem with a test site being made available at Hilversum by Railpro Holland.

Project Summary 25
SILENT TRACK Overview

Objective
Silent Track will develop pre-normative concepts for low noise infrastructure. The project is closely linked to Silent Freight and shares a common test programme. New solutions will be derived to be applied to existing track to give a predicted noise reduction of 2.5 dB(A) (10 dB(A) or more when optimised with freight rolling stock). The aim is to reduce the noise at source rather than noise suppression by barriers.

Duration and Costs
Start Date: January 1997 End Date: March 2000
Total cost: 3.75 million ecu UIC funding: 23% (875kecu)

Participating organisations
Co-ordinator: ERRI
Partners: British Steel, Pandrol SNCF, Sogérail, Chalmers University, Vibratec, TU Berlin and ISVR
Sub-contractors: DB, SNCF, NS, LU Ltd, Banverket, AEA Technology Rail, Eresman

Background
Future legislation may introduce limits on railway noise in residential areas which would prevent certain trains running at night. Infrastructure has been proven to have a major effect on rolling noise generation. Current solutions to reduce the noise would be expensive. A successful outcome from this project would enable a significant noise reduction at acceptable cost. The project will assist the railways in lobbying for "sensible" noise regulations.
Reduction of railway rolling noise was identified as a key issue within the ENVIRAIL Project Declaration. EU DG XII accepted the project at the 2nd call of the Fourth Framework Programme.

Method
State of the art:
Produce a review of existing developments concerning modelling design and operation of low noise infrastructure equipment
Theoretical Studies:
Carry out an investigation of Roughness Generation Growth (RGG) including radiation and vibration mechanisms: develop enhanced models of RGG models.
Solutions for track components:
Refine models to enhance or be incorporated in TWINS. Using models develop designs and prototypes for infrastructure components: pads, fasteners, modified rail shape and damping. Suitable components to be tested in validation exercise.
Track environment:
Develop tools and methods to produce low close proximity barriers which would work in conjunction with bogie shield design being developed in Silent Freight. Manufacture prototype and perform qualification tests.
Roughness investigation:
Perform measurement campaign to determine development of roughness growth in normal traffic conditions; study parameter influence with the target of producing concepts for low RGG track designs.
Validation exercise:
Field test campaign to test low noise solutions for effectiveness and cross-correlate against modelling activities.

Prepared by ERRI Noise and Vibration Unit

Exploitation policy:
Assessment of exploitation potential of low noise solutions using noise mapping cost benefit tool. Determine social and economic impact of solutions derived in Silent Track (exercise carried out in parallel with Silent Freight and Eurosabot projects)

Results and Residual Issues

State of the Art

Report completed to time and within budget.

Modelling

Two Roughness Generation and Growth (RGG) models under development. One modified to consider pad/ballast non-linearities. Other is including long term wear characteristics. Benchmarking tests to correlate track test results with RGG models are under development. Sleeper variation and noise radiation tests have been carried out. Track radiation model is being developed. TUB is working on Multi-pole model. Some difficulties being experienced in compatibility between VIBRAIL and TWINS which is delaying development of interface.

Track Component Solutions

TWINS simulations to assess options have been completed. These indicate potential benefit of new rail design. Pandrol are reviewing fastening systems. Initial ideas for rail damping are being scrutinised for production by British Steel. Prototypes on schedule for initial lab testing and delivery for field tests in May 1999.

Noise Propagation Solutions

Envelope for low, close trackside barrier defined using UIC gauging data. Barriers have been built by British Steel. Combined tests with bogie shields planned for September 1998 at railpro test site.

Roughness Control

Delays in starting test campaign. Initial measurements carried out in Netherlands and UK. NS carrying out analysis of rail samples removed from Dutch test sections. Further measurements carried out in April 1998. Options being considered of low RGG track designs.

Validation Exercise

First meeting held with Test Centre and provisional testing scheme developed. Tests planned for May 1999. Test protocol defined for principle evaluation of prototypes; test programme for shields and close proximity barriers under development. Negotiations continuing with Test Centre.

Exploitation

Cost Benefit studies proposed using NS GERANO model to assist exploitation decisions. Exploitation advice is being provided by Mr Zaalberg (Manager, Civil Engineering Unit ERRI).

Additional Studies

Further scope remains for studies on other low noise infrastructure applications such as slab track, embedded rail and points and crossings which were taken out of the Silent Track project as a result of budget reductions by the EU.

