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Virtual certification of acoustic performance for freight and passenger trains

Deliverable 1.2:

Recommendations for a future certification process

Virtual testing implementation in the framework of the TSI Noise

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EXECUTIVE SUMMARY

This document corresponds to the first recommendations for the implementation of virtual testing for the certification of railway rolling stocks according to the TSI Noise.

General principles of the implementation of Virtual Testing, presented in the first chapters of this document, have been used to build the fundamental basis for a reliable procedure. In particular, the V&V process (Verification & Validation process) has been adapted to the framework of TSI Noise and acoustic simulations carried out for global noise levels computation.

Some recommendations are also presented about the legal and formal aspects of a VT procedure. ACOUTRAIN will provide a methodology to assess the noise levels required by the TSI technical requirements together with an estimate of variability on these noise levels.

The first recommendations as described in this report should be viewed as preliminary: they will be evaluated and demonstrated in work package 5. This will result in an updated and finalised proposal for a virtual certification process that will be described in deliverable D1.8 at the end of the project.

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1. INTRODUCTION

The aim of ACOUTRAIN is to provide methodology to assess the noise levels required by the TSI technical requirements by introducing simulation elements in combination with testing. Further, the aim is to lay out procedures to estimate the variability of the predicted noise levels.

The first year of work of the ACOUTRAIN consortium has led to a set of the first recommendations for the implementation of a procedure of Virtual Testing within a TSI Noise certification process.

General principles of Virtual Testing have been used to build the fundamental basis for a reliable procedure and are presented in the first chapters of this document, backed up with a vocabulary list specifically created for the acoustic virtual testing activity and a short section that presents the context of the TSI Noise today. The Verification & Validation process (V&V process) has been adapted to the framework of TSI Noise and the general approach applied in the most common simulation tools and virtual vehicles already in use. Moreover, the section 4.3 is dedicated to the general principles of the Verification and Validation process which defines the frame of a reliable virtual certification process. Chapter 5 details the conditions of application of a reliable virtual testing within the frame of the acoustic certification. Chapter 6 consists in a summary of the most important points and recommendations for a new procedure that form the starting point for the elaboration of a detailed procedure. The basic concepts for the evaluation of the global procedure now roughly defined are detailed in chapter 7. Finally, chapter 8 introduces, outside the scope of TSI Noise certification, the other fields of action for virtual testing.

Some recommendations are also presented about the legal and formal aspects of a VT procedure. A proposal for general principles for accrediting a person or a lab to the virtual testing activity is also detailed in the annex A of the document.

The first recommendations as described in this report should be viewed as preliminary. They will be demonstrated and assessed in work package 5 resulting in an updated and finalised proposal for a virtual certification process to be described in deliverable D1.8 “A virtual certification process (validated)” at the end of the project.

Throughout in the document, the term “present/current TSI Noise” refers to the TSI Noise 2005 (1).

2. VOCABULARY

The following definitions are assumed throughout this document:

Accreditation	The process to give authority or sanction to someone or something when recognized standards have been met
Calibration	The process of adjusting physical modelling parameters (parameters with physical meaning the value of which is unknown or variable within a range, e.g. speed of sound, porosity of a material, etc) in the virtual vehicle to improve agreement with experimental data
Certification	Procedure to attest that an object or person fulfils certain requirements or meets a standard. In ACOUTRAIN we talk about two different certification processes: - *Certification (homologation) of rolling stock*: To fulfil some requirements to provide the assurance that a railway vehicle can be operated on railway networks. - *Certification of simulation tool*: To enable the tool to be used for virtual testing.
Notified body (NoBo)	Organisation that has been accredited by a Member State to assess whether a product meets certain preordained standards. Assessment can include inspection and examination of a product, its design and manufacture.
Real Testing	Measurements as defined in the current TSI Noise.
Recommendations for virtual testing	Technical scope for a Virtual testing implementation within the TSI Noise framework.How can we use numerical simulation in a certification process? In which cases? Which numerical tool should be used? How to be sure that this procedure is as reliable as the field tests? Is this procedure accurate enough to form a decision basis for certification?
Simulation tool or code	Numerical software that allows computation of the exterior noise levels of a rail vehicle, defined as a set of acoustic sources
TDR	Track Decay Rate
TSI	Technical Specification for Interoperability
TSI Technical requirements	Requirements in term of noise limits to be fulfilled by a vehicle to be TSI compliant
TSI Technical specifications	Operation conditions for the TSI Noise tests i.e. measurement details as found in the Appendix C-E of the TSI Noise
Type	Category of rolling stock that has as common characteristics the range of speed and/or the motorization and/or the kind of traffic they are used for. In ACOUTRAIN, 5 different types of rolling stock have been considered: Freight wagon, locomotive, coach, EMU/DMU and high speed trains.
Uncertainty	Parameter, associated with the result of a measurement or the results of a computation that characterizes the dispersion of the values that could reasonably be attributed to the measured quantity or computed data. Uncertainty is a parameter characterizing the range of values within which the value of the measured quantity can be said to lie within a specified level

	of confidence. An uncertainty estimate should address error from all possible effects (both systematic and random) and, therefore, usually is the most appropriate means of expressing the accuracy of results.
Validation	The process of compiling evidence to establish that the appropriate mathematical models were chosen in the implementation of virtual testing, to answer the questions of interest (its noise emission prediction) by comparing simulation results with experimental data. It addresses assessment of a model's capability (simulation tool or virtual vehicle) to represent the real world accurately by comparing calculations with experiments. See section 4.3 for details. In ACOUTRAIN, validation will concern: - the validation of the simulation tool which deals with the reliability of the transmission model (propagation + basic principles of the tool i.e. energetic adding of the sources acoustic contributions) compared to the real world - the validation of the virtual vehicle which deals with the accuracy of the equivalent noise sources that represent real noise sources
Variability	The extent to which data points in a statistical distribution or data set diverge from the average or mean value. Variability also refers to the extent to which these data points differ from each other. There are four commonly used measures of variability: range, mean, variance and standard deviation. Variability in the results of repeated measurements arises because variables - that can affect the measurement result - are impossible to hold constant.
Verification	This process addresses the accuracy of the numerical solution produced by the computer code as compared to the exact solution of the conceptual model. It therefore demonstrates that a simulation tool accurately represents the underlying mathematical model and its solution in terms of computation. It addresses programming errors and estimation of numerical errors See section 4.3 for details
Virtual Testing	Use of simulation models for the assessment of regulatory (enforced by law) technical requirements, e.g TSI Noise in ACOUTRAIN
Virtual vehicle or simulation model:	Model of a vehicle as a set of acoustic sources/inputs, created in a simulation tool that represents the real vehicle that is being assessed.

3. TSI NOISE: PRESENT SITUATION

Currently the need for conformity assessment of a new vehicle according to the TSI Noise represents a significant element of both cost and time to market, due to the need to carry out expensive and time consuming field tests.

The certification process consists in demonstrating that a vehicle complies with the technical specifications and limits for exterior noise level defined in the TSI Noise for different situations: stationary noise, pass-by noise and starting noise. In addition, interior noise level in the driver's cab is assessed.

The certification process follows the diagram presented in Figure 1. A precise acoustic description of the rolling stock is required, normally given as a list of the relevant noise sources together with a functional description for each of them.

The exterior measurement should be performed according to the requirements of ISO 3095:2005 (2) and specifically pass-by measurements have to be carried out on a TSI compliant track.

