ISVR consulting | noise & vibration specialists

Consultancy Report

Ref: 11089-R01

Submitted to:

Stephen Byrne
Transport Infrastructure Ireland
Parkgate Business Centre, Parkgate St., Dublin 8, Ireland, D08 DK10

Prepared by:

Dr. Martin Toward
Senior Consultant Engineer

In accordance with our quality assurance procedures this document is countersigned by:

Dr. Daniel Lurcock
Senior Consulting Engineer

CNOSSOS-EU SOURCE TERMS FOR LUAS

June 2022

ISVR Consulting, University of Southampton,
Highfield Campus, Southampton SO17 1BJ United Kingdom
Tel: +44 (0)23 8059 2162 Fax: +44 (0)23 80592728

email: consultancy@isvr.co.uk www.isvr.co.uk

University of Southampton

Contents

1. Introduction

European Union Directive 2002/49/EC [1] relating to the assessment and management of environmental noise is the main EU instrument to identify noise pollution levels and to trigger the necessary action both at Member State and at EU level. The Directive requires Member States to prepare and publish, every 5 years, noise maps and noise management action plans for transport.

Strategic noise maps are now required to be calculated in line with the methodology set out in EU Directive 2015/996 [2] establishing common noise assessment methods (CNOSSOS-EU) [3]. Since publication, Directive 2015/996 has been amended by a Corrigendum [4] in May 2018, and most recently by a Delegated Directive [5] in December 2020. The consolidated current version will be referred to as CNOSSOS-EU:2020 within this report.

To calculate the strategic noise maps for railways, input datasets are needed. These include data on the rail vehicle, including traction type, wheel type and typical wheel roughness, as well as data on the track, such as the rail roughness, track type, track fasteners and sleepers. With these datasets, the combined roughness can be calculated which, along with vehicle and track-dependent transfer functions are then used to determine the sound power emitted by the wheels, the rails and the superstructure. Additionally, allowances for traction noise, impact noise and curve squeal are provided.

CNOSSOS-EU:2020 Annex II comes with a limited range of default values for rail and wheel roughness as well as the various transfer functions. However, tramway vehicles and tracks are not well represented in these default values and are therefore not sufficient to produce accurate and representative noise maps for specific networks. As such, there is a need to establish appropriate, and reliable, rail vehicle emission data for CNOSSOS-EU:2020 relevant to the LUAS tramway in Dublin, Ireland.

An extensive measurement campaign has been conducted on the LUAS network to acquire input data for CNOSSOS-EU:2020. In 2018, measurements were made of wheel roughness and the wheel dynamics of Citadis 402 trams, which operate on the network. In addition, measurements were made of the track roughness, and track dynamics in the form of track decay rates of most of the LUAS track types as well as noise measurements for model validation [6].

In 2022, further measurements were made to fill in gaps in the dataset. These included repeat roughness measurements on all track forms (as roughness varies over time); track decay rate and roughness measurements on embedded slab track in the city centre (not measured in the first round); as well as additional validation noise measurements.

This data has been used to define the various track, wheel, and roughness transfer function required for CNOSSOS-EU:2020. The definition of these is described below.

2. Definition of CNOSSOS transfer functions

In most situations of the LUAS network the dominant noise source is rolling noise. This is caused by the surface unevenness of the wheel and rail (roughness) exciting the track components and wheels. Noise is radiated by the wheel, rails, sleepers (ballast track), and booted sleepers (slab track).

Rolling noise terms have been calculated based on the TWINS approach to derive sound powers. The TWINS prediction method was developed to predict rolling noise from input parameters relating to the track (rail roughness, track static and dynamic characteristics) and vehicle parameters (wheel roughness, wheel dynamics etc.). TWINS is sufficiently validated for this and ISVR have, through the Track 21 project, conducted validations on English situations (e.g. EMUs at Fishbourne [7]).

ISVR have developed the prediction software package "Train Noise Expert" which employs the TWINS methodology for the calculation of rolling noise, and this has been validated against TWINS itself. Train Noise Expert has additional functionality to include recent research developments and also to allow other sources besides rolling noise to be included in a global train model. These other sources are specified and modelled based on the Acoutrain approach [8] where point, area or 'box' type noise sources can be located specifically on the train. These sources can be speed dependent.

Source terms required for the Train Noise Expert rolling noise predictions for the English situation are described in the sections below, with the main inputs required described below.

2.1 Wheel roughness spectra

Within the CNOSSOS-EU dataset, wheel roughness is characterised for different rolling stock based on a database of measurement data for heavy rail wheels.