Prepared by ERRI Noise and Vibration Unit

Project Summary 26

Eurosabot Work Activity
Laboratory Tests (Hypotheses Validation)

Objective
To perform laboratory tests to verify thermo-elastic and vibration instability hypotheses and provide base data for modelling activities.

Duration and Costs
Eurosabot Project: 1996 – 1999

Total project	3.2 million ecu	UIC Funding: 4.6% (147 kecus)
This activity:	500 kecu	UIC Funding: 0%

Participating organisations
DB, SBB, NS, Chalmers TH, SLM, Sulzer-Innotec, Metravib, HEF, Ferodo

Method
- Determine hypotheses for thermal and vibration phenomena causing roughness generation and development during the braking process
- Using a round robin process evaluate possible laboratories where tests could be carried out to validate (or disprove) the hypotheses and provide parametric information for the modelling activities
- Carry out tests and feed results to the modelling and design activities
- Further testing as required to fine-tune selection and final design of prototypes

Results and Residual Questions

Two families of hypotheses for roughness generation and development were proposed relating to thermo-elastic (23 hypotheses) and vibration effects (6 hypotheses). Material transfer from the block was also considered.
A series of three laboratory tests were carried out:

1. Tests to investigate thermo-elastic instability at ABB test rig in Surahammer (drag braking and stop braking).

   These tests carried out with the aid of a thermal camera highlighted that the main cause of roughness generation is thermo-elastic instability and the results give valuable insight to hot spot creation and other effects.
   Other notable results:
   - Cast iron blocks develop hot spots and material is transferred to the wheel
   - Stop braking in cast iron blocks stimulates roughness development with peaks generated by material transfer: neither sinter or composite blocks exhibited hot spots
   - Drag braking resulted in a high level of roughness (up to 10µm, with a dominating wavelength of around 6cm): sinter and composite blocks tested indicated low roughness with a dominating wavelength of around 13cm
   - Vibration does not generate roughness but determines its periodicity
   - The wavelength of hot spot and vibration patterns are shorter than block length
   - During drag brakingthe surface structure undergoes a transformation and becomes harder

- Material structure is different for drag braked and stop braked wheels
- Good correlation to field tests

Vibration measurements were also taken to assist the modelling activities.

2. Investigation of vibration instability at HEF France

   Tests were satisfactory in terms of braking performance, block vibration and temperature. Good correlation was achieved with the Surahammer rig and valuable parametric information provided for the models.

   Principle conclusions for improvement of block design were:
   - Smooth material best for block surface to limit the initial development of corrugation
   - Block impedance should be low to reduce vibration

3. Material transfer and inclusion tests using rolling contact (pin/disc) at Sulzer-Innotec

   Tests were performed to study
   - Temperature behaviour of brake block material and wheel
   - Wear of wheel and block material
   - Compatibility with field tests

   These revealed particular characteristics for the different block types
   - Cast iron blocks characterised by growth of material build up from block to wheel at peaks on the wheel surface
   - Sinter block samples acted abrasively on the wheel surface
   - Composite brake block samples were characterised by the transfer of material to depressions in the wheel surface

Metallurgical tests were made at the Surahammer rig of cast iron (c.i.) block with abrasive wear resistant ends. In this case the contact area fluctuated making abrasion intermittent. No hot spots were observed and the wear rate was high enough to suppress non-uniform thermal expansion.

Test campaigns at the Surahammer rig proved to be so valuable that these facilities were used for extensive testing in the prototype design and development stage

Project Summary 27

Eurosabot Work Activity
Field Tests

Objective
To perform initial field tests on freight wagons and locomotives to provide initial data to support development of hypotheses and modelling activities.
To carry out final testing programme to test performance of prototype brake blocks for endurance and acceptability against brake test requirements

Duration and Costs
Eurosabot Project: 1996 – 1999

Total project	3.2 million ecu	UIC Funding: 4.6% (147 kecus)
This activity:	1.42 million ecu	UIC Funding: 1% (14 kecus)

Participating organisations
DB, SBB, NS, FS, SLM, Metravib, Ferodo, KTH, ERRI (Talbot withdrew from project)

Method
Define initial test campaign to ensure appropriate coverage of parameters under investigation

Initial tests to provide insight into the influence of operational conditions on:

- braking performance
- traction adhesion characteristics
- roughness generation
- rolling and braking noise

Final test campaign to assess prototype brake block performance and information for input and validation data to modelling exercise. Tests to comprise of long term endurance tests, measurement exercise and UIC acceptance test.