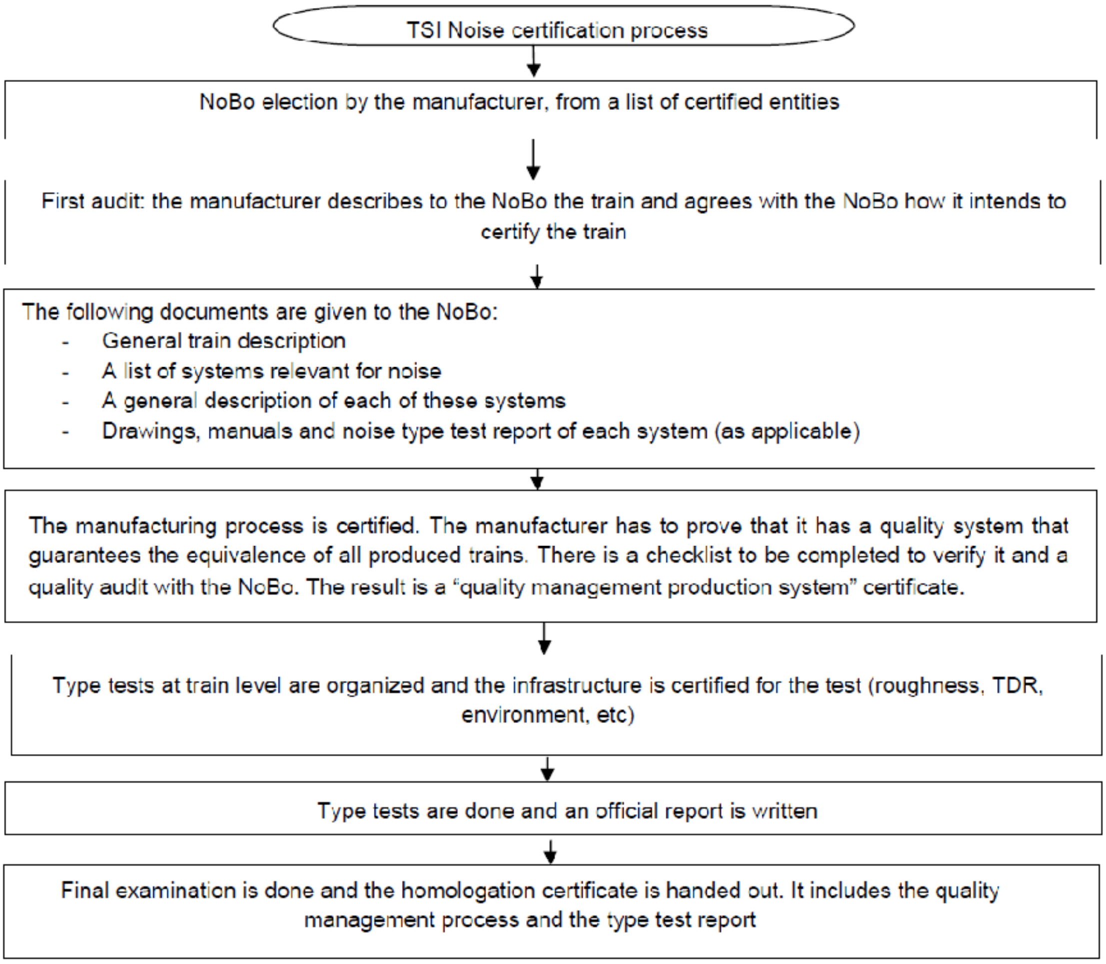

Figure 1: TSI Noise certification process

The time needed to carry out a complete TSI Noise certification is estimated to ca. 450 hours of effective work spread over a period of 2 to 6 months. The total cost for a noise certification is ca. 70 k€ for an EMU/DMU or ca. 80 k€ for a high speed train, depending on the considered network (which determines the track access charges) and other factors like vehicle rental costs. This is a rough estimation based on two input sets.

More detailed cost figures, based on estimates provided by the ATSA, BT and SNCF measurement teams, is displayed in Table 1 below:

	Costs categories	Detailed costs	Total
Stationary noise	Man-days	From 12 to 20 man-days	From 13k€ to 19k€
	logistics	From 1k€ to 3k€	
Pass-by noise regular speed	Man-days	From 24 to 30 man-days	From 27k€ to 50k€
	Logistics	From 3k€ to 5k€	
	Track access charge	From 5k€ to 25k€*	
Pass-by noise high speed	Man-days	From 24 to 30 man-days	From 27k€ to 67k€
	Logistics	From 3k€ to 5k€	
	Track access charge	From 5k€ to 40k€*	
Starting noise	Man-days	From 12 to 20 man-days	From 10k€ to 19k€
	logistics	From 1k€ to 3k€	

Table 1: Costs associated with TSI Noise certification testing

* *The track access charges fully depend on the infrastructure manager and therefore on the country considered. Some countries can even offer free track access.*

According to the manufacturers involved in the ACOUTRAIN project, certification of a new rolling stock or a large vehicle upgrade is carried out 2 to 4 times a year, for each manufacturer.

This process could be made more efficient by introducing **virtual testing** and thereby speeding up the product authorisation while retaining the same degree of reliability and accuracy. This is the aim of ACOUTRAIN.

A successful simplification of the TSI conformity assessment process could result in a strengthening of the competitiveness of the European railway sector. The risks associated with not allowing such a simplification are that the expense of excessive certification of new products hampers the introduction of new innovations and contributes to maintaining an unnecessarily high cost structure for operators and train passengers.

For example, for a case in which virtual testing can avoid carrying out pass-by measurement, with only a few additional measurements at standstill (for noise source characterization for example), the cost of testing within a noise certification procedure could be reduced by a factor of 2.

4. VIRTUAL TESTING: GENERAL PRESENTATION

4.1 PRINCIPLES

Virtual testing is based on the principle that some or all tests carried out in a given process can be replaced by numerical simulations.

The concept of virtual testing has gained acceptance in other fields, such as crash testing or fatigue. Certification based on virtual testing is used in areas where full scale tests are highly impractical or even impossible, for example when assessing an aircraft fuselage for its capability to withstand aerodynamic loads. In many fields, simulation activities have reached maturity in terms of calculation accuracy and reliability. The feedback of the industry is that such activities are ready to be used for certification purposes. Also for acoustic prediction, numerical prediction tools are already extensively used in the conception and design phases.

In the ACOUTRAIN project, the goal is to develop virtual testing methods, mainly to assess stationary noise and pass-by noise but also if possible for starting noise assessment, corresponding to the technical specifications of the TSI Noise. In other words there should be no changes to the defined limiting values that are set according to the specific measurement details described in the appendices C-E of the TSI. Hence the concept is to simulate exactly the measurement situations. For example should vehicle conditions, measurement positions and pass-by speeds as they are defined for the real testing be reproduced in the case of virtual testing.

A specific simulation tool is used to carry out the required simulations. Currently, there is a small number of such tools, mostly developed, verified and owned by the major manufacturers. At the time of writing there are no commercial tools that are available on the market, but a simple tool will be developed within the ACOUTRAIN project. A numerical model of the rolling stock, or in case of ACOUTRAIN a so-called virtual vehicle, is implemented in this tool. It is defined as a set of acoustic sources: all the relevant information is gathered in the vehicle geometry and the acoustic characteristics of sources. The simulation tool calculates the global noise levels that correspond to the virtual vehicle pass-by or stationary noise by adding the acoustic single noise source powers of the relevant sources, taking into account the acoustic propagation and the propagation delay due to the sources distribution. This model aims at reliably representing a test situation.

4.2 ISSUES

Before being able to answer the question “whether a virtual vehicle built in a simulation tool is reliable enough” first we need to define:

- What has to be predicted?

Every TSI Noise test is intended to assess the acoustic behaviour of a system according to some specified conditions of measurement (for instance speed, environmental conditions or the TSI compliant track for the pass-by test). We can simplify the situation saying that a system shows a certain physical behaviour, which should be reproduced by the simulation model in the case of VT. Then, this physical behaviour of the complete system can be described by measuring the behaviour of the constituent components. A simulation model (virtual vehicle) is reliable when it can reproduce the system from its single components.

- How can we assess the reliability of a virtual vehicle built in a simulation tool?

A comparison of simulation results against the physical magnitudes of interest defined in the tests procedure is necessary.

- How can we quantify the “level of accuracy” of the prediction?

The “level of accuracy” of the prediction from a virtual vehicle, built in a simulation tool, can be viewed as a measure for how close the predicted result is to the equivalent measured one, namely the expected difference between simulated and measured values.

There are several possible approaches for the implementation of virtual testing. What they all have in common is that they include both measurement and simulation activities but to different extents.

The ratio between measurement and numerical simulation results is driven by the confidence that one can have about the virtual vehicle used for simulation:

- Results of certification of the simulation tool
- Results of virtual vehicle validation
- The complexity of the simulated case, with regard to the number of inputs and the quality of the source characterisation.
- The background knowledge and experience in the specific case. For instance if the vehicle is of a well-known design with customary sound sources or completely newly developed with innovative components.

Reliability of a rolling stock certification based on VT is provided by:

- he verification of the simulation tool
- The validation of each virtual vehicle of the rolling stock under test

This is called the verification and validation (V&V) procedure.

4.3 V&V: VERIFICATION AND VALIDATION PROCEDURE

According to the ASME "Guide for Verification and Validation in Computational Solid Mechanics" (3), Verification and validation (V&V) are the processes by which evidence is generated, and credibility is thereby established, that computer models have adequate accuracy and level of detail for their intended use. In ACOUTRAIN computer models are simulation tools in which virtual vehicles are implemented to predict exterior noise. As described in Figure 2, V&V analyse links between mathematics, numerical simulations and physics.

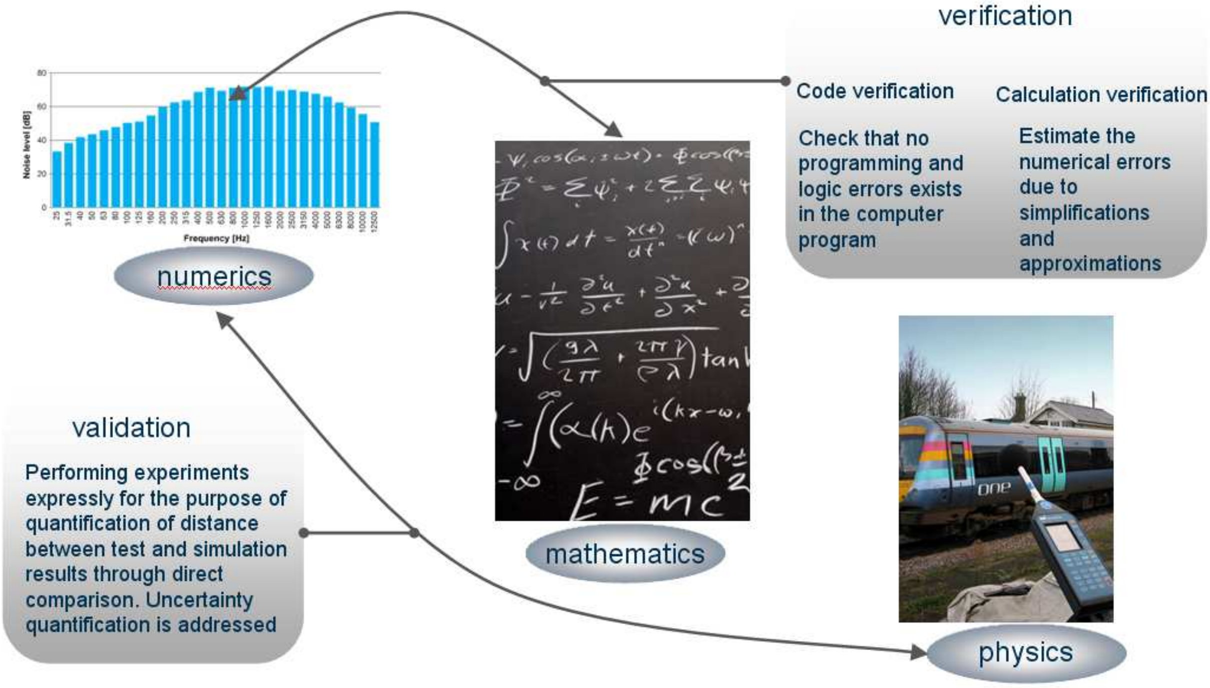

Figure 2: Verification and Validation basics

Verification: this is the procedure that allows the determination of whether a computational process as it is implemented in a simulation tool like ACOUTRAIN accurately represents the underlying mathematical model and its solution and that there are no programming errors or bugs. Two distinct levels of verification can be distinguished: code verification[1] and calculation verification[2].

Validation: comparison of simulation predictions and test results obtained under equivalent test scenarios, in order to assess the degree to which a model is an accurate representation of the real world and real physical system. It is important that model verification is completed before the validation process can begin. The goal is to represent the real world with a mathematical model. The only way to get a result from the model is to implement it in software code. So, when comparing the model with the real world we have to know beforehand that the code corresponds to the model we want to test. The general principles of this validation process is developed by Oberkampf and Barone in (4) and illustrated in Figure 3: from , validation process for the measures of agreement between computation and experimentFigure 3.

[1] Code verification: activities aiming to establish confidence, through the collection of evidence that the mathematical model and solution algorithms implemented in a code (simulation tool) are working correctly, i.e. there are no errors or bugs. One common code verification activity is to compare code (simulation tool) solutions against analytical solutions for an equivalent problem. Among the code (simulation tool) Verification techniques, ACOUTRAIN have chosen to compare code outputs with analytical solutions In ACOUTRAIN this part is dealt with in “Certification of numerical global tools” (WP4).

[2] Calculation Verification - activities aiming to establish confidence, through the collection of evidence, that a particular discrete solution of a simulation model (virtual vehicle) is obtained, i.e., that the model equations are convergent and can be solved. It may also be referred to as numerical error estimation. In this case discretization errors are observed to assure their low occurrence. This process is only applicable to simulation tools in which discrete numerical techniques are used as best approximations to analytical solutions.

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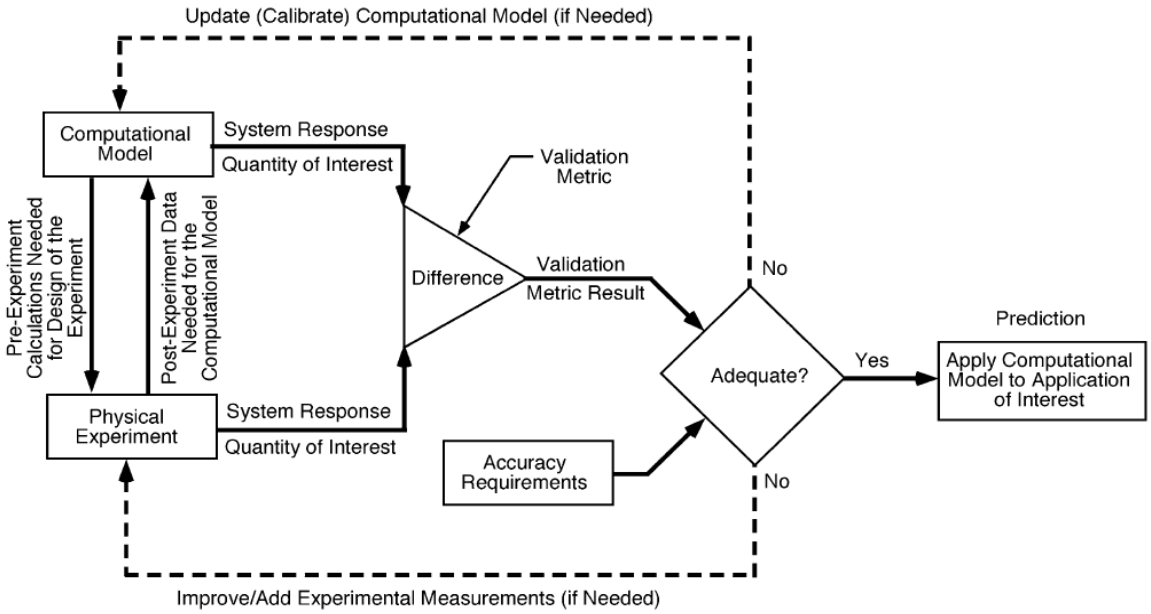

Figure 3: from (4), validation process for the measures of agreement between computation and experiment

The Verification and Validation (V&V) approach is a methodology that allows the identification and quantification of the reliability of a virtual vehicle. **The main issue in the implementation of Virtual Testing is how to identify when a virtual vehicle is reliable enough for its intended use, in our case rolling stock performance against TSI Noise requirements.** Thus when we say reliable enough we mean that the virtual vehicle can predict with a certain level of accuracy the behaviour of a rolling stock, system or subsystem being analysed under certain requirements. After the last definition, the issue of implementing VT is translated into the expression “predict with a certain level of accuracy”. In ACOUTRAIN besides V&V, specific steps will be defined to control and ensure the reliability of simulation tools within a set of requirements for tools certification, as shown in Figure 4.

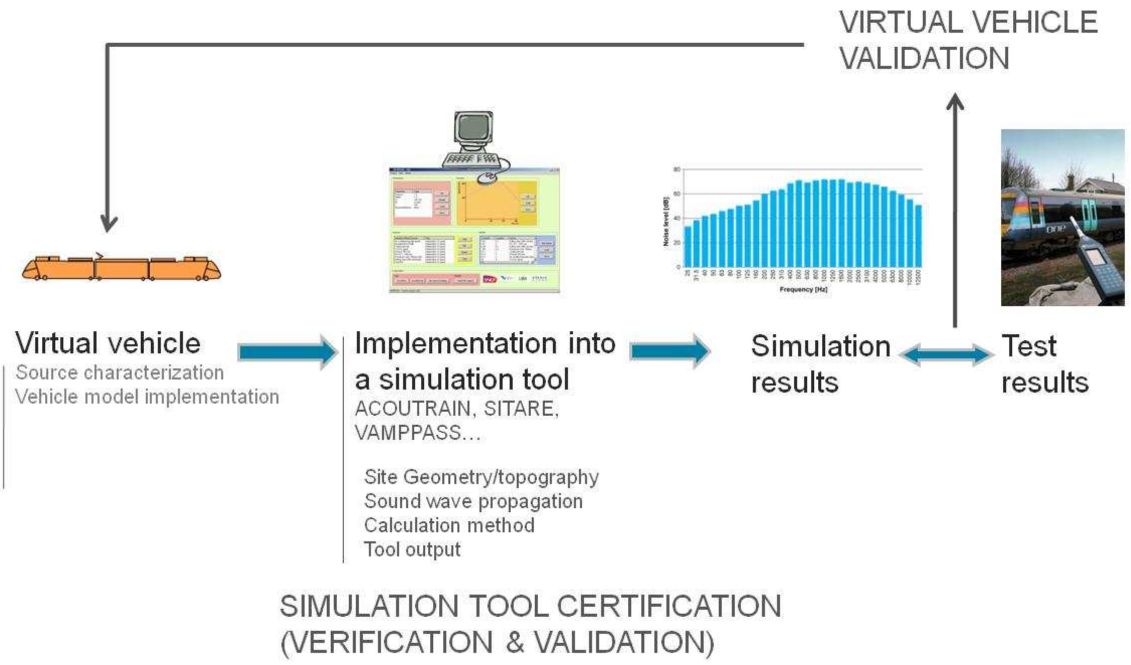

Figure 4: Verification, Validation and simulation tools certification

After the previous theoretical discussion we can conclude that through the V&V methodology we can specify what the difference is between the predictions given by a virtual vehicle built in a simulation tool and its physical counterpart. Moreover, a full carrying out of the V&V methodology provides insights into further questions such as:

- Can the conditions defined by the “measurement details” (TSI Noise Appendix C-E) be completely reproduced with a simulation model (virtual vehicle built in a simulation tool)?
- Does it make sense to simply compare one by one test results and simulation predictions (deterministic comparison) and not consider uncertainties?
- How can we define what is an acceptable deviation between test and simulation results?

ACOUTRAIN will attempt to answer these questions by performing different verification and validation activities relating to the whole virtual testing procedure and methods that are being developed in the project. It will include benchmarking and comparison between simulated and experimental data for a number of application cases.

Additionally it is considered to be necessary that it is proven that the model represents reality each time virtual testing is used. This is why V&V-methodologies are integrated as a necessary step in the proposed virtual testing procedure. For instance verification and validation will be implemented in the requirements for a certification procedure of simulation tools.

4.4 The various approaches in VT

Depending on how test and simulation results are used in the assessment of regulatory (in ACOUTRAIN TSI Noise) requirements, three possible approaches can be identified (this classification is not exhaustive, other alternatives might also be useful) for virtual testing:

- Full VT: assessment of requirements only based on simulation predictions. The Notified Body would grant or reject the type approval after evaluating the outcomes of a virtual vehicle developed with a certified simulation tool
- Hybrid VT: in this case both test and simulation results would be evaluated by the Notified Body. Testing and simulation would be complementary, and different requirements would be assessed with each method.
- Extension of Approval based on VT: in this approach the assessment of requirements is based on simulation predictions, as in Full VT, but the virtual vehicle is derived from a previously available validated virtual vehicle. This approach is indicated when modifications are to be assessed to an already type approved rolling stock material.

The three approaches are described in more detail below, together with examples of cases in which they may be applied in the context of TSI Noise.

4.4.1 Full Virtual Testing

Full virtual testing implies that we are assessing the total vehicle external noise level solely by assessing the single noise sources. This means that no real assembled vehicle is required for the certification. Only a virtual vehicle will be used to compute all or some of the levels that are to be compared with the limiting values of the TSI. We can also refer to this approach as **Virtual certification configuration**, in which absolute levels can be obtained with simulation only.

After a verification and validation process (see section 4.3), simulation models (virtual vehicle built in a simulation tool) are deemed validated and reliable enough to be used as the only mean in the assessment of technical requirements. It does not mean that there are no testing activities; on the contrary during the validation phase prior to the assessment of technical requirements, specific validation tests shall be defined and implemented. These tests will mainly concern the reliability of equivalent noise sources definition. Present optimal ways for characterizing these equivalent noise sources will be detailed in the deliverables produced in the workpackages dedicated to noise sources (WP2 for the rolling noise and WP3 for vehicle specific noise sources). The methodologies developed in these workpackages aims at assessing the accuracy/uncertainty linked to each of the characterized source. Obviously those validation tests should not be exactly the same tests as those specified in the regulatory document according to the conventional approach for two reasons:

- If same tests and set up are used, there would be no benefit in using Virtual Testing, in fact time and budget would be increased
- For validation of simulation models (validation of virtual vehicles), test set-ups different to the one specified in the regulatory document can be more convenient, because the aim of conventional homologation tests and validation tests is not the same. It might be more useful to measure different parameters, or perform different data post processing, or use different measurement points.

The quality of the results is assessed by:

- quality assurance of the input data, here mainly the source data and

- that the tool used is validated (and verified) in such that the important physics is correct.

The reliability of a virtual vehicle will always depend on the accuracy of inputs. In the case of full virtual testing, the validation of the virtual vehicle relies only on the input characteristics. Therefore, all the input (the noise sources) should be very precisely defined according to measurement standards already existing or methodologies developed in ACOUTRAIN, including precise uncertainty assessment. Error assessment is performed with an analysis of propagation of errors.

→ A full virtual approach implies higher requirements on the documentation (particularly for the input characterization) than the other virtual testing approaches presented below.

Example within the scope of the TSI Noise:

A new freight wagon has to be certified:

- Rolling noise is the only source to be considered
- Wheels on this wagon are fully characterized:
  - Roughness with the given brake system is determined through a database
  - Vibro-dynamic behaviour is computed with a FEM computation
  - Radiation pattern is characterized with numerical or analytical analysis
- Rolling noise contribution for one wheel is computed with TWINS simulation for example
- Global pass-by noise is assessed with the implementation of the virtual vehicle of this wagon in a certified simulation tool

4.4.2 Hybrid Virtual Testing

The hybrid approach is a combination of measurements and computations. The hybrid approach is the one to be used if we do not have a reference vehicle for which we have developed a validated virtual vehicle.

Moreover, this approach is useful when the measurements are carried out on a non TSI compliant track and have to be converted to TSI track pass-by results.

As in full virtual testing described above, it is required that the hybrid virtual testing approach is verified and validated, but there is a main difference in the assessment of the TSI Noise requirements; in this case both conventional/physical tests and virtual vehicle predictions can be used. We can say that simulation supports real tests and vice versa. When virtual testing is implemented for the first time this approach is preferred, because advantages from real tests and simulation are mixed without needing a reference virtual vehicle that is already validated (see Extension to Approval method); confidence in the well-known test methods and the potential of the new virtual test method.

It requires several experimental tests on sub-systems as well as on the train itself.

Example within the scope of the TSI Noise:

For example, a vehicle is measured at standstill according to the TSI technical specifications and some additional measurements are carried out in laboratory or at standstill to accuratly characterize the most important single noise sources (these could be identified during standstill measurement for example). This set of measurements allows the corresponding virtual vehicle to be defined that will be validated for the standstill case. Simulations could then be carried out for the pass-by case, supposing that the sources at standstill can be interpolated for pass-by running conditions and that rolling noise can accurately be predicted.

4.4.3 Virtual Testing in an Extension to Approval

Nota: the term "Extension of Approval" used in this document is characteristics to ACOUTRAIN scope and does not refer to the terminology of the TSI Noise.

This third approach basically differs from the previous two in one aspect: it does not start from scratch but from a validated virtual vehicle of a similar rolling stock family. From this validated virtual vehicle a derivative model is defined through modifications of the input data of the original model (e.g. changes in geometry, noise source positions, noise source amplitudes), which are expected not to produce a strong influence on the reliability of the model. Hence the existing validation is still considered acceptable also for the new derivative model. However, at the request of the Notified Body, the manufacturer would have to provide evidence to show that the model validation is still applicable so that the updated model is still valid for homologation purposes (it has be demonstrated that the contribution of new or modified parts to the overall acoustic performance is not strongly affected, and can be still predicted accurately with the modified virtual vehicle).

It is foreseen that a vehicle that has been certified with an EoA approach cannot function as a reference vehicle for further EoA-certifications, although the original reference vehicle can be used again in this way (the original reference train can be used again for EoA if the number of changes from the reference to the final train is still limited). A reference vehicle should be validated with tests.

Example within the scope of the TSI Noise:

A newly developed DMU is identical to an existing DMU except that it is equipped with wheel dampers and a different cooling system. The existing DMU has been chosen to be the reference for the new vehicle (and possibly a whole vehicle family with similar designs): the virtual reference vehicle has been created and validated in an earlier phase and all relevant sound sources have been characterized.

- The reference DMU has been fully certified with field tests
- A virtual vehicle is developed for this reference DMU and validated (by comparison with field test results)
- Contribution of the wheels equipped with dampers is assessed with TWINS
- The new cooling system is characterized with lab tests
- The validated virtual vehicle of the reference DMU is used as the basis to create the virtual vehicle of the new DMU, with new wheels and new cooling system.
- The new DMU is certified if the simulated L_{eqTp}(A) is below the noise limits defined in the technical requirements of the TSI Noise.

Remark: The above definitions mean that the reference vehicle of the rolling stock fleet is built using measurement results or a hybrid approach and the noise levels of the other vehicles of the rolling stock fleet are assessed using an extension of approval approach.

4.4.4 Comparison of the V&V methods

A comparison of the three different methods presented in this section is shown in Table 2.

			Differences		
similarities			1	2	3
			Full VT	Hybrid VT	EoA based on VT
	1	Full VT		In the assessment of technical requirements, 1 uses only virtual vehicle results, while 2 uses both test and simulation results	In 1 a new virtual vehicle has to be validated while in 3 the process starts from a previously existing and validated virtual vehicle built in a simulation tool
	2	Hybrid VT	In 1 and 2 a virtual vehicle validation is performed based on the comparison of test and simulation results		In 2 a new virtual vehicle has to be validated while in 3 the process starts from a previously existing and validated virtual vehicle built in a simulation tool In the assessment of technical requirements, in 3 only simulation results are used while in 2 both test and simulation results
	3	EoA based on VT	In 1 and 3 assessment of technical requirements is made using only simulation results from already validated tools and models	In 2 and 3 a virtual vehicle validation is performed based on the comparison of test and simulation results, although validation tests in 3 should be much less extensive than in 2 (less cases for comparison)	

Table 2 : Summary of similarities and differences between VT approaches

5. VIRTUAL TESTING WITHIN THE TSI NOISE FRAME

5.1 CANDIDATE APPLICATIONS FOR VIRTUAL TESTING

The cases proposed below are only candidates for VT implementation. Some of them will be or not turn into VT applications depending on the results of the validation carried out in the WP5.

Virtual testing is considered to be a possible alternative to real testing in many cases of the TSI Noise procedure. The partners of ACOUTRAIN WP1 have been questioned about the typical cases where virtual testing will be useful and how to implement it. The tables in the annex B summarise the different scenarios and corresponding VT process proposed by the ACOUTRAIN WP1 consortium, depending on the type of rolling stock (Freight wagon, locomotive, coach, EMU/DMU, high speed train). These different cases of interest have been confirmed by the participants of the ACOUTRAIN WP1 workshop, held on the 26th of September 2012 where the major players of the TSI Noise were represented (see deliverable D1.7 for more details).

Most of the time, the cases where VT is foreseen concern a **hybrid approach** or **extension of approval approach** since these two approaches are considered to be the most reliable ones using current methods and experience**.**

A **Hybrid approach** will be used in any kind of application where stationary measurements are performed and pass-by noise is simulated. Transposition from non TSI-compliant track to TSI-compliant track is also a typical application for a hybrid approach.

Extension of approval could be used for example for:

- A change of number of axles per unit length, APL (for freight wagon, locomotive, coach, EMU/DMU and high speed train)
- A change of the maximum speed (for freight wagon, locomotive, coach, EMU/DMU and high speed train)
- A different formation of multiple units (for EMU/DMU and high speed train)
- A wheel modification (for freight wagon, locomotive, coach, EMU/DMU and high speed train)
- A brake system modification (for Freight wagon, locomotive, coach, EMU/DMU and high speed train)
- A modification of traction system (engine, powerpack, cooling system) and/or change of its installation (for locomotive, EMU/DMU and high speed train)
- A change of any component that is a sound source, which could be an auxiliary system (for freight wagon, locomotive, EMU/DMU and high speed train)

For the starting noise configuration, sources whose characteristics change with speed have to be taken into account in the numerical software and the simulation tool has to be able to handle this kind of simulation. At the present time, the complexity of the numerical simulation process makes starting noise not implementable in a virtual testing approach.

Virtual testing for a complete new design, i.e. with a change of the platform of the rolling stock manufacturing, requires a full experimental-based certification. These measurements could thereafter be used in a Hybrid approach to build the corresponding virtual vehicle. It also applies in the case when the modifications of noise sources are so extensive or many that the reference virtual vehicle is no longer considered valid.

Certification of the tool includes both verification and validation of the acoustic model which is implemented in the tools steps.

5.2.1 Process

A simulation tool is certified to be used for simulations of a running condition in the framework of TSI Noise if:

- it corresponds to the basic functionalities required for a tool as defined in deliverable D4.1 e.g. inputs, outputs and formatit is proven that the mathematical model and solution algorithms implemented in this tool are working correctly. Particularly, that the simulation tool can correctly represent relevant noise sources and determine associated way-side sound levels, accounting correctly for propagation in a specific environment (for example, ground effect reflections).

The first step for the definition of the procedure to certify a simulation tool consists in defining common input/output. The input format corresponds to the most common formats used in the existing simulation tools that are known to the ACOUTRAIN consortium. The outputs correspond to the acoustic indicators used in technical requirements of the TSI and some additional acoustic indicators such as pass-by signature or third-octave band spectrum that allow verification of the numerical process in the verification step.

In a second step, reference cases (numerical reference cases in the deliverable D4.4 and experimental reference cases in the deliverable D4.3) have been defined to validate the reliability of the simulation tools in terms of propagation computation, ground effect computation, pass-by simulation…

The simulation tools will have to be tested with the same reference cases and their results will be compared to the reference values. Reference corridors will be defined (deliverable D4.6): they correspond to an interval of confidence in which the simulation tool results should lie in order to be certified. These corridors should be adapted to the discrepancy level that could be found in case of real tests.

Note: the verification of a simulation tool could be carried out for all the running cases or only for one running case i.e. stationary or pass-by (or starting noise: currently, no reference cases have been defined in WP4 for this running condition).

5.2.2 Tool Certification Report

Once the process for the certification of a simulation tool has been standardized by a standardization group, the certification should be done presumably by the developer or the main user once, for each running condition, and a certificate will then be produced.

Meanwhile, each time a simulation tool is used to assess one or more parameters needed for a vehicle certification; it should be proved that the tool holds a valid certification, according to ACOUTRAIN certification process.

The report concerning the certification of a simulation tool is a new document that does not exist in the conventional rolling stock homologation based on RT. Its format and content includes all the relevant information related to verification activities. It shall be drafted based on information from the developer but supplied by the manufacturer and reviewed by the Notified Body. This document is drafted at the end of the first stage in the V&V process, regardless of whether the approach is Full VT, Hybrid VT or Extension of Approval.

This certification report includes the following contents:

- → The set-up for the simulation tool
- → Information about the simulation tool: ground model used, source model used…
- → The computed results for the reference cases tested, to be compared to the corresponding reference corridors

5.3 THE VIRTUAL VEHICLE VALIDATION

5.3.1 Process

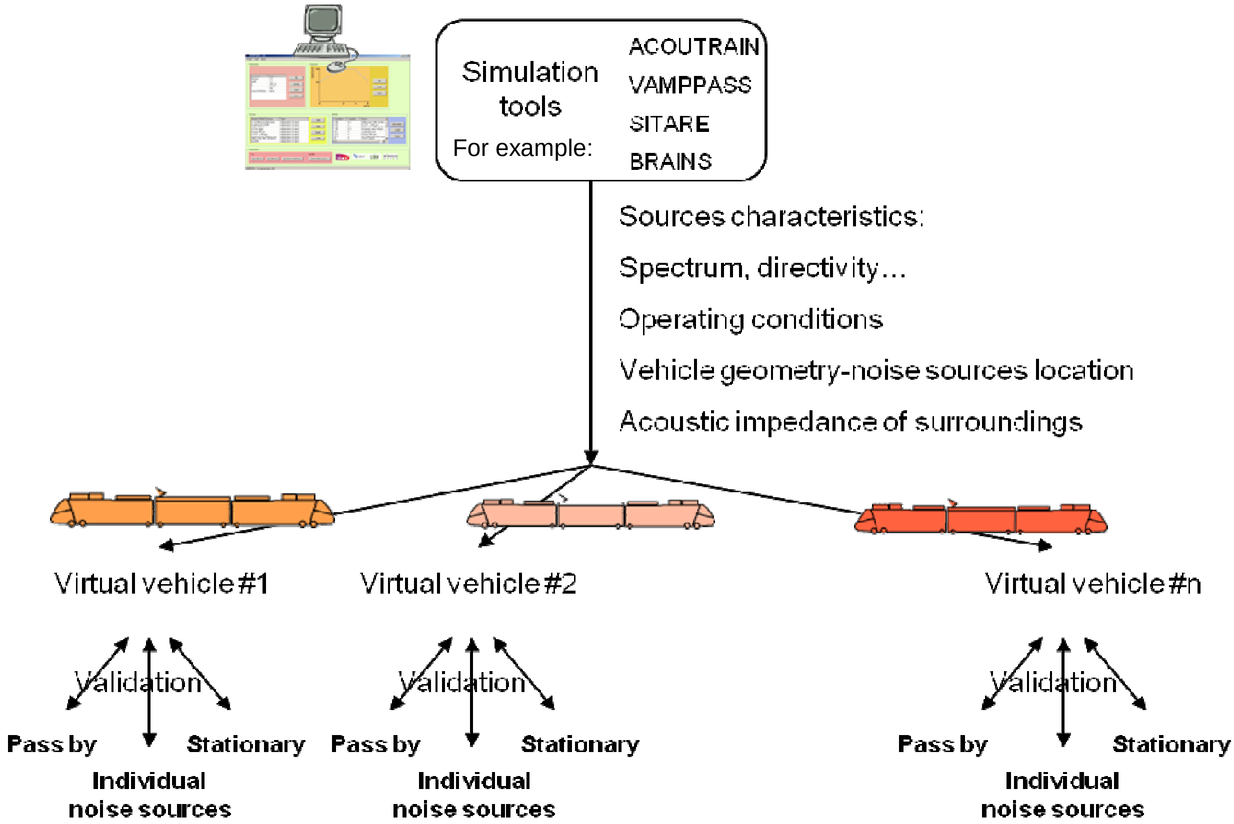

Figure 5: virtual vehicle validation step within a VT procedure

The validation of the virtual vehicle mainly depends on the virtual testing approach used (full VT, hybrid VT or VT in an EoA). At this point of the work in ACOUTRAIN, the validation procedure has not yet been fully developed. Here the basic concepts and ideas are outlined and a more detailed description will be found in the deliverable D5.4 which is still ongoing work.

For a full VT approach:

No measurements are available for the validation of the virtual vehicle (measurements are only used at the level of the single noise source characterization). The process relies on the reliability of the simulation tools used, which has already been proven in the tool certification process as well as on the correct characterization of the single noise sources.

Validation tests should comprise single noise source level characterisation, like individual validation of input data for relevant noise sources.

→ Only a certified/validated tool should be used, in application cases for which they have been proven to be valid.

For a hybrid VT approach:

Some measurement results are available for the virtual vehicle validation.

→ Validation tests should comprise single noise source level characterisation measurements, like individual validation of all relevant noise sources

→ Additionally to these tests on single noise source characteristics, a full system validation test could be used, for example stationary tests

For an Extension of Approval VT:

A complete set of measurement results allow validation of the reference virtual vehicle, for stationary, pass-by and starting noise computation.

→ Validation tests should comprise single noise source level characterisation measurements for the new sources or modifications that have to be implemented in the simulation tool.

→ It should be demonstrated that the new vehicle is largely based on the reference one, so that the reference virtual vehicle is valid.

5.3.2 Virtual Vehicle Validation Report

A Virtual Vehicle Validation Report has to be produced every time a new virtual vehicle is used for the assessment of external noise in the framework of vehicle certification. Its format and content includes all the relevant information related to validation activities (test and simulation results). All its contents shall be collected by the manufacturer during the validation phase and provided to the Notified Body at its end, once the second stage in the model V&V is completed. The content of the Validation Report depends on the VT approach implemented (Full VT, Hybrid VT or Extension of Approval based on VT). The VT approach is chosen at the beginning of the procedure, depending on the case considered. Since the three VT approaches correspond to different cases and levels of complexity the requirements for the Validation Report are specifically defined for each approach. If the Notified Body deems that virtual vehicle validation is acceptable based on this document, it can be used for VT in the homologation process.

NB: this is an important document that will be presented to the NoBo. It means that NoBo should be able to evaluate the quality of such validation: it has to refer to clear standards or procedures. This problem has been recognized by ACOUTRAIN and one objective is to develop user friendly procedures.

It includes the following contents:

- Validation plan: This is an important part. After the tool certification report is accepted by the Notified Body, the manufacturer, following the technical specifications of the TSI Noise, defines a validation plan including the number of validation tests and set up to be carried out, what parameters will be studied, which calculations will be compared, which metrics and criteria will be used for comparison, and any other aspect that is considered relevant for validation. This document is a proposal, which shall be submitted to the Notified Body. After examining the manufacturer's proposal, the Notified Body will accept it or request modifications. Possibly, there will be a validation plan meeting in which both parties will come to an agreement. This document is the basis for all validation activities to be carried out next.
- Simulation results: Before performing validation tests, calculations done by the manufacturer could be reported to the Notified Body. A blind validation approach is preferable, when possible. The actual process of comparison between simulation and test results shall be described in the validation plan (this kind of blind validation is commonly used in virtual procedure. However, the interest and the feasibility of such blind validation tests within acoustic virtual certification have still to be investigated in ACOUTRAIN).
- Validation test results: After calculations are done, test results are also reported by the manufacturer to the Notified Body. At the request of the Notified Body, validation tests can be witnessed.
- Validation metric and criterion: A formal comparison of simulation and test results is reported by the manufacturer, according to the physical parameters, metrics and criteria specified in the validation plan. As a conclusion it shall be indicated whether validation requirements are met or not. The level of complexity or the kind of validation metrics and criteria depends on each particular TSI Noise technical requirement.

5.4 Virtual testing implementation: input characterization

5.4.1 Process

The characterization of the input is one of the key issues for every kind of procedure that involves numerical simulations.

Noise source characterization is the scope of WP2 and WP3. These work packages will propose dedicated methods to characterize the significant sources for implementation in a simulation tool.

In the annex C, some existing methodologies are summarized.

In WP2, dedicated to rolling noise assessment, TWINS is considered as the reference software for the rolling noise computation. Common methodologies for using TWINS have been developed in deliverable D2.1. TWINS input characterization is intended to be made more robust and reliable with a proposal of wheel roughness measurement process (as already exists for the rail roughness measurement). Moreover, rolling noise variability, depending on the variability of wheels and variability of TSI track parameters, is studied.

In WP3, several equipment noise sources are studied. Methodologies will be developed to efficiently characterize their acoustic contribution in order to be used in global numerical tool. A part of these methodologies will also be dedicated to variability assessment, for each kind of source.

5.4.2 Input Characterization Report

This report should gather information of the different inputs used to compile the virtual vehicle, and how these inputs have been characterized. It should be delivered to the NoBo.

5.5 VIRTUAL TESTING IMPLEMENTATION: OUTPUT COMPUTATION

5.5.1 Uncertainty assessment

It was stated at the beginning of the project that the new methods based on virtual testing should be at least as accurate as the established methods in order to gain confidence from the railway sector. A way to evaluate the accuracy is to determine the uncertainty of a result. Currently no quantification of the uncertainties is required when certifying vehicles against the TSI Noise. The accuracy and the comparability are ensured by performing the measurements according to well defined established procedures and the requirement of a reference track. Additionally to reduce error, the pass-by noise measurement has to be repeated three times at each speed and the discrepancy between each measurement should be less than 3 dB.

In the **future**, with a VT approach:

All the inputs (noise sources) are characterized, with a given uncertainty (depending on the lab test conditions for example if the source is characterized in a free field environment or if reflections and background noise may influence the results). The numerical simulation will combine these source uncertainties with the uncertainties coming from the numerical process (ground effect model for example).

With a numerical approach not only the dispersion can be determined, but also a probability density function. For the input uncertainty, if no PDF (Probability Density Function) is available, we could assume a Normal distribution (defined with a mean value and a standard deviation value).

The PDF of the output can be computed with two different methods:

Monte Carlo method:

- each input is given with its uncertainty (for example, dispersion corridor or a mean value and a standard deviation)
- A large number of numerical computations is carried out, with input values randomly selected according to the dispersion of inputs
- this allows the PDF function of the output to be determined (its accuracy depends on the number of computation cycles)

Or parametric method:

- Each input is given with its own PDF (which could be Uniform law or Gaussian law for example)
- A numerical process allows combining and propagating all the distribution laws from the different inputs, through the simulation tool to compute the PDF of the output.
- This parametric method is generally used when too large an amount of computation cycles is required in a classic Monte Carlo approach.

Uncertainties will be taken into account in the validation procedure of the virtual vehicle, in particular in the definition of the validation criteria.

Uncertainty is important:

- in the validation step, when experimental testing and virtual testing are compared

- and also when comparing the results from certification process to the limiting values of the TSI technical requirements

In the case of an extension of approval approach, we assume that the method to characterize the sources remains the same between reference and new sources, for instance the same test benches, same set up, measurement environment and even operator, therefore the uncertainty due to the method used for the characterization of the source is the same order of magnitude for the reference source and for the new one. The calculation of a delta could even reduce a number of systematic errors.

5.5.2 Virtual Testing Results Report

This report will gather the results of:

- The experimental certification tests if some are carried out
- The numerical tests carried out with a virtual vehicle which has passed the V&V procedure.

The numerical test results (with uncertainty assessment of the global noise levels) will be compared to TSI Noise limit levels or limit corridors to determine compliance.

5.6 Legal and Formal Aspects

There is a clear need for research associated with the implementation of Virtual Testing: a method to demonstrate that virtual vehicles are reliable enough for their intended application. Such demonstration shall be based on scientific evidence, and the method must be objective and independent.

But there are other aspects linked to the homologation process that need to be adapted for a successful VT implementation:

- Parties involved in the TSI Noise homologation process, their roles and interaction
- Collection of evidence showing the fulfilment of technical requirements described in the TSI Noise

The two main parties in the homologation process are the manufacturer and the certified Notified Body. Besides these, there is also the homologation authority in each member state. Their roles can be easily described:

- Manufacturer: responsible for starting the homologation process and creating and providing all necessary evidences, as described in the TSI Noise
- Notified Body: certified entity responsible for leading the homologation process, collecting evidence provided by the manufacturer and assessing its validity against the technical requirements (test methods and limits established in the reference documentation). The Notified Body shall also submit all documentation and evidence to the Homologation Authority.

- Homologation Authority: is the entity or body responsible for reviewing all evidences collected by the Notified Body, and deciding whether the studied rolling stock can be homologated or not.

When the assessment method used is shifted from real to virtual testing, normally manufacturers have the required knowledge and skills to work with the new simulation environment, but this is not necessarily the case for Notified Bodies. They are experts in measurement methods but not in simulation methods, because they have never been involved in development processes. Nevertheless, Notified Bodies are required to assess whether verification and validation evidence provided by manufacturers is appropriate and sufficient to demonstrate that virtual vehicles are reliable enough to be used in the homologation framework. We shall not forget that Notified Bodies are entities accredited according to the requests necessary to be inspection bodies (ISO 17020 and ISO 17025). But there is no equivalent standard that can be used by accreditation bodies to analyse and evaluate the adequacy of Notified Bodies to witness and assess VT activities. Notified Bodies will have to gain new knowledge and skills, but first those new requirements must be described in a recognised standard.

Another aspect to be taken into consideration in a potential implementation of VT would be the definition of what kind of information is to be exchanged between the Notified Body and manufacturer, and how that information would be managed. It is important to note that in the conventional approach it is test results that are exchanged, thus in VT the equivalent information would be simulation results. Two possibilities concerning the exchange of information between Notified Bodies and manufacturers can be:

- A virtual vehicle representative of the rolling stock under assessment is provided to the Notified Body. Then it would be the Notified Body who would investigate the acoustic behaviour of the system, produce in-house and collect all necessary outcomes from the simulation tool, both for the validation process and for the TSI Noise assessment. This option would require Notified Bodies to have at their disposal suitable hardware, software and skilled staff.

The manufacturer is responsible to create and develop all simulation and test results. At the request of the Notified Body, simulation activities, assessment of input data and assembly of the virtual vehicle can be witnessed at the manufacturer facilities. The latter way of working implies less requirements for Notified Bodies, since all necessary hardware and software is provided by the manufacturer, but still skilled staff in simulation and VT methods shall be available at the Notified Body.

5.7 TSI CERTIFICATION WITH VT: COMPLETE FOLDER

The complete folder compiled by the NoBo will therefore gather:

- The Tool Certification Report, see section 5.1.2
- The Validation Report of the virtual vehicle, see section 5.2.2
- The Input Characterisation Report: a complete description of all the single noise sources of the vehicle + the test reports for the noise sources / input characterization (it is the counterpart of the description of sub-systems presented today in the Module B for a TSI Noise certification)
- The Virtual Testing Results Report

6. PRELIMINARY RECOMMENDATIONS

The preliminary recommendations of the ACOUTRAIN consortium for the implementation of virtual testing within a TSI Noise certification process are the following:

- Obligation of accreditation of entities in charge of the virtual testing activities for the TSI Noise certification should be discussed in the future by ERA and working group of the TSI Noise. If accreditation process is required, it shall be defined by accreditation body. Definition and role of accredited person are detailed in the annex A. Meanwhile, the virtual testing procedure in its whole should be performed by experts in railway acoustics.

- The simulation tool used for the calculations should be certified. That means:
  - The simulation tool should use the input and compute the output described in the deliverable D4.1
  - The certification of the simulation tool will be based on the comparison of the simulation tool results for given reference cases with the reference values provided in the deliverables D4.3 and D4.4. The cases defined as mandatory in these 2 deliverables should be compiled as a priority
  - Reference corridors will be decided, defining the “validation area” for each reference case
  - Since the rolling noise is calculated in another external tool, there is one reference case including only rolling noise which will ensure a validation of the combination of the tools. The tool certification will only be valid as long as the rolling noise tool used for the calculation of the reference case is used also for the assessment of the vehicle. If another rolling noise tool is to be used, the tool certification has to be updated accordingly.
- The certification of the software should be fully described in a dedicated Tool Certification Report
- The adequacy of the person in charge of the certification of the simulation tool to perform calculations shall be reported as part of the Tool certification Report. This person shall be recognized as an expert (in the future, if accreditation process is developed for such activity, this person should be accredited).
-

- The input should be defined by a location, a power spectrum in 1/3rd octave band (or a pressure spectrum at 1m from the source), a directivity pattern, as required in the deliverable D4.1,
- The inputs should be characterized according to:
  - For the rolling noise equivalent sources, the harmonized process for using TWINS described in the deliverable D2.1
  - For the vehicle specific sources, the guidelines provided in the deliverables D3.1, D3.2, D3.3, D3.5, D3.6 and D3.7
- The input uncertainties should be quantified according to the *Guide to the expression of Uncertainty in Measurement* (6)
- The characterization of the inputs should be described in a dedicated Input Characterisation Report

- The virtual vehicle should be built in a certified simulation tool, with inputs characterized as mentioned above.
- It is proposed that the virtual vehicle definition and validation as well as the calculations made from it should be performed by an accredited person.
- The virtual vehicle should be validated:
  - In the case of an extension of approval approach, the validation should be carried out on the model of the reference rolling stock, regarding the global pass-noise levels, time signature and third-octave band spectrum
  - In the case of a hybrid approach, