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The TRANSIT project: innovation towards train pass-by noise source characterisation and separation tools

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Abstract

In TRANSIT, experimental methods are developed to separate and characterise noise sources on moving trains. Improved microphone array techniques allow quantification of sound power and directivity. Source separation methods based on the Pass-By Analysis method, Advanced Transfer Path Analysis and the TWINS model are also developed. For trains at standstill, new test methods are developed to quantify noise transmission paths from sources to the standard microphone positions accounting for installation effects. Several measurement campaigns are used to demonstrate and verify these methods. In addition, innovative materials and methods are investigated for improved sound comfort in trains. Approaches considered include optimal sound absorption at the source, attenuation along ducts for air conditioning systems and innovative meta-structure designs for the car-body parts.

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1. Introduction

Railway transport produces less CO_2 and consumes less energy than road and air transport modes; it also requires less space than road transport. However, noise and vibration levels in the vicinity of railways are a major environmental challenge for the railway sector. Populations in the vicinity of railways no longer accept the increasing annoyance due to noise and vibration. Moreover, a competitive railway transport system demands better passenger comfort.

The overall goal of TRANSIT is to provide the railway community with a proven set of innovative tools and methodologies to reduce the environmental impact and improve the interior acoustic comfort of railway vehicles. The main objectives of the TRANSIT project are:

- Streamlining of rail vehicle noise certification to reduce lead time and costs, and lower the operator's track occupation requirement for testing by providing accurate virtual certification tools,
- Reducing the need for a TSI-compliant test track by developing and demonstrating accurate separation and transposition techniques,
- Deriving a more precise and better-founded definition of acoustic requirements for equipment suppliers, hence reducing time and cost,
- Improving source quantification for noise mapping and a more accurate assessment of noise abatement measures,
- Enabling lighter vehicles, thus lower energy consumption, while maintaining high levels of interior acoustic comfort.

Most of the activities in TRANSIT are focused on the experimental characterisation, modelling and separation of railway noise sources (at standstill and during pass-by) as well as the further development of the Acoutrain external noise prediction tool to account for installation effects in the transmission paths. New test methods are also developed to quantify noise transmission paths from sources on rail vehicles to the standard microphone positions accounting for installation effects.

In addition, the project is also focused on the investigation on innovative materials and methods for an improved sound comfort. Those approaches will be used to improve the design of the interior acoustics of future rolling stock. Several possible approaches are being considered, including optimal sound absorption at the source, attenuation along ducts for air conditioning systems and innovative meta-structure designs for the car-body parts. The technical focus of the project lies in four work streams which are described in the following sections.

2. Source and transmission characterisation for exterior noise

One problem for railway noise predictions is to characterise noise from various auxiliary equipment sources, e.g., fans, compressors, transformers. The noise from such sources can be a dominating contribution under low-speed operation or standstill. To handle this problem better, TRANSIT investigates improved methods for acoustic source characterisation. As a starting point it is assumed that an acoustic source is enclosed by a control surface. The surface is sub-divided into smaller areas and each area is assumed to act as an acoustic one-port coupled to all the other areas, see Fig. 1.

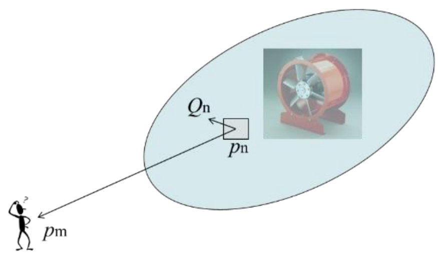

Fig. 1. Illustration of the source multi-port model.

The properties of each area can then be described by its volume flow and internal impedance. The resulting acoustic pressure at a receiving point, can finally be expressed as a product of the source volume flows and a matrix representing the acoustic installation effects ("source+radiation impedances") (Åbom, et al., 2020; Feng, et al., 2015). To simplify the method one can assume the sources are uncorrelated and use an ISO standard procedure for sound power to determine the volume flows. The acoustic installation effects can be obtained using a calibrated monopole point source to measure or calculate the pressure at selected receiving positions. The proposed simplified model is based on averaging the complete equivalent monopole model (Åbom, et al., 2020; Feng, et al., 2015) in frequency bands, e.g., 1/3-octaves. This removes the phase information which is appropriate for sources with broad-band noise character, e.g., a HVAC fan. Tonal noise and coherent sources should also be handled, by assuming that either there are a number of tones in the frequency band or multiple source-receiver transmission paths, e.g., for a source placed inside a reverberant box. For cases where these conditions are not satisfied it is recommended to use the complete equivalent monopole method, e.g., by applying iterative Bayesian focusing (Le Magueresse, et al., 2020; Antoni, et al., 2019; Pereira, et al., 2015).

The proposed method has been validated by controlled measurements at the Marcus Wallenberg laboratory at KTH using generic loudspeaker sources on a train mock-up, see Fig. 2.

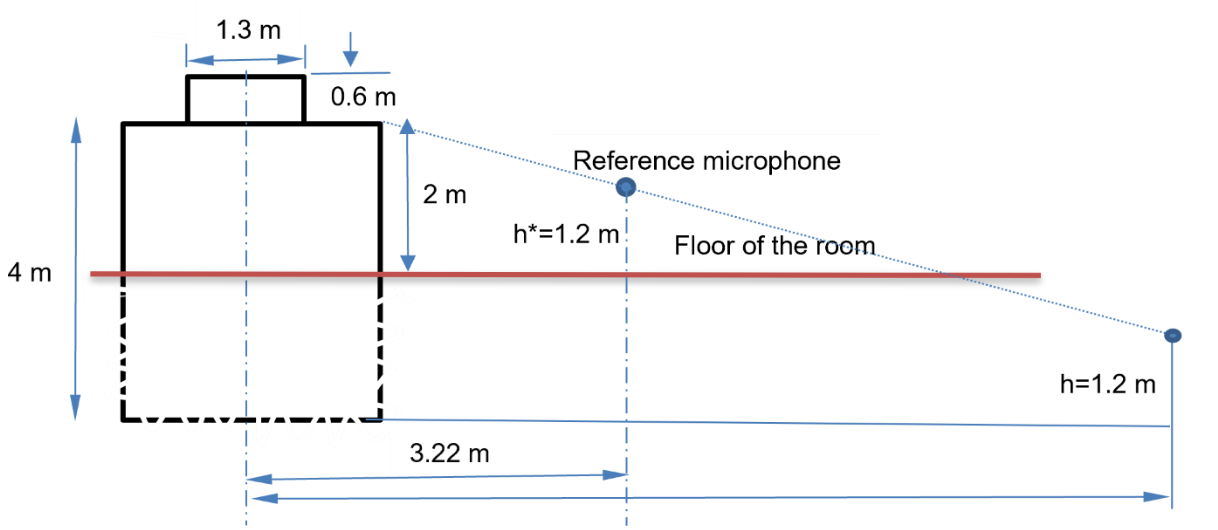

Fig. 2. Illustration of train mock-up geometry with a roof mounted box with open top and the position of the reference microphone. The generic sources were placed inside the box (Åbom, et al., 2020).

Based on the investigations carried out, it is concluded that the simplified equivalent monopole method has been validated for generic sources under laboratory conditions (Åbom, et al., 2020). Since the tested sources represent the three basic sources (monopole, dipole, quadrupole) from which any real sources can be built up, it is believed that the results also support that the method will work for real sources. The effort to validate this last statement is delayed due to Covid-19, but is planned to be finished by June 2022.

3. Pass-by noise source separation

For noise sources on a moving train, such as aerodynamic noise, traction noise, rolling noise, and equipment noise, advances are achieved in obtaining the sound power level and directivity during the pass-by of the train at a constant speed. Furthermore, at least two different methods are provided: one with a microphone array, and the other based on single microphones using the Pass-By Analysis (PBA) approach (Sarradj, et al., 2022; Janssens, et al., 2006).

The method with the microphone array is based on the CLEANT procedure (Cousson, et al., 2019; Kujawski, et al., 2020) and allows the calculation of acoustic source maps of an entire train. Since the method uses deconvolution and is working on a moving grid, effects like the Doppler effect and convective amplification are taken into account. In addition, spatial integration can be used to determine the strength of source regions. An example application is shown in Fig. 3 (left), where the method was applied to the measurement of a diesel-powered train moving at 80 km/h. Due to the confidentiality of the measurement data, no absolute level is given but only the dynamic range. The source map allows a clear identification of primary sound sources, in this case the area of the powerpack at 4 – 6 m.

Furthermore, an angle-dependent evaluation strategy has been developed, which can estimate the directional characteristics of selected source regions. In Fig. 3 (right), this strategy was used to investigate the directivity of the powerpack region. The evaluation of this area shows a monopole-like directivity characteristic which is to be expected for this source.

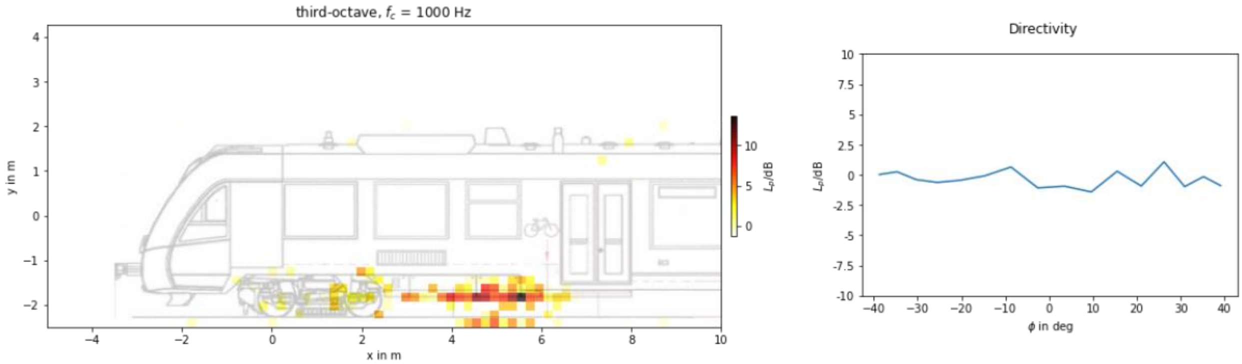

Fig. 3. Source map obtained using the CLEANT method (enlarged view of the first coach) third-octave band, 1000 Hz (left). Estimated directivity of the power pack area (right).

The method based on PBA determines the combined transfer function from roughness to sound pressure for rolling noise by subtracting of the total roughness level from the measured sound pressure level. The combined transfer function is used to characterise rolling noise. It is assumed that all spectral deviations from the rolling noise transfer functions are due to other sources.

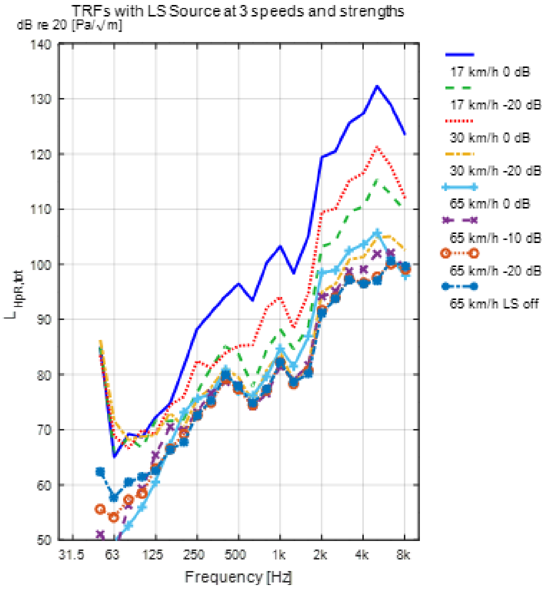

Fig. 4. Evaluated total transfer functions of the test train for different speeds and loudspeaker source settings (0 dB is highest).

An application of the method is shown in Fig. 4 using data measured at Metro de Madrid. Pass-by speeds of 17, 30 and 65 km/h were investigated with an omnidirectional, broadband loudspeaker attached to the train, operating at different source strengths in addition to the rolling noise. Sound power level estimates can be obtained using backward propagation models including ground effects. Source directivity can be approximated from the level history slope in individual frequency bands.

4. Separation of track noise and vehicle noise

The TSI Noise (2014) specifies noise limits for new vehicles, which must be achieved on a track with a low contribution to the noise, specified in terms of track decay rate and rail roughness level. However, the track contribution to the noise, and its roughness, are still important contributors to the overall level, meaning it is difficult to compare results measured at different sites. It is therefore important to be able to separate the contributions of vehicle and track. In TRANSIT, promising techniques from the Roll2Rail project for the separation of rolling noise contributions (Thompson, et al., 2018) are being further developed, simplified and/or enhanced. The methods should also be able to 'transpose' pass-by data measured on one track to another track; wheel and rail roughness separation is also investigated. Three proposed separation methods are considered and further developed.

4.1. TWINS model

The TWINS model (Track-Wheel Interaction Noise Software) for rolling noise (Thompson, et al., 1996) is based on a series of engineering models for the vibration and noise radiation of wheel, rail, and sleepers which are excited by the combined surface roughness. To use this model for source separation, it is combined with measured rail vibration. Improvements to this approach in TRANSIT are based on recent developments in modelling track sound radiation (Zhang, et al., 2019). The effect of reflections from the underside of the vehicle is also being investigated, by using 1:5 scale models and boundary element calculations (Fig. 5).

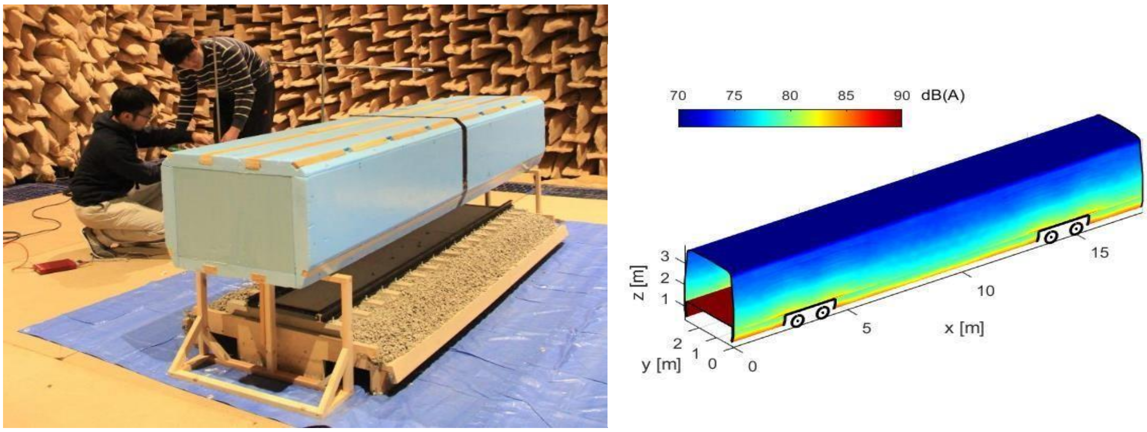

Fig. 5. Investigations of the effect of the vehicle on rolling noise. Left: 1:5 scale model tests; right: boundary element model.

4.2. Pass-By Analysis (PBA)

The PBA method uses sound pressure and rail acceleration signals of multiple pass-bys at different speeds (Janssens, et al., 2006). From the analysis of these signals, the track decay rate, combined effective roughness levels, and combined vibro-acoustic transfer function are obtained. This allows the separation of roughness excitation and combined (vehicle and track) response. Further separation of vehicle and track components is considered in the project, based on separately measured transfer functions for vehicle and track (static measurements). Two different methods are considered: direct excitation with a hammer and a reciprocal method using loudspeaker excitation. Separation of wheel and rail roughness will also be performed through PBA by monitoring mixed traffic, identifying minimum combined roughness levels in each wavelength band, and providing an upper bound for rail roughness.

4.3. Advanced Transfer Path Analysis (ATPA)

Advanced Transfer Path Analysis (ATPA) is an experimental method for obtaining noise contributions from different parts of a system, by decomposing the sound pressure at the target location as the sum of the noise contributions considered (Magrans, 1981; Malkoun, et al., 2019). To apply ATPA to rolling noise separation, the relevant track section is divided into subsections (Fig. 6). Both static measurements (with hammer excitation) and dynamic (pass-by) measurements are carried out and combined. Each subsection (red dashed box) includes a vertical accelerometer on each rail, a horizontal accelerometer on each rail, and a vertical accelerometer on one sleeper. The four wheels of one bogie are instrumented in radial and axial directions. The aim in TRANSIT is to simplify ATPA in terms of equipment, time, and resources. Various simplifications are being considered: measuring a reduced set of static functions and deducing the rest from calculation, assessing the use of reciprocally measured static functions, or measuring the static functions without the train present and applying some corrections.

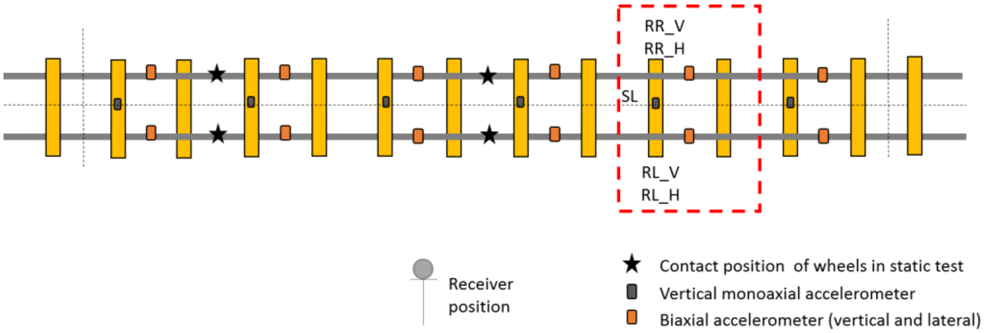

Figure 6: Diagram of instrumentation set-up on the track for ATPA method.

5. Field tests

Extensive field measurements are being carried out to validate the various methods developed in the project, both for wheel/track separation and for the characterisation of other sources on a moving train. A preliminary set of tests was carried out at Metro de Madrid. Fig. 7 shows pass-by noise measurements on a moving train and the sound sources used for reciprocal measurements of acoustic transfer functions.

Fig. 7. Measurements at Metro de Madrid. Left: pass-by noise measurements. Right: sound sources used for reciprocal measurement.

Three further test campaigns are organised in collaboration with the FINE-2 project. The first, in November 2021, was on a metro train, focusing only on wheel/track source separation. For this, the methods described in Section 4 are being applied. The second campaign, in March 2022, was on a regional train with various types of auxiliary equipment, traction noise and rolling noise. The third campaign is planned on a high-speed train that additionally includes aerodynamic noise. All methods in Sections 3 and 4 will be applied to these two campaigns.

6. Innovative designs for interior noise

In the final workstream, innovative approaches and material designs are being explored for improved interior sound comfort. A feasibility study was first carried out into several potential solutions. These focused on meta-structure designs and other tailored material design. The potential for interior noise reduction and the possibility for practical implementation have been assessed and the two most promising solutions have been chosen for further development.

Noise reduction in an HVAC duct system is targeted at frequencies associated with the fans. Ultra-thin low frequency (UTLF) resonator arrays were considered in a feasibility study with the result that many single UTLF would be needed. A simplified design is proposed based on a membrane with an array of small masses and a perforated plate (Fig. 8). A reduction of 15 dB has been found to be achievable at 250 Hz. The second solution aims to minimise the noise from the train horn inside the driver's cab. To achieve this, acoustic metamaterials (Fig. 8) are placed in a box surrounding the horn. These are tuned to have a very high absorption at the two target frequencies, 370 Hz and 660 Hz, which reduces the sound transmission from the horn into the driver's cabin. For both solutions prototype tests will be carried out in the laboratory and in a realistic set-up.

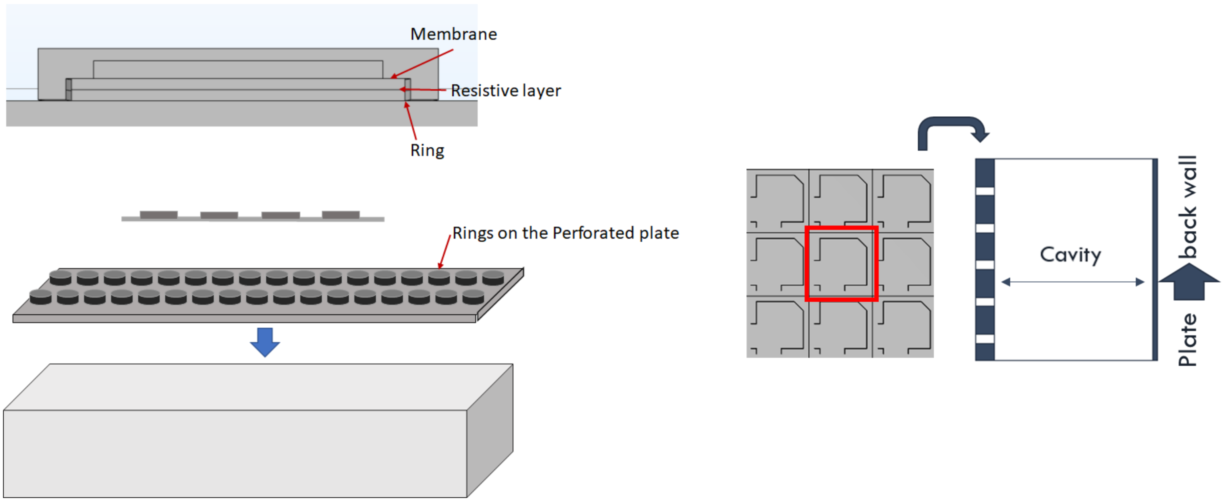

Fig. 8. Left: Concept for ultra-thin low frequency resonator array for application in HVAC duct. Right: Micro-slit metamaterial backed by a cavity used for horn cover.

