UK Tram

Support to UKTram Activity 4
"Operational Noise and Vibration"
Phase 1 Reports

Peer Review of Existing and Proposed UK Schemes

Peer review of existing noise and vibration legislation, standards and guidelines

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"Operational Noise and Vibration"

Phase 1a Information Gathering -
Peer Review of Existing and Proposed UK Schemes

21 Aug 2007

Executive Summary

UK Tram Activity Group 4 (the Operational Noise and Vibration Team) is in the process of carrying out a study into environmental Noise and Vibration issues for the Tram and Light Rail industry in the UK.

In order to carry out a peer review of existing and proposed UK schemes, a structured approach has been taken to information gathering. A questionnaire was designed by the Team and issued to representatives of the UK industry. The recipients were asked to consider the questions contained within the questionnaire in preparation for face-to-face interviews that took place with Team members, using the questionnaire to guide the discussion.

This report comprises a presentation and analysis of the questionnaire responses and supplementary information that has emerged from additional documentation.

Generally, it has been found that UK schemes take a very similar approach to the control of noise and vibration at all stages of the design and operation of the systems, with the application of accepted criteria for noise and vibration, and models for noise, that apply to heavy rail.

There is clearly a need, however, to understand in more detail exactly how the various criteria truly reflect the impact of tram systems, and on the effectiveness of available methods for controlling that impact both at the design stage and during operation, including proactive and reactive maintenance regimes.

By considering these matters, and defining best practice in the light of current experience and science through its ongoing work, UK Tram will advise the industry on coherent and cost-effective approaches to minimising its impact on local communities.

Contents

1. Introduction

UK Tram Activity Group 4 (the Operational Noise and Vibration Team) is in the process of carrying out a study into environmental Noise and Vibration issues for the Tram and Light Rail industry in the UK, with the following elements:

1 Establish the existing Noise and Vibration Environment
1a Peer review of existing and proposed UK schemes
1b Peer review of existing noise and vibration legislation, standards and guidelines

2 Establish Best Practice in Noise and Vibration Design and Management
2a Development of noise and vibration acceptability guidelines
2b Establish best practice in evaluation, monitoring and mitigation of long and short-term noise emissions
2c Interface between Activity Group 4 and other Activity Groups

In order to carry out the peer review of existing and proposed UK schemes, a structured approach was taken to information gathering. A questionnaire was designed by the Team and issued to Serco, GMPTE, Midland Metro, Centro, SYPTE, Stagecoach Supertram, Blackpool Transport Services, Tramtrack Croydon Ltd, NET, TfL WLT and TfL CRT. The recipients were asked to consider the questions contained within the questionnaire in preparation for face-to-face interviews with Team members using the questionnaire to guide the discussion.

As a result of this process completed questionnaires were obtained for the existing schemes:

- Nottingham Express Transit
- Manchester Metrolink (GMPTE)
- Midland Metro (Centro)
- South Yorkshire Supertram (Sheffield)
- Blackpool

AND FOR THE PROPOSED SCHEME

- Edinburgh Tram

In addition to these questionnaire responses, other relevant documentation has been obtained from the existing schemes:

- Manchester Metrolink (GMPTE)
- Midland Metro (Centro)
- Croydon Tramlink

and the proposed schemes:

- Edinburgh Tram
- Merseytram

This report comprises a presentation and analysis of the questionnaire responses and the supplementary information that has emerged from the additional documentation.

2. The Questionnaire

The questionnaire was as follows:

1. Standards, acceptance and monitoring criteria
What criteria have you applied, or do you continue to apply, at each of the following stages of the project? (e.g. Noise Insulation Regulations for Railways [see 2], VDV 154, ISO 2631, ISO 3095, ISO 148371-1, Conventional Rail Noise TSI, BS 5228, BS 6472, BS 7385, DIN 4150, PPG 24, Land Compensation Act) **Please also indicate any prediction methodologies that were used for comparison with criteria** (e.g. Calculation of Railway Noise 1995 [see 2], SRM/RMVR, purpose-designed analytical techniques)
1.1 Powers:
1.2 Tender:
1.3 Commissioning:
2. Noise Insulation Regulations for Railways 1996
2.1 If an assessment of your scheme has been carried out under the requirements of the Noise Insulation Regulations for Railways 1996, please indicate the nature and extent of that assessment, and the methodology applied : (e.g. Calculation of Railway Noise 1995, by manual calculation, at discrete points, over a grid, using a particular software package or consultancy)
2.2 If insulation, or a grant to cover insulation, has been provided, please indicate the nature and extent of that insulation
2.2.1 Where the trigger levels of the Regulations have been met:
2.2.2 Where the trigger levels have not been met, or where an assessment has not been carried out, but insulation has been provided nevertheless:

3. Where predictions of levels have been made prior to operations (either via purpose-designed analytical techniques, or by application of an established procedure such as Calculation of Railway Noise 1995) and measurements have been made after the commencement of operations, how accurate did the predictions prove to be?
3.1 For noise:
3.2 For vibration:
4. To what extent is noise & vibration monitored on your system, and is this programmed and routine, or in response to complaints, or both?
4.1 Noise (rolling, squeal, warning bells etc, OHLE, vibration-induced rumble):
4.2 Vibration:
5. Noise & vibration problems (including those identified by public complaint and claim) that arose following the opening of your system, and the extent to which these had been anticipated, and in theory mitigated, within the system specification:
6. Noise- & vibration-related claims
6.1 Claims that have been made against your system:
6.2 What is your management approach to such claims? Are there, for example, procedures in place for addressing and processing complaints as they appear and subsequently escalate to become a claim?
7. The effectiveness of noise & vibration mitigation. **Please indicate the mitigation that has been designed in to your system either via bespoke design or by the use of proprietary methods, its effectiveness in terms of noise & vibration control and the lifecycle cost implications:**
8. Tramway maintenance plant **If available, please provide an indication of the noise and vibration characteristics of plant used for routine and ad-hoc maintenance of the infrastructure:**

The responses to the questionnaire, together with equivalent information obtained from other supplied documents, were collated in the set of Tables attached as Appendix 1.

The following is a commentary on these results, together with the conclusions that can be drawn on current philosophy and practice.

3. Questionnaire Section 1 - Standards, acceptance and monitoring criteria

Under this category, by far the greatest consideration of noise and vibration criteria has arisen at the earlier stages of schemes, where the environmental aspirations of promoters are normally required to be clearly stated and to demonstrate a strong commitment to minimising impact.

3.1 QUESTIONNAIRE SECTION 1 - NOISE

Where modelling techniques have been stated and where criteria have been used, they are normally based on standard approaches applied for heavy rail. The Noise Insulation Regulations are typically expected to be complied with, even in Edinburgh where there is not a legal requirement to do so, and the associated Calculation of Railway Noise 1995 methodology is used to predict noise levels generally. Some more detailed modelling with the software "TWINS" has been carried out for Croydon.

It is evident that noise criteria have become more detailed with time, so that newer schemes, or extensions to existing schemes, would normally expect more criteria to be complied with. In recent years, limit levels have typically been based on the Planning Policy Guidance 24 "Planning and Noise" Noise Exposure Category where "Noise need not be a determining factor in granting planning permission..." (Nottingham Extensions, Centro Extensions, Mersey, Edinburgh). These values are, in terms of A-weighted energy average level (L_{Aeq}), 55 dB(A) for day and 45 dB(A) for night, and the occurrence of individual noise events that regularly exceed 82 dB(A) (with a "Slow" meter response) "several times in any hour". Nottingham has "unacceptable levels" at the façade of 68 dB(A) (day) and 63 dB(A) (night), i.e. the Noise Insulation Regulations triggers, translated to free-field values (i.e. with no reflections) of 66 dB(A) and 61 dB(A) respectively for the extensions, levels which are also applied for Mersey.

Centro, Croydon, Mersey and Edinburgh also take the approach of requiring the systems not to increase existing levels by a certain amount, normally between 3 and 5 dB(A). Mitigation is indicated as being a possible requirement, where practicable, when the increases are greater than this.

It is assumed that all new vehicles are required to meet some form of noise-related type test, but the details are not always clear from the questionnaire responses. Nottingham Line 1 had a pass-by test that the Promoter considered unrealistic because it took place at constant speed on straight track, conditions that rarely occur in practice in Nottingham. Centro had a pass-by test in its Concession Deed, based on ISO 3095 conditions, and commercially confidential specifications for the extensions were also made available. Sheffield noise type testing appears to have been comparatively limited. Croydon required trams not to exceed 76 dB(A) at 40 km/h and 82 dB(A) at 65 km/h, 7.5m from the track.

Public Address system noise is considered by Centro and Croydon. Bells and horns receive little attention in this Section, although Sheffield did test them during vehicle acceptance to check that they are sufficiently loud.

The implications of road noise are referred to by GMPTE and Mersey. There are several issues relating to road traffic. Firstly, when comparing the noise impact of a new tram system with the prevailing background level, current road traffic noise levels should be used as a baseline if a true representation of the change in level due to the tram is to be quantified. Predictions of the future noise situation should take into account not only the presence of tram noise but also possible reduced road traffic due to modal shift. (If applying the Noise Insulation Regulations, however, the required calculation is in absolute, rather than relative, terms, and only considers the noise from tram/rail systems.) The introduction of street-running trams can lead to road traffic lanes being closer to roadside properties. New parkway stops/stations may lead to increased road traffic noise.

Beyond the normally-applied criteria from PPG24 and the Noise Insulation Regulations, the Institute of Acoustics/Institute of Environmental Management and Assessment draft "Guidelines for Noise Impact Assessment" of 2002 have been used in the Mersey impact assessment.

3.2 QUESTIONNAIRE SECTION 1 - VIBRATION

For vibration, the available criteria are somewhat limited, and this is reflected in the use, predominantly, of BS 6472 "Evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)" to limit disturbance. Vibration Dose Value limits in properties of 0.2-0.4 $m/s^{1.75}$ for the day and 0.1 (or 0.13) $m/s^{1.75}$ for the night are set, (the "Low probability of adverse comment" category) by Nottingham extensions, Centro, Croydon, Mersey and Edinburgh. GMPTE also refer to the Standard. Nottingham Line 1 also had a night time limit, similarly based.

Consideration of building damage potential is covered by Mersey (with "Peak Particle Velocity" values that derive from BS 7385 "Evaluation and measurement for vibration in buildings".

Centro and Edinburgh have vibration Peak Particle Velocity limits close to the track. The Edinburgh value is a design specification of 2mm/s at 2m from the rails. The Centro value is 2mm/s 1m from the outside rail.

Ground borne noise (rumble) is also considered by Nottingham and Croydon, using the commonly–accepted criterion of 40 dB(A) "Slow" within buildings, and, in addition, lower values of 35 dB(A) for the Nottingham University Library and Council House, and 25 dB(A) in the Royal Centre Concert Hall.

There is little information on vibration modelling, but Croydon used a process developed by Southampton University (ISVR) where measured Sheffield tram levels were used as a basis and adjusted appropriately.

4. Questionnaire Section 2 – Noise Insulation Regulations for Railway 1996

Generally the newer schemes apply the Noise Insulation Regulations as a matter of course, although the tendency is to find that very few properties would qualify. The associated "Calculation of Railway Noise 1995" is nevertheless accepted as a general model of noise from the trams. Without prejudice grants were made by the Contractor for insulation in Nottingham due to an accepted issue of squeal from curves, but CRN does not model this. Blackpool made the point that much of its system predates a lot of the adjacent housing.

5. Questionnaire Section 3 – Accuracy of noise and vibration prediction

There was little useful information in response to this question, except in the case of Croydon, where some locations have been found to be exposed to levels exceeding the system noise criteria when original predictions suggested this would not arise.

6. Questionnaire Section 4 – Noise and vibration monitoring

Generally there is no routine monitoring, although Nottingham measures internal noise levels on each car annually and Centro inspectors monitor internally, subjectively, 2-monthly. Edinburgh propose to monitor noise routinely, 6-monthly for the first 3 years. Blackpool and Sheffield would monitor in response to complaints. Extensive monitoring has been carried out for Croydon in connection with Part 1 claims. Some monitoring has also been carried out by the Local Authority for Croydon because of complaints regarding squeal. GMPTE state that there were no vibration problems with Phase 1.

