FINE 1

D8.4 - Standardization proposals and specifications for IP1

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EXECUTIVE SUMMARY

The objective of this task, T8.4, is to agree in an industrial methodology for the specification of noise and vibration requirements of sources (e.g. traction motor, HVAC, gearbox,…) and sub-assemblies (e.g. floor, door, windows,…).

- In task T8.2, an analysis of the different standards used by rolling stock manufacturers in order to characterise acoustic sources and subassemblies was carried out. The main strengths and weaknesses were identified and proposals for improvement were made. In task T8.4 links to current standardization working groups for the characterisation of sources and train assemblies will be established in order to inform them about the main results and recommendations for improvements will be issued.
- On the other hand, the objective of T8.1 was to define the requirements necessary for the characterisation of sources and sub-assemblies to be used as inputs for interior and exterior noise simulation tools. In T8.4 the specifications with targets defined in task 8.1 will be transmitted and discussed to S2R IP1 projects dealing with sources and train assemblies.

ABBREVIATIONS AND ACRONYMS

ABN	Airborne noise
SBN	Structure-borne noise
SUB	Train subassembly
S2R	Shift2Rail
SPL	Sound pressure level
SWL	Sound power level
TL	Transmission loss

LIST OF SYMBOLS

$\mathbf{v}_r$	Velocity vector (m.s^{-1});
$\bar{\mathbf{f}}_c$	Vector of blocked forces at the contact degrees of freedom (N);
$\mathbf{Y}_{rc}$	Mobility matrix connecting the indicator and contact degrees of freedom (s kg-1).
$\mathbf{v}_v'$	Predicted vector of velocities (or accelerations) at the validation degrees of freedom
$\mathbf{Y}_{vc}$	FRF matrix of validation degrees of freedom
$\bar{\mathbf{f}}_c$	Vector of blocked forces at the contact degrees of freedom
$\mathbf{p}$	Sound pressure
$\bar{\mathbf{f}}_c$	Vector of blocked forces at the contact degrees of freedom
H_r	Matrix of train vibro-acoustic transfer functions (measured without the source)
Y_s	Source mobility matrix.
Y_r	Train (or receiver) mobility matrix

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The FINE 1 project aims to reduce operational costs of railway vehicles by a reduction of energy use and noise related to rail traffic. The project is divided into eight technical work packages (WPs), from which WP5 to WP9 address noise objectives. Among the various noise objectives, the project aims at developing practical methods for predicting noise and vibration performance on system level including rolling stock, infrastructure and its environment.

The scope of WP8 “Sources and assemblies” is to develop characterization and specification methodologies for sources and train assemblies.

- The objective of T8.1 was to define the requirements necessary for the characterisation of sources and sub-assemblies to be used as inputs for interior and exterior noise simulation tools. As such, the work was carried out in coordination with work package 7 “Interior noise modelling” and the results of the European project Acoutrain. A prioritisation of the type of sources and sub-assemblies was done related to their importance for interior and exterior noise contributions in different scenarios (free-field, tunnel, and viaduct).
- In task T8.2, the current source and sub-assembly characterisation and specification methods used by the rolling-stock manufacturers were compiled and analysed in order to identify their strength and weakness. Based on the results, recommendations for improvements were provided.
- Agreed new and improved methodologies from task 8.2 were applied in task 8.3 to analyse different sources and sub-assemblies for its validation. The structure-borne noise of an air generation unit and a traction motor were analysed as well as the airborne noise of a gearbox. For train sub-assemblies, the validation was focused on the comparison of laboratory performances with in-situ measurements. Uncertainties of the testing methods were analysed in order to take into account noise predictions.
- The objective of T8.4 is to agree on an industrial methodology for the specification of sources and sub-assemblies. An analysis of current standards and the link needed for the application of the new methods will be done. Links to current standardization working groups for the characterisation of sources and train assemblies will be established and recommendations for improvements will be issued. In addition, specifications with targets defined in task 8.1 will be transmitted and discussed to S2R IP1 projects dealing with sources and train assemblies.

2. STANDARDIZATION WORKING GROUPS

This chapter deals with the first objective established for task 8.4, that is, to analyse the current standards in order to agree in an industrial methodology for the specification of sources and sub-assemblies. In T8.2, the current source and sub-assemblies characterisation and specification methods used by the rolling-stock manufacturers were compiled and analysed in order to identify their strength and weakness and propose some recommendations for improvement. The goal here is to contact the different standardization groups and provide the results of the analysis done to them.

This section indicates the contacted standardization groups and summarizes the information provided to each of them.

2.1 AIRBORNE NOISE RELATED STANDARDIZATION GROUPS

Current methodologies for the characterization of airborne noise sources rely on international standards well known by the railway industries. The most used ones were compiled and analyzed in order to identify strengths and weaknesses and make proposals for improvements. Within a previous task of WP8 proposals of improvements of airborne noise characterization methods were applied to the derivation of the airborne noise sound radiated by a gearbox. The results were presented at the Internoise Conference in June 2019 in Madrid (“Airborne sound source characterization for railway noise predictions - based on vibration measurements and numerical simulations”).

This analysis was sent to the corresponding working groups to be considered in future revisions. This section presents the information provided to each standardization group.

2.1.1 ISO 9614 – Determination of sound power levels of noise sources using sound intensity

Description

The ISO 9614 standard series [1]-[3] describes the method for the determination of the **sound power level** of a noise source based on the measured sound intensity. This standard is widely used as it does not require access to anechoic or reverberant. Part 1 is based on the measurement of the intensity at discrete locations and part 2 defines a further sound power measurement method that allows the use of a scanning method.

Strengths

- The intensity-based approach for determining the total sound power level and sound power level per face, as covered by ISO 9614-2:1996, is a reliable method with engineering (grade 2) accuracy which is sufficient for the characterisation of stationary (i.e. not transient) noise sources. Sound intensity measurements following this standard are highly repeatable and can be conducted under less strict environmental conditions than the pressure-based method of ISO 3744:2010.

Weaknesses

- ISO 9614-2 does not offer precision grade measurements.
- ISO 9614 is not an accurate means of characterising non-stationary noise sources such as intermittent noise sources.

Proposals for improvement

- Compliance with ISO 9614-2:1996 (or ISO 3744:2010) must be specified in the determination of sound power level, depending on the nature of the source, i.e. stationary or non-stationary and whether sound power per face and/or directivity is required.
- An improvement for the support of FINE2 WP6 would define the necessary acoustic properties that are needed for the reproduction of integration effects on real trains. This is still an open point from ACOUTRAIN.

2.1.2 ISO 3744 – Determination of sound power levels of noise sources using sound pressure

Description

ISO 3744 [4] specifies methods for determining the sound power level of a noise source from sound pressure levels measured on a surface enveloping the noise source in an environment that approximates to an acoustic free field near one or more reflecting planes. The sound power level is calculated using those measurements.

Strengths

- The sound pressure-based approach for determining the total sound power level described in ISO 3744:2010, enables the characterisation of non-stationary noise sources such as intermittent noise sources, as well as stationary sources.
- ISO 3744:2010 is also suitable for characterising noise sources in general, under different operating conditions. This is particularly relevant to sub-system or component such as traction motors and gearboxes, which, due to their operation, may have non-stationary noise components.

Weaknesses

- ISO 3744 does not offer precision grade measurements.
- ISO 3744:2010 requires a free-field testing environment which may be problematic for some sources.

Proposals for improvement

- Compliance with ISO 3744:2010 (or ISO 9614-2:1996) must be specified in the determination of sound power level, depending on the nature of the source, i.e. stationary or non-stationary and whether sound power per face and/or directivity is required.
- If precision grade pressure-based measurements of sound power level are required, instead of ISO 3744:2010, ISO 3745:2012 must be specified for testing in anechoic or semi-anechoic chambers [16] or ISO 3741:2010 must be specified by the FINE1 manufacturers for testing in reverberation chambers.
- Validation should be carried out for the use of assemblies on trains in the free field with reflecting the surface. This supports the modification of inventory stock with support of models.

2.1.3 ISO 2151 –Noise test code for compressors and vacuum pumps

Description

ISO 2151 describes a method for determining and presenting the acoustical characteristics of stationary compressors and vacuum pumps, i.e. the total noise level from the compressor or vacuum pump expressed as sound power level, or emission sound pressure level at the work station or other specified positions. It prescribes the mounting, loading and working conditions under which measurements are to be made, and includes measurement or determination of the noise emission expressed as the sound power level under specified load conditions and the emission sound pressure level at the work station under specified load conditions.

Strengths

- The use of specific standardised test methods for determining sound power levels of compressors and pumps, enable the characterisation of these noise sources under defined and relevant operating conditions.

Weaknesses

- Not all manufacturers follow the test methods defined for specific types of machinery.

Proposals for improvement

- Standardised test methods should be specified by all manufacturers, as they provide testing guidelines for a specific type of machinery.
- Very useful would be a validation for HVAC Systems used on trains. A lot of noise, as well as vibration, issues occur on new trains since a defined intersection between the car body and HVAC system is missing.
- Contact forces should be added as a boundary condition, If possible mutable.

- Worthful would be an enhancement of the directivity for the use of the data in models (like ACOUTRAIN or the corresponding work in FINE 2 WP6).

2.1.4 ISO 13347 Determination of fan sound power levels under standardized laboratory conditions

Description

ISO 13347:2004 deals with the determination of the acoustic performance of industrial fans. The text of the standard comprises four distinct parts, a general introduction and presentation of the three test methods adopted, i.e. the reverberant room, enveloping surface and intensity methods.

Strengths

- The use of specific standardised test methods for determining sound power levels of fans, enable the characterisation of these noise sources under defined and relevant operating conditions.

Weaknesses

- Not all manufacturers follow the test methods defined for specific types of machinery.

Proposals for improvement

- Standardised test methods should be specified by all manufacturers, as they provide testing guidelines for a specific type of machinery.
- HVAC noise characterisation measurement methods that take into account the multisource characteristics should be developed and standardised.

  The method should be validated for fans with owlet wings which were successfully used in S²R PINTA for a noise reduction of an HVAC System while keeping the cooling performance.

2.2 Structure-borne noise related standardization groups

Within the second task of the work package 8, strength and weaknesses of methodologies related to structure-borne noise specification and characterisation and currently applied by the train manufacturers have been identified and proposal of improvements have been made to improve them. Main characterisation methodologies are summarized in the following table.

	Direct Contact Force Measurement	Blocked Force Direct Measurement	In-Situ Blocked Force	Inverse Force Synthesis	Free Velocity
Allow Independent Characterisation	No	Yes	Yes	No	Yes
Associated Standards	**ISO18312:2012**	**ISO18312:2012**	**ISOCD20270 (2020)**	**NA**	**ISO 9611:1996 ISO 13332:2000**
Uncertainty at low frequencies	Unknown	Low	Low	Low	Low
Uncertainty at high frequencies	Unknown	Low	Low	Low	Low
Required Expertise Level	Med/High	Med/High	High	High	High
Setup Costs	Bespoke test rig needed	Bespoke test rig needed. Blocked condition difficult to achieve	Bespoke test rig needed.	Bespoke test rig needed.	Bespoke test rig needed. Free-free condition difficult to achieve
Allow measurements to be performed under load	Yes	Yes	Yes	Yes	Often Not

Table 1: Methodologies for structure-borne noise characterisation

Within the third task of the same work package, proposals of improvements have been applied and validated on 3 cases: an AGTU (air generation treatment unit), an HVAC unit and an electric traction motor. The AGTU case will be presented at the Internoise Conference in June 2019 in Madrid ("Structure-borne noise characterization of an air generation and treatment unit (AGTU) for a train by using blocked forces method").

2.2.1 ISO/DIS 20270 - Acoustics – Characterization of sources of structure-borne sound and vibration – Indirect measurement blocked forces

Based on the analysis carried out, it is proposed to set ISO/DIS 20270 "Acoustics – Characterization of sources of structure-borne sound and vibration – Indirect measurement blocked forces" as the new standard for the characterisation of rolling stock components.

This standard is currently under development within the ISO / TC 43 / SC 1 and is available for download in the draft version. It will be approved and published by 2020. The AGTU case has strictly followed the recommendations provided within this ISO standard.

The ISO/DIS 20270 proposes a method of characterizing sources of structure-borne sound and vibration by the indirect measurement of blocked forces at the points of connection to supporting, or receiver, structures.

The measurement method is applied in situ, which means that the source is connected to a supporting, or receiver structure, whilst the measurements are performed. In theory, the use of any receiver structure is valid provided the vibration source mechanisms of the specimen remain representative of those in a real installation. Therefore, the receiver structure can be part of a real installation, such as a machine foundation or a building, but can also be a specially designed test stand provided it provides representative dynamic loading for the source.

The blocked forces are obtained in narrowband by solving the inverse problem. A means of estimating the uncertainties in the blocked force, through a process called on-board validation, form an essential part of this measurement procedure.

The test consists of two parts, the operational test and the FRF test plus, in most cases, an additional operational test using artificial excitation.

The in situ blocked force vector shall be obtained by solving Formula (1) at every frequency:

$$\mathbf{v}_{\mathrm{r}} = \mathbf{Y}_{\mathrm{rc}}\bar{\mathbf{f}}_{\mathrm{c}} \tag{1}$$

Where

$\mathbf{v}_{\mathrm{r}}$	is the velocity vector (m.s^{-1});
$\bar{\mathbf{f}}_{\mathrm{c}}$	is the vector of blocked forces at the contact degrees of freedom (N);
$\mathbf{Y}_{\mathrm{rc}}$	is the mobility matrix connecting the indicator and contact degrees of freedom (s kg-1).

Test results shall be accompanied by the results of an on-board validation consisting of a comparison of predicted and measured validation velocity (or acceleration) vectors.

Given the component blocked forces, the structure-borne noise sound pressure $\mathbf{p}$ can be calculated thanks to the following formula (3),

$$\mathbf{p} = \mathrm{H}_{A}\bar{\mathbf{f}}_{\mathrm{c}} \tag{3}$$

Where

$\mathbf{p}$	is the sound pressure
$\bar{\mathbf{f}}_{\mathrm{c}}$	is the vector of blocked forces at the contact degrees of freedom

and H_{A} is the matrix of sound pressure due to unit force inputs applied at the source-receiver contact points that can be calculated thanks to the following formula (4),

$$\mathrm{H}_{A} = \mathrm{H}_{\mathrm{r}}\,[\mathrm{Y}_{\mathrm{s}} + \mathrm{Y}_{\mathrm{r}}]^{-1}\mathrm{Y}_{\mathrm{s}} \tag{4}$$

Where

H_{r}	matrix of train vibro-acoustic transfer functions (measured without the source)
Y_{s}	source mobility matrix.
Y_{r}	train (or receiver) mobility matrix

2.3 Train assemblies characterization related standardization groups

Current methodologies for the characterization of train subassemblies rely on international standards. Some of the most used standards in this respect are ISO 10140 series, ISO 15186 and EN 16286. Unfortunately, unlike EN 16286, the first two standards have been developed for building acoustics applications.

One of the main disadvantages is that ISO 10140 and ISO 150186 require a diffuse field environment. This, however, may not be representative of practical installations, where the incident field may not be diffuse, for example, side walls, windows and external doors. Also, the size and construction of the test sample and the method of attachment at their boundaries affect the test results.

In task 8.3 the TL differences found when using laboratory and in-situ tests results were analyzed. Figure 1 shows the example of a door measured in the laboratory and in-situ conditions. In the laboratory measurements, two reverberant chambers were used. In the in-situ measurements, an acoustic field was created inside the vehicle compartment and the transmitted sound was measured with and intensity-probe.

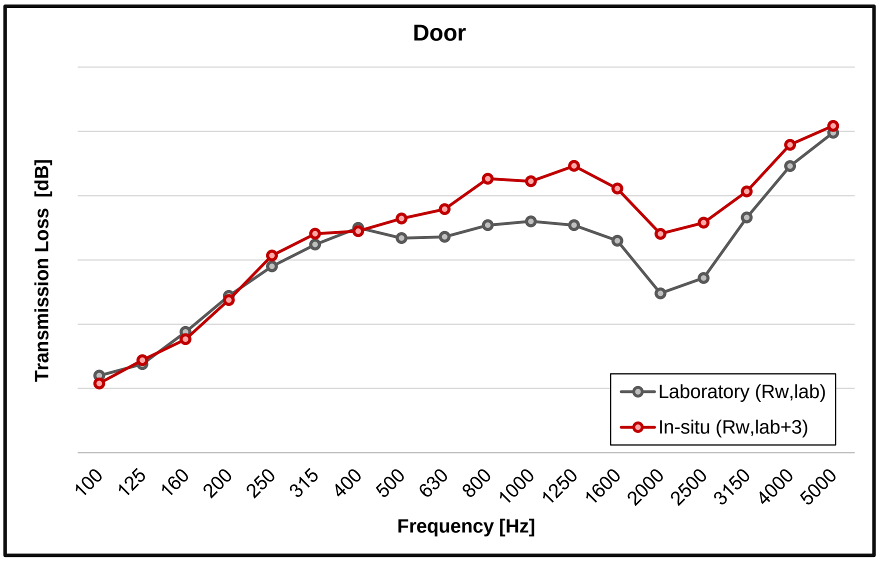


Figure 1. Door transmission loss.

As shown in the figure above, the results are similar in the low-frequency range but show significant spectral differences in the mid- and high-frequency range. In terms of sound radiation index, the in-situ measurement was 3 dB higher than the laboratory measurements. Thus, it is necessary to analyse the current characterization methods and propose improvements in order to set the best practices for train subassemblies characterization.

In the following subsections, a short description of each standard, together with an analysis of strengths, weaknesses and proposals for improvements are listed below.

This analysis was sent to the corresponding standardization committees in order to give feedback on the applicability of the methodologies described in the standards in the railway sector.

2.3.1 ISO 10140 - Laboratory measurement of sound insulation of building elements

Description

The ISO 10140 series of standards [13][17] provides measurement methods for determining the sound insulation in buildings under laboratory conditions. The standard has five parts, which provide general measurement methods for airborne sound insulation and impact sound insulation, test procedures for specific elements, and details related to suitable test facility criteria and experimental setups.

Strengths

- The transmission loss (or sound reduction index) provides a standardised means of assessing the airborne insulation performance of a sub-assembly.
- The specification of the transmission loss in 1/3 octave bands with defined tolerances ensures that the vibroacoustic performance of the sub-assembly as a function of frequency can be matched to the characteristics of the noise source (and vice versa).
- The guidelines are given in ISO 10140-2:2010 for the measurement of airborne transmission loss are well established.

Weaknesses

- There are often discrepancies between in-situ measurements and laboratory-based measurements.
- Transmission loss measurements conducted according to ISO 10140 require a diffuse field environment. This may not be representative of practical installations.
- ISO 10140 has been developed for building acoustics applications. Therefore, the characterisation methods stated in these standards do not take account of the particular features of train sub-assemblies.
- ISO 10140 specifies a method for calculating the structure-borne transmission loss. The measurement of transmission loss due to impact excitation is covered in ISO 10140-3, specifically for application to floors, in order to mimic vibration due to walking. For trains, this is only relevant for floors of double-deck trains.
- The justification of the levels of tolerances for the deviation from the specification of transmission loss in 1/3 octave bands is not completely clear.
- The size and construction of the test sample and the method of attachment at their boundaries affect the test results.

Proposals of improvements

- Compliance with ISO 10140-2:2010 for pressure-based sound insulation measurements should be specified. For testing involving two reverberation chambers, guidelines stated in ISO 10140- 2:2010 should be followed.
- The test sample size should be defined in the specifications, based on the ISO standard specified for sound insulation measurements. This will reduce variability between tests.
- The impact of the sound field incident on train sub-assemblies during operational conditions needs to be taken into account during the characterisation process. In practical situations, train sub-assemblies are subjected to a directional rather than a diffuse sound field. Adaptations of the test methods are required to allow for this.
- Lessons can be learned from ISO 16283 which is used for field-based testing in building acoustics based on the sound pressure level measurement approach. In particular, however, this gives conditions on the source room which may be difficult to achieve in a train.
- Additionally, ISO 16283-3:2016 provides a method for measuring the sound insulation of a building façade. This test method may be more representative for in situ measurements of rolling stock sub-assemblies such as sidewalls.
- The tolerances defined for the transmission loss in 1/3 octave bands should be set by consideration of the resulting full system performance. For example, tolerances should not allow a transmission loss that might significantly adversely affect comfort, by allowing strong tonal components to be transmitted or noise in critical frequency bands. This depends on the specification for the interior noise of the vehicle.
- The evaluation of structure-borne noise transmission could be achieved through the use of a structural excitation rather than an acoustic source during transmission loss measurements. The noise transmitted by the sub-assembly under test could be measured when it is subjected to a structural excitation which could potentially be one of the following: (1) a structural excitation representative of the actual excitation, or (2) one or several, potentially three-axis shakers providing a repeatable and defined structural excitation.
- The estimation of single number quantities such as Rw should be conducted according to the calculation guidelines provided in ISO 717-1:2013. The spectral adaptation term R C w tr + may be a more appropriate measure of the overall performance.

2.3.2 ISO 15186 - Measurement of sound insulation in buildings and of building elements using sound intensity

Description

ISO 15186 [19][21] covers engineering (grade 2) test procedures similar to those discussed in ISO 10140; however, the measurements at the receiver side are based on sound intensity rather than sound pressure level. This standard consists of three parts, with the first part focusing on laboratory-based measurements, the second part covering the procedures for field-based testing, and the last part covering specific processes to follow for laboratory-based testing at low frequencies.

Strengths

- The intensity probe measurement methods described in ISO 15186 reduce the impact of flanking paths, allow testing in less strict environments, with potential for field testing, and provide a method for testing at lower frequencies. Therefore, there may be significant benefits to using the intensity-based approach. The third part of this ISO standard also covers laboratory-based testing at low frequencies.

Weaknesses

- Transmission loss measurements conducted according to ISO 15186 require a diffuse field environment in the emitting part. This may not be representative of practical installations.
- ISO 15186 has been developed for building acoustics applications. Therefore, the characterisation methods do not take account of the particular features of train sub-assemblies.
- ISO 15186 does not specify a method for calculating the structure-borne transmission loss.
- The justification of the levels of tolerances for the deviation from the specification of transmission loss in 1/3 octave bands is not completely clear.
- The size and construction of the test sample and the method of attachment at their boundaries affect the test results.

Proposals of improvements

- Compliance with ISO 15186 (all parts) for intensity-based sound insulation measurements should be specified. For testing involving one reverberation chamber, ISO 15186 (all parts) should be specified.
- In practical situations, train sub-assemblies are subjected to a directional rather than a diffuse sound field.

- The tolerances defined for the transmission loss in 1/3 octave bands should be set by consideration of the resulting full system performance.
- The evaluation of structure-borne noise transmission could be achieved through the use of a structural excitation rather than an acoustic source during transmission loss measurements.
- The estimation of single number quantities such as Rw should be conducted according to the calculation guidelines provided in ISO 717-1:2013. The spectral adaptation term $R_w + C_{tr}$ may be a more appropriate measure of the overall performance.

2.3.3 ISO 16286-2 - Railway applications - Gangway systems between vehicles - Acoustic measurements

<u>Description</u>

EN 16286-2:2013 [22][24] describes the acoustic testing of gangway systems. It has been developed specifically for and by the railway industry and, therefore, provides an engineering (grade 2) test procedure that is more suitable for the specific application area than some of the other standards utilized in the characterization process. Specifically, the standard describes a test method for assessing the sound reduction index provided by a gangway system.

In general, the test setup requires the generation of a diffuse sound field in a source room and the measurement of the sound intensity within the gangway system. There are a number of different test configurations allowable, such as the gangway system mounted inside the room on the dividing wall, outside the room on the dividing wall, or within the room between two closing covers.

<u>Strengths</u>

- EN 16286-2:2013 provides specific procedures for testing gangway systems. This process has been developed by the rail industry for this application and should, therefore, provide the most applicable and reliable means of testing these sub-assemblies.

<u>Weaknesses</u>

- There are often discrepancies between *in-situ* measurements and laboratory-based measurements.
- Measurements require the generation of a diffuse field environment. This may not be representative of practical installations, where the incident field may not be diffuse, for example, side walls, windows and external doors.

Proposal for improvements

- The impact of the sound field incident on train sub-assemblies during operational conditions needs to be taken into account during the characterisation process. In practical situations, train sub-assemblies are subjected to a directional rather than a diffuse sound field. Adaptations of the test methods are required to allow for this.
- The estimation of single number quantities such as R_w should be conducted according to the calculation guidelines provided in ISO 717-1:2013. The spectral adaptation term may be a more appropriate measure of the overall performance.

3. CHARACTERISATION AND SPECIFICATION REQUIREMENTS AND LINK TO IP1 PROJECTS

This chapter deals with the second objective established for task 8.4, which is to transmit the sources and subassemblies specification methods defined in T8.1 to the S2R IP1 project dealing with sources and train subassemblies.

The following subsections summarize the main outputs of T8.1. As such, a minimum set of requirements that shall be defined and documented as a part of the source characterisation are listed. These requirements are then exemplarily applied to particular sources and subassemblies. The intention is not to provide a perfect technical characterisation or specification of a source or sub-assembly, but to check if the defined requirement disposition enables a full technical compilation of the characterisation and specification based on the demanded or derived needs for rail-vehicle design (e.g. simulations).

3.1 TEMPLATE FOR CHARACTERISATION AND SPECIFICATION REQUIREMENTS

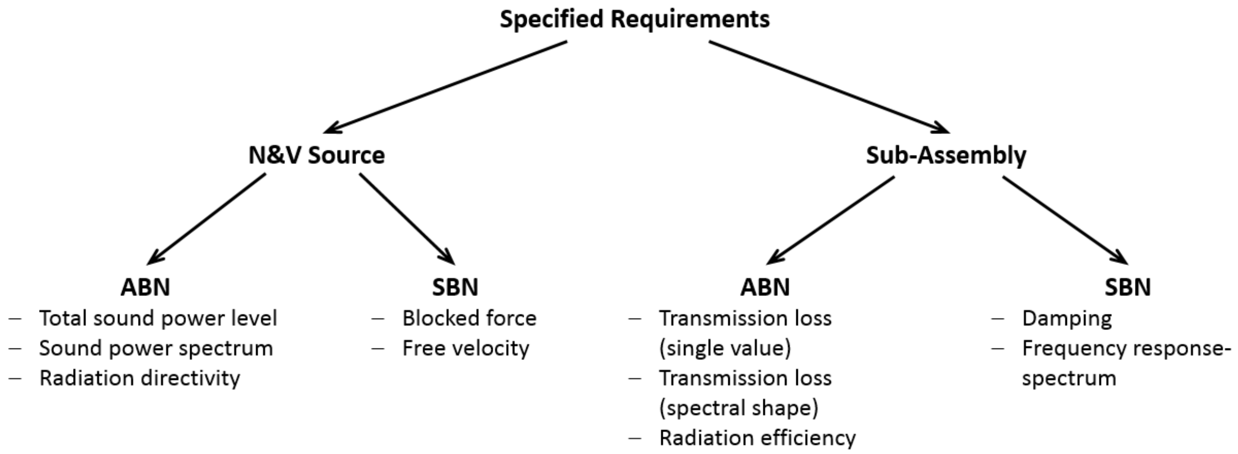
Objectives

The source /sub-assembly shall provide a defined ABN and SBN performance.

Source / Sub-assembly Characterisation

1. Specified Requirements

The characterisation variable shall be attainable, verifiable and shall be part of a commonly accepted standard if possible. Examples of specified requirements can be seen below:

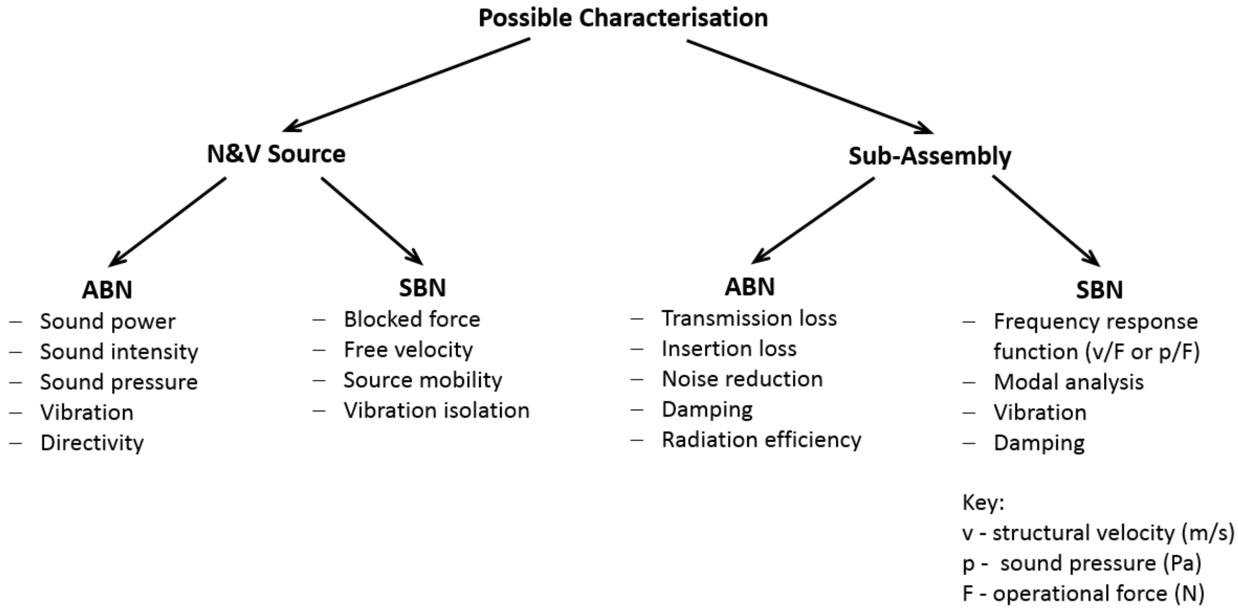


2. Characterisation Method

The engineering demands require the quantitative, verifiable, and standardised results for the characterisation of N&V sources and sub-assemblies. The common methods for this purpose are:

- Measurement
- Simulation
- Hybrid (mix of measurement and simulation)
- Technical Standard / Norm

Technical standards are included in this Deliverable since they are defined for certain measurement methods (e.g. sound power or sound intensity) and enable a direct quantitative characterisation for a defined source / sub-assembly comparison. Possible characterisation quantities are listed below:



3. Constraints and Conditions

3.1 Boundary Conditions

Boundary conditions could refer to a defined source or sub-assembly mounting (clamped, simply supported) or a certain test environment (e.g. diffuse sound field) or test-rig.

3.2 Operating Conditions

Operating conditions describe adjustments of the source. In the case of a sub-assembly, it can refer to a functionality test e.g. repeated mechanical opening of a door.

4. Documentation & Deliverables

4.1 System Source Characterisation

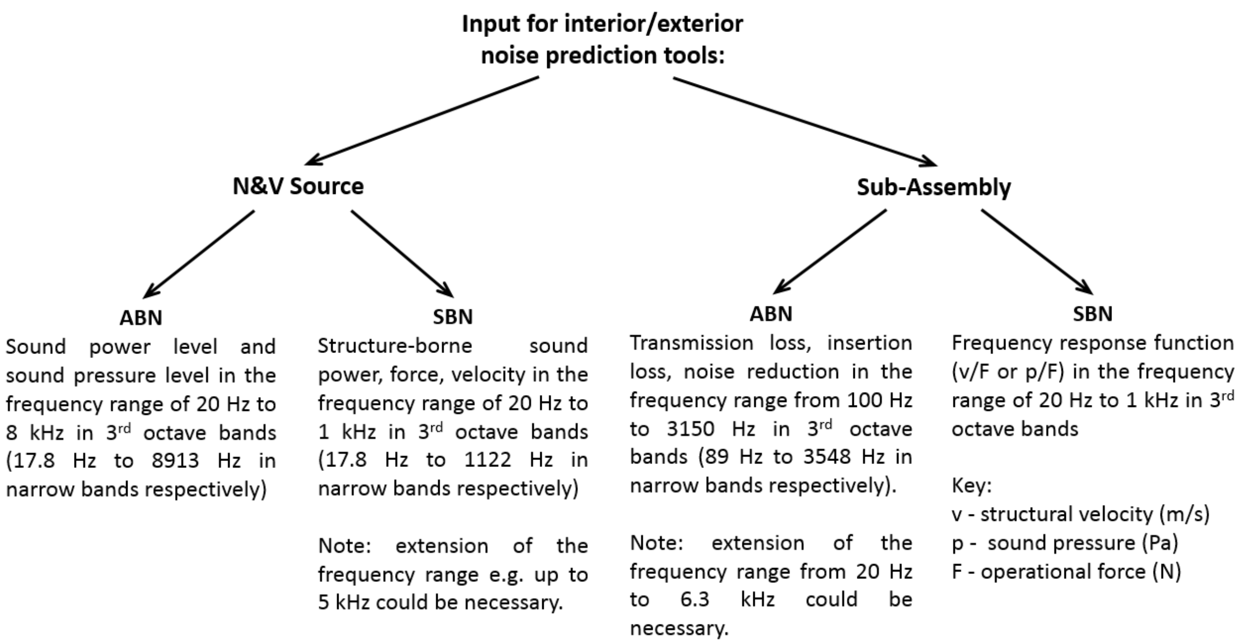
System source characterisation defines the way the source / sub-assembly analysis shall be documented: e.g. as a single source; with sub-source or as multiple source characterisation respectively as a single assembly or as sub-system or combination of assembly characterisation.

4.2 Statistics of Sources and Measurement Results

Statistics source refers to the necessity to know and to document the quantitative characteristics and variation of sources / sub-assemblies (e.g. is there a need to measure more than one source / assembly?) as well as of the measurement itself (e.g. how many measurements must be done?). Standard methods sometimes correspond to a certain degree of accuracy as well as a clear definition and reporting of the statistics.

4.3 Input for Interior/Exterior Simulation

A common way to describe and document engineering statistics is the definition of a location, a shape and a dispersion-report, referring respectively to the kind of mean average (e.g. arithmetic, geometric or harmonic), the distribution (e.g. normal, uniform) and variation / deviation (e.g. variance, standard deviation). Possible input for interior/exterior noise prediction tools could be:



4.4 Time Signals for Auralisation

Spectrum types are the Fourier transform, power spectral density (PSD) or auto power-spectra. The required time signal offers not only the first audible impression of the source but could also document certain time structures (not necessarily captured by the spectrum) or give some information about the measurement quality.

3.2 Example 1: Traction Motor

Objectives

The traction motor shall be compliant with the below airborne and structure-borne noise specifications.

Air-Borne Characteristics

1. Specifications

The sound power level of the equipment shall be measured and reported per face. The overall acoustic power L_{wA} (dB(A)) of all the faces shall be less than 106 dB(A).

1/3 Oct Bands (Hz)	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**
Lw (dBA)	67	70	71	73	73	81	92	91	88	93	95
1/3 Oct Bands (Hz)	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**TOTAL**
Lw (dBA)	96	101	96	95	94	94	94	92	87	84	**106**

The measured spectra shall not exhibit tones as defined in ISO 1996-2 Annex D (simplified evaluation) [25].

Deviations in 1/3 octave bands of up to [+3: -20] dB may be acceptable as long as the total level and the pure tones requirements are fulfilled.

2. Characterisation Method

Measurement according to ISO 9614-2:1996 [2].

3. Constraints and Conditions

The specified requirements for air-borne noise levels apply to test conditions in an anechoic chamber at maximum speed, no load.

4. Documentation and Deliverables

Test report with a description of the characterization test and results from the application of ISO 9614-2:1996 [2]. Tonality report with a description of the application of ISO 1996-2 Annex D [25] and analysis.

Structure-Borne Characteristics

1. Specifications

The supplier should take into consideration the following information:

The maximum sound pressure level **p** in the train in dB

1/3 Oct Bands (Hz)	50	63	80	100	125	160	200	250	315	500	630	800	1000	1250	1600	2000	OAL
p dBA (ref 2.10^{-5} Pa)	20	25	30	30	32	32	33	35	35	36	38	38	40	40	30	20	47

2. Characterisation and Verification Methods

Characterisation method:

- Blocked forces calculation following ISO/DIS 20270 "Acoustics – Characterization of sources of structure-borne sound and vibration – Indirect measurement blocked forces".

Verification method:

- Calculation of the sound pressure **p** in narrowband and with phase according to the following formula:

$$\mathbf{p} = \mathrm{H}_A \bar{\mathbf{f}}_c$$

Where

$\mathbf{p}$ is the sound pressure
$\bar{\mathbf{f}}_c$ is the vector of blocked forces at the contact degrees of freedom
and H_A is the matrix of sound pressure due to unit force inputs applied at the source-receiver contact points that can be calculated thanks to the following formula:

$$\mathrm{H}_A = \mathrm{H}_r\,[\mathrm{Y}_s + \mathrm{Y}_r]^{-1}\mathrm{Y}_s$$

Where

H_r matrix of train vibro-acoustic transfer functions (measured without the source)
Y_s source mobility matrix.
Y_r train (or receiver) mobility matrix

- Then conversion into 1/3 octave bands for comparison with specification values.

In order for the supplier to perform the calculations, train mobility matrix and train acoustic transfer functions are provided.

3. Constraints and Conditions

The specifications apply to all working modes and loading conditions of the traction motor. The vibrations of the traction motor shall be measured for acceleration and constant speed. The measurement shall be done with the correct power converter and PWM sequence.

4. Documentation and Deliverables

- Test report with a description of the characterization test according to ISO/DIS 20270.
- Measurement data in a narrowband with phase (file format readable by Excel).

3.3 Example 2: HVAC

Objectives

The HVAC unit shall be compliant with the below airborne and structure-borne noise specifications.

Air-Borne Characteristics

1. Specifications

a. Specifications for exterior noise requirements

The acoustic power shall be measured for each of the faces of the HVAC unit that is facing the exterior of the coach when the HVAC unit is installed on the train. The overall acoustic power L_w (dB(A)) of all the faces shall be less than 106 dB(A).

1/3 Oct Bands (Hz)	50	63	80	100	125	160	200	250	315	400	500
Lw (dBA)	67	70	71	73	73	81	92	91	88	93	95
1/3 Oct Bands (Hz)	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**TOTAL**
Lw (dBA)	96	101	96	95	94	94	94	92	87	84	**106**

The measured spectra shall not exhibit tones as defined in ISO 1996-2 Annex D (simplified evaluation) [25].

Deviations in 1/3 octave bands of up to [+3: -20] dB may be acceptable as long as the total level and the pure tones requirements are fulfilled.

b. Specifications for interior noise requirements

Specified sound power levels L_w (dBA) of the air-conditioning unit and the extractor unit for interior noise are given for three surfaces: Openings of the air-conditioning unit (HVAC outlets from evaporator fans), HVAC unit sides facing the interior of the coach, excluding the HVAC outlets / inlets, return air openings of the air-conditioning Unit (HVAC inlets).

Openings of the air conditioning: the sound power level shall not exceed the following levels:

1/3 Oct Bands (Hz)	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**
Lw (dBA)	67	70	71	73	73	81	92	91	88	93	95
1/3 Oct Bands (Hz)	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**TOTAL**
Lw (dBA)	96	101	96	95	94	94	94	92	87	84	**106**

HVAC unit sides facing the interior of the coach. The sound power level shall not exceed the following levels:

1/3 Oct Bands (Hz)	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**
Lw (dBA)	67	70	71	73	73	81	92	91	88	93	95
1/3 Oct Bands (Hz)	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**TOTAL**
Lw (dBA)	96	101	96	95	94	94	94	92	87	84	**106**

Return air openings of the air-conditioning unit. The sound power level shall not exceed the following levels:

1/3 Oct Bands (Hz)	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**
Lw (dBA)	67	70	71	73	73	81	92	91	88	93	95
1/3 Oct Bands (Hz)	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**TOTAL**
Lw (dBA)	96	101	96	95	94	94	94	92	87	84	**106**

For all sound power level requirements, a maximum positive deviation of 3 dB is allowed for every 1/3 octave band providing that the overall A-weighted level is not exceeded.

2. Characterisation Method

Measurement according to ISO 9614-2:1996 [2].

3. Constraints and Conditions

The specified requirements for air-borne noise levels apply to test conditions in an anechoic chamber at maximum cooling capacity.

4. Documentation and Deliverables

Test report with a description of the characterization test and results from the application of ISO 9614-2:1996 [2]. Tonality report with a description of the application of ISO 1996-2 Annex D [25] and analysis.

Structure-Borne Characteristics

Exact same specification/characterisation/verification methodologies than for the traction motor.

3.4 EXAMPLE 3: BOGIE WHEELS

Objectives

The bogie wheels shall be compliant with the below airborne specification.

Air-Borne Characteristics

1. Specifications

The A-Weighted Sound Power Level L_{wA} (dB(A)) of the wheel for a reference roughness of 10^{-6} m is specified for its radial and axial parts following the TWINS methodology; it shall not exceed the following levels in 1/3 octave bands:

1/3 Oct Bands (Hz)	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**
LwA rad (dBA)	-	-	-	38	46	51	54	58	60	62	65
LwA ax (dBA)	-	-	-	30	37	45	56	70	69	66	68
1/3 Oct Bands (Hz)	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	-
LwA rad (dBA)	68	74	81	87	94	105	108	110	111	112	-
LwA ax (dBA)	72	78	83	85	95	106	110	113	116	113	

Moreover, the global sound power level of the wheel (radial + axial) shall not exceed 110 dB(A) when calculated for a trainset speed of 250km/h, with TSI rail roughness and typical roughness corresponding to a manufactured brand-new wheel and a static load of 7.5 tons.

2. Characterisation Method

Simulation according to the TWINS methodology.

3. Constraints and Conditions

The wheel acoustic performances should be calculated using TWINS software. The wheel diameter to consider is “new wheel diameter” (not worn / reprofiled wheel diameter).

4. Documentation and Deliverables

TWINS prediction report with the description/assumptions of TWINS modelling, modal shapes of the wheel from 100 to 6000 Hz, radial/axial acoustic powers for unity roughness and global sound power level results for the condition detailed in 1.2.

TWINS model (report file and all input files in order to be able to relaunch TWINS computations including the FEM of the wheel).

3.5 Example 4: Rolling noise requirements for airborne transmission

Objectives

The aim of this section is to describe briefly the requirements and characterization method in order to describe rolling noise ABN performance.

Air-Borne Characteristics

1. Specifications

The total Sound Power Level of wheel + track should be below X dB. The limit X is established based on previous projects and assuming:

- A reference track
- New wheel roughness + EN ISO 3095 [27] rail roughness
- Track decay rate acc. to EN ISO 3095 [27]

2. Characterisation Method

Numerical simulation (e.g. TWINS) in order to obtain the Sound Power Level spectra of the wheel (radial, axial and torsion motion) and track (rail, sleeper) and study the contribution of each part. Standards ISO 3095 [27] and ISO 13979 [28] are taken into account (roughness limits, TDR, reference track).

In project Roll2Rail [29] different test methods have been developed in order to obtain track and wheel SWL separately.

3. Constraints and Conditions

The specified requirements for rail roughness level and TDR should be fulfilled.

4. Documentation and Deliverables

Only a single source (one wheel) is analysed.

The input for interior and exterior simulations is the total SWL spectrum (20 – 6000 Hz) in 1/3 octave bands

In the simulations, the source is treated as a point source, however, the track radiates in a finite length.

Documentation: Report including input data (roughness, wheel and track parameters, speed), sound power level spectra for each component (wheel radial/axial/torsional + track rail/sleeper/slab/…)

3.6 Example 5: Floor Assembly

Objectives

The floor assembly shall be compliant with the below airborne specification.

Air-Borne Characteristics

1. Specifications

The floor assembly transmission loss (TL) in dB, in 1/3 octave bands from 100 up to 5000 Hz, shall comply with the following.

1/3 Oct Bands (Hz)	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**
TL (dB)	-	-	-	26	28	31	34	36	38	40	42
1/3 Oct Bands (Hz)	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**R_W**
TL (dB)	43	45	46	48	49	50	50	49	45	47	**45**

Deviations in 1/3 octave bands of up to [-3;20] dB may be acceptable as long as the Rw value requirement of 45 is fulfilled.

2. Characterisation Method

Measurement according ISO 10140-2:2010 [14].

3. Constraints and Conditions

The transmission loss of the floor assembly should be measured in conditions representative of the effective installation on the train.

4. Documentation and Deliverables

Test report with a description of the characterization test and results from the application of ISO 10140-2:2010 [14].

3.7 Example 6: Sidewall subassembly - airborne transmission

Objectives

The aim of this section is to describe briefly the requirements and characterization method in order to describe sidewall subassembly ABN performance.

Air-Borne Characteristics

1. Specifications

For the sidewall, a global sound reduction index, Rw, is specified. The chosen value depends on the vehicle type and interior noise requirements. For a metro type, the Rw to fulfilled could be 38 and the transmission loss (TL) in dB, in 1/3 octave bands from 100 up to 5000 Hz, to comply could be the following:

1/3 Oct Bands (Hz)	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**
TL (dB)	-	-	-	23.4	26.4	28.2	29.5	30.6	30.3	29.4	31.7
1/3 Oct Bands (Hz)	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**R_W**
TL (dB)	33.5	38.7	39.6	37.4	41.1	45.5	44.1	44.6	41.9	44.6	**38**

2. Characterisation Method

Laboratory or in-situ measurements based on standard series ISO 10140 [14] or numerical simulation using hybrid FEM/SEA techniques.

3. Constraints and Conditions

The transmission loss of the sidewall should be measured in conditions representative of the effective installation on the train.

4. Documentation and Deliverables

The input used for interior noise simulations is the transmission loss spectra (100 – 3150/5000 Hz) in 1/3 octave band

Test report with a description of the characterisation test and results from the application of ISO 10140 [14].

3.8 Link to IP1 projects

Deliverable *D5.1- List of TDs influencing the N&V performance of the system* presents the results of Task 5.1 of FINE 1. The objective of this task was to ensure a link to other Shift2Rail projects in which noise and vibration aspects may have an impact. To this end, the Technical Demonstrators having an influence on noise and vibration on IP1 projects were identified and a company from the FINE 1 project was designated in order to ensure efficient communication between projects.

Table 2 presents the list of Technical Demonstrators having an influence on the noise and vibration performance of the railway system, the agreed contact partner of FINE 1 and the name of the Shift2Rail project taking care of the Technical Demonstrator.

	Partner in FINE 1 to keep contact to TD leader	Shift2Rail project TD contact person S2R	ABN	SBN	SUB
TD1.1 Traction Systems	Alstom	PINTA	X	X	
TD1.2 Carbody Shell	CAF	PIVOT			X
TD1.4 Running Gear	Bombardier	PIVOT	X	X	
TD1.5 Brake Systems	Siemens	PIVOT	X		
TD1.6 Doors and Access Systems	Talgo	PIVOT			X
TD1.7 Train modularity in use	Bombardier	TBA			

Table 2. Identified TDs, responsible partner and corresponding S2R project.

The results presented in the present chapter of this deliverable will be forwarded to different TD contact persons of S2R-IP1 PINTA and PIVOT projects.

4. SUMMARY

The present report has given an insight into the two main activities carried out:

- In task T8.2, the current source and sub-assembly characterisation methods used by the rolling-stock manufacturers were compiled and analysed in order to identify their strength and weakness. Based on the results recommendations of improvements were provided. In task T8.4, links to the current standardization groups have been established in order to provide the results of the analysis carried out. Chapter 2 indicates for each of the standards analysed the strengths, weakness and proposals of improvement made to the different standardization groups.
    - For airborne noise characterization rolling stock manufacturers agree on continue applying ISO 9614 and ISO 3744 (or ISO 3744 and ISO 13347 for specific equipment). However, the identified proposals for improvements have been already sent to the corresponding standardisation Working Groups in order to consider them in future revisions.
    - For structure borne noise, it is proposed to set the indirect measurement procedure of blocked forces described in ISO/DIS 20270 as the preferred method for the characterisation of rolling stock components. This standard is currently under development but will be approved and published by 2020.
    - For subassemblies characterization, the main concern regards the acoustic field used to conduct the tests. Transmission loss measurements conducted according to ISO 10140 require a diffuse field environment. However, this may not be representative of practical installations. Thus, a recommendation made to the corresponding working group to be included in future revisions is to account for the impact of the sound field incident on train sub-assemblies during real operational conditions.
- On the other hand, in task T8.1 current source and sub-assembly specification methods were analysed. Chapter 3 has shown different examples in order to specify airborne and structure-borne transmission limits for different sources and subassemblies. These specification methods have been transmitted to S2R IP1 projects dealing with sources and train assemblies.

5. REFERENCES

[1] ISO 9614-1:1993, Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 1: Measurement at discrete points," International Organization for Standardization, Geneva, 1993.

[2] ISO 9614-2:1996, Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 2: Measurement by scanning," International Organization for Standardization, Geneva, 1996.

[3] ISO 9614-3:2002 - Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 3: Precision method for measurement by scanning," International Organization for Standardization, Geneva, 2002.

[4] ISO 3744:2010 – Determination of sound power levels and sound energy levels of noise sources using sound pressure -- Engineering methods for an essentially free field over a reflecting plane, International Organization for Standardization, Geneva, 2010.

[5] ISO 2151:2004 - Acoustics - Noise test code for compressors and vacuum pumps - Engineering method (Grade 2)., International Organization for Standardization, Geneva, 2004.

[6] ISO 13347-1:2004 - Industrial fans - Determination of fan sound power levels under standardized laboratory conditions - Part 1: General overview," International Organization for Standardization, Geneva, 2004.

[7] ISO 13347-2:2004 - Industrial fans - Determination of fan sound power levels under standardized laboratory conditions - Part 2: Reverberant room method," International Organization for Standardization, Geneva, 2004.

[8] ISO 13347-3:2004 - Industrial fans - Determination of fan sound power levels under standardized laboratory conditions - Part 3: Enveloping surface methods," International Organization for Standardization, Geneva, 2004.

[9] ISO 13347-4:2004 - Industrial fans - Determination of fan sound power levels under standardized laboratory conditions - Part 4: Sound intensity method," International Organization for Standardization, Geneva, 2004.

[10] ISO 9611:1996 - Acoustics -- Characterization of sources of structure-borne sound with respect to sound radiation from connected structures -- Measurement of velocity at the contact points of machinery when resiliently mounted, International Organization for Standardization, Geneva, 1996.

[11] ISO 13332:2000 - Reciprocating internal combustion engines. Test code for the measurement of structure-borne noise emitted from high-speed and medium-speed reciprocating internal combustion engines measured at the engine feet, International Organization for Standardization, Geneva, 2000.

[12] ISO 18312-1:2012 - Mechanical vibration and shock. Measurement of vibration power flow from machines into connected support structures. Direct method, International Organization for Standardization, Geneva, 2012.

[13] ISO 10140-1:2016 - Acoustics - Laboratory measurement of sound insulation of building elements - Part 1: Application rules for specific products," International Organization for Standardization, Geneva, 2016.

[14] ISO 10140-2:2010 - Acoustics - Laboratory measurement of sound insulation of building elements - Part 2: Measurement of airborne sound insulation," International Organization for Standardization, Geneva, 2010.

[15] ISO 10140-3:2010 - Acoustics - Laboratory measurement of sound insulation of building elements - Part 3: Measurement of impact sound insulation," International Organization for Standardization, Geneva.

[16] ISO 10140-4:2010 - Acoustics - Laboratory measurement of sound insulation of building elements - Part 4: Measurement procedures and requirements," International Organization for Standardization, Geneva, 2010.

[17] ISO 10140-5:2010 - Acoustics - Laboratory measurement of sound insulation of building elements - Part 5: Requirements for test facilities and equipment," International Organization for Standardization, Geneva, 2010.

[18] ISO 717-1:2013 - Acoustics - Rating of sound insulation in buildings and of building elements," International Organization for Standardization, Geneva, 2013.

[19] ISO 15186-1:2000 - Acoustics - Measurement of sound insulation in buildings and of building elements using sound intensity - Part 1: Laboratory measurements," International Organization for Standardization, Geneva, 2000.

[20] ISO 15186-2:2003 - Acoustics - Measurement of sound insulation in buildings and of building elements using sound intensity - Part 2: Field measurements," International Organization for Standardization, Geneva, 2003.

[21] ISO 15186-3:2002 - Acoustics - Measurement of sound insulation in buildings and of building elements using sound intensity - Part 3: Laboratory measurements at low frequencies," International Organization for Standardization, Geneva, 2002.

[22] ISO 16283-1:2014 - Acoustics - Field measurement of sound insulation in buildings and of building elements - Airborne sound insulation," International Organization for Standardization, Geneva, 2014.

[23] ISO 16283-2:2013 - Acoustics - Field measurement of sound insulation in buildings and of building elements - Part 2: Impact sound insulation," International Organization for Standardization, Geneva, 2013.

[24] ISO 16283-3:2016 - Acoustics - Field measurement of sound insulation in buildings and of building elements. Façade sound insulation," International Organization for Standardization, 2016.

[25] ISO 1996-2:2017 - Acoustics -- Description, measurement and assessment of environmental noise -- Part 2: Determination of sound pressure levels

[26] ISO 7626-5:1994 - Vibration and shock -- Experimental determination of mechanical mobility -- Part 5: Measurements using impact excitation with an exciter which is not attached to the structure

[27] ISO 3095:2013, Acoustics - Railway applications - Measurement of noise emitted by railbound vehicles

[28] DIN EN 13979-1:2003+A2:2011 - Railway applications - Wheelsets and bogies - Monobloc wheels - Technical approval procedure - Part 1: Forged and rolled wheels; German version

[29] Roll2Rail: New Dependable Rolling Stock for Sustainable, Intelligent and comfortable Rail Transport in Europe, http://www.roll2rail.eu