Results and Residual Questions

During the initial test campaign measurements were made of:

- vibration of wheels, blocks and rigging
- pass-by and interior noise
- wheel and brake block roughness
- rail roughness
- wheel and brake block hardness
- temperature (using IR equipment)
- micro-roughness (2D patterns)

Principle conclusions concerning cast iron and sinter block brake block characteristics derived from these tests:

- Cast iron blocks produce severe local material transfer on the wheel. New material transferred often builds up on existing transferred layers. Hot spots are well correlated to zones of material transfer and material changes. Vibration does not appear to generate wheel roughness but governs the periodicity of roughness patterns. Noise level increases during braking applications.

- Sintered blocks through wear mechanisms produce smooth wheels even in the case where there is some minimal material transfer. Sinter block roughness is equivalent to rail roughness on good track. Noise generation is 9 to 12 dB(A) lower than with cast iron.

Additional measurements on thermal behaviour were obtained by consortium during internal SLM locomotive test campaign in February 1997.

Final Test Campaigns

Final test campaigns are in preparation to start in September 1998. Reports on this second wave of tests are expected in the last quarter of 1998.
Endurance tests will be carried out on NS and on SBB Gotthard line. NS will carry out initial brake tests concerning optimum brake system pressures. Data from tests will also include:

- wheel roughness
- transverse wheel profile
- hardness, cracking and material transfer data
- variation of friction coefficient with speed
- residual stress
- block and wheel wear

If a locomotive brake block solution is forthcoming a brake distance test will be carried out by SLM before further testing in the final campaign at Erlen (CH).

Project Summary 28

Eurosabot Work Activity
Modelling Mechanical and Acoustic Elements associated with Tread Braking

Objective
To develop models of thermo-mechanical and acoustic effects in order to assist in the development of innovative solutions for low noise brake blocks

Duration and Costs
Eurosabot Project: 1996 – 1999
Total project   3.2 million ecu   UIC Funding: 4.6% (147 kecus)
This activity: 929 kecu   UIC Funding: 0%

Participating organisations
DB, NS, KTH, Chalmers TH, Metravib, Polytechnico Torino

Method
Initial project planning was to develop a series of models based on a number of hypotheses of roughness generation and development.
The hypotheses are checked against the results of initial lab and field tests.
Relevant hypotheses modelled further and the completed models used to support the design of new solutions.
Different families of models are being developed:

- Mechanical behaviour of wheel/block system considering the interaction of the brake system, wear and vibration of the wheel under brake-induced excitation
    - 3 dimensional (3D) Finite Element (FE) model of wheel and block (3DFEWB)
    - 2D dynamic model of block vibrations (2DDBV)
    - 1D wear instability model (1DWI)
- Friction and contact models considering the contact mechanisms which generate roughness
    - 2 dimensional (2D) model of thermo-elasticity and wear instability (2DTEWI)
    - 2D quasi-static FE model for time domain thermo-mechanical and wear simulation (2DFETDTMWS)
    - Model of heat distribution in wheel and block during braking (provides boundary conditions for the first family of models above) (HDWBB)
    - Simple mechanical model of wheel, block and rigging which uses Monte Carlo to vary parameters such as wheel initial roughness, exciting force and friction coefficient can be varied randomly (MCM).
- Noise emission during braking (NSS) and in normal rolling conditions

Results and Residual Questions

The modelling process has proved to be more complicated than originally envisaged mostly caused by the difficulty in determining how the numerous phenomena involved in roughness generation inherent in the braking process interfere with each other in the initiation process.
Some information relating to the hypotheses were forthcoming from the field tests but problems with measuring equipment and high squeal levels in the initial wheel rig tests failed to produce adequate

information for the vibration models. However these same tests provided some very valuable information concerning hot spot formation and support for particular hypotheses and associated models.
The project philosophy towards the tests was modified when it became apparent that model development would take longer than anticipated. Rather than use the models to assist in the design process the sample block tests have been used to feed information to fine-tune the modelling process.