7. Questionnaire Section 5 – Operational problems

Squeal has been a problem for Nottingham and Croydon, and is identified as a potential problem for Edinburgh. In Nottingham this has largely been controlled with wheel

dampers. Public address systems at stops have caused concern for GMPTE and Centro, and on-board PA systems are reported as potential problems for Croydon. Noisy street running is reported as causing problems for GMPTE and Centro. Bells initially caused complaints for Nottingham, but these have subsided with reduced use by staff and as the public have become accustomed to them. Nottingham has had problems with ground borne noise/vibration at the Royal Centre Concert Hall, despite isolated slab track. It is thought that the local crossover is the primary cause.

Sheffield, Blackpool and Croydon have referred to actual or potential rail corrugation problems.

8. Questionnaire Section 6 – Claims

Nottingham have had 464 Part 1 Claims lodged since opening, but none have been resolved as there has been no substantiation provided by the agents acting for the residents. A co-ordinated approach to responding to claims has been agreed between the two promoting bodies, i.e. the City and County Councils.

No claims against GMPTE have reached court. Claims would be handled internally through the customer complaint team and the legal team.

Blackpool have not had any recent claims. If any were received BTS and BBC would assess them jointly to assign responsibility.

Centro do not report any claims, as contractually these are the responsibility of the Concessionaire, who has signed confidentiality agreements with the small number of claimants involved.

Sheffield have had a few unsuccessful claims relating to vibration damage supposedly caused by trams but not known to have been proven. One vibration-related claim due to settlement in the vicinity of an OLE pole is outstanding. Normally mitigation (e.g. grinding) is applied, or the claims are passed to the PTE legal/property departments, or passed to the PTE's insurers.

Croydon have been presented with around 1500 Part 1 claims that are largely generic, with little evidence provided to justify their submission.

No detail on proposed claims procedures was available from Mersey or Edinburgh.

9. Questionnaire Section 7 – Effectiveness of noise and vibration mitigation

Nottingham had flange lubricators designed into Line 1, and retrospectively fitted wheel dampers (tuned absorbers) to control curve squeal, which have proved largely successful. A trial of Kelsan friction modifier was carried out but contamination with sand on the braking approach rendered it ineffective. This was not pursued due to the success of the wheel dampers. ALH pre-coated rail is used for street running. Investigations are continuing to address ground borne noise at the Royal Centre, including alternative S&C (e.g. the Kihn lift over crossover, as is more typically used on the continent with good effect. Extensive mitigation is planned for the extensions, e.g. wheel dampers, flange lubrication, barriers, careful positioning of S&C, isolating slab and other track isolation.

GMPTE had flange lubrication originally at the entrance to the street running section, which was replaced with on-board stick lubricators, which didn't work. Minimum desirable curve radius was specified for the Eccles route and is believed to have reduced squeal. ALH pre-coated rail is used on Phase II.

Vehicle-mounted stick lubricators were initially installed on Midland Metro trams, but have proved problematic in use so little information on their effectiveness is available. ALH pre-coated rail is installed in tramway situations and in 2005 two additional trackside mechanical rail flange lubricators were installed to supplement the 8 already in use.

Resilient embedding (Edilon) was used at Sheffield with some subsequent replacement with ALH pre-coated rail. A grinding programme is carried out annually.

Croydon has resilient mats built in at the Almshouses in George St West, Sandilands tunnels and New Addington, and uses vehicle-mounted stick lubricators and flange lubrication. The effectiveness of these measures is not clear from available documentation.

No detail was available on mitigation from Mersey or Edinburgh, but Edinburgh does anticipate extensive measures.

In general, no information was provided on life cycle costs. However, this is an important issue that should be taken into account whenever considering noise and vibration mitigation. This should not only include the capital cost and the cost of maintenance, removal and disposal, with associated operational downtime, but also the cost implications for activities that are not possible cost-effectively when mitigation is installed. An example of this is the difficulty that arises when welding is required to be carried out on a section of rail that is resiliently embedded. There can also be financial consequences of mitigation measures, such as the possibility that soft rail embedding can lead to long pitch corrugation, requiring increased maintenance costs. As well as absolute costing, there will be other mitigation options that can be financially optimised via cost-benefit analysis, for example the use of frequent light rail grinding as opposed to infrequent aggressive grinding. Factors other than noise and vibration mitigation tend to take precedence in

considering life cycle costs of tram systems, but mitigation elements are not always trivial in this respect and should not be ignored.

10. Questionnaire Section 8 – Tramway Maintenance Plant

No information was provided on the noise and vibration characteristics of maintenance plant. Grinding was referred to by Nottingham, GMPTE, Centro and Sheffield, with an acknowledgement from Nottingham and Sheffield that this can cause public disturbance and complaint.

11. Discussion and conclusions

Generally the schemes take a very similar approach to the control of noise and vibration at all stages of the design and operation of the systems, with the application of accepted criteria for noise and vibration, and models for noise, that apply to heavy rail. Blackpool, as a long-established operator, has not had to focus so closely on such issues because it is a part of the fabric of the community and not a new factor in the environment, but it is possible that there will be greater pressure on even that system in the future as public expectations for low noise and vibration increase.

There is clearly a need, however, to understand in more detail exactly how the various criteria truly reflect the impact of tram systems, and on the effectiveness of available methods for controlling that impact both at the design stage and during operation, including proactive and reactive maintenance regimes.

Sources to take into account are rolling noise, impact noise at joints, crossovers, switches etc, curve squeal, ground vibration, ground-borne noise, ancillary equipment noise, bells, horns, public address systems on trams, public address systems at stops (a potentially major cause for complaint), depots, and even the noise from people at stops. If parkway stops/stations are built then the additional noise from the arrival and departure of cars might also need to be considered. The same consideration would apply for park and ride facilities.

The responses have generally focussed on physical measures to control noise and vibration, but traffic flows and hours of operation are also of relevance. It is unlikely that reduced flows will be enforced to reduce energy-averaged noise levels on existing systems, but conversely it is important that provision and justification is made at the planning and orders stage for the noise consequences of any foreseen future intensification of flows and hours, to avoid restrictions.

By considering these factors, and defining best practice in the light of current experience and science through its ongoing work, UK Tram will advise the industry on coherent and cost-effective approaches to minimising its impact on local communities.

12. Acknowledgement

UK Tram Activity Group 4 are grateful to Steve Mitchell, Technical Director, ERM for his help in reviewing this report.

Appendix 1. Collated information from questionnaires and other relevant documents

1.1 Powers .

Nottingham	For extensions: LCA, CRN, NIR, PPG24. Calcs based on Tramlink and other measurements (ERM preparing ES, in draft) . BSI Evaluation and Measurement for Vibration in Buildings Pt 2. Metrolink Vibn estimates for Metrolink 1996. BS6472/PPG 24: VDV levels for Day (0.4) and Night (0.13). For Line 1 only night value of 0.1 Operational proposed stds in draft N&V Policy 55/45 as for Edinburgh, with unacceptable limits for 0600-0000 day of 66 dB(A), night 61. Equivalent in Line 1 Act (1994) was 68.
GMPTE	CRN used to map contours for Order applications. Contours drafted to inform designs. Always better to mitigate than compensate . John Hyde Anglia Consultancy, advisor to GMPTE. Vibration predictions based on Metrolink measurements. BS6472 used to assess . Concern that the Environmental Noise Directive "leads to noise mapping and possible action of redress - risk to future" . PPG 24 treats different sources of noise in different ways, and is quite complicated. Also be aware of combination of effects, eg removal of parking puts traffic closer to housing . Change in road traffic noise more often a problem than tram noise. Extra noise from ac traction packages?
Blackpool	No recent new powers - concern that this work will increase standards and adversely impact systems with "grandfather rights"
Centro	TWA. Evidence to enquiries. Concession deed: Wayside levels with an LRV travelling at 65 km/h, with all ancillaries running, shall not exceed 75 dB(A) @ 7.5m, using ISO3095 PA systems shall not increase ambient levels by more than 3 dB(A). Vibration ppv not to exceed 2mm/s on any axis 10-200Hz 1m from outside rail . Testing: Internal monthly on at least 2 LRVs. External monthly on one LRV, unless no complaints or no judged non-compliant external levels in which case twice/annum . For extensions, Oct 2003, NIR, 82 dB(A) slow several times in an hour and Leq 0700-2300 55, night 45 (ie PPG24) Revised noise policy 2003 - increase of up to 3 dB, no mitigation, > 3 dB, mitigation considered (bunds, barriers, track treatment) Internal NR 65 and 75 dB(A) under ISO 3381 all ancillaries running Vibn BS6472 Day 0.4, night 0.13 Tram spec extensions external: Available but commercially confidential Tram spec extensions internal: Available but commercially confidential
Sheffield	N&V not considered in preparation for or granting of powers for the initial system
Croydon	ES under the Town and Country Planning Regs 1988. Planning permission under the Croydon Tramlink Act 1994 Performance spec: No more than 4 dB(A) Leq 24h @ 1m from facades above levels specified for opening. For areas with levels less than or equal to 59, noise not to exceed 59. For areas > 59 the increase in noise should not be greater than 3 dB(A) GBN 40 dB(A) slow. Vibn BS6472 0.3 day, 0.1 night Depot 5 dB using BS4142. Noise insulation policy Oct 2002 - follows NIR.
Mersey	Construction BS5228. Specified criteria 75 dB(A) daytime façade for dwellings/offices, 65 educational, 65 evening residential, 45 night time 23.00 - 07.00 Operation: Thresholds drawn from PPG24 and NIR: Day 07.00 - 23.00 55 (ff), Night 45. Unacceptable Day 66, Night 61. CRN used Levels of tram added to ambient and IoA/IEAM draft guidance used for significance. NIR would also apply, where sufficient mitigation not possible Mitigation preferred. Max pass by based on PPG24 82 ff for sleep disturbance. Vibn BS 6472 0.4 day, 0.1 night. PPV 50 mm/s reinforced/framed, 15mm/s unreinforced/light (BS7385 Road traffic noise considered. Vibration predicted from GMPTE measurements. Suggested mitigation discounts barriers, at source where possible, insulation at properties one location. Stop design, PAs at these locations. Use of water on wheels for squeal, or flange lubrication, proposed. Vibration complaints/damage not expecte
Edinburgh	Phase 1/2 noise and vibration policy developed through parliamentary process. Tiered approach: procurement, track design, barriers, insulation - BPM . Daytime 0700 - 2300 55 ff, night 45. If 3-5 above, mitigation considered. If >5 above mitigation implemented if reasonably practicable . Grass track? Plenums? NIR used despite strictly not applicable in Scotland. Attempt to quantify claims - no outcome to report . Prediction methodology not available. Insulation may be offered, beyond NIR, for squeal or ff peak of 82 slow > 2x per hr . Vibn BS6472 Day 0.2, Night 0.13. PPV <= 2mm/s @ 2m .

1.2 Tender .

Nottingham	Too early for extensions, although main experience from Line 1 makes the specified requirements much clearer in respect of tests to be carried out, their conditions, pass criteria, post-implementation monitoring. Line 1, pass-by, SEL ? 7.5m Stationary 58 dB(A), 79 @ 40 km/h, 84.5 @ 60 km/h . Contractor considered test unsatisfactory as no accel or braking and on straight track. Ground-borne noise 40 dB(A) slow, 35 at University Library and Council House . 25 dB(A) Royal Theatre (not achieved) . 0.1 ref BS6472 - understood to have been met, depending on definition of value .
GMPTE	Output spec. Vehicle shouldn't increase ambient noise level by > 3 dB(A) - accepted threshold trigger value . 24 hour operation for Airport, very close to trigger levels
Blackpool	N/A
Centro	ISO 3095
Sheffield	No criteria for infrastructure. Spec included rail in elastomer. No PA at stops Limited standard type test for tram, included bell and horn, for use appropriate to area .
Croydon	Tram pass-by 82 dB(A) @ 65 km/h, 76 dB(A) @ 40 km/h, 7.5m from track CL using ISO 3095 conditions .
Mersey	
Edinburgh	Compliance with N&VP a requirement of infrastructure contract. Tram supply contract specifies levels currently under review .

1.3 Commissioning .

Nottingham	See 1.2
GMPTE	Not as a commissioning test, but in collecting more data for Phase 3 tender .
Blackpool	N/A
Centro	N/A
Sheffield	Tram type test undertaken and passed .
Croydon	Nothing in the docs supplied .
Mersey	
Edinburgh	Commissioning tests will occur - subject to development .