Wheel roughness strongly depends on the braking systems. The Citadis 402 trams operating on the LUAS network are disc-braked. Wheel roughness measurements of eight wheels of a LUAS tram were made by the ISVR during a measurement campaign in 2018 [6] according to EN15610 [9] (Figure 1). Although differences might occur over time due to maintenance regimes these would be expected to be relatively small; as unlike rail roughness which increases over time, wheel roughness stabilises fairly quickly after reprofiling. Therefore, the energy average of the eight measured wheels has been used to defined roughness for the Luas vehicles in preference to the default CNOSSOS-EU values.

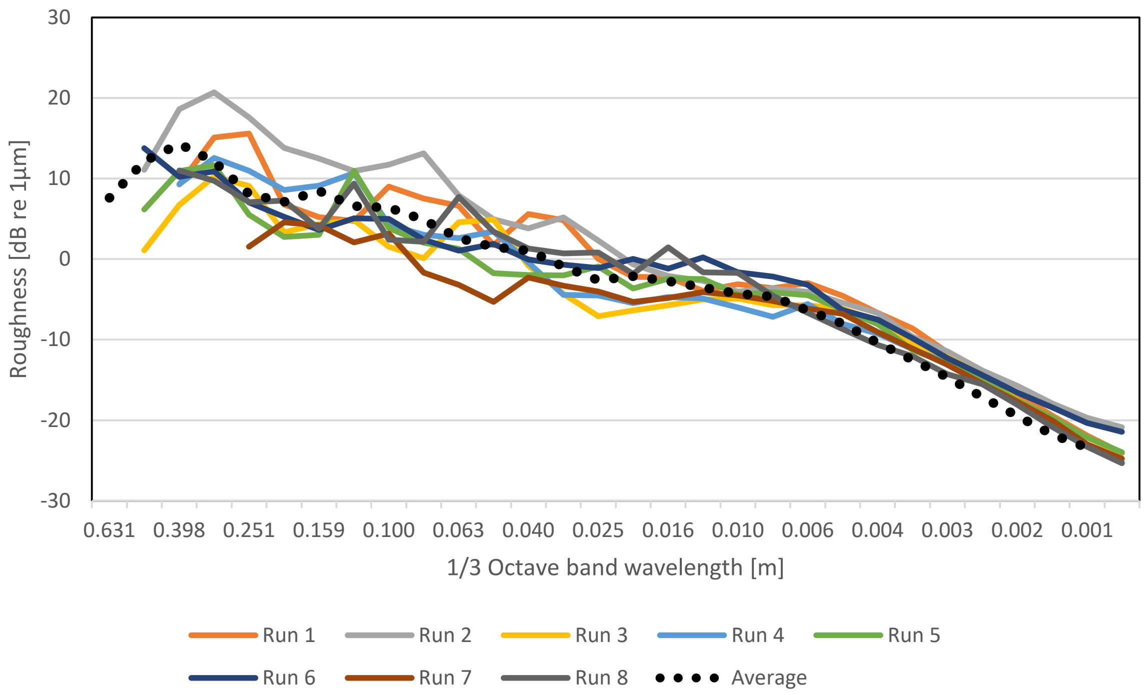

Figure 1 Wheel roughness of 8 wheels of a LUAS Citadis 402 tram

2.2 Wheel sound power transfer functions

The wheel sound powers depend primarily on the geometry of the wheel and if there is any additional noise mitigation (damping treatment) or resilient layers. In terms of the geometry, the diameter of the wheel is very important – as might be expected bigger wheels tend to be noisier. In addition, the shape of the profile can also be important. Tread braked wheels have a curve profile to allow for thermal expansion under braking. Whereas disc braked wheels have straight webs which tend to result in less noise.

The Citadis 402 trams operating on the Luas network have small (600mm), resilient, disc-braked wheels. These are relatively quiet. Measurements of the modal properties of the wheel were made in 2018 [6] and the wheel was modelled using an axisymmetric Finite Element model. These were used to generate inputs into the Train Noise Expert software to derive the vehicle transfer function. The assumed vehicle transfer function is shown in Figure 2.