As a result the models are representative of observed behaviour and the table below shows the capabilities of the particular models. It also highlights both the instances where particular models are best suited to be applied and also those where effects indicated by the models have been witnessed during the laboratory and field testing programmes

	DRAG BRAKING	STOP BRAKING	Effects witnessed and confirmed by experiment	Parametric influence on	Parametric trends to reduce roughness
2DTEWI	X		hot spot formation	hot spot	↓ Young's modulus
HDWBB	X	X	hot spot movement, changing from one brake history to another	hot spot formation	not yet
2DFETDTMWS		X	Vibration increase in final stage of stop braking	vibration, stick-slip, wear-induced roughness formation	↑ tangential stiffness, damping ↓ block mass, contact stiffness
MCM	X		to be verified against laboratory tests	Per 2DFETDTMWS	↑ damping, stiffness of block holder / brake application system
3DFEWB	X	(x)	Local contact of Cast Iron blocks, not compensated by wear ; moving contact points	Too cumbersome a model to be used as optimisation tool	could be extended to other materials, and varying friction coefficient
1DWI	X		to be verified against laboratory tests	Regions of parametric instability	↑ damping, friction coefficient, thermal expansion, stiffness, ↓ block rotation
NSS	X	X	Squeal noise	Noise during braking	not yet

protocol developed by DBard

Additional Studies

Detailed proposals for Phase 3 are under development for presentation to C12.

Project Summary 29

Eurosabot Work Activity
Design of Solutions

Objective
To develop new brake blocks capable of reducing noise creation from existing freight wagons and locomotives without having to make major adjustments to vehicle systems using the experience gained from the laboratory and field tests and modelling activities.

Duration and Costs
Eurosabot Project: 1996 – 1999

Total project	3.2 million ecu	UIC Funding: 4.6% (147 kecus)
This activity:	855 kecu	UIC Funding: 0%

Participating organisations
DB, NS, Ferodo, Frendo, Chalmers TH, SLM, (Talbot withdrew from project)

Method
Develop ideas for new brake blocks based on the results of the initial laboratory and field tests and the remaining hypotheses which had been validated by these tests

Fine tune feasibility of ideas using the criteria of :
- Potential cost
- Technical feasibility
- Potential for improvement

Manufacture first series of blocks to test validity of designs

Based on these tests manufacture a small series run of 6 types of prototype blocks which would be subjected to a more rigorous test campaign (qualification tests). The most promising blocks would then be tested in the second wave of field tests (September - November 1998).

Results and Residual Questions

A workshop was held in April 1997 to analyse the results of the field and laboratory tests carried out to that date and evaluate the proposed hypotheses to determine future areas of investigation and potential families of brake blocks which offered the most promising solutions.

The most significant phenomena relating to roughness generation and development noted in the testing campaigns were:
- Material transfer (primarily for cast iron blocks)
- Hot spot formation (primarily for ci blocks)
- Periodic patterns governed by vibrations (possibly all types)
- Stop braking

Three families of block solutions were identified where further work could be carried out (these are shown overleaf). The third family of solutions dealing with the block environment (braking system, wheel characteristics etc.) was considered to fall out of the scope of the existing Eurosabot project.

Prepared by ERRI Noise and Vibration Unit

Family 1 Block Architecture	Family 2 material + thermal properties	Family 3 Environment of the block
• Contact area (pins, perforations). Ex : trapezium shaped block, perforated blocks • Damping of the block itself. • Modifications in 3D of the surface contact. E.g. block hollow in the length • Multi-element design	• Incorporated friction modifier • Cast Iron mixed with composite • Cast Iron with polishing sinter • Abrasive material as part of the block	• Wheel damping (specifications could be set, even if outside the scope of EUROSABOT,). • Process of controlled roughness (e.g. when the wheels are machined.).

A series of blocks were manufactured to test on the Surahammer rig to investigate the validity of initial design ideas:

- trying to govern cast iron friction as a way of avoiding final adhesion and material transfer
- splitting contact area of cast iron blocks into slots to avoid uncontrolled local contact
- introducing abrasive parts in cast iron (either within the material itself or at blocks ends) in order to wear transferred material peaks, without reaching such high general wear levels as on "usual" sinter shoes
- introducing inclusions in composition shoes to make the thermal and braking behaviour more acceptable, but keeping the positive properties of organic matrix in terms of low roughness
- reducing the general wear rate created by sinter, without losing the advantage of smoothing the irregularities.