2.1 NIR

Nottingham	CRN used for extensions. Extensive baseline assessment carried out for the ES, presently in draft. N&V policy has been prepared to accompany the ES: 55/45 day/night similar to Edinburgh, 68/63 day/night + Free Field 82 LAmax for insulation (ie NIR and PPG 24) . BS7445 used to define receptors .
GMPTE	CRN carried out manually for specific locations where predictions were close to trigger values, but also discussed with Local Authorities to see if other locations need considering
Blackpool	Consider railway requirements do not/should not apply to tramways
Centro	WS Atkins report (Ref 54697) July 2001 concludes no properties found to qualify under the NIR .
Sheffield	N/A at the time
Croydon	Noise insulation policy based on NIR.
Mersey	
Edinburgh	Will be applied, but currently N/A .

2.2.1 Insulation trigger .

Nottingham	15 properties in Noel St had payments made for insulation due to an accepted issue with squeal in curves (68 dB(A) trigger) to pre-empt any hindrance to opening . 7 properties adjacent to Terrace St curve (NB squeal no crossing) and 8 adjacent to Gladstone St Junction .
GMPTE	No insulation grants provided for any property, no successful claims against GMPTE. No case to answer, but has not been proven by GMPTE as no need to .
Blackpool	Trams predate a lot of housing. Tram noise should have been taken into account when building these by BTS and BBC building planning department . No insulation knowingly provided .
Centro	N/A
Sheffield	N/A
Croydon	Not known from docs .
Mersey	
Edinburgh	N/A

2.2.2. Insulation no trigger .

Nottingham	N/A
GMPTE	N/A
Blackpool	N/A
Centro	N/A
Sheffield	N/A
Croydon	Not known from docs .
Mersey	
Edinburgh	N/A

3.1 Accuracy noise predictions .

Nottingham	Some post-operation measurements undertaken, in selected locations related to some initial Pt 1 Claims (Andy Holdstock may provide more info) .
GMPTE	Measurements taken to aid predictions for future routes .
Blackpool	N/A
Centro	N/A
Sheffield	Not made at the time
Croydon	Some instances where predicted compliance has not occurred - hence successful claims .
Mersey	
Edinburgh	Predictions were carried out for the Parliamentary process, with further work under way for the design stage .

3.2 Accuracy vibn predictions .

Nottingham	See 3.1
GMPTE	Measurements taken to aid predictions for future routes .
Blackpool	N/A
Centro	N/A
Sheffield	Not made at the time
Croydon	Not known from docs
Mersey	
Edinburgh	Predictions now being carried out for the parliamentary process .

4.1 Monitor noise .

Nottingham	Each car monitored internally annually, with a target LAeq of 7 dB(A) above benchmark at new . Promoter is awaiting further proposal for long term (external) monitoring intentions from the operator Grinding has been carried out once - resulting in complaints, apparently because of increased high frequency sound despite lower overall levels. This required a revisit and a final polish as rail was left rough. Next time a revised sequence will rectify this .
GMPTE	Not monitored thus far by GMPTE, as responsibility of Concessionaire to comply with contractual requirements, ie to live within the set 3 dB(A) limit . Liability of Pt 1 claims however lay with GMPTE. Facades photographed before construction as a precautionary "pre-crack" survey, but not subsequently used . Agreements with Oldham College (to avoid disturbing exams with construction noise) and also Lowry Centre . No problems caused for Bridgewater Hall, track on ramp 15-20m from building, built after Metrolink opened. Building foundations designed by CDM of Brussels .
Blackpool	Would only respond to complaints, but none received so no testing carried out . Driver reports could lead to remedial action for N or V, eg corrugation of rails or wheel problems . Council may hire grinder but not regularly and nor for last 3-4 years. Walking grinder used after welding . Drivers mainly report corrugation, which is also picked up through Council track inspection .
Centro	Each tram tested by a Centro inspector on a 2-monthly cycle, initially subjectively, during a journey. If a tram is considered noisy it will be examined by a TMM, then re-tested with a meter if noisiness persists. Concession Deed requires Altram to test the trams .
Sheffield	Noise not monitored regularly. Actions considered in response to complaints from the public or reports by crew . Complaints mainly from residents near to tracks, or in higher speed areas, eg Ridgeway Rd (40mph limit, central running) . Usually related to corrugation . No OLE issues. In recent times only one complaint (re horn, none re bell) .
Croydon	Extensive measurements of noise upon opening, in connection with Part 1 Claims Local Authority measurements in 2002 in response to squeal complaints .
Mersey	
Edinburgh	Monitoring proposed to take place at commissioning, 6-monthly for 3 years from opening to assess need for insulation. A follow-on monitoring scheme will be established, agreed with the Local Authority, yearly at least

4.2 Monitor vibration .

Nottingham	Nothing specific, although some work related to localised problem areas .
GMPTE	No vibration requirement for Phase 2, as not a problem in Phase 1 .
Blackpool	See 4.2
Centro	As 4.1
Sheffield	As 4.1. Only ever corrugation-related (street and segregated sections) .
Croydon	No info from docs
Mersey	
Edinburgh	N/A

5 Operational n&v .

Nottingham	Mainly elsewhere in responses, but initial complaints re excessive use of the bell. Use has now declined with experience of drivers and other road users . Squeal largely resolved with wheel dampers, except at Wilkinson St curve where check rails are fitted and track-based lubrication on gauge corner retrofitted early . Ground Borne Vibration at Royal Theatre (where there is isolated slab track) remains a cause for concern. Initial monitoring by the BBC did not give rise to concerns . but concerns have arisen since. Not clear if characteristics of any transmitted noise have changed with wear or other factors, but it is clear that the problem comes . from the crossover located on the isolated section of trackslab and not from plain line running .
GMPTE	Phase 2 complaints ie public address system - no spec requirement for a distributed sound system. Only 3 speakers per stop (so they were turned down) . and more speakers stipulated for future extensions. Bury Line is still (c50%) jointed bullhead rail - now in the course of replacement (Summer 2007) . No claims due to "grandfather rights" but ongoing bad publicity - which has led to planned relaying of track . Noisy street track and people complain but no legal action eg points and crossovers due to wheel/rail profile, material properties, design etc .
Blackpool	No claims in the previous 10 years, either to operator BTS or track owner BBS .
Centro	Sandwell MBC served noise abatement notice re Black Lake Stop PA system on Altram c 2001 . Volume turned down, also at St Paul's Stop following public complaints. Also complaints re track noise between Lodge Rd and W Bromwich Central from passengers unable to hear mobile phones .
Sheffield	No mitigation specified, other than rails in elastomer . No sensitive locations such as theatres, hospitals, labs along route
Croydon	Squeal, leading to the fitting of flange lubricators .Stick lubricators also used . On-board PAs . Returning to depot at the end of the evening shift .
Mersey	
Edinburgh	N/A but areas identified in parliamentary process: Roseburn corridor - disused railway quiet area, Baird Drive, tram close to backs of houses Queen St curves, squeal concerns on sharp combination curve

6.1 Claims .

Nottingham	Pt 1 Claims lodged 1 year after opening through 3/4 agents. None mention noise. No strong correlation between those predicted and received . Actual 464 (total current value £9.6M) against a predicted 806 but value/claim much higher than allowed for (~ £20k in 2005 compared with ~ £1k around 1993) . No new claims since initial receipt. Letter sent 08/05 seeking substantiation - nothing further received in respect of any claim .
GMPTE	All have fallen away without making it to court. 15-20 notified since 1992, but none have proceeded. None pending .
Blackpool	None recently
Centro	Not aware of any since opening
Sheffield	Some claims received re vibration damage. None successful - either mitigation applied (usually grinding) or nothing proven .
Croydon	1500 Part 1 Claims received .
Mersey	
Edinburgh	N/A yet

6.2 Management of claims .

Nottingham	Approach must be agreed between promoting bodies, ie City and County Councils (Ph 2 more in County than City) . Land budget to be reviewed shortly - will reflect emerging experience with Line 1 and from Croydon . At present around 2-5% of value of properties along route allowed for? .
GMPTE	Handled internally, through customer complaints team to legal services, but none have escalated to become a claim . Planning applications within 200m scrutinised for S106 contributions etc, but double glazing/secondary glazing advised where appropriate, and/or waive rights to future claims .
Blackpool	If received would be jointly assessed by BTS/BBC to try to assign responsibility .
Centro	Under the Terms of the Concession Deed, claims should be directed to the Concessionaire. Travel West Midlands have signed confidentiality agreements . with claimants but can confirm only a handful of cases have been pursued through reference to a tribunal . **NB Further confidential information has been provided on this .**
Sheffield	Number of claims is small. Nothing under LCA . Generally mitigation is applied (eg grinding), the claims are dismissed via PTE legal/property department, or are passed to . the PTE's insurers for action/settlement. If related to structural issues, the PTE may send structural engineers to investigate . [Further info re claims to be supplied] . One particular claim identified as outstanding for settlement, relating to ground-borne noise/vibration, related to an OLE pole mounted over or adjacent to a basement .
Croydon	Not stated in docs .
Mersey	
Edinburgh	Not yet known

7 Effectiveness of n&v mitigation .

Nottingham	Designed into Line 1: Flange lubricators, wheel dampers (as mitigation - need maintenance to avoid becoming loose), track (flange) lubrication Wilkinson St . Friction modifier (Kelsan trail Radford Rd, Hyson Green Market Stop, before curves in Terrace St) . Removed due to success of wheel dampers. Promoter disappointed with lack of info on effectiveness of measures, limiting usefulness in assessing measures for Ph 2 . Extensive mitigation planned for Extensions - virtually only issues of complaint Line 1 were n&v - to include wheel dampers, flange lubrication, barriers, . S&C location, isolating slab, special trackform in sensitive locations (isolated slab, mass spring mounting eg University music/lab) Use of bells and PA . Promoter recognises that mitigation measures are limited and that manufacturers' claims should be treated with caution . No flange running. Two affected locations: Royal Theatre, Noel St/Terrace St crossing. Clear that the latter should have been isolated trackslab at least . Severe speed restrictions in st through direction imposed for a time early on in operation to limit vibration, now slightly eased . Other issue was squeal from Terrace St. The curve imposes a severe speed restriction anyway, extended to the straight section, dealt with by wheel dampers .
GMPTE	Flange lubrication originally used at the entrance to the street-running section, then replaced by sticks on vehicles which didn't work! . Street running is noisy in dry weather, but the city centre is noisy anyway and therefore this is not an issue . Increased curve radius used on Eccles route and squeal is reduced as a result . Mitigate in alignment and design from the outset, to avoid the need to insulate .
Blackpool	Proprietary systems used to isolate new rail. All new track fully embedded in busy areas of tramway . Segregated ballasted track all on concrete sleepers, with coarser ballast than previously used .
Centro	Some cladding/insulation on trams, and bogies are skirted . Regular tyre reprofiling maintains ride quality and keeps noise levels down because of reduced hollowing . Stick lubricators, little info on effectiveness. Flange lubricators
Sheffield	Resilient embedding (Edilon) used. No difference noted when Edilon embedded rail replaced with ALH . Remedial grinding programme, primarily to remove corrugation, initially every 3 years by operator . now annually at the insistence of the PTS . Grinding itself generates significant complaint, but improved operational noise balances this . Procedure in place to limit unnecessary use of horn/bell .
Croydon	Resilience built in at Almshouses, Sandilands tunnel and New Addington .
Mersey	
Edinburgh	Awaiting details from designer, to be provided to tenderers to assist in refining offers . Anticipate extensive measures, incl barriers and isolated slab track .

8 Maintenance plant .

Nottingham	No major maintenance likely to lead to complaints. One exception - grinding which generated significant complaint at one location .
GMPTE	Rail grinder hired in when necessary - Code of Construction Practice agreed for each extension. Single document for next routes agreed through all AGMA . Construction noise for new-build also now applied retrospectively for "maintenance", rather than hiding behind "railway power" .
Blackpool	Maintained by BBC (track) and BTS (OLE). Vehicles may be diesel powered. Hand held breaking tools may be used . No noise restrictions placed on this work - work covered by an annual permit issued by BBC/BTS Joint Committee . "The Tram Track Safety Group" (meets monthly and includes ORR-HMRI) . Any noisy night work would almost certainly be due to (say) remedial emergency actions following (say) an RTA .
Centro	A rail grinder is hired on an annual basis in cooperation with the other members of the Light Rail Operator Group . No tamping has been carried out .
Sheffield	Large scale grinding generates complaint. A small hand grinding unit has been acquired to deal with localised areas . Nothing specific from rail relaying, mostly on embedded street sections so far. Mostly due to side wear . No other problems identified with maintenance actions .
Croydon	Not available from docs .
Mersey	
Edinburgh	N/A yet .