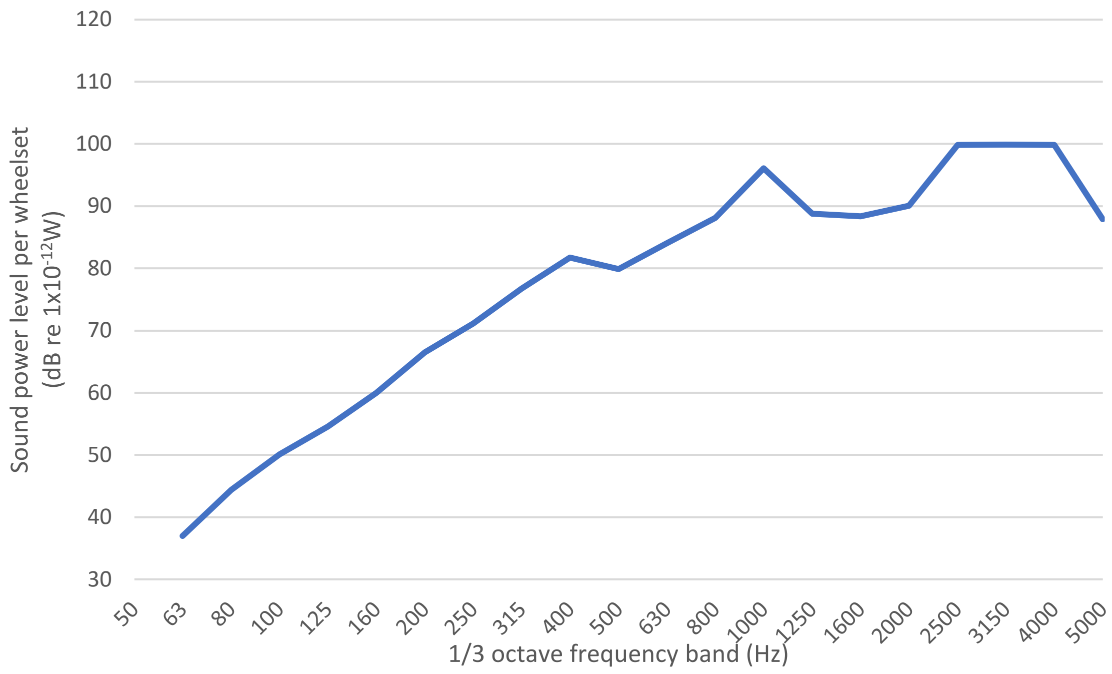

Figure 2 Vehicle transfer function for the Citadis 402 tram (CNOSSOS-EU directional sound power value)

Note that the definition of sound power in CNOSSOS-EU includes a directivity aspect (rolling noise is assumed to exhibit a 'dipole' directivity), and as such, this differs from the 'true' sound power of a source. The sound power results presented in this report are in terms of the CNOSSOS-EU directional sound power.

2.3 Rail roughness spectra

ISVR made measurements of rail roughness of the trackforms used on the LUAS Network in 2018 (except from embedded slab) using a CAT trolley according to EN15610 [9]: Ballast track, Slab track, slab track with dampers, slab track with track absorption, embedded grass track. These measurements were repeated for the recent project in 2022. In addition, a section of embedded slab track in the city centre was measured.

Due to the variation of roughness over time and maintenance interventions (e.g. the ballast track had been ground in the interim period), it has been considered than the recent (2022) roughness measurements were most applicable to the current state of roughness on the network. These are shown in Figure 3. The sections of slab track fitted with dampers and absorbers are only short sections of track where these mitigation measures were trialled. As can be seen, the roughness is very similar to the unmitigated slab and therefore the "Slab" roughness has been assumed for these in the CNOSSOS database. Whilst the grass and slab track are similar in roughness, these have been considered separately in the database as it is likely than these will experience different maintenance regimes in subsequent rounds of noise mapping and may differ going forward. Therefore, the following trackform roughnesses are defined in the database for LUAS:

- Ballast track
- Slab track
- Embedded grass track
- Embedded slab track

Rail roughness is the input parameter with greatest uncertainty and has the strongest potential to influence predictions. Rail roughness tends to be dominant over the wheel roughness at most wavelengths/frequencies – as is the case for LUAS. Rail roughness tends to increase over time in the absence of track interventions e.g., grinding or track renewals. Going forward, for the next round of noise mapping, it is recommended that ongoing network wide rail roughness measurements are made to understand variations of roughness over time, as these calculations could be further refined e.g., to consider maintenance history, time elapsed since grinding, traffic tonnage.