These concepts were not yet really thought as "industrial" solutions. The purpose of the test was mainly to verify whether trends were confirmed when some key parameters were significantly varied.
It was decided to carry out an assessment for each block type. This involved measurement of roughness growth, squeal noise, thermal behaviour at Surahammer and wear characteristics at Sulzer (as a continuation of the laboratory test).
A further set of samples was developed for testing including a segmented cast iron multi-block, variations on composite blocks (including in some cases metallic inclusions and damping interlayer), a low abrasion sinter block and a composition block from South African Railways (SAR) for comparison.

Principle conclusions concerning roughness were:

- the cast iron blocks were roughest - typically in the range of +5 to +10 dB over the whole 1/3 octave spectrum, i.e. about +10 to +20 dB(A) for 2 to 20 cm wavelengths which are of interest for noise
- composite blocks generate very low roughness solution , although large differences were observed from one variant to another, but the range is between + 5 to -11 dB(A), the last one being the SAR reference ; if this is removed, the range is between +5 and -9.5 dB(A)
- sinter always produces very low roughness, between -3 and -9.5 dB(A).

(Note: 1/3 octave data above are expressed as dB re 1µm ; overall levels are expressed in dB(A) re 1µm, after application of the A weighting based upon a 920 mm wheel diameter rolling at 100 km/h)
CONFIRM THIS NEXT SET OF DATA
The multi-block cast iron block showed a very low wheel roughness pattern in the long wavelength range, and a roughness of about -3 dB between 2.5 and 8 cm. This is translated into an acoustically efficient roughness of about +3 dB(A), i.e. nearly 7 to 17 dB(A) lower than all other cast iron blocks tested.

The semi-metallic and damped composite blocks appeared to be the most promising options to develop alternative solutions to cast iron. This is consistent with hypotheses validated by the first series of tests and with some of the trends indicated by models. The sinter block with low abrasion produced one of the smoothest levels.

Following these tests 6 block types have been selected for qualification tests (4 composite, the low abrasion sinter and the multi-block). Due to the lack of availability of the Minden test rig the blocks are being tested at FS, Ferodo and Frendo using a protocol developed by DB based on the standard UIC testing criteria. Best performing blocks will then be subjected to the final field tests.

Project Summary 30
METARAIL Overview

Objective
To develop measurement procedures and systems to

- measure and monitor external noise of complete trains and individual vehicles
- monitor daily levels of received noise
- quantify the effectiveness of noise control measures
- identify the contribution of wheels, vehicle superstructure and track to total noise
- perform vehicle type testing

Duration and Costs
Start Date: February 1997 End Date: January 1999
Total cost: 1.9 million ecu UIC Funding: 3% (57.5 kecu)

Participating organisations
Co-ordinator: Schreiner Consulting (Austria) **Partners**: ERRI, NS, ÖBB, IPSE , TNO/TPD

Background
The EU has plans, as developed in the Green Paper on Future Noise Policy to propose noise creation standards for railway vehicles. This is already included in Austrian and Italian legislation.

To UIC members this presents a challenge on two fronts. Firstly, current measurement standards of ISO and CEN are not precise enough to categorise with sufficient accuracy the noise attributed to rolling stock design when testing against a specification. Secondly a data base of noise levels is required, using an acceptable, harmonised measurement method, so that the implication on railway operation of the proposed limits can be assessed with a minimum of time delay.

Method
Framework Definitions: produce State of the Art assessment and recommendations
Investigation of Measurement Parameters :Carry out an assessment of influence of site parameters, speed/vehicle identification etc
Development of methodologies: Define measurement methodologies to be used
***Method Application:* Carry out measurement campaign of round robin tests to check the validity of the measurement methodologies**
***Evaluation:* Evaluate results and methodologies to check their robustness; dissemination of results**

Results and Residual Questions
The following deliverables have been sent to the EU:

- D1 Review of Measurement Methods for Railway Pass-by Noise

Type testing: methods need to be improved to take wheel & track roughness and wheel/track dynamics into account. Increased complexity needed to improve accuracy and repeatability will limit number of type testing sites
Monitoring: procedure must be developed to take transient nature of single pass-bys into account
Diagnostics: Antenna and special rail vibration measurement techniques would allow reliable source ranking and noise creation comparison, facilitating type testing and monitoring

- D2 Foundation for Noise Monitoring and Type Testing - Overview of Parameter Sensitivities

Analysis of parameter sensitivities based on results of 1st test campaign (ÖBB), literature data and calculations using TWINS was carried out to produce recommendations for measurement conditions, and monitoring systems. Noted that monitoring measurements only relate to local conditions, but these measurements should be related to databases on reference standard values and information concerning vehicle wheel arrangement to identify specific vehicle types.

Prepared by ERRI Noise and Vibration Unit

- D3b Antenna Systems for Railway Noise Analysis

Antenna system tested in 2nd Metarail campaign (NS) proved capability for:

- Determining sound emission of separate wheels
- Determining total emission of superstructure(tests validate Silent Freight results that freight wagon superstructure noise is at least 10-15 dB lower than rolling noise)
- Locating source distributions on superstructure where emission level no more than10-15 dB below rolling noise

System could not separate track and wheel noise in a single antenna image or locate very low frequency sources
System could be used for monitoring and in parallel with type testing measurements

- D4 Pass-by Spatial Track Vibration: indirect determination of total track noise contribution

Variant of equivalent forces method which can separate track noise from wheel/vehicle noise. Results compare favourably with TWINS calculations. The technique can give a thorough analysis of track sound emission during pass-by and should be able to assess in detail the effect of measures applied to train or track to reduce noise creation.

- D5 Diagnostic Tools and Methods for Measurement of Railway Noise - Direct Wheel Roughness Estimation

The report describes an improved method of directly measuring wheel roughness which is carried out on a jacked wheel with a single LVDT connected to a data acquisition system.
The benefits of the system are:

- In situ result feedback
- Speed of measurement and result reporting
- Increased user friendliness
- Improved result presentation

- D6 Diagnostic Tools and Methods for Measurement of Railway Noise - Site calibrations

The report provides data on the measurement sites in Austria and the Netherlands to determine the critical site characteristics which need to be taken into account to improve measurement repeatability.
The characteristics examined were rail roughness, vibration isolation, track spatial decay and track mobility.
Substantial differences found between the five sites for vibration isolation requiring further investigation. Track spatial decay showed clear differences between the sites. However both parameters will probably need to be taken into account as site characteristics once measurement techniques have been improved and standardised. Rail roughness needs to be measured directly or indirectly.

- D7 Investigation of Speed and Vehicle Identification Systems

The report lists methodologies for speed and train detection, reviews systems for wheel flat detection, acoustic/meteorological analysis and noise measurement systems and defines the requirements for an automatic train and speed detection interface.

- D8 Indirect Roughness Measurement (using vibration measurements)

Three stage technique developed:

- Calculate wheel-rail contact vibration from measured average vertical rail vibration
- Determine apparent roughness from contact vibration (using TWINS software)
- Calculate indirect roughness from apparent roughness using inverse contact filter

The method has been verified with measurement data and allows estimations of average roughness from all train wheels, wheel roughness and rail roughness from many vehicle passes.

A series of round robin tests is being organised in Austria, Italy, the Netherlands (and potentially France) during August and September 1998.
Work is continuing to link the activities of Metarail and the Noise Measurement Standards elements of Basnoise with the CEN 256 Working Group 3/ISO 3095 proposals for track conditions in relation to the standard on the measurement of noise created by rail vehicles.
A workshop organised by ERRI in October 1997 brought together participants from various projects and other railway acoustics experts to present the work that had been carried out at that time and discuss the shape of the future work programme. A second workshop will be held towards the end of the project as part of the exploitation/dissemination programme.

Prepared by ERRI Noise and Vibration Unit

Additional Studies
Scope for further development of project in relation to CEN/ISO work.
Closely aligned to DGVII task description for 5th Framework Programme.

Project Summary
RENVIB II Overview

Objective

The project ***RENVIB II*** is planned to have three Phases. The objective of the first phase is to review the current state of the art in groundborne noise and vibration technology. The second will comprise short term, and the third long term, research tasks identified from the first Phase.

Duration and Costs

Phase 1	1997	
Project cost	200 kecu	UIC Funding: 100%
Phase 2	1998 - 1999	
Project cost	380 kecu	UIC Funding: 100%

Participating organisations

Coordinator: ERRI

Phase 1 Consultants: Institute of Sound and Vibration Research, Civil Engineering Dynamics (CED), Centre Scientifique et Technique du Batiment (CSTB), Vienna Consulting Engineers (VCE) , Müller BBM (MBBM), AEA Technology Rail and Dr J Melke

Phase 2 sub-contractors: DB, SBB, SNCF, NS, Banverket, AEA Technology Rail, Müller BBM , KTH

Background

Public concern regarding the impact on society of existing rail transport systems is growing, in particular with the trend towards higher speeds. Coupled with this is a trend towards increasingly stringent environmental standards and legislation. Ground borne noise and vibration are therefore important issues for railway companies and may increasingly affect their future operation and development.

Method

Phase 1 comprised of five areas of concern to railway companies.

- Task 1 Environmental Standards and Guidelines: covering National and International Standards and practices governing railway vibration emission;
- Task 2 Prediction of Ground borne Noise and Vibration Impact: covering empirical and semi-empirical methods for prediction of impact from new, upgraded and existing railway lines;
- Task 3 Mathematical Modelling of Railway Vibration: covering models for the analysis of all aspects of vibration generation, propagation and reception;
- Task 4 Mitigation Measures for Railway Tunnels: covering all aspects of such track based, or other measures;
- Task 5 Mitigation Measures for Surface Railways: covering track and ground based measures.

In Phase 1, each Task was researched and reviewed by experienced consultants under contract.

The results of Phase 1 were used to define a programme for Phase 2

The areas of work for Phase 2 relate to:

- Definition of Appropriate Measurement & Estimation Practice
- Feasibility Study for a Combined Database of Recorded Vibration Data
- Collaboration with Tunnel Vibration Mitigation Projects
- Collaboration with Surface Vibration Mitigation Projects
- Cost Benefit/Engineering Appraisal of Mitigation Options
- Development of Mitigation Measures for Surface Railways on Soft Ground

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Prepared by ERRI Noise and Vibration Unit

The tasks for Phase 2 are defined in order to maximise the possibility of co-operation with existing national projects on vibration e.g. on SBB and DB. Other links in Phases 2 and 3 may take the form of industrial collaboration or national research, development and testing programmes of work. One aim of Phases 2 and 3 of ***RENVIB II*** is to bring economic and technical benefits to such work by enabling co-operation across national boundaries by providing an expert and well focused core project.

Results and Residual Questions
Phase 1
The scheduled work has been completed, with individual task reports submitted to ERRI. A draft summary report was prepared by ERRI and was approved by the UIC Task Force Noise. The final report is being published for C12.

- Task 1
  The principle conclusions of this study were:
  - There are no recognised international standards for ground borne noise assessment
  - $L_{a\ max}$ in common usage (<30dB(A) no problems, >50dB(A) significant reaction)
  - Various national and international standards exist for feelable vibration
  - ISO 2631 on low frequency feelable vibration is currently under revision
- Task 2

A review was made of 17 empirical and semi-empirical prediction models. The models varied in complexity from a simple point scoring system to frequency dependent calculations incorporating the effect of a large number of parameters (identified in the report). The accuracy is not always quoted but varies from ± 2dB to 10 – 15dB depending on the complexity of the model with greater accuracy for those which included site measurements. A series of recommendations were made in terms of harmonising data collection and creating a combined database.

- Task 3
  This task reviewed existing mathematical models covering all aspects of vibration generation, propagation and reception and evaluated their potential for application. The major drawback of all models is the lack of experimental validation. No model currently considers the whole vibration process. A number of areas were identified where either techniques could be enhanced or additional data could be obtained to give more confidence in the derived results. These included:
  - experimental validation of track models
  - parametric studies with train/track models to determine maintenance requirements for vibration control
  - develop common method for deriving soil properties and data base
  - validate transfer admittance modelling for ground/tunnel interface
- Task 4

This task compiled a list of measures to mitigate vibration from trains in tunnels . two options were considered; active measures to reduce noise at source and passive measures to reduce the effects at the receiver. The most effective and economical active measures were perceived to be track related. Information was provided from a number of tunnel projects in Austria, Germany and Switzerland. These indicate a great variability in effectiveness but on ballastless track substantial insertion losses can be gained above 20 Hz with mass-spring systems or sub-ballast mats.

- Task 5

Mitigation measures were considered for surface railways. A number of track related measures are available to mitigate vibration. No reliable measurements are available which demonstrate insertion loss at frequencies appropriate to low frequency feelable vibration, although theoretical studies suggest that wave impedance blocks could be effective.

Additional Studies
Detailed proposals for Phase 3 are under development for presentation to C12

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