7. Conclusion and Outlook

The main expected impacts of TRANSIT arise from the methods and tools that will give a better understanding and quantification of the contribution of the different sources to the total pass-by noise. That will, in turn, lead to innovations in low noise design of vehicles and tracks, virtual testing for certification, and the derivation of source terms for EU and national prediction models, among others.

The common endeavour in TRANSIT will provide an accurate description of sound power levels and directivities of individual noise sources, which is the key to future breakthrough developments in railway design and (virtual) certification testing. The expected impacts include a reduction in cost and effort required for certification testing, greater comparability and reproducibility of test results and ultimately improved competitiveness for the EU rail industry and increased social acceptance of railways facilitating modal shift.

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References

Åbom, M., et al., 2020. Validated procedure for source characterization based on equivalent monopoles and tests involving generic sources. TRANSIT Deliverable D1.1.

Antoni, J., Le Magueresse, T., Leclère, Q., Simard, P., 2019. Sparse acoustical holography from iterated Bayesian focusing. Journal of Sound and Vibration 446, 289-325.

Cousson, R., Leclère, Q., Pallas, M.-A., Bérengier, M., 2019. A time domain CLEAN approach for the identification of acoustic moving sources. Journal of Sound and Vibration 443, 47-62.

Feng, L., Åbom, M., Orrenius, U., 2015. Engineering methods to predict noise levels at reference points with known source properties. Applied Acoustics 96, 68-74.

Janssens, M.H.A., Dittrich, M.G., de Beer, F.G., Jones, C.J.C., 2006. Railway noise measurement method for pass-by noise, total effective roughness, transfer functions and track spatial decay. Journal of Sound and Vibration 293, 1007-1028.

Kujawski, A., Sarradj, E., 2020. Application of the CLEANT method for high-speed railway train measurements. Proceedings of the 8th Berlin Beamforming Conference (BeBeC), Berlin, Germany.

Le Magueresse, T., Outrequin, A., Thivant, M., Antoni, J., Jouvray, J-L., Rober, E., 2020. 3D acoustical characterization of an electrical motor by Bayesian Focusing. Proceedings of the 8th Berlin Beamforming Conference (BeBeC), Berlin, Germany.

Magrans, F.X., 1981. Method of measuring transmission paths. Journal of Sound and Vibration 74, 321-330.

Malkoun, A., Iturritxa, E., Cierco, E., Guiral, A., Sapena, J., Magrans, F.X., 2019. Vehicle and track noise separation methodology based on Advanced Transfer Path Analysis technique. Proceedings of the 13th International Workshop on Railway Noise, Ghent, Belgium.

Pereira, A., Antoni, J., Leclère, Q., 2015. Empirical Bayesian regularization of the inverse acoustic problem. Applied Acoustics 97, 11-29.

Sarradj, E., Czuchaj, M., Dittrich, M., Jansen, E., 2022. Innovative separation techniques: theoretical description and validation testing campaign proposal. TRANSIT Deliverable D2.2.

Thompson, D.J., Hemsworth, B., Vincent, N., 1996. Experimental validation of the TWINS prediction program for rolling noise, part 1: description of the model and method. Journal of Sound and Vibration 193, 123-135.

Thompson, D.J., et al., 2018. Assessment of measurement-based methods for separating wheel and track contributions to railway rolling noise. Applied Acoustics 140, 48-62.

TSI Noise, 2014. Commission Regulation (EU) No 1304/2014 of 26 November 2014 on the technical specification for interoperability relating to the subsystem 'rolling stock — noise' amending Decision 2008/232/EC and repealing Decision 2011/229/EU. Official Journal of the European Union L356 (12 December 2014) 421-437.

Zhang, X., Thompson, D., Quaranta, E., Squicciarini, G., 2019. An engineering model for the prediction of the sound radiation from a railway track. Journal of Sound and Vibration 461, 114921.