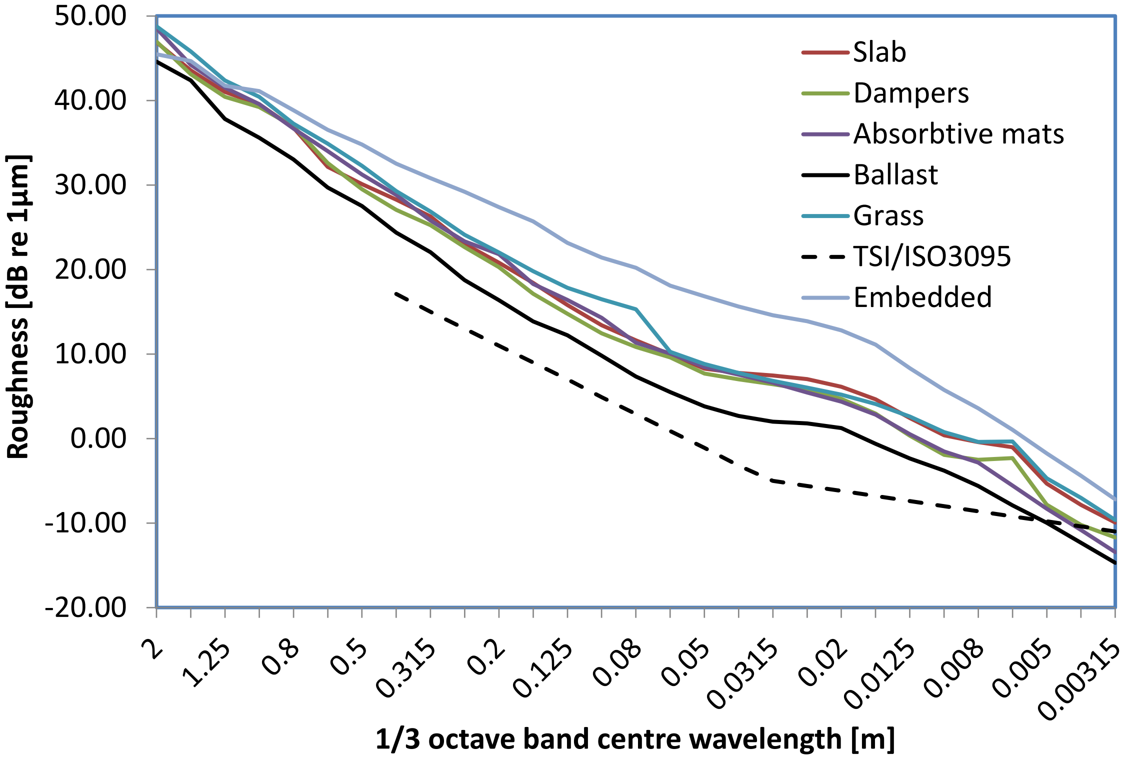

Figure 3 Rail roughness measurements on track forms of the LUAS Network (2022)

2.4 Track transfer functions

The rail sound power transfer functions are strongly dependent on the track formation (sleepers, rails, blast/slab etc). Of these parameters by far the most dominant is the stiffness of the rail pads between the rails and the sleepers. With softer pads the vibration is transmitted further down the track and the rails emit more noise. The track responses were derived using measured track decay rates according to EN15461 [10].

Unlike rail roughness, track decay rates tend to be consistent over time in the absence of track interventions (e.g., tamping, renewals). Although, there are some reported differences with ambient temperature e.g. [11].

The track decay rates were measured for the different trackforms of LUAS in 2018 (except for embedded slab). These measurements are still acceptable to use for inputs to CNOSSOS-EU as there have been no significant interventions since. In additional to these, measurements of the embedded slab track were made in 2022.

The sound power transfer functions were derived by inputting the relevant measured decay rates and the other track/rolling-stock parameters into the Train Noise Expert rolling noise model. These have been calculated for the main track types of the LUAS network (excepting the short trial sections of rail dampers and track absorption) (Figure 4).

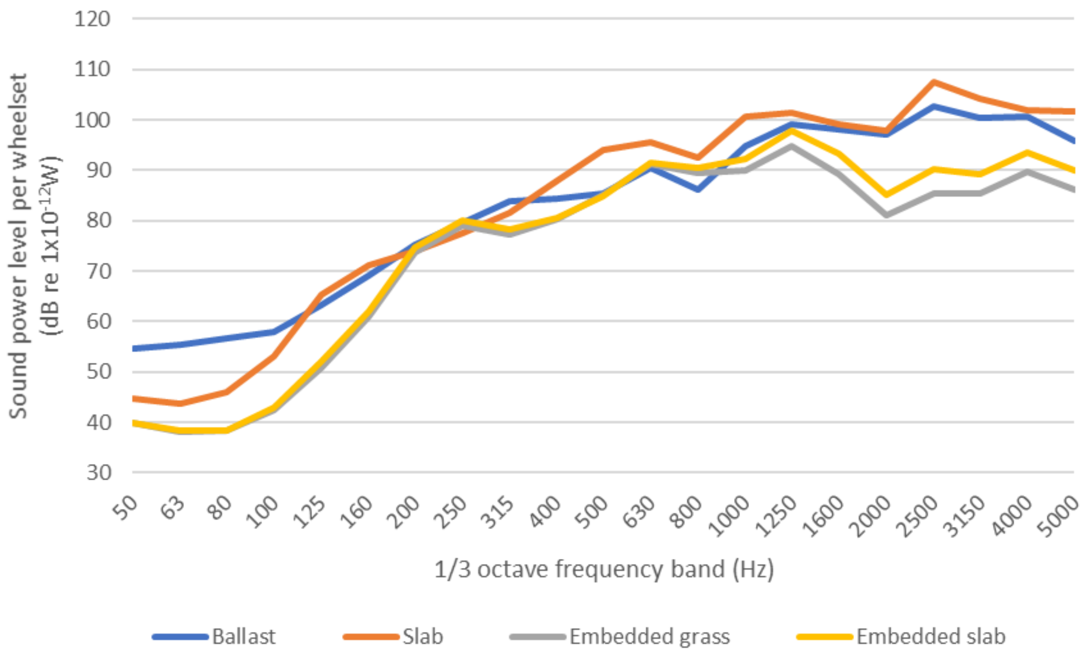

Figure 4 Track transfer functions for the LUAS network (CNOSSOS-EU directional sound power value)

2.5 Traction/Idling (engine) noise

CNOSSOS-EU:2020 includes data from IMAGINE for NL locomotives, DMUs and EMUs in terms of sound pressure level (L_p) but not the associated ground geometry required to allow for a good calculation of the ground attenuation.

TSI data for starting noise of all English heavy rail rolling stock type-accepted since TSI Noise came into force have been recorded. However, this data is not generally recorded for trams. In any case, measurement results in terms of spectra are required for CNOSSOS-EU whereas typically only the overall levels are reported for these tests.

The traction noise of seven in-service trams pulling away from Beechwood Station on the LUAS network were recorded to 'sense-check' the CNOSSOS-EU values. It was noted at the time of the measurements that rolling noise was generally dominant over the traction noise at the measurement position. Whereas idling noise was sufficiently low that it was dominated by other background sources. At this stage, due to the uncontrolled nature of the measurements it is considered more prudent to use the CNOSSOS default (Electric multiple unit) for this round of mapping. This should be reviewed for future rounds of mapping.

2.6 Aerodynamic noise

The assessment of noise from Luas has a reduced requirement for aerodynamic noise calculations as it is dominated by other sources.

2.7 Bridges

CNOSSOS gives default transfer functions for “steel bridges” and “steel bridges with wooden sleeper on girders”. Noise from concrete viaduct and masonry structures is not considered significant above the rolling noise.

It is our understanding that there are no steel bridges on the LUAS network, therefore no adjustments are necessary.

2.8 Squeal

Dealing with squeal presents a problem in that its occurrence is not predictable and the tonal sound is perceived differently so that it cannot usually be assessed using the same dBA scale as broadband noise.

Squeal is not a single phenomenon. There is the flange contact during curving (e.g. in points) if the vehicle does not travel at the designed speed of the cant; then there is rail-head contact steady howling squeal as a train traverses a curve in steady-state curving. Not every wheel or every train induces squeal, so a statistical estimate of the increase in noise is therefore required.

A correction factor for curve-squeal is currently included within CNOSSOS-EU:2020 based on the radius of curvature of the rail line, below a certain radius of curvature it should be considered that squeal will occur. A fairly arbitrary broadband sound level adjustment is then added.

Should a more realistic approach be seen as beneficial for local assessment, ISVR have a model that is able to predict the likelihood of curve squeal occurring, taking into account the curve radius as well as vehicle parameters. From ISVR's modelling, it may be possible to determine an improved criterion.

As with rail corrugation, squeal might be considered a correctable fault. It is not often the case that a correctable situation should be considered for strategic noise mapping predictions. However, unlike the clear maintenance solution to corrugation (grinding), squeal solutions are less certain. On the other hand, flange lubrication, friction modifiers etc. are gaining better evidence of their efficacy.

2.9 Horns/bells

CNOSSOS-EU:2020 does not include the sound emitted by horns on rail vehicles.

LUAS trams are fitted with bells that are sounded as general non urgent warnings e.g. approaching stations, approaching crossings etc. In addition, a horn is fitted for emergency warnings.

Measurements were made of trams sounding the bell at Beechwood Station at around 10 m. At this stage, these have not been included in the noise mapping within CNOSSOS. However, the data is available for either this round or subsequent rounds if it seen as being desirable for localised modelling, sound power for horns/bells could be dealt with by modelling them as static sources at sounding locations for the number of trams (and types of horn) within the time period. They would therefore be separate from the rest of the calculation of the rail noise source term.

2.10 Rail vehicles

CNOSSOS vehicle types have been defined in terms of the various transfer functions described in the relevant sections above. These are defined for the two variants of Citadis 402 tram operating (44m and 55m). These are based on the measured data and the various CNOSSOS-EU transfer functions and noise spectra in the database. They are summarised below:

- Axles – either 8 or 10, depending on variant of Citadis 402 (44 m or 55 m).

- Vehicle roughness – measured wheel roughness (2018)
- Contact filter transfer function. Calculated using Train Noise Expert for LUAS resilient wheel, 32.5 kN load, wheel diameter 600 mm.
- Wheel transfer functions – calculated using Train Noise Expert using measured wheel modal measurements (2018)
- Idling/traction noise – CNOSSOS defaults for Electric Multiple Unit
- Aerodynamic noise – Not included

2.11 Noise validation

Passby noise measurements were made on the main track forms of the LUAS system to validate the rolling noise predictions made using Train Noise Expert. The predictions were made using the input characteristics described in the sections above. The comparisons are shown in Figure 5 to Figure 8 below.

As can be seen there is reasonable agreement between measured and predicted results for most trackforms both in terms of the spectra and the overall A-weighted levels (given in the legends). However, the model under predicts the noise from the embedded slab track at high frequency and the overall A-weighted level by around 3.5 dB. It was noted during the measurements that the embedded slab track had a number of significant track defects which resulted in impact type excitations as the tram passed. For this type of excitation noise is not directly proportion to roughness as with normal roughness, which could account for the discrepancy. The current track transfer function for embedded slab in the CNOSSOS database could be corrected to account for impact noise in the current round of noise mapping – subject to discussion with LUAS.

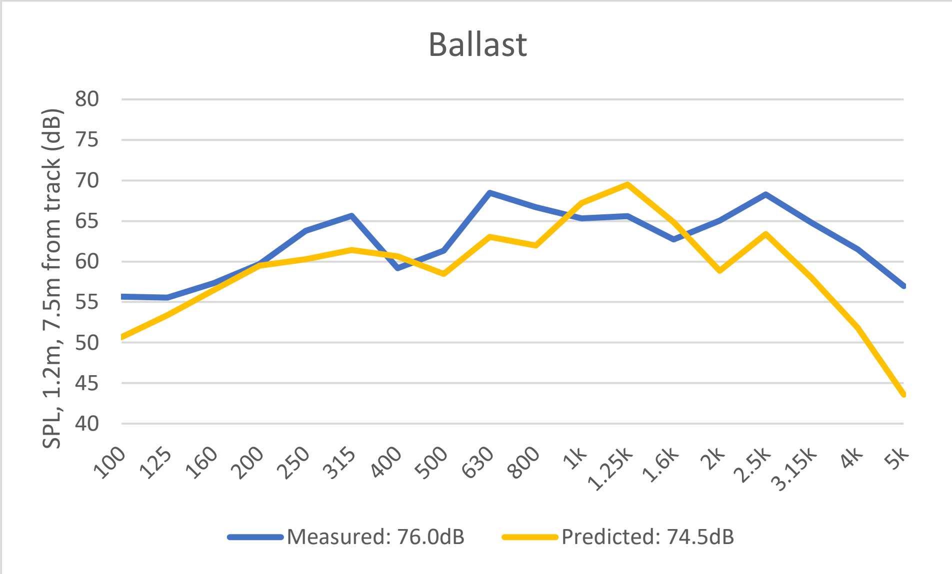

Figure 5 Ballast track Train Noise Expert predictions of rolling noise compared to 2022 measurements

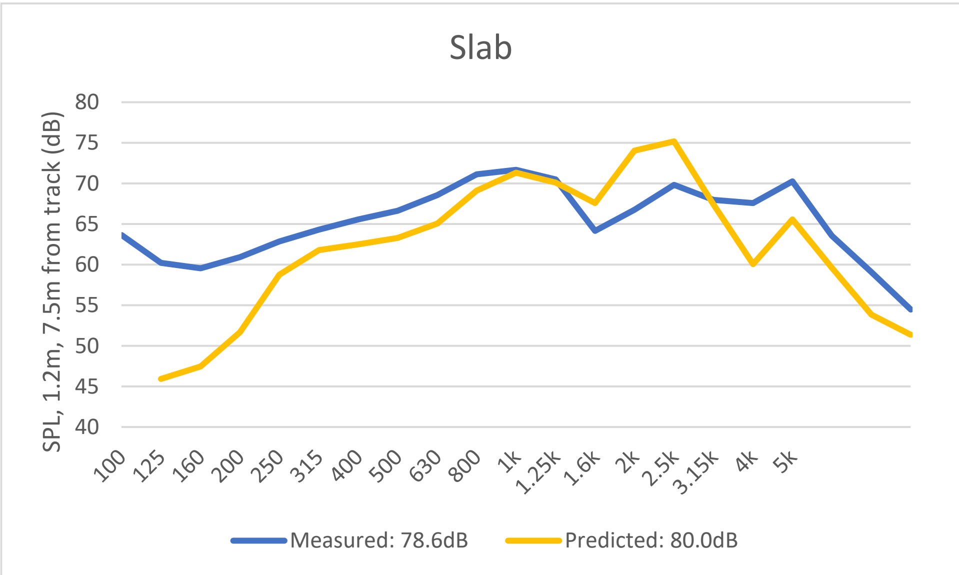

Figure 6 Slab track Train Noise Expert predictions of rolling noise compared to 2022 measurements

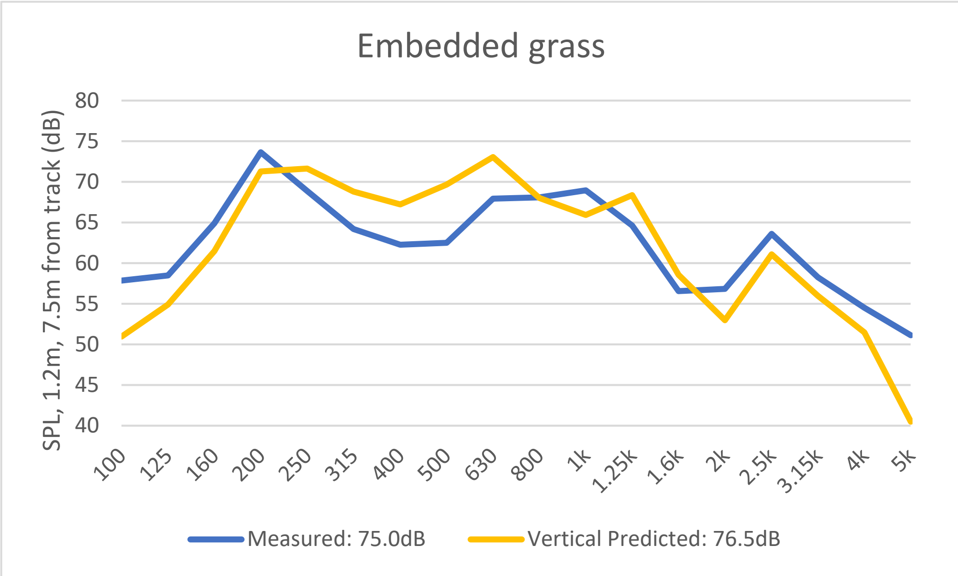

Figure 7 Embedded grass track Train Noise Expert predictions of rolling noise compared to 2022 measurements

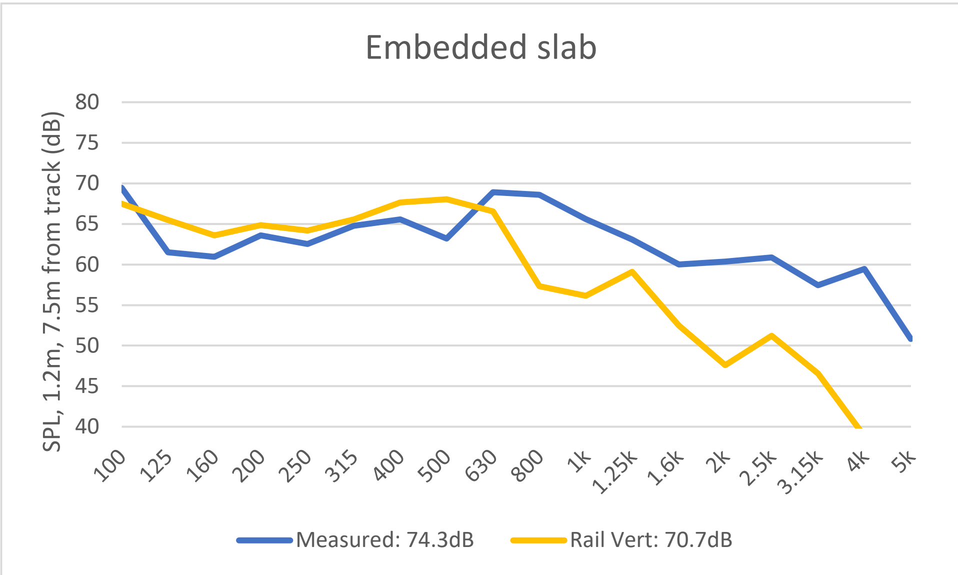

Figure 8 Embedded slab Train Noise Expert predictions of rolling noise compared to 2022 measurements

3. Conclusions

European Union Directive 2002/49/EC requires Member States to prepare and publish, every 5 years, noise maps and noise management action plans for transport including railway noise. LUAS have appointed ISVR Consulting to determine source terms of the Dublin tram network according to the new CNOSSOS methodology that is stipulated for the latest round of mapping.

In most situation of the LUAS network the dominant noise source is rolling noise, for which the CNSOSSOS-EU methodology uses a series of transfer functions for the vehicle, track, contact filter, wheel and rail roughness to determine sound powers per unit length of vehicles. We are proposing to base rolling noise terms on the TWINS approach (implemented through the Train Noise Expert software). This requires a series of inputs relating to the track and vehicle. Following an extensive measurement campaign, sufficient data was available to make these predictions for the LUAS network.

Track transfer functions have been presented (and provided separately in tabulated form) for the various LUAS track forms. Likewise, vehicle and contact filter transfer functions for the two variants of Citadis 402 tram operating on the network, and rail and wheel roughness transfer functions are presented based on measurement data. CNOSSOS defaults have been assumed for traction and idling noise as recorded data of trams leaving a station were not considered sufficiently robust.

Noise validation measurements agree reasonably well with predictions made using the input data for most track forms. Predictions were found to underestimate the high frequency noise for the embedded slab track – it is thought likely due to the way that the evident track defects are dealt with using the TWINS approach. A correction could be applied to the predictions to account for these track conditions.

Going forward, ongoing rail roughness measurements and controlled measurements of track/idling noise are recommended for the next round of mapping.

References

1. Commission Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. 18.07.2002 (2002)
2. Environmental Noise (England) Regulations 2006, UK Statutory Instruments, 2006 No. 2238
3. CNOSSOS: Commission Directive (EU) 2015/996 of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council, Official Journal of the European Union L 168/1
4. Corrigendum to Commission Directive (EU) 2015/996 of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council (Official Journal of the European Union L 168 of 1 July 2015), OJEU L 5 of January 2018
5. Commission Delegated Directive amending, for the purposes of adapting to scientific and technical progress, Annex II to Directive 2002/49/EC of the European Parliament and of the Council as regards common noise assessment methods, 21.12.2020, C(2020) 9101 final
6. Sun W., Thompson D.J., Toward M., Wiseman M., Ntotsios E., Byrne S. The influence of track design on the rolling noise from trams. Appl. Acoust., 170 (2020)
7. X. Zhang, H. Jeong, D.J. Thompson, G. Squicciarini. The noise radiated by ballasted and slab tracks. Appl Acoust, 151 (2019), pp. 193-205
8. Final Report Summary - ACOUTRAIN (Virtual certification of acoustic performance for freight and passenger trains) 2014
9. EN 15610 Railway applications - Acoustics - Rail and wheel roughness measurement related to noise generation (2019)
10. EN 15461 Railway applications - Noise emission - Characterisation of the dynamic properties of track sections for pass by noise measurements (2008)
11. Squicciarini, G, Thompson, DJ, Toward, MGR The effect of temperature on railway rolling noise. Proc IMechE, Part F: J Rail and Rapid Transit (2016)