Support to UK Tram Activity 4
“Operational Noise and Vibration”

Phase 1b - Peer review of existing noise and vibration legislation, standards and guidelines

8 Jun 2007

Title	Support to UK Tram Activity 4 “Operational Noise and Vibration” Phase 1b - Peer review of existing noise and vibration legislation, standards and guidelines
Customer	UK Tram via Faber Maunsell and Centro
Customer reference	FMJ-5W-1048
Confidentiality, copyright and reproduction	
File reference	CD 47211
Report number	DeltaRail-ES-2007-059
Issue number	Issue 1

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Introduction

UK Tram Activity Group 4 (the Operational Noise and Vibration Team) is in the process of carrying out a study into environmental noise and vibration issues for the tram and light rail industry in the UK, with the following elements:

1 Establish the existing noise and vibration environment
1a Peer review of existing and proposed UK schemes
1b Peer review of existing noise and vibration legislation, standards and guidelines

2 Establish best practice in noise and vibration design and management
2a Development of noise and vibration acceptability guidelines
2b Establish best practice in evaluation, monitoring and mitigation of long and short-term noise emissions
2c Interface between Activity Group 4 and other Activity Groups

Phase 1b is reported within this document. In order to carry out this Phase of the work, documents available to members of UK Tram Activity Group 4, and others found from literature search, were considered.

The key documents that emerged were as follows:
(The points at which they are relevant are indicated by **[PDP]** = Planning/Design/Powers, **[VSA]** = Vehicle Specification/Acceptance, **[OPL]** = Operational):

- Planning Policy Guidance (PPG) 24 “Planning and Noise” 1994 **[PDP]**
- American Public Transit Association: “Guidelines for Design of Rapid Transit Facilities, Section 2.7, ‘Noise and Vibration’” 1981 **[PDP]**
- Federal Transit Authority “Transit noise and vibration impact assessment” FTA-VA-90-1003-06 May 2006 **[PDP]**
- DETR “Guidance on the Methodology for Multi-Modal Studies (GOMMMS), 2000 **[PDP]**
- IEMA and IoA “Guidelines for Noise Impact Assessment” Consultation Draft, 2002 **[PDP]**
- German Association of Engineers “Airborne and structure-borne noise in local public transport railways” VDI 2716 **[PDP]**
- DIN 4150 Part 2:1995 “Vibration and shock in buildings; Human exposure to vibration in buildings” and Part 3 1999 “Vibrations and shock in buildings; influence on structures” **[PDP, OPL]**
- World Health Organisation: “Guidelines for Community Noise” 1999 **[PDP, OPL]**
- Statutory Instrument 1996 No 428 “The Noise Insulation Regulations (Railways and other guided transport systems)” 1996 **[PDP, OPL]**
- BS 4142 Method for rating industrial noise affecting residential and industrial areas, 1997 **[PDP, OPL]**
- BS 6472 “Evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)” 1992 **[PDP, OPL]**

- BS 7385 Part 1:1990 Evaluation and measurement for vibration in buildings (Basic principles for vibration measurement and processing), Part 2:1993 Guide to damage levels from groundborne vibration [PDP, OPL]
- ISO 2631 Part 1:1997, Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration – Part 1: General requirements, Part 2:2003 – Vibration in buildings (1 Hz to 80 Hz) [PDP, OPL]
- ISO 14837 Pt 1 "Mechanical vibration – Ground-borne noise and vibration arising from rail systems – General guidance" 2005 [PDP, OPL]
- ANSI "Guide to evaluation of human exposure to vibration in buildings" ANSI S2.71-1983 (R2006) (Formerly ANSI S3.29-1983) 1983 [PDP, OPL]
- French legislation relating to railway noise [PDP, OPL]
- Association of German Transport Undertakings (VDV) Paper 154 "Noise of railway vehicles for short-distance traffic – trams, light rail, metros" 2002 [VSA]
- ODS "A study of European Priorities and Strategies for Railway Noise Abatement" Report for EC DG-Tren, 2002 [VSA]
- Bordeaux tram procurement specification, 1999 [VSA]
- ISO 3095:1975 "Railway Applications Acoustics – Measurement of noise emitted by railbound vehicles" (superseded but used as a basis for testing some existing stock) [VSA]
- EN ISO 3095: 2005 "Railway Applications Acoustics – Measurement of noise emitted by railbound vehicles" [VSA]
- European Commission decision "concerning the technical specification for interoperability relating to the subsystem 'rolling stock - noise' of the trans-European conventional rail system" (The Conventional Rail Noise TSI) Published 2005 [VSA]
- Land Compensation Act 1973 [OPL]
- Environmental Protection Act 1990 [OPL]
- ANSI "Guidelines for the measurement of vibrations and evaluation of their effects on buildings" ANSI S2.47-1990 [OPL]
- Association of Noise Consultants (ANC) Guidelines on "Measurement and Assessment of Groundborne Noise and Vibration, 2002 [OPL]
- ISO 4866 "Mechanical vibration and shock – Vibration in buildings – Guidelines for the measurement of vibration and evaluation of their effects on buildings" 1990 [OPL]
- Directive 2002/49/EC The Environmental Noise Directive [OPL]
- European Commission Working Group on Assessment of Exposure to Noise (WG-AEN) "Good Practice Guide for Strategic Noise Mapping" Version 2, 2006 [OPL]
- Libertin EC Thematic Network Project Noise Final Report, 2004 (unpublished)[general]

The following is a review of each of these documents.

Planning and Noise: Planning Policy Guidance (PPG) 24 1994

(Applies in England, but in Wales "TAN 11" 1997, and in Scotland "PAN 56" 1999 are very close equivalents)

PPG 24 gives guidance to local authorities on the use of their planning powers. It outlines considerations in determining planning application for noise sensitive developments and activities that will generate noise. It uses "noise exposure categories" (NEC) and advises on the use of conditions to minimise noise impact. The criteria are based on consideration of WHO recommendations and Noise Insulation Regulations triggers.

Metrics

- A-weighted equivalent noise level $L_{Aeq,T}$

Criteria (open site) where developments are planned in the vicinity of existing railways:

Period	NEC A	NEC B	NEC C	NEC D
07:00-23:00	<55	55-66	66-74	>74
23:00-07:00	<45	45-59	59-66	>66

NEC Category	Action
A	Noise need not be considered as a determining factor in granting planning permission
B	Noise should be taken into account when determining planning applications and, where appropriate, conditions imposed to ensure an adequate level of protection
C	Planning permission should not normally be granted
D	Planning permission should normally be refused

Pan 56 only suggests the use of NECs and places more emphasis on noise impact assessment. PPG 24 and TAN 11 state that the Local Authority "must ensure that development does not cause an unacceptable degree of disturbance". PAN 56 states that "planning authorities should generally aim to ensure that development does not cause unacceptable noise disturbance".

PPG 24 is currently under revision and will re-emerge as Planning Policy Statement 24, possibly during 2007, with a companion guide including technical advice. The new documents are expected also to include advice on the situation where new rail systems are introduced in the vicinity of existing buildings (which is not currently the case). Although the number of categories will reduce, the fundamental advice regarding acceptable levels is expected not to change.

PPG 24 (TAN 11 and PAN 56) are routinely used in the planning process, and the expected emergence of PPS 24 will probably increase the emphasis on noise impact assessment and control from tram systems both for new building developments and for new tram systems.

American Public Transit Association: Guidelines for Design of Rapid Transit Facilities, Section 2.7, "Noise and Vibration," 1981

The APTA Guidelines include criteria for acceptable community noise and vibration.

Metrics

- Ground Borne Vibration in terms of an rms vibration velocity level with a 1 second time constant
- Ground Borne Noise in terms of the A-weighted level

Criteria

Groundborne vibration and noise impact assessment

Land use category	**GBV impact levels**		**Groundborne noise impact levels**	
	mm/s		dB(A) re 20 micro Pascals	
	Frequent events[1]	Infrequent events[2]	Frequent events[1]	Infrequent events[2]
Category 1 : buildings where low ambient vibration is essential for interior operations	0.04[3]	0.04[3]	-[4]	-[4]
Category 2 : residences and buildings where people normally sleep	0.10	0.25	35	43
Category 3 : institutional land uses with primary daytime use	0.14	0.35	40	48

Notes:
1 - Frequent events are defined as more than 70 vibration events per day. Most rapid transit systems fall into this category.
2 - Infrequent events are defined as less than 70 vibration events per day. This category includes most commuter rail systems.
3 - This limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. Vibration sensitive manufacturing or research will require detailed evaluation to define the acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the HVAC systems and stiffened floors.
4 - Vibration sensitive equipment is not sensitive to airborne noise.

Groundborne vibration and noise impact criteria for special buildings

Type of building or room	**GBV impact criteria**		**Groundborne noise impact levels**	
	mm/s		dB(A) re 20 micro Pascals	
	Frequent events[1]	Infrequent events[2]	Frequent events[1]	Infrequent events[2]
Concert halls	0.04	0.08	25	30
TV studios	0.04	0.08	25	30
Recording studios	0.04	0.08	25	30
Auditoriums	0.10	0.25	30	38
Churches	0.10	0.25	35	43
Theatres	0.10	0.25	35	43

Notes:
1 - Frequent events are defined as more than 70 vibration events per day. Most rapid transit systems fall into this category.
2 - Infrequent events are defined as less than 70 vibration events per day. This category includes most commuter rail systems.
3 - If the building will rarely be occupied when the trains are operating, there is no need to consider impact. As an example consider locating a commuter rail line next to a concert hall. If no commuter trains operate after 7pm, it should be rare that the trains interfere with the use of the hall.

This publication is an important one for tram and railway scheme operators and promoters, as it is the basis of the ground-borne noise criteria that have been used for a number of UK schemes in recent years (e.g. Channel Tunnel Rail Link tunnels, Jubilee Line Extension, Crossrail, and Croydon)

FTA-VA-90-1003-06, Federal Transit Authority, Transit noise and vibration impact assessment. May 2006

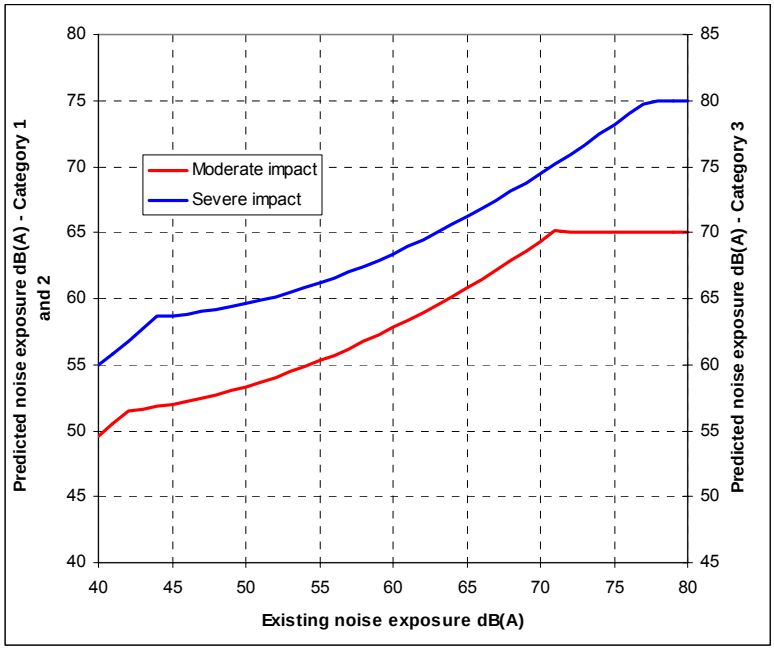
Second edition of a guidance manual originally issued in 1995. Presents procedures for predicting and assessing noise and vibration impacts of proposed mass transit projects (bus and rail). Procedures for assessing noise and vibration impacts are provided for different stages of project development, from early planning to preliminary engineering and final design. Contains noise and vibration impact criteria and mitigation measures.

Metrics

- Hourly Equivalent Sound Level $L_{eq}(h)$, which describes a receiver's cumulative noise exposure from all events over a one-hour period
- Day-Night Average Sound Level L_{dn}, which describes a receiver's cumulative noise exposure from all events over a full 24 hours, with events between 10pm and 7am increased by 10 decibels to account for greater night time sensitivity to noise.
- GBV in terms of an rms vibration velocity level with a 1 second time constant
- GBN in terms of the A-weighted level

Criteria

- Noise, criteria in terms of:
    - L_{eq} for Category 1 and 2
    - L_{dn} for Category 3



Land use category	Noise metric dB(A)	Description of land use category
1	Outdoor $L_{eq}(h)$*	Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, and such land uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included are recording studios and concert halls.
2	Outdoor L_{dn}	Residences and buildings where people normally sleep. This category includes homes, hospitals and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.
3	Outdoor $L_{eq}(h)$*	Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, theaters, and churches where it is important to avoid interference with such activities as speech, meditation and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds and recreational facilities can also be considered to be in this category. Certain historical sites and parks are also included.
* L_{eq} for the noisiest hour of transit-related activity during hours of noise sensitivity.		

- Vibration

Ground-Borne Vibration (GBV) and Ground-Borne Noise (GBN) Impact Criteria for General Assessment

Land use category	**Groundborne vibration impact levels**			**Groundborne noise impact levels**		
	mm/s			dB(A) re 20 micro Pascals		
	Frequent events[1]	Occasional events[2]	Infrequent events[3]	Frequent events[1]	Occasional events[2]	Infrequent events[3]
Category 1 : buildings where low ambient vibration is essential for interior operations	0.04	0.04	0.04	-[4]	-[4]	-[4]
Category 2 : residences and buildings where people normally sleep	0.10	0.14	0.25	35	38	43
Category 3 : institutional land uses with primary daytime use	0.14	0.20	0.36	40	43	48

Notes:
1 - "Frequent events" is defined as more than 70 vibration events of the same source per day. Most rapid transit systems fall into this category.
2 - "Occasional events" is defined as between 30 and 70 vibration events of the same source per day. Most commuter trunk lines have this many operations.
3 - "Infrequent events" is defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.
4 - This limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. Vibration-sensitive manufacturing or research will require detailed evaluation to define the acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the HVAC systems and stiffened floors.
5 - Vibration sensitive equipment is generally not sensitive to airborne noise.

Ground-Borne Vibration and Noise Impact Criteria for Special Buildings

Type of building or room	**Groundborne vibration impact levels**		**Groundborne noise impact levels**	
	mm/s		dB(A) re 20 micro Pa	
	Frequent events[1]	Infrequent events[2]	Frequent events[1]	Infrequent events[2]
Concert halls	0.04	0.04	25	25
TV studios	0.04	0.04	25	25
Recording studios	0.04	0.04	25	25
Auditoriums	0.10	0.25	30	38
Theatres	0.10	0.25	35	43

Notes:
1 - Frequent events are defined as more than 70 vibration events per day. Most rapid transit systems fall into this category.
2 - Infrequent events are defined as less than 70 vibration events per day. This category includes most commuter rail systems.

3 - If the building will rarely be occupied when the trains are operating, there is no need to consider impact. As an example consider locating a commuter rail line next to a concert hall. If no commuter trains operate after 7pm, it should be rare that the trains interfere with the use of the hall.

This document expands on the APTA guidelines and is therefore also of relevance to tram operators and promoters.

DETR “Guidance on the Methodology for Multi-Modal Studies” (GOMMMS), 2000

GOMMMS provides a table of “Annoyance Response” values for road and rail traffic noise separately. These show the % annoyed against L_{10} values for road (approximately L_{eq} +3 dB) and against L_{eq} for rail, both over the 18 hours from 06.00 – 24.00. This enables the trade off between road and rail traffic in terms of noise impact on the population to be calculated when options for multi-modal plans are being considered.

Such an analysis may be particularly valuable when considering the effects of modal shift with the proposed introduction of a new tram system.

Institute of Environmental Management and Assessment and Institute of Acoustics “Guidelines for Noise Impact Assessment” Consultation draft, 2002 (expected to be published in revised form 2007).

In its draft form this document provides detailed information regarding the issues that need to be taken into account when assessing noise impact, including modelling considerations, and suggests that the significance of impact may be categorised in terms of noise change. It is not known at the time of writing, however, how closely the published document will follow the consultation draft. There are references to railway noise and to the use of CRN specifically in the consultation document.

It is likely that the published version will be of use to the promoters and designers of new tram systems.

German Association of Engineers, VDI 2716, Airborne and structure-borne noise of local public transport railways, 2001

This document defines procedures and instruments for the design and planning process of urban light rail systems. Test methods, prediction methods and noise control measures are presented. Ground-borne noise and vibration are included.

Reference to this document would be useful during the design process of tram systems. It is to be drawn on during the formulation of guidelines in Phase 2 of this study.

DIN 4150 Part 2:1995, Vibrations and shock in buildings; Human exposure to vibration in buildings

This document specifies the evaluation of human exposure in buildings to periodic and transient structural vibration, 1 to 80 Hz. It includes limit values to prevent human discomfort in dwellings and similar buildings. It does not include ground borne noise.

Metrics

- weighted vibration severity ($KB_{Fast}(t)$ and $KB_{Fast,max}$)

Exposure period

- 16 hour day (06:00 to 22:00)
- 8 hour night (22:00 to 06:00)
- rest periods
    - Monday to Saturday 06:00 to 07:00 and 19:00 to 22:00
    - Sunday and holidays 06:00 to 22:00

Measurements

- 3 orthogonal directions (vertical and two horizontal)
- on floor of room in question, at points of maximum vibration
- at least five per train type

Criteria

- guideline values, for day and night periods
- 5 building usage/location categories

This German standard includes rail-specific recommendations. It has been used in the UK by Local Authorities to support their view that a vibration nuisance due to railways does exist. The standard has shown greater probability of adverse comment from railway vibration than the equivalent UK standard BS 6472. It could therefore be used either in support of a Noise Abatement Notice against tram operators (see the Environmental Protection Act below) or to justify very stringent vibration criteria for tram systems at the powers stage.

DIN 4150 Part 3:1999, Vibrations and shock in buildings; influence on structures

This document presents guideline values, below which vibration will not result in damage in terms of structure or component stability or reduction of load bearing capacity. It includes crack formation and enlargement plus separation of partitions for dwellings and sensitive buildings (lines 2 and 3 in table below)

Guideline values of vibration velocity for evaluating the effects of short-term vibration					
Line	Type of structure	Vibration velocity (mm/s)			
		Foundation			Uppermost storey
		f <10 Hz	10<f<50 Hz	50<f<100 Hz	All
1	Buildings used for commercial purposes, industrial buildings and buildings of similar design	20	20 to 40	40 to 50	40
2	Dwellings and buildings of similar design and/or use	5	5 to 15	15 to 20	15
3	Structures that, because of their particular sensitivity to vibration, do not correspond to those listed in lines 1 and 2 and are of great intrinsic value (e.g. buildings under preservation orders)	3	3 to 8	8 to 10	8

This German standard is more conservative than the BSI equivalent BS 7385, but it should be noted that BS values were arrived at following significant research into the structural integrity of buildings exposed to severe vibration environments.

Guidelines for Community Noise, World Health Organisation, 1999

These guidelines suggest values for community noise in specific environments.

Specific environment	Critical health effect(s)	LAeq [dB(A)]	Time base [hours]	LAmax fast [dB]
Outdoor living area	Serious annoyance, daytime and evening Moderate annoyance, daytime and evening	55 50	16 16	- -
Dwelling, indoors Inside bedrooms	Speech intelligibility & moderate annoyance, daytime & evening Sleep disturbance, night-time	35 30	16 8	 45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60
School class rooms & pre-schools, indoors	Speech intelligibility, disturbance of information extraction, message communication	35	during class	-
Pre-school bedrooms, indoor	Sleep disturbance	30	sleeping time	45
School, playground outdoor	Annoyance (external source)	55	during play	-
Hospital, ward rooms, indoors	Sleep disturbance, night-time Sleep disturbance, daytime and evenings	30 30	8 16	40 -
Hospitals, treatment rooms, indoors	Interference with rest and recovery	#1		
Industrial, commercial shopping and traffic areas, indoors and outdoors	Hearing impairment	70	24	110
Ceremonies, festivals and entertainment events	Hearing impairment (patrons:<5 times/year)	100	4	110
Public addresses, indoors and outdoors	Hearing impairment	85	1	110
Music and other sounds through headphones/ earphones	Hearing impairment (free-field value)	85 #4	1	110
Impulse sounds from toys, fireworks and firearms	Hearing impairment (adults) Hearing impairment (children)	-	-	140 #2 120 #2
Outdoors in parkland and conservations areas	Disruption of tranquility	#3		

#1: As low as possible.
#2: Peak sound pressure (not LAF, max) measured 100 mm from the ear.
#3: Existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low.
#4: Under headphones, adapted to free-field values.

The WHO is expected to publish key conclusions of its Night Noise Guideline project in 2007.

These guidelines are often used to justify a very stringent approach to noise control, and could be considered as being excessively cautious as well as often difficult to achieve. However, it should be noted that these values can be taken as being those below which there is minimal likelihood of adverse effects. This does not necessarily mean that once the values are exceeded there will be significant impact.

Statutory Instrument 1996 No. 428, The Noise Insulation (railways and other guided transport systems) Regulations 1996

These “Noise Insulation Regulations for Railways” specify when buildings are eligible for noise insulation as a result of airborne noise from new, additional and altered railways, tramways and other guided transport systems. Assessment is by prediction of noise levels (only from railway sources) using DfT “Calculation of Railway Noise 1995”. It is mandatory for new or additional railways.

Metrics

- A-weighted day and night equivalent noise level L_{Aeq} for day (06:00 to 24:00) and night (00:00 to 06:00) periods, 1m from façade.

Criteria for insulation (all three must be triggered), based on the worst case in the 15 years from opening.

- $L_{Aeq,day} \geq$ 68dB or $L_{Aeq,night} \geq$ 63dB
- The predicted level must exceed the prevailing railway noise level by at least 1 dB(A)
- Noise from vehicles using new or additional track to make an effective contribution to the predicted future levels of 1 dB(A)

These regulations do not apply in Scotland, but have nevertheless been used there, as well as in the rest of the UK, to assess the impact of new or additional railways and trams. However, it is extremely unlikely that a tram system, with its low speeds of operation, will trigger these Regulations, especially as the prediction methodology only covers running/rolling noise so that such additional sources as curve squeal, bells, horns and public address systems are not included in the calculations.

BS 4142 Method for rating industrial noise affecting residential and industrial areas, 1997

This standard compares a “rating level” (measured or calculated) L_{eq} (1 hr day or 5 min night) for the introduced noise, corrected for pure tones or impulses with + 5dB where present (once only) with the background noise L_{90}. If the introduced noise exceeds background by 10 dB or more then complaints are considered likely. If this reduces to 5 dB the situation is considered marginal, and if the introduced noise is 10 dB or more below the background level, complaints are unlikely.

The method is not appropriate for the operating tram system, but is of relevance for public address systems at stops and for depot activity.

This approach may well be required to be applied at the Powers stage of a new tram system to ensure that non-operational noise is not a nuisance to local residents, and may also be used by Local Authorities to justify Noise Abatement Notices.

BS 6472:1992, Evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)

This document provides general guidance on human exposure to vibration in buildings. Measurement methods are described and curves of equal annoyance for humans are presented. Methods are described for assessing continuous, intermittent and impulsive vibration, together with guidance on vibration conditions, which may cause adverse comment.

This standard is currently under revision and a change of frequency weighting is proposed. The effect of this is expected to increase the degree of predicted adverse reaction for some railway vibration spectra. However, Defra are also carrying out research into the topic, and there has been some concern from consultees to the draft revised standard that the results of this research should be taken into account before the standard is reissued.

Metrics

- frequency weighted rms acceleration (W_g and W_d)
- vibration dose value for 16 hour day, 8 hour night

Measurement position

- at input point to body, i.e. floor, seat or bed

Criteria

Frequency weighted rms acceleration (m/s^2 rms) corresponding to a low probability of adverse comment					
Place	Exposure period				
	16 hours	1 hour	225 secs	14 secs	0.9 secs
Residential buildings day time	0.01-0.02	0.02-0.04	0.04-0.08	0.08-0.16	0.16-0.32

Vibration dose values ($m/s^{1.75}$) above which various degrees of adverse comment may be expected in residential buildings			
Place	Low probability of adverse comment	Adverse comment possible	Adverse comment probable
Residential buildings 16 h day	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings 8 h night	0.13	0.26	0.51

BS 6472 is routinely used both in terms of quantifying existing vibration complaints from railways and in setting specifications for new railway and tram systems. It is likely to remain of equal importance following revision if the expected change in predicted adverse reaction for a given vibration spectrum is incorporated within the document.

BS 7385 Part 1:1990 (equivalent to ISO 4866:1990) Evaluation and measurement for vibration in buildings (Basic principles for vibration measurement and processing), Part 2:1993 Guide to damage levels from groundborne vibration

Part 2 provides guidance on the assessment of vibration-induced building damage. Guide values are presented for building vibration based on the lowest vibration levels above which damage has been demonstrated.

Metrics

- peak particle velocity (ppv)

Transducer location

- base of the building on the side facing the source

Criteria

Transient vibration guide values for cosmetic damage			
Line	Type of building	Peak component particle velocity in frequency range of predominant pulse	
		4 Hz to 15 Hz	15 Hz and above
1	Reinforced or framed structures. Industrial and heavy commercial buildings	50 mm/s at 4 Hz and above	
2	Unreinforced or light framed structures. Residential or light commercial type buildings	15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz	20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above
Note 1 : values referred to are at the base of the building			
Note 2: for line 2, at frequencies below 4 Hz, a maximum displacement of 0.6 mm (zero to peak) should not be exceeded.			

The guidance values in this standard are rarely found to arise, even at properties adjacent to main line railways. It could be used, nevertheless, to reassure occupants of buildings adjacent to an operational tram system that vibration is not going to cause any structural damage to the property. It could also be used as the basis for setting maximum levels adjacent to tracks within system specifications.

ISO 2631 Part 1:1997, Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration – Part 1: General requirements, Part 2:2003 – Vibration in buildings (1 Hz to 80 Hz)

The effect on humans is assessed with respect to comfort and annoyance. Measurement and evaluation methods are described. Acceptable magnitudes of vibration are not stated.

Metrics

- maximum transient vibration value (MTVV), preferred
- vibration dose value (VDV), optional
- frequency weightings
    - W_g vertical direction
    - W_d horizontal direction
    - W_m combined/any direction (preferred)

Transducer locations

- three orthogonal directions
- position of greatest vibration magnitude

The earlier issue of Part 2 of this standard did include guidance on acceptable magnitudes, but the latest issue avoids this, and therefore the standard is of questionable relevance in its current form.

ISO 14837 Part 1:2005 Mechanical vibration - Ground-borne noise and vibration arising from rail systems - Part 1: General guidance

This standard provides general guidance on ground-borne vibration generated by the operation of rail systems, and the resultant ground-borne noise in buildings. It lists the factors and parameters that need to be taken into consideration and gives guidance on prediction methods appropriate for a range of circumstances. It covers all forms of wheel and rail systems, including light-rail, high-speed trains and freight, at-grade, on elevated structures and in tunnels. It does not, however, provide any guidance on levels.

The following parts are now under preparation, but are not likely to be published until 2009 at the earliest:

Part 2. Prediction methods
Part 3. Measurement
Part 4. Evaluation criteria
Part 5. Mitigation

All these will be of interest and relevance for tram systems when they are eventually published.

ANSI S2.71-1983 (R2006), (Formerly ANSI S3.29-1983), Guide to the Evaluation of Human Exposure to Vibration in Buildings

This document assesses the reactions of humans to vibrations of 1 to 80 Hz inside buildings by use of degrees of perception and associated vibration levels and durations. Accelerations or velocities inside buildings may be measured to assess perceptibility and possible adverse reactions from those inside. A variety of building types and situations are covered by the use of multiplying factors applied to the basic curves. Responses are related to the event durations, frequencies of vibration, and body orientation with respect to the vibration. Adherence to the vibration magnitudes corresponding to the perceptibility threshold ensures minimum discomfort and annoyance.

This document is unlikely to be preferable for application to UK tram systems when compared either with the current BS 6472 or with the expected revision of that standard.

France – Edict 95-22 of January 1995, the Decrees of Nov 8th 1999 and 5 May 1995, Circular no 97-110 of Dec 12th 1997 and the Circular of Feb 2002 under Law 92-1444 1992 "The noise law"

Article 12 of 92-144 describes the principles of noise limitation that apply both to new and upgraded transport infrastructure. Edict 95-22 details the way in which 92-144 should be interpreted in the case of land transportation infrastructure.

The two decrees apply not only to trams but to all types of segregated-lane public transport projects.

Noise exposure is defined in terms of L_{Aeq} from 06.00 h – 22.00 h (day), and from 22.00 h – 06.00 h (night), 2m in front of the building façade.

Zones are classified as "Moderée", "Moderée de Nuit" and "Non Moderée". Maximum admissible levels are defined for both day and night, and insulation has to be provided for properties in areas classified as Moderée.

The noise criteria appear to be rigorous compared with UK practice, but it is not apparent from the available documentation to what extent they are enforced.

For vibration, there are no specific norms in France, although ISO 2631/2 and ISO 14837 (see above) are both referred to in the French context. Figures relating vibration velocity to perception are available from the impact study of the Angers Tramway.

Association of German Transport Undertakings (VDV) Paper 154 (2002), "Noise of railway vehicles for short-distance traffic – trams, light rails, metros"

The European Union Committee of the International Union of Public Transport (UITP) Committee "Formally approved" this VDV paper in 2003, and therefore can be taken as indicating UITP policy.

The paper specifies measurement procedures and criteria for trams, light rail and metros.

Metrics

- exterior noise
    - stationary: maximum level, L_{Am} with averaging time T≥ 15secs
    - pass by:
        - average maximum level $L_{AFmax,m}$ (approximately TEL+1dB)
        - time-averaged pass by level $L_{Am,V}$
- interior noise: stationary and running: L_{Am} with averaging time T≥ 10secs

Test environment

- Test track according to prEN ISO 3095 (2001 draft, but very similar to 2005 issue) or suitable section of track of the operator (must "approach" the quality requirements of prEN ISO 3095)

Microphone positions (d=distance from track centreline, h=height above rail)

- exterior as per prEN ISO 3095:
    - pass by d=7.5m (track centre line), h=1.2m and 3.5m (above rail head level)

Criteria

- Recommended maximum noise levels, specification for ordering new vehicles

Exterior noise prEN ISO 3095	Light Rail, Metro	Low-floor Tram	Metric
Stationary (not exceeded at any mike position)			
• without air con	55	55	L_{Am}
• with air con:			
partial load (1.2/7.5m)	55/58	55/58	L_{Am}
full load (1.2/7.5m)	60/63	60/63	L_{Am}
Acceleration	75	75	$L_{AFmax,m}$
Pass by 60 km/h	77	79	$L_{AFmax,m}$

Component	Average A-weighted exterior noise level at 1m $L_{A,m}$
Compressor (encapsulated)	65
Voltage converter	52
Fan	60
Air con – partial load	70
Air con – full load	75

This document is an important one for tram promoters and operators, as it is specifically aimed at relevant stock. The levels are all relatively low, and will not always be easy to achieve. The pass-by noise limits are, however, probably achievable for a smooth-wheeled tram (i.e. no cast-iron tread brakes) without extra mitigation but this is by no means certain if the track roughness only just meets the ISO 3095 limit spectrum.

EU Rail noise study, A Study of European Priorities and Strategies for Railway Noise Abatement, ODS Report for DG-Tren, EU Commission February 2002

This study recommends the following:

Metric

- average A-weighted pass by noise level $L_{pAeq,Tp}$

Measurement method

- according to prEN ISO 3095 (which is very similar to EN ISO 3095 2005)

Criteria

Short term and long term goals for Light Rail Transit

Operating condition		$L_{pAeq,Tp}$ at 7.5 m dB(A)	
		Short term	Long term
Pass by	40km/h	72	69
	80km/h	80	77
Stationary	Without air conditioning	55	52
	With air conditioning	60	57

This report was used by the European Commission as the basis for some very ambitious noise reduction aspirations for the future, including recommendations that appear in the current High Speed Rolling Stock TSI. The “short term” values in the table above are likely to be only just achievable with current technology, while the “long term” values will be very difficult without additional, specialised, noise control treatments.

It is unlikely in the short term, however, that such low values will be imposed by legislation on the tram industry.

Bordeaux tram procurement specification, 1999

For external noise, the Bordeaux tramway noise specification was as follows:

Metric

- A-weighted equivalent noise level L_{Aeq}
- linear 1/3 octave spectrum limits “Courbes enveloppes A to G” from 30 to 8000 Hz

Measurement position

- d=7.5m, h=1.2m

Criteria, measured under Norm NF S 31-019

Speed km/h	L_{Aeq} dB	“Courbes enveloppe”
0	51	A
40	73	F
60	78	G

The pass-by values are somewhat higher than those within VDV 154 for light rail metros and the Conventional Rail Noise TSI, and therefore should just be achievable without any additional acoustic treatment. However, the stationary level is very low, and might not be easy to achieve.

ISO 3095:1975, Acoustics – Measurement of noise emitted by railbound vehicles

This early standard specifies conditions for obtaining reproducible and comparable measurements of the noise level and spectrum emitted by all vehicles running on rails or other types of fixed track.

Metrics
- maximum A-weighted sound pressure level with Fast time constant L_{AFmax}

Instrumentation
- IEC Publication 179

Test environment
- free from reflecting objects for 50m
- wind speed less than 10m/s, less than 5m/s preferred
- background noise more than 10 dB below A-weighted SPL with vehicle

Microphone positions (d=distance from track centreline, h=height above top of rail)
- vehicles in motion:
    - d=7.5m, h=1.2 to 1.5m
    - d=7.5m, h=3.5m for vehicles with sources located high on vehicle
    - both sides for non-symmetric vehicle
- stationary vehicles:
    - d=7.5m, h=1.2 to 1.5m opposite centre of vehicle
    - d=7.5m, h=3.5m for vehicles with sources located high on vehicle
    - additional positions defined around vehicle
- accelerating
    - d=7.5m, h=1.2 to 1.5m
- at platforms and stopping points
    - d=3m, h=1.2 to 1.5m above platform
- on bridges
    - d=7.5m, h=1.2 to 1.5m above upper surface of rails
    - also recommended d=25, 50, 100m, h=3.5m above ground
- in tunnels
    - d=3m, h=1.2 to 1.5m

Vehicle condition
- wheel treads smooth and free from wheel-flats
- doors and windows closed
- auxiliary equipment operating provided it contributes significantly to noise level and if present for more than 1 minute
- for constant motion, vehicles at maximum speed plus:
    - 80 km/h interurban
    - 60 km/h urban and underground

    - 40 km/h tramcars
- stationary vehicles
    - coaches and power units with electrical power: all equipment operating including main engines, auxiliaries at maximum load
    - power units with internal combustion engines: range of conditions from idling, minimum load to maximum speed unloaded, maximum load
    - power units with turbines and other engines: conditions comparable with those above

Test procedure

- at least 3 measurements at each microphone position
- arithmetic mean, rounded to nearest integer decibel, maximum allowable spread of 3dB

This early specification was aimed at standardising railway environmental noise measurement and, although superseded, forms the basis for many more recent specifications.

EN ISO 3095:2005, Railway applications – Acoustics – Measurement of noise emitted by railbound vehicles

This latest issue of the standard specifies conditions for obtaining reproducible and comparable measurements of external noise by all vehicles running on rails or other types of fixed track, excluding track maintenance vehicles in operation.

Metrics

- whole or part of train, constant speed pass by (TEL or $L_{pAeq,Tp}$)
- stationary vehicles (L_{pAeq}), use slow or impulse time-constant for noise with impulsive character
- accelerating, braking vehicles and at stopping points (L_{pAFmax})

Instrumentation

- Type 1 EN 61672-1

Test environment

- flat, 0 to –1m relative to top of rail
- free from reflecting objects for a radius of 3 times measurement distance
- area between vehicle and microphone not saturated and free from sound absorbing material
- wind speed less than 5 m/s
- background noise more than 10 dB below A-weighted SPL with vehicle

Microphone positions (d=distance from track centreline, h=height above top of rail)

- constant speed pass by:
    - d=7.5m, h=1.2m
    - d=25m, h=3.5m
    - d=7.5m, h=3.5m for vehicles with sources located high on vehicle
    - both sides for non-symmetric vehicle
- stationary vehicles:
    - d=7.5m, h=1.2m opposite centre of vehicle
    - d=7.5m, h=3.5m for vehicles with sources located high on vehicle
    - addition positions defined around vehicle
- accelerating or decelerating
    - d=7.5m, h=1.2m
    - d=7.5m, h=3.5m for vehicles with sources located high on vehicle
    - up to two additional sets of microphones along the track
- at platforms and stopping points
    - d=3m, h=1.5m above platform
- on bridges
    - d=7.5m, h=1.2m above upper surface of rails
    - also recommended d=25, 50, 100m, h=3.5m above ground

Vehicle condition

- normal operating conditions during tests, including auxiliary equipment
- run in normal conditions for at least 1000km (trams and metros) or 3000km (mainline)
- wheels free from irregularities, e.g. flats
- unloaded and unoccupied except for train crew
- doors and windows closed

Track condition
- conventional vehicles on ballasted track
- other track designs used if integral with operation of vehicles
- track in good condition, no joints, welds, burns, pits, spikes
- maximum gradient 3:1000
- curve radius
    - $r \geq 1000$m for $v \leq 70$km/h
    - $r \geq 3000$m for $70 < v \leq 120$km/h
    - $r \geq 5000$m for $v > 120$km/h
- rail roughness limit wavelength spectrum specified

Test procedure
- at least 3 measurements at each microphone position
- arithmetic mean, rounded to nearest integer decibel, maximum spread of 3dB permitted
- constant speed:
    - for maximum vehicle speed of 80km/h, test at 40 and 80km/h
- accelerating from standstill
    - maximum tractive effort without wheel skid
    - individual power units: standstill to 30km/h
    - for distributed power: with normal service acceleration from standstill to 30km/h, then constant
- decelerating
    - a normal service stop from 30km/h
- stationary
    - one measurement per microphone position, 20s in length (5s as an exception)
    - coaches, wagons, electric power: all equipment operating, auxiliary equipment at full load
    - power units with internal combustion engines: range of conditions from idling, minimum load to maximum speed unloaded, maximum load

This standard has emerged after many years of deliberation from CEN, and is to a certain extent a compromise between the views of a range of railway acoustics experts. It nevertheless presents a controlled, preferred, approach to the acquisition of rail vehicle environmental noise characteristics, with applicability to trams. There is a concern, though, that the acoustically ideal conditions required by the standard can be difficult to find in a real tram operating environment, and therefore some pragmatic interpretation of the requirements may often by necessary.

EU Commission Decision 2006/66/EC, Technical specification for interoperability relating to the subsystem “rolling stock – noise” of the trans-European conventional rail system

This Conventional Rolling Stock Noise TSI must be complied with by all new rolling stock. However, it is understood, through UK Tram, that trams are exempt from this. The following summary is therefore for completeness only.

Limiting external noise values for rolling stock are specified.

Metrics

- pass by noise: A-weighted equivalent continuous SPL over pass by time $L_{pAeq,Tp}$
- stationary noise: A-weighted equivalent continuous SPL $L_{pAeq,T}$
- starting noise: A-weighted maximum level, fast time constant L_{pAFmax}

Test environment

- as prEN ISO 3095:2001 except for rail roughness, track decay rate (prEN ISO 3095 2001 is very similar to the 2005 issue of EN ISO 3095)

Microphone positions (d=distance from track centreline, h=height above top of rail)

- as prEN ISO 3095:2001

Vehicle condition

- as prEN ISO 3095:2001

Track condition

- as prEN ISO 3095:2001

Test procedure

- as prEN ISO 3095:2001

Criteria

Condition	Level dB @ 7.5m	Metric
Stationary (EMU)	68	$L_{pAeq,T}$
Starting (EMU)	82	L_{pFmax}
Pass by (EMU) @ 80 km/h	81	$L_{pAeq,Tp}$

Although the European Commission is not understood to require these limits to be met for trams, its aspiration to reduce all noise levels across the Community could lead in the future to trams being subject to similar limits. If tram-trains operate in the UK, they will probably not be exempt when operating on heavy rail infrastructure.

If the TSI EMU values were to be applied, the pass-by levels will be achievable on the defined test track, provided wheels are not cast-iron tread-braked, while stationary and starting levels should easily be met by trams.

Land Compensation Act 1973 Part 1 (Implemented separately in Scotland)

Part 1 provides for the payment of compensation for depreciation caused by use of Public Works. The Responsible Authority may be liable to pay compensation for depreciation in the value of an interest in land, which is attributable to the use of the Public Works. Compensation is limited to depreciation in market value of the qualifying interest as attributable to noise and vibration. Limited to new works, reconstruction, extension or alteration, not intensification.

Claims may be submitted during a period of 5 years commencing 1 year after the commencement of operation of the system.

When depreciation is considered, the balancing appreciation brought by proximity to the tram network may be of relevance.

This legislation is of great relevance to tram promoters and operators, and many claims have already been submitted under Part 1 in connection with Croydon Tram, Nottingham and Midland Metro.

Environmental Protection Act 1990 Part III

Local Authorities, magistrates' court for the Local Authority or a magistrates' for an individual can issue an Abatement Notice to a person responsible for the noise or vibration. The Local Authority of magistrate's court has to be satisfied that a nuisance exists. The defence of Best Practicable Means is available. Contravention of a Notice is an offence. It is possible to appeal within 21 days of a Notice.

This Act will often be used by Local Authorities to impose Abatement Notices, although there is sometimes the opportunity to agree a deferment of its imposition provided there is an undertaking by the alleged perpetrators of the nuisance to address the problem. Historically, railways would argue that, as statutory undertakers, they were exempt from such legislation, but in recent years this has not proved to be a defence. It is likely that tram operators would be equally unlikely to be able to avoid notices should a Local Authority or magistrates' court decide a noise or vibration nuisance (e.g. from operations, maintenance activities, public address systems) exists.

ANSI S2.47-1990, Guidelines for the measurement of vibrations and evaluation of their effects on buildings

The following information on the potential for building damage from vibration is provided in these guidelines.

Criteria for vibration monitoring based on vibration levels and a low probability of adverse vibration impact on structures				
Monitoring	Peak vibration levels mm/s			
	Cosmetic or architectural cracking		Reduction in serviceability, structural damage	
	LF	HF	LF	HF
Preliminary assessment	5	10	10	20
Exploratory monitoring	10	20	25	50
Field survey	20	50	50	100
Engineering analysis	Note 1	Note 1	50, Note 2	100, Note 2

No differentiation is made between transient and continuous vibration sources
LF is defined as all frequencies below 2 x NF
HF is defined as all >= 2 NF
NF is the highest principal NF (natural frequency) of structure or class of structures of concern
Note 1: the type of structures subject to cosmetic cracking are generally non-engineered, such as residences. Except in special circumstances, the Field Survey of multi-point response would as sophisticated as ever needed
Note 2: the need for a complete engineering analysis, as contrast to a field survey, is not as much dependent on vibration level, but more on the nature of the structure and the risk created by impacting vibration. Examples here are complex and potentially dangerous structure, such as nuclear plant, and those under high ambient load, such as earthen dams.

This is the equivalent document to BS 7385 and DIN 4150 Pt 3, and does not provide any additional useful guidance for application to tram systems.

Association of Noise Consultants (ANC) Guidelines on "Measurement and Assessment of Groundborne Noise and Vibration, 2002

The Association of Noise Consultants has produced a detailed set of guidelines on methodologies for measuring and assessing groundborne noise and vibration, including specific reference to railways. It also provides some background in the subject, and discusses vibration mitigation via track treatment and maintenance standards. It also cross-references various criteria of relevance.

In general this is a very useful reference work for the assessors of vibration issues relating to tram systems.

ISO 4866:1990, Mechanical vibration and shock - Vibration of buildings - Guidelines for the measurement of vibrations and evaluation of their effects on buildings

This standard covers basic principles for carrying out measurements and processing data, with regard to evaluating vibration effects on buildings. The structural response of buildings depends upon the excitation; hence this standard covers the methods of measurements as affected by the source, i.e. frequency, duration, and amplitudes as induced by any source, such as earthquakes, explosions, wind effects, sonic booms, internal machinery, traffic, construction activities and others.

Directive 2002/49/EC, 25 June 2002 "relating to the assessment and management of environmental noise" (also known as the Environmental Noise Directive or "END")

Objectives of the Directive:

- To determine the noise exposure of the population through noise mapping
- To make information available on environmental noise to the public
- To establish action plans based on the mapping results to reduce levels where necessary and to preserve environmental noise quality where it is good

Noise exposure is to be quantified in terms of annual average "day-evening-night level" (L_{den}) which is an energy-averaged A-weighted level for a complete day, where the evening level is enhanced by 5 decibels (dB) and the night level is enhanced by 10 dB.

Although measurement is permissible, in reality it is not practical to do so for large-scale mapping and therefore calculation will be the standard approach. The night time level, L_{night}, without any enhancement, also has to be mapped. Levels are to be mapped over a grid that is 4m above the ground.

Strategic noise maps are to be produced for "agglomerations" (larger urban areas), and road, rail, air and industry separately.

The timetable defined in the END sets up a rolling 5-year programme relevant to railways and tram systems as follows:

- By 30 June 2005, then every 5 years – Inform EC of agglomerations of 250000+ people and railways with 60000+ train passages per annum
- By 30 June 2007, produce maps for the preceding year, for the agglomerations and railways identified
- By 18 July 2008, the "Competent Authority" is to draw up Action Plans to manage noise issues and effects, including noise reduction where necessary
- By 31 December 2008 – Inform EC of agglomerations of 100000+ people and railways with 30000+ train passages per annum
- By 30 June 2012 and thereafter every 5 years, produce maps for the preceding year, for agglomerations and railways identified
- By 18 July 2013, the "Competent Authority" (to be nominated by the Member State) is to draw up Action Plans to manage noise issues and effects, including noise reduction where necessary, based on the latest maps
- 6 months after mapping and the production of action plans, information must be passed to the Commission. This includes noise control programmes, the number of people exposed to various noise bands and a summary of the action plans.

The Directive allows Member States to apply their own national methods for the prediction of noise contours, but also recommends interim methods that may be used in the absence

of an appropriate national method. In the case of railways this method is the Dutch methodology "RMR '96". However, the Directive also states that common assessment methods are to be established by the Commission. These are currently being developed via the EC-funded research projects HARMONOISE and IMAGINE, with the current expectation that they will be applied for the second round of mapping in 2012.

The Directive has been transposed separately in England, Wales, Scotland and Northern Ireland, via a set of "Environmental Noise Regulations", all of which are substantially similar. The "Competent Authorities" are the Secretary of State (Defra), the Welsh Assembly, the Scottish Ministers and the Northern Ireland Transport Holding Company respectively.

Initially, in the UK, "Calculation of Railway Noise 1995" (CRN) will be used to model railway and tram noise, amended to take into account rail head roughness via a procedure developed by AEA Technology Rail (now DeltaRail).

For railways, all the transposed Regulations require supplementary noise indicators to be calculated and mapped, in addition to L_{den} and L_{night}. These are $L_{Aeq,\ 16h}$ (as required under Planning Policy Guidance "Planning and Noise" PPG 24), $L_{Aeq,\ 18h}$ and $L_{Aeq,\ 6h}$ (as required under the Noise Insulation Regulations for Railways, and also L_{day} and $L_{evening}$ (the latter without the 5 dB enhancement of L_{den}).

It is expected that all tram systems in the UK will be noise-mapped, irrespective of traffic flow, as they all operate in the major agglomerations that are to be included within the 2007 mapping round. Action plans may also be required for tram systems following the mapping exercise. At present no criteria are proposed in association with such Action Plans.

European Commission Working Group on Assessment of Exposure to Noise (WG-AEN), "Good Practice Guide for Strategic Noise Mapping" Version 2, 2006

WG-AEN has produced guidance for noise mapping under the END, including a section focusing specifically on light rail issues.

The recommendations are that:

- Trams are mapped as 'regular trains' when they run on segregated track
- Trams running along roads the Member State is either to map them together with the road traffic, or separately. In either case the resulting noise exposure should be kept separated for the purpose of Action Planning.

Guidance on the setting of noise source levels for mapping, if not available from the operators, is given via a "Toolkit". Similarly, advice is given on source terms for curve squeal (not included in the UK method "CRN"), rail joints and track type.

This document may provide some useful advice for those modelling tram systems at an early stage, but its main aim is to assist in cost-effective noise-mapping of existing systems.

European Commission Light Rail Thematic Network Project Libertin, Noise Final Report, 2004 (Unpublished)

The Libertin project ran for 30 months from 2002 with the objective of increasing the cost effectiveness and reliability of light rail systems in Europe. The noise topic brought together a number of experts and industry representatives to discuss the issues and to produce a set of reports and position papers, but it proved very difficult to reach a general consensus, and therefore a noise final report was produced but not officially issued.

Topics covered are

- Exterior noise control, including the related costs and benefits, and conflicting requirements between noise control and other issues
- Ground-borne noise and vibration
- Curving noise
- Modification to testing standards, especially ISO 3095, to make them more appropriate for light rail
- The appropriateness of VDV 154 criteria

UK Tram Activity Group 4 members participated in the Noise Topic of Libertin, and therefore have access to its output, which provides valuable material that is being drawn upon in the formulation of the best practice guidance of Phase 2 of this UK Tram Activity.

Summary table

The following table summarises the findings of the Phase 1b study.
("Stages where applicable" are: PDP = Planning/Design/Powers, VSA = Vehicle Specification/Acceptance, OPL = Operational)

Source	**Railway specific**	**Tram specific**	**Noise**	**GBV**	**GBN**	**Measur-ement proced-ure**	**Criteria**	**Stage where applicable**		
								PDP	VSA	OPL
PPG 24	-	-	√	-	-	-	Planning permission	√		
APTA Guidelines	√	-	√	√	√	-	Environmental impact criteria	√		
FTA-VA-90-1003-06	√	-	√	√	√	-	Environmental impact criteria	√		√
GOMMMS	√	-	-	-	-	-	Dose-response information	√		
IEMA IoA Draft Guidelines	√	-	√	-	-	√	General guidance	√		
VDI 2716	√	√	√	√	√	√	-	√		
DIN 4150 Part 2,3	-	-	-	√	-	√	Humans in buildings Structural damage	√		√

Source	Railway specific	Tram specific	Noise	GBV	GBN	Measur-ement proced-ure	Criteria	Stage where applicable		
								PDP	VSA	OPL
WHO Community Noise	-	-	√	-	-	-	Indoor and outdoor Annoyance Sleep disturbance Speech intelligibility Hearing impairment	√		√
Noise Insulation Regulations	√	√	√	-	-	-	System noise emission	√		√
BS 4142	-	-	√	-	-	√	Introduced noise vs B/G	√		√
BS 6472	-	-	-	√	-	√	Human annoyance	√		√
BS 7385 Part 1+2	-	-	-	√	-	√	Building damage	√		√
ISO 2631 Part 1+2	-	-	-	√	-	√	None in the latest issue of Pt 2	√		√
ISO 14837 Part 1	√	-	-	√	√	-	-	√		√
ANSI S2.71-1983 (R2006)	-	-	-	√	-	-	-	√		√
France general	√	-	√	-	-	√	Prevailing and new levels	√		√
VDV Paper 154	√	√	√	-	-	√	Vehicle external noise		√	

Source	Railway specific	Tram specific	Noise	GBV	GBN	Measur-ement proced-ure	Criteria	Stage where applicable		
								PDP	VSA	OPL
ODS EU Rail noise study	√	√	√	-	-	√	Vehicle external noise		√	
Bordeaux specification	√	√	√	-	-	-	Vehicle external noise		√	
ISO 3095:1975	√	-	√	-	-	√	-		√	
EN ISO 3095:2005	√	-	√	-	-	√	-		√	
Conventional Rail Noise TSI	√	-	√	-	-	√	Vehicle external noise		√	
Land Compensation Act	-	-	√	√	√	-	-			√
Environmental Protection Act	-	-	√	√	-	-	-			√
ANSI S2.47-1990	-	-	-	√	-	√	Building damage			√
ANC Vibration measurement guidelines	√			√	√	√	Ref to other docs			√
ISO 4866	-	-	-	√	-	√	-			√
Environmental Noise Directive	√	√?	√	-	-	-	-			√
EC WG-AEN Good Practice Guide	√	√	√	-	-	-	-			√
Libertin EC Thematic Network		√	√	√	√	√	Ref to other docs	General		

Key points from the commentary

Source	
PPG 24	PPG 24 (TAN 11 and PAN 56) are routinely used in the planning process, and the expected emergence of PPS 24 will probably increase the emphasis on noise impact assessment and control from tram systems both for new building developments and for new tram systems.
APTA Guidelines	This publication is an important one for tram and railway scheme operators and promoters, as it is the basis of the ground-borne noise criteria that have been used for a number of UK schemes in recent years (e.g. Channel Tunnel Rail Link tunnels, Jubilee Line Extension, Crossrail, Croydon)
FTA-VA-90-1003-06	This document expands on the APTA guidelines and is therefore also of relevance to tram operators and promoters.
GOMMMS	The analysis technique for comparing road and rail noise impact may be particularly valuable when considering the effects of modal shift with the proposed introduction of a new tram system.
IEMA IoA Draft Guidelines	There are references to railway noise and to the use of CRN specifically in the consultation document and, provided the document expected to be published in 2007 reflects this, it is likely that the official version will be of use to the promoters and designers of new tram systems.
VDI 2716	The procedures and instruments for design and planning of urban light rail defined in this document make it a useful reference during the design process of tram systems.

Source	
DIN 4150 Part 2,3	Part 2 of this German standard has been used in the UK by Local Authorities to support their view that a vibration nuisance due to railways does exist. The standard has shown greater probability of adverse comment from railway vibration than the equivalent UK standard BS 6472. It could therefore be used either in support of a Noise Abatement Notice against tram operators or to justify very stringent vibration criteria for tram systems at the powers stage. Part 3, referring to building damage, is more conservative than the BSI equivalent BS 7385, but it should be noted that BS values were arrived at following significant research into the structural integrity of buildings exposed to severe vibration environments.
WHO Community Noise	These guidelines are often used to justify a very stringent approach to noise control, and could be considered as being excessively cautious as well as often difficult to achieve. However, it should be noted that these values can be taken as being those below which there is minimal likelihood of adverse effects. This does not necessarily mean that once the values are exceeded there will be significant impact.
Noise Insulation Regulations	It is extremely unlikely that a tram system, with its low speeds of operation, will trigger these Regulations, especially as the prediction methodology only covers running/rolling noise so that such additional sources as curve squeal, bells, horns and public address systems are not included in the calculations.
BS 4142	The method is not appropriate for the operating tram system, but is of relevance for public address systems at stops and for depot activity. Its use may well be required to be applied at the Powers stage of a new tram system to ensure that non-operational noise is not a nuisance to local residents, and may also be used by Local Authorities to justify Noise Abatement Notices.

Source	
BS 6472	This standard is routinely used both in terms of quantifying existing vibration complaints from railways and in setting specifications for new railway and tram systems. It is likely to remain of equal importance following its imminent revision if the potential expected change in predicted adverse reaction for a given vibration spectrum is incorporated within the document.
BS 7385 Part 1+2	The building damage guidance values in this standard are rarely found to arise, even at properties adjacent to main line railways. It could be used, nevertheless, to reassure occupants of buildings adjacent to an operational tram system that vibration is not going to cause any structural damage to the property. It could also be used as the basis for setting maximum levels adjacent to tracks within system specifications.
ISO 2631 Part 1+2	The earlier issue of Part 2 of this standard included guidance on acceptable magnitudes, but the latest issue avoids this, and therefore the standard is of questionable relevance in its current form.
ISO 14837 Part 1	This general guidance standard on ground vibration will eventually be followed by a set of six detailed documents on Prediction, Measurement, Evaluation, Mitigation and Asset Management, all of which will be of interest and relevance for tram systems when they are published.
ANSI S2.71-1983 (R2006)	This document is unlikely to be preferable for application to UK tram systems when compared either with the current BS 6472 or with the expected revision of that standard.
France general	The noise criteria appear to be rigorous compared with UK practice, but it is not apparent from the available documentation to what extent they are enforced. For vibration, there are no specific norms in France.

Source	
VDV Paper 154	This document is an important one for tram promoters and operators, as it is specifically aimed at relevant stock. The levels are all relatively low, and will not always be easy to achieve. The pass-by noise limits are, however, probably achievable for a smooth-wheeled tram (i.e. no cast-iron tread brakes) without extra mitigation but this is by no means certain if the track roughness only just meets the ISO 3095 limit spectrum.
ODS EU Rail noise study	This report was used by the European Commission as the basis for some very ambitious noise reduction aspirations for the future. The “short term” values proposed are likely to be only just achievable with current technology, while the “long term” values will be very difficult without additional, specialised, noise control treatments. It is unlikely in the short term, however, that such low values will be imposed by legislation on the tram industry.
Bordeaux specification	The pass-by values are somewhat higher than those within VDV 154 for light rail metros and the Conventional Rail Noise TSI, and therefore should just be achievable without any additional acoustic treatment. However, the stationary level is very low, and might not be easy to achieve.
ISO 3095:1975	This early specification was aimed at standardising railway environmental noise measurement and, although superseded, forms the basis for many more recent specifications.
EN ISO 3095:2005	This standard has emerged after many years of deliberation from CEN, and is to a certain extent a compromise between the views of a range of railway acoustics experts. It nevertheless presents a controlled, preferred, approach to the acquisition of rail vehicle environmental noise characteristics, with applicability to trams. There is a concern, though, that the acoustically ideal conditions required by the standard can be difficult to find in a real tram operating environment, and therefore some pragmatic interpretation of the requirements may often by necessary.

Source	
Conventional Rail Noise TSI	Although the European Commission is not understood to require these limits to be met for trams, its aspiration to reduce all noise levels across the Community could lead in the future to trams being subject to similar limits. If the TSI EMU values were to be applied, the pass-by levels would be likely to be achievable on the defined test track, provided wheels are not cast-iron tread-braked, while stationary and starting levels should easily be met by trams.
Land Compensation Act	This legislation is of great relevance to tram promoters and operators, and many claims have already been submitted under Part 1 in connection with Croydon Tram, Nottingham and Midland Metro.
Environmental Protection Act	This Act will often be used by Local Authorities to impose Abatement Notices, although there is sometimes the opportunity to agree a deferment of its imposition provided there is an undertaking by the alleged perpetrators of the nuisance to address the problem. Historically, railways would argue that, as statutory undertakers, they were exempt from such legislation, but in recent years this has not proved to be a defence. It is likely that tram operators would be equally unlikely to be able to avoid notices should a Local Authority or magistrates' court decide a noise or vibration nuisance (e.g. from operations, maintenance activities, public address systems) exists.
ANSI S2.47-1990	This is the equivalent document to BS 7385 and DIN 4150 Pt 3, and does not provide any additional useful guidance for application to tram systems.
ANC Vibration measurement guidelines	In general this is a very useful reference work for the assessors of vibration issues relating to tram systems.
ISO 4866	This standard covers basic principles for carrying out measurements and processing data, with regard to evaluating vibration effects on buildings.

Source	
Environmental Noise Directive	It is expected that all tram systems in the UK will be noise-mapped, irrespective of traffic flow, as they all operate in the major agglomerations that are to be included within the 2007 mapping round. Action plans may also be required for tram systems following the mapping exercise. At present no criteria are proposed in association with such Action Plans.
EC WG-AEN Good Practice Guide	This document may provide some useful advice for those modelling tram systems at an early stage, but its main aim is to assist in cost-effective noise-mapping of existing systems.
Libertin EC Thematic Network	The Noise Final Report was not published because the various industry representatives could not reach a consensus, but its content provides valuable input to Phase 2 of Activity 4