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Deliverable D8.1 – Characterisation and specification requirements

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EXECUTIVE SUMMARY

The deliverable 'D8.1 – Characterisation and specification requirements' is part of WP8-'Sources and Assemblies' of FINE1. To achieve the noise performance objectives of rolling stock it is necessary to establish vibro-acoustic targets for sources (e.g. mechanical drive) and sub-assemblies based on a quantitative characterisation and specification.

Alstom, BT, CAF and DB are the stakeholders of WP8, e.g. for the requirement elicitation and activities for source and sub-assembly selection.

The present report describes the activities (e.g. the compilation of questionnaires, exemplary requirement definitions). The work includes inputs of FINE1 WP7 - 'Interior Noise Modelling' and Acoutrain (exterior noise) and provides information about the Technical Demonstrators (requirement setting TDs). The procedure for prioritising sources and sub-assemblies accounts for both interior and exterior noise. This deliverable documents the process and presents a list of sources and subassemblies.

The deliverable provides a short section about the basic demand of good requirements, a requirement skeleton as well as some requirement examples for a selection of sources and sub-assemblies.

Overall, the report provides the translation of the needs regarding acoustic performance into verifiable, attainable system requirements for the characterisation and specification of sources and sub-assemblies.

ABBREVIATIONS AND ACRONYMS

ABN:	Air-borne Noise
BT:	Bombardier Transportation
BTG:	Bombardier Transportation Germany
CCA:	Cross-Cutting Areas
DB:	Deutsche Bahn
dB:	Decibel
DUT:	Device Under Test
FRF:	Frequency Response Function
HST:	High Speed Trains
HVAC:	Heating, Ventilation, Air condition
IP:	Innovation Programme
ITD:	Integrated Technology Demonstrators
Lw:	Sound Power Level
N&V:	Noise and Vibration
PSD:	Power Spectral Density
R2R:	Roll2Rail
Rw:	Sound reduction index
S2R:	Shift2Rail
SBN:	Structure borne Noise
SPD:	System Platform Demonstrators
SPL:	Sound Pressure Level
SWL:	Sound Power Level
SWOT:	Strengths Weakness Opportunities Threats
WP:	Work Package
TD:	Technology Demonstrator
TL:	Transmission Loss
IL:	Insertion Loss
NR:	Noise Reduction or Level Difference
Noise Reduction:	Level Difference

Strengths: characteristics of the business or project that give it an advantage over others

Weaknesses: characteristics of the business that place the business or project at a disadvantage relative to others

Opportunities: elements in the environment that the business or project could exploit to its advantage

Threats: elements in the environment that could cause trouble for the business or project

Derived Requirement: requirement deduced or inferred from the collection and organization of requirements into a particular system configuration and solution BS ISO/IEC/IEEE 29148:2011 [6]

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1 INTRODUCTION

The main objective of the deliverable D8.1 - 'Characterisation and specification requirements' is the definition of the requirements for the characterisation of sources and sub-assembly to be used as inputs for noise control and acoustic performance simulations. This includes a prioritisation of sources and sub-assemblies with regard to interior/exterior noise in certain special acoustic environments (e.g. free-field, tunnel, viaduct) for different types of rolling stock as well as type of equipment. The requirement definition for these noise control (acoustic performance) necessities demands an appropriate concise and clear wording for the translation into verifiable, attainable system requirements. To avoid misunderstandings, the document includes basic definitions since requirement engineering is a huge field with many applications and a huge vocabulary of non-standardized terms.

Alstom, BT, CAF and DB took part in the activities for source and sub-assembly selection and requirement definition for 'WP8.1: Definition of requirements for characterization and specification methods'. These activities include e.g. the compilation of documents (PowerPoint and Word) with regard to task specification, questionnaires and exemplary requirement definitions.

There are various links to the work of the other work packages of FINE 1 and preceding research projects:

A strong link exists to WP7 – Interior Noise modelling – where methodologies for efficient and accurate predictions of interior noise are developed. Railway interior noise level results from the contributions of various noise sources and transfer paths. The deliverable D7.1 [9] gathers the review and assessment of the current interior noise modelling methods, the most relevant sources and transmission paths and the input data, which are used for the current predictions models.

The FINE 1 project is part of the S2R CCA themes supporting the five S2R Innovation Programmes (IPs). The demonstration of technical achievements in the Innovation Programmes is based on Technology demonstrators (TDs), which are combined into Integrated Technology Demonstrators (ITDs) and System Platform Demonstrators (SPDs).

Within WP5 – Technical Assessment and integration on system level of Noise &Vibration (N&V) – the components are identified, which are included in the S2R TDs and have an influence on the noise and vibration performance of the railway system. The identified TDs were taken into account during the selection and prioritisation process.

The FINE1 target to advance the state of art of exterior noise is a continuation of Acoutrain (a European research project in the years 2011-2014 for 'virtual certification of acoustic performance for freight and passenger trains'). The Acoutrain objective was 'to simplify and improve the acoustic authorization of new rolling stock (with TSI-focus) by developing methodologies and defining a possible virtual noise process for authorization. The Acoutrain work packages include relevant topics for WP8: e.g. methodologies to measure noises sources, the improvement and harmonization of the rolling noise characterization and validation methodologies. One relevant deliverable of Acoutrain is the exterior noise prediction software 'Acoutrain-Tool'. Acoutrain investigated several sources (e.g. traction motor cooling, transformer and cooling, converter cooling and HVAC-system). With regard to the definition of the requirements the general necessity for a virtual certification of the acoustic performances and the consequential demands are of major relevance.

A postponement of the work package ‘Exterior Noise’ to FINE2 (as part of the reorganization of FINE1) demands a slightly different requirement elicitation necessary for the exterior noise, since no official work package of FINE1 provides a formal input document. WP7 Interior Noise is to be continued in FINE2, but WP8 Sources & Sub-Assemblies ends with FINE1 in 2019.

The main results of the presented deliverable are a selection of sources and sub-assemblies for WP8 according to a prioritisation and a definition of requirements for the characterisation and specification of sources and sub-assemblies.

2 SOURCE AND SUB-ASSEMBLY PRIORITISATION

2.1 APPLIED PROCEDURE

2.1.1 General introductory Remarks with regard to applied procedure

The following section describes the activities for requirement elicitation (extraction or acquisition of expressed needs) and source and sub-assembly selection. The aim is to gain understanding about the requirements, i.e. the needs or necessities of a defined source or sub-assembly. Several techniques are available for requirements elicitation, see [1], [3]:

- Interviewing.
- Questioning,
- Observing,
- Discussing,
- Negotiating,
- Supposing.

Interviewing is probably the most often used technique. The following procedure description shows that the WP8.1 requirement elicitation as well as the source and sub-assembly selection (prioritisation) are mainly based on questionnaires (a collection of questions that is intended for attaining data, standardized information and knowledge) and discussions (teleconferences). As mentioned in the introduction, the technical terms and definitions for requirement engineering vary strongly: there are available standards (norms) for requirement engineering, but these focus mainly of software requirements (e.g. [6],[7]). The amount of available literature is huge (see e.g. [1], [3]).

2.1.2 Prioritisation

Three different questionnaires with different, complementary objectives were used for requirement elicitation, requirement definition process as well as a source/sub-assembly selection process.

Questionnaire I

The aim of the first questionnaire was to identify which were the most important source and sub-assemblies. Questionnaire I template classified rail vehicles in four groups (URBAN, REGIONAL, LOCOMOTIVE and HIGH_SPEED trains) and focused on interior and exterior noise in three different operating conditions (standstill, running at constant speed and acceleration/braking). Examples for listed sources are main transformer, mechanical drive and HVAC-system. The sub-assembly list included e.g. sidewall, floor and wind-screen. Questionnaire I also include a section named ‘architecture’ to account for other relevant aspects (e.g. referring to position of equipment, duct concept and layout). The questionnaire is filled in by means of a point scale ranging from ‘not considered / irrelevant’ (0 points) to ‘relevant’ (3 points). The selection of sources and sub-assemblies (respectively the prioritisation) is based on the analysis of the point scale ranking. There are several possibilities for the analysis of the point scale matrix: e.g. a calculation of sums along rows/columns and/or a pure ranking analysis. The selected solution would be the sources/assemblies with the highest score and/or ranking. The analysis process would be similar to a weighted decision matrix analysis and could be visualized with ‘Radar Plots’ (displays all criteria together in one plot and offers thereby a retrospective strength and weakness analysis of the opted selections) or Criteria Positions (Importance of Criterion vs. Rating/Ranking of criterion). For this type of analysis is software available (e.g. Open-Source Excel-Sheets as well as commercial software like ‘Decision Making Helper’ [10]). The analysis of the questionnaire provides results for each single questionnaire ranking, but enables also a comparison of the different member ranking, since a different prioritisation could be a cause for different basic requirements. The comparison between the different rankings was based on a correlation analysis (Spearman’s Rank Correlation Analysis).

Criteria: Fake-Examples	HVAC	Traction Motor	Wheel/'Track Interaction	weight
1. Interior Noise (main contributor)	3	2	0	
2. Exterior Noise (main contributor)	3	5	5	
3. Member Priority (Alstom, BT, CAF, DB)	1	5	4	
4. Train Segment Coverage (e.g. Regional, HighSpeed)	5	5	2	
5. Source Knowledge (Low /highPoint & High/lowPoint)	3	4	2	
6. Technical Demonstrator ('part of')	3	4	2	
7. Exterior Noise - Acoutrain	5	5	0	
8. Exterior Noise - Free Field	3	4	0	
9. Exterior Noise - Tunnel	5	5	0	
10. Exterior Noise - Viaduct	5	5	0	
Score (/6) + Choosen Source	6.0	7.3	2.6	
1. Interior Noise (main contributor)	0.75	0.50	0.00	25%
2. Exterior Noise (main contributor)	0.75	1.25	1.25	25%
3. Member Priority (Alstom, BT, CAF, DB)	0.10	0.50	0.43	10%
4. Train Segment Coverage (e.g. Regional, HighSpeed)	0.75	0.75	0.25	15%
5. Source Knowledge (Low /highPoint & High/lowPoint)	0.15	0.20	0.12	5%
6. Technical Demonstrator ('part of')	0.25	0.25	0.00	5%
7. Exterior Noise - Acoutrain	0.25	0.25	0.00	5%
8. Exterior Noise - Free Field	0.15	0.20	0.00	5%
9. Exterior Noise - Tunnel	0.25	0.25	0.00	5%
10. Exterior Noise - Viaduct	0.6	0.7	0.3	100%
Weighted Score + most important Source				

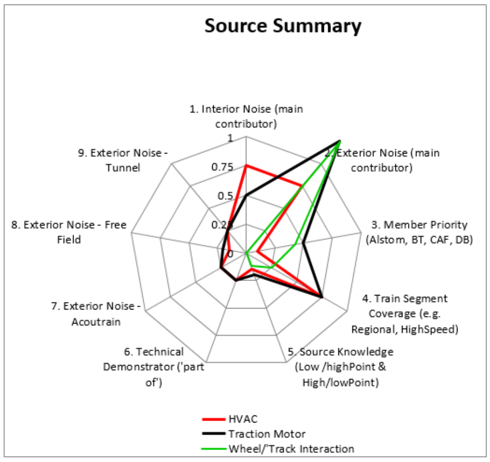

Figure 1: Radar Plot Example (weighted decision matrix with ‘invented’ values)

The questionnaire matrix contained 28 Sources, 28 sub-assemblies and 8 elements (‘architecture’) and offered the possibility for a relevance summary (e.g. an explicit designation/nomination of sources).

The first result of the source prioritisation based on questionnaire I: is mechanical drive; HVAC – system and compressor. The main transformer was due to the relevance summary ranking added to three selected sources. The sub-assemblies ranking resulted in a first nomination of floor, HVAC-ducts/silencer and Fairings/Skirts. The sidewall was selected due to the relevance summary ranking. A discussion of the assembly selection agreed to an assembly replacement/exchange of fairings/skirts with sidewall.

The prioritisation and point scale analysis of the first questionnaire did reveal a few general weak points: a point range scale of 0, 1-10 (instead of 0, 1-3) could increase the demarcation for a clear first selection process. The questionnaire did not separate for structure/air-borne noise or free-field/tunnel/viaduct. The ‘needs’ for the selection process are somehow hidden and might be changed depending on the selected element.

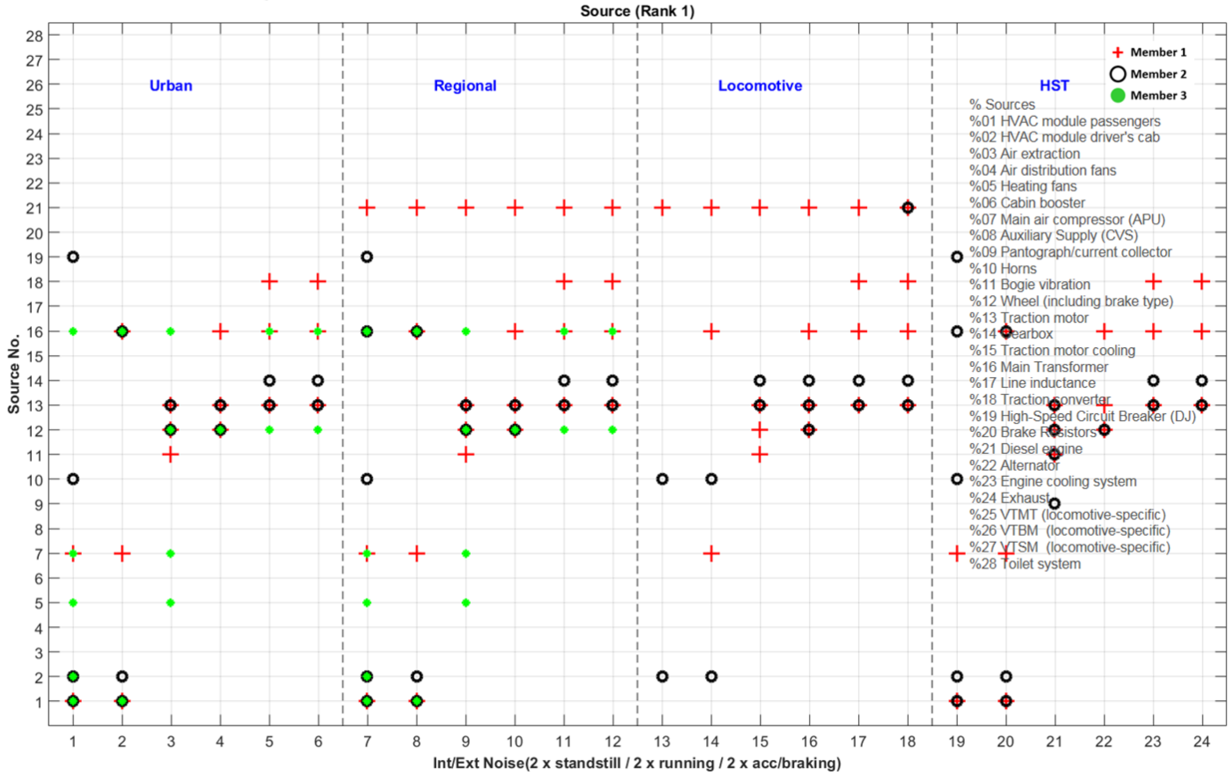

Figure 2: Example of point scale analysis for source with highest priority (x-axis: interior /exterior Noise and operations conditions; y-Axis: 28 Sources)

Questionnaire II

In questionnaire I there were few sources and sub-assemblies, which were ranked highly by two or three members, but also different rankings were evident. To agree in a final selection of sources, a second Questionnaire II was launched. Four sources and sub-assemblies were filtered out from questionnaire I and presented. The possibility to add two new sources and two sub-assemblies were also offered.

For each source and subassembly, each partner should answer to the following questions:

- Whether the characterisation of a specific source/sub-assembly was important for SBN, ABN or both.
- If the source/sub-assembly characterisation was an important input for interior noise modelling (as a link of WP8 and WP7 Interior Noise)
- Source/sub-assembly measurement equipment and test facility availability during FINE1 project;
- Need and reasons for definition of the requirements.

The questionnaire II offered 11 'needs' and the possibility of limitless adding of reasons. The defined needs referred to:

- Dominance / importance for vehicle performance;
- Incomplete or very complex characterization;

- A missing of or dissatisfaction with an existing specification;
- Limited source knowledge;
- Known technical, standardisation or definition issues;
- Demands of the prediction software (WP 7 Interior Noise or Exterior Noise);
- A necessity caused/motivated by a supplier;
- Be selected for DESTINATE or
- A need for an appropriate test procedure of the selected and ranked sources/sub-assemblies.

Source/Assembly	Agreement with Ranking acc. to Questionnaire I (Yes / No / new Rank)	relevant for WP7 (Interior Noise) ? (Yes / No)	relevant for ABN ('x')	relevant for SBN ('x')	Reason for Selection	Source/Assembly Availability	Test Facility / Measurement Equipment
Mechanical Drive (Motor & Gear)	1	Yes	x	x	1 2 6 10		
HVAC	3	Yes	x		1 4 7 10		
Compressor	2	Yes	x	x	1 2 10		
Main Transformer	4	Yes	x	x	2 10		
Missing Source 5 (optional, if required):	5 traction converter	Yes	x	x	2 10		
Missing Source 6 (optional, if required):	6 auxiliary converter	Yes	x	x	2 10		
Floor	1	Yes	x		1 4 10 11		
HVAC-Ducts/Silencer	3	Yes	x		1 4 7 11		
Fairings/Skirts	6	Yes	x		3		
Sidewall	2	Yes	x		1 4 10 11		
Missing Assembly 5 (optional, if required)	4 gangway	Yes	x		1 4 10 11		
Missing Assembly 6 (optional, if required)	5 door	Yes	x		1 4 10 11		

Reason for Selection (Need = Requirement)

1 Dominance / Importance on vehicle performance
2 Characterization is incomplete or very complex
3 Specification is missing so far (also dissatisfaction with current or available specifications)
4 Missing source knowledge (physical / dependence on operation conditions)
5 Known technical issues
6 Known standardisation issue (e.g. not covered / wrong /not suitable)
7 Demands of prediction software
8 Selection motivated by Supplier (Knowledge transfer)
9 Selection for testing performed by DESTINATE [11]
10 for common definition / future standards
11 Need for an appropriate test procedure (depending on operation conditions, difficult boundary conditions)

Figure 3: Example for questionnaire II

Questionnaire III

Questionnaire III is an extension of Questionnaire II. For each source and subassembly two new columns were added in order to analyse strengths and weaknesses of current airborne and structure-borne characterization. The results of the questionnaire analysis are here solely considered with regard to the definition of requirements, since the SWOT analysis of the characterization and specification methods is expected to be carried out in WP8.2 in detail.

The SW-analysis demonstrates some of the already listed needs, such as the necessity for the application of standards/norms, the demands of prediction software, missing characterisation methods (or the sole availability of in-situ vehicle characterisation) , the non-availability of systematic or standard characterisation methods, the demand for improved characterisation methods (with regard to uncertainty [e.g. boundary conditions]; accuracy; for certain frequency regions, for sound field properties under defined vehicle operating conditions), the need to enable a supplier testing capability; increase source knowledge (insight/understanding: e.g. wheel/rail separation; source descriptor, dependence of receiving structure).

Questionnaire III provided beside the earlier listed needs also a few new necessities, such as the need for improving measurement competence (e.g. mobility), the prediction of a full transfer path (e.g. vibro-acoustics, FRF's, sub-structuring) and the need for improving understanding for quantitative characterization of structure-borne sound transmission.

Source/Assembly	Current ABN charact		Current SBN charact	
	(+)	(-)	(+)	(-)
Mechanical Drive (Motor & Gear)	- application of ISO3744 and ISO9614-2 - estimation of global Lw	- no stand. meth. to characterize the directivity - uncertainty regarding integration effect (changed boundary conditions)	vibration velcoity with original mounting	- no descriptor of the system available - difficulty to provide correct boundary conditions (for instance free velocity measurements or completely blocked) - difficulty to specify the source strenght in dependence on the receiving structure - difficulty to predict the full transfer path from vibration excitation to sound pressure level at interior measurement position
HVAC	ISO9614-2	- difficulty to provide the correct boundary conditions (pressure drop etc.)	blocked forces	
Compressor	- application of ISO3744 - estimation of global Lw	- same than motor	blocked forces	- no assessment of tilting effects, moments or transfer matrices - difficulty to specify the source strenght in dependence on the receiving structure - difficulty to predict the full transfer path from vibration excitation to sound pressure level at interior measurement position
Main Transformer	ISO3744 and ISO9614-2	- same than HVAC	blocked forces	- no assessment of tilting effects, moments or transfer matrices - difficulty to specify the source strenght in dependence on the receiving structure - difficulty to predict the full transfer path from vibration excitation to sound pressure level at interior measurement position
Missing Source 5 (optional, if required):				
Missing Source 6 (optional, if required):				
Floor	ISO 15186-2 Transmission Loss (in-situ) - EN ISO 10142-1(in Lab)		seldom: average velocity /radiation efficiency/ estimate of eigenfreq	- characterisation as transfer path for structure borne sound
HVAC-Ducts/Silencer	insertion loss for silencer		- no characterization	
Fairings/Skirts		- no standard test to perform the characterization	- no characterization	
Sidewall	EN ISO 10142-2/EN ISO 10142-1 / ISO 15186-2 Transmission Loss		- no characterization	- characterisation as transfer path for structure borne sound
Missing Assembly 5 (optional, if required):	EN ISO 10142-2/EN ISO 10142-1 & ISO 15186-2 Transmission Loss		- no characterization	
Missing Assembly 6 (optional, if required):				

Figure 4: Example for questionnaire II

2.2 Survey of selected Sources and Sub-assemblies

The selected sources (listed without ranking) are

- Mechanical drive (motor & gear),
- HVAC-system,
- Compressor,
- Main transformer,
- High-speed circuit breaker,
- Traction converter,
- Auxiliary converter and
- Rolling noise (squeal & low frequency).

The selected sub-assemblies (listed without ranking) are

- Floor,
- HVAC-ducts/silencer,
- Fairings/skirts,
- Sidewall,
- Gangway,
- Gangway doors and
- Exterior passenger doors.

The six most frequently given reasons (No.1 = highest count; No. 6= lowest number of selections) for the selection of the above sources and sub-assemblies are the:

1. Dominance/importance on vehicle performance;
2. Need for common definition or future standards;
3. Incomplete or very complex characterization;
4. Limited source/assembly knowledge (physical / dependence on operation conditions);
5. Specification is missing (or dissatisfaction with available specifications);
6. Need for an appropriate test procedure (depending on operation conditions or difficult boundary conditions).

Table 1 shows the list of identified Technical Demonstrators, the agreed contact partner of FINE 1 and the name of the Shift2Rail project taking care of the TDs. It is taken from D5.1 [8].

The acoustic source “Mechanical Drive” is represented in TD1.1, the source mechanism “Rolling Noise” in TD1.4. The subassemblies “Floor” and “Door” have corresponding projects as TD1.2 and TD1.6.

Table 1: Identified TDs, responsible partner and corresponding S2R project

N°	Partner	Shift2Rail project
TD1.1 Traction Systems	Alstom	PINTA
TD1.2 Carbody Shell	CAF	PIVOT
TD1.4 Running Gear	Bombardier	PIVOT
TD1.5 Brake Systems	Siemens	PIVOT
TD1.6 Doors and Access Systems	Talgo	PIVOT
TD1.7 Train modularity in use	Bombardier	TBA
TD3.1 Enhanced Switch and Cross	DB	TBA
TD3.2 Next Generation Switch	DB	TBA
TD3.3 Optimized track system	DB	TBA
TD3.4 Next generation track system	DB	TBA
TD3.5 Proactive Bridge and Tunnel	DB	TBA
TD5.1 Freight electrification	Bombardier	TBA
TD5.3 Wagon design	Bombardier	TBA
TD5.4 Novel Terminal, Hubs, Marshalling Yards, Sidings	Bombardier	TBA
TD5.5 New Freight Propulsion	Bombardier	TBA

3 REQUIREMENTS FOR CHARACTERISATION OF SOURCES AND SUB-ASSEMBLIES

3.1 BASIC DEMANDS FOR GOOD REQUIREMENTS

The basic demands for writing good requirements are based on Hooks 'Writing good requirements' [5]: 'A good requirement states something that is **necessary**, **verifiable**, and **attainable**.' System engineering transforms stakeholders defined 'necessities/needs' into attainable, verifiable system requirements using simple, clear and laconic wording.

The requirement shall state **what** is needed, not **how** it is accomplished. To ensure that the requirement engineer states the necessity correctly, it should be asked: why the requirement is needed? The why-question supports the definition of the needs and a clear formulation of the requirements. The requirement engineer should reflect the consequences of these demands.

Attainability refers to the technical feasibility within the existing constrains (budget, time, equipment, environment). Verification is concerned with verifying/examining/validation procedure based on quantitative values and defined criteria for acceptance.

With regard to the wording: requirements use **shall;** statement of facts use **will** and goals use **should.** For clearness and simplicity, it is recommended to keep non-requirement information (e.g. complicated explanations of operations) separated, e.g. in an introduction to requirements.

'The following is a list of the most common problems in writing requirements [5]:

- Making bad assumptions,
- Writing implementation (**HOW**) instead of requirements (**WHAT**),
- Describing operations instead of writing requirements,
- Using incorrect terms,
- Using incorrect sentence structure or bad grammar,
- Missing requirements,
- Over-specifying.

3.2 Definition of Requirements

The definition of requirements starts with the functional part (noise control & acoustic performance) and provides a requirement skeleton (a form of organization and presentation of a set of requirements) with given explanations. The general skeleton for sources and sub-assemblies is kept identical. The air- and structure-borne characterisation are kept separate for ease of use and practical reasons, but the subsections are named in the same way.

One part of WP8 work is the development of new / improved characterisation and specification methods for certain sources or sub-assemblies. The requirement skeleton should therefore be open for modifications with regard to the noise control/acoustic performance necessities (e.g. the use of new characterisation methods). The definition of requirements should on the other hand enable the development engineer of new methods to understand the more general or non-acoustic requirements with regard to the technical and organisational frame / procedure, measurement and deliverables.

The technical frame refers to the use of available or future standards. The organisational frame requires methodologies (e.g. simple / robust / useable by main suppliers); interfaces, technical preconditions (e.g. power supply) and measurement effort (e.g. financial/time budget, number of operational points / measurement points). The 'need' of technical measurements should transform simplicity, robustness, common techniques and not too scientific into verifiable system requirements. With regard to the deliverable engineering the demand (needs) of further use of characterisation values (e.g. simulation, evaluation, analysis) and the amounts of digital data and formats should be defined. For the development of new methods could the origin of requirements (derived / law / customer / technical feasibility / limits) be of importance

This section lists a minimum set of requirements that should be defined and documented as a part of the source characterisation.

3.2.1 Objectives

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

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

Comment: This gives an introduction regarding the type of characterisation. For clarity and ease of use these sentences (the topic ABN and SBN) are separated.

3.2.2 Source / Sub-assembly Characterisation

1. Specified Requirements

The characterisation variable shall be attainable, verifiable and, if possible be part of a common accepted standard (see 2. Characterisation Method).

Examples of specific requirements:

Source

ABN: Total sound power level, a sound power spectrum or radiation directivity

SBN: Blocked force or free velocity

Sub-assembly

ABN: Transmission loss (single value or spectral shape) or radiation efficiency

SBN: Damping or a defined frequency response-spectrum

2. Characterisation Method

2.1 Measurement

2.2 Simulation

2.3 Hybrid

2.4 Technical Standard / Norm

Requirement engineering demands quantitative, verifiable, standardized results for the characterisation of sources. Simulation is in principle able to provide the same characterisation methods as measurements. Measurement, simulation and a mix of both (here named 'hybrid') refers to verifiable defined processes without anticipating the planned work of WP8 or excluding new or improved characterisation methods. Standards are included into this section 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:

Source

ABN: sound power, intensity, pressure, vibration or directivity

SBN: [blocked] force, [free] velocity, source mobility or vibration isolation

Sub-assembly

ABN: transmission loss, insertion loss, noise reduction, damping, radiation efficiency

SBN: v/F or p/F – frequency response function, modal analysis, vibration, damping, where v is the structural velocity in m/s, p the sound pressure in Pa and F the operational force in N

3. Constraints and Conditions

3.1 Boundary Conditions

3.2 Operating Conditions

The term '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. The 'operating conditions' describe the e.g. the adjustment 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
4.2 Statistics Source and Measurement Results
4.3 Input for Interior/Exterior Simulation
4.4 Time Signals for Arabisation

‘System Source Characterisation’ defines the way the source/sub-assembly analysis should 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.

The term ‘statistics’ refers to the necessity to know and document the quantitative characterisation and variation of sources/sub-assemblies (e.g. is there a need to measure more than one source/assembly?) as well as about the measurement (e.g. how many measurements have to be done?). Standard methods (see Characterisation Methods) sometimes correspond to a certain degree of accuracy (Precision / Engineering / Survey) as well as a clear definition and reporting of the statistics. 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, and harmonic), the distribution (e.g. normal, uniform) and variation/deviation (e.g. variance, standard deviation).

	Possible input for interior/exterior noise prediction tools:
Source	
ABN:	Sound power level (SWL), sound pressure level (SPL) in the frequency range of 20 Hz to 8 kHz in 3rd octave bands (17.8 Hz to 8913 Hz in narrow bands respectively).
SBN:	Structure-born sound power (SBN-SWL), force, velocity in the frequency range of 20 Hz to 1 kHz in 3rd octave bands (17.8 Hz to 1122 Hz in narrow bands respectively). An extension of the frequency range e.g. up to 5 kHz could be necessary.
Sub-assembly	
ABN:	Transmission loss, insertion loss, noise reduction in the frequency range from 100 Hz to 3150 Hz in in 3rd octave bands (89 Hz to 3548 Hz in narrow bands respectively). An extension of the frequency range from 20 Hz – 6.3 kHz could be necessary.
SBN:	The input for interior/exterior simulation tools cold be e.g. v/F or p/F – frequency response function in the frequency range of 20 Hz to 1 kHz in 3rd octave bands

Spectrum types are the Fourier transform, power spectral density (PSD) or auto power-spectra. A required time signal offers not only a 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.

3.3 Examples

The aim of this section is a test of the requirement skeleton (a set of requirements) with focus on noise control (acoustic performance) necessities. Since the full description, analysis and development (improvement) of the characterisation method and the related specification are part of the other WP8-tasks 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).

3.3.1 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 Lw (dBA) 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).

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

3. Constraints and Conditions

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

4. Documentation and Deliverables

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

Structure Borne Characteristics

1. Specifications

The supplier should take into consideration the following information:

The maximum velocity level on the train in dB, $\mathbf{L_{VT}}$

1/3 Oct Bands (Hz)	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000
L_{VT} (dB ref 1 nm/s)	75	78	79	86	95	101	113	104	112	108	103	107	110	120	130	135	135

The equivalent mobility of the train, $\mathbf{Y^{\Sigma(T)}}$

1/3 Oct Bands (Hz)	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000
$Y^{\Sigma(T)}$ (dB ref 1 m/s.N)	-90	-88	-86	-84	-82	-80	-78	-76	-74	-72	-70	-68	-66	-64	-62	-60	-58

The maximum velocity level of the equipment on the test bench in dB, L_{VR}, must fulfill the following:

$$\boxed{L_{VR} \leq L_{VT} + C_1 + C_2}$$

The definitions details of C1 and C2 are also provided to the supplier (description in task 8.2).

2. Characterisation Method

Mobility measurement according ISO 7626-5:1994 of:

- Test bench without the traction motor,
- Test bench with the traction motor,
- Frequency resolution of 1 Hz from 45 Hz up to 2240 Hz

Velocity vibrations measurement of:

- Test bench with the traction motor.
- Frequency resolution of 1 Hz from 45 Hz up to 2240 Hz.

3. Constraints and Conditions

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

The supplier should also take into account the following restrictions for the mobility of the reception structure:

$$\left\| \Delta_{R|T} \right\| < 75 \text{ dB}$$

4. Documentation and Deliverables

Test report with description of characterization test and results in third octave bands. Measurement data in narrow band with phase (file format readable by excel).

3.3.2 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 Lw (dBA) 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).

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

b. Specifications for interior noise requirements

Specified sound power levels Lw (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 ISO 9614-2:1996

3. Constraints and Conditions

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

4. Documentation and Deliverables

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

Structure Borne Characteristics

1. Specifications

The supplier should take into consideration the following information:

The maximum velocity level on the train in dB, $\mathbf{L_{VT}}$

1/3 Oct Bands (Hz)	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000
L_{VT} (dB ref 1 nm/s)	75	78	79	86	95	101	113	104	112	108	103	107	110	120	130	135	135

The equivalent mobility of the train, $\mathbf{Y^{\Sigma(T)}}$

1/3 Oct Bands (Hz)	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000
$Y^{\Sigma(T)}$ (dB ref 1 m/s.N)	-90	-88	-86	-84	-82	-80	-78	-76	-74	-72	-70	-68	-66	-64	-62	-60	-58

The maximum velocity level of the equipment on the test bench in dB, L_{VR}, must fulfill the following:

$$\boxed{L_{VR} \leq L_{VT} + C_1 + C_2}$$

The definitions details of C1 and C2 are also provided to the supplier (description in task 8.2).

2. Characterisation Method

- Mobility measurement according ISO 7626-5:1994 of:
  - Test bench without the HVAC unit,
  - Test bench with the HVAC unit,
  - Frequency resolution of 1 Hz from 45 Hz up to 2240 Hz
- Velocity vibrations measurement of:
  - Test bench with the HVAC unit.
  - Frequency resolution of 1 Hz from 45 Hz up to 2240 Hz.

3. Constraints and Conditions

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

The supplier should also take into account the following restrictions for the mobility of the reception structure:

$$\left\| \Delta_{R|T} \right\| < 75 \text{ dB}$$

4. Documentation and Deliverables

- Test report with description of characterization test and results in third octave bands.
- Measurement data in narrow band with phase (file format readable by excel).

3.3.3 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 LwA (dBA) 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 dBA 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 modeling, 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).

3.3.4 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.

Airborne Characteristics

1. **Specified requirements**

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 [13] rail roughness
- track decay rate acc. to EN ISO 3095 [13]

2. **Characterisation Method**

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

In R2R [12] 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/…)

3.3.5 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**	**Rw**
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

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 description of characterization test and results from the application of ISO 10140-2:2010.

3.3.6 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.

Airborne Characteristics

1. **Specified requirements**

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

2. **Characterisation Method**

Laboratory or in-situ measurements based on standard series ISO 10140 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**

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

Test report with description of characterisation test and results from the application of ISO 10140.

4 SUMMARY

The deliverable 'D8.1 – Characterisation and specification requirements' is part of WP8 - 'Sources and Assemblies' of FINE 1. To achieve the noise performance objectives of rolling stock it is necessary to establish vibro-acoustic targets for sources (e.g. mechanical drive, HVAC-system, compressor, main transformer, rolling noise (squeal & low frequency) and sub-assemblies (e.g. floor, HVAC-ducts/silencer, fairings/skirts, sidewall, gangway & gangway doors and doors) based on a quantitative characterisation and specification.

Alstom, BT, CAF and DB are the stakeholders of WP8 and responsible for the extraction, acquisition and definition of requirements and activities for source and sub-assembly selection. The present report gives insight into the 3 step by step compiled complementary questionnaires and related discussions (teleconferences) for requirement elicitation and definition. The questionnaires list sources and sub-assemblies combined with questions regarding rail vehicle segments (e.g. Urban, Regional, Locomotive and High-speed), interior/exterior noise, ABN/SBN as well as certain acoustic boundary conditions. The selection of sources and sub-assemblies is based on a point scale ranking. For the analysis and prioritization are different ranking techniques, software tools and plot-types tested. A short strength & weakness-analysis of characterization methods with focus on requirements is included. The report provides a list of selected sources and sub-assemblies and documents reasons for the selection. The work includes input of WP7 - 'Interior Noise' and Acoutrain (exterior noise) and provides information about the Technical Demonstrators.

Beside a short section about the basic demand of good requirements is a requirement skeleton (a form of organization and presentation of a set requirements) for air- and structure-borne noise for sources and sub-assemblies provided. The general skeleton is for sources and sub-assemblies identical, but the air- and structure-borne characterisation are intentionally kept separate for practical reasons All definitions of requirements start with a functional part (noise control & acoustic performance) and provide each section of requirement skeleton with explanatory comments.

The given requirement examples are a 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). The full description, analysis and improvement of the characterisation method and the related specification are part of the following WP8-tasks.

In summary, the deliverable provides a translation for the acoustic performance needs into verifiable, attainable system requirements for the characterisation and specification of sources and sub-assemblies and documents a selection of sources and sub-assemblies as well as the reason for prioritization.

REFERENCES

[1] ACOUTRAIN European research project: Virtual certification of acoustic performance for freight and passenger trains, http://www.acoutrain.eu/

[2] Fernandes and Machado: Requirements in Engineering Projects; Springer International 2016

[3] Adams: Non-functional Requirements in Systems Analysis and Design; Springer International 2015

[4] IEEE Guide for Developing System Requirements Specifications; IEEE Std 1233, 1998 Edition

[5] Hooks: Writing Good Requirements; Published in the Proceedings of the Third International Symposium of the NCOSE - Volume 2, 1993

[6] ISO/IEC/IEEE 29148:2011, Systems and software engineering — Life cycle processes — Requirements engineering

[7] IEEE Guide for Developing System Requirements Specifications; IEEE Std 1233, 1998 Edition

[8] D5.1- List of TDs influencing the N&V performance of the system

[9] D7.1 - Review of state of the art for industrial interior noise predictions

[10] Decision Making Helper INFONAUTICS GmbH in Switzerland (https://www.infonautics-software.ch/decisionmakinghelper/)

[11] DESTINATE "Decision supporting tools for implementation of cost-efficient railway noise abatement measures" S2R-OC-CCA-03-2015

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

[13] EN ISO 3095:2013, Acoustics — Railway applications — Measurement of noise emitted by railbound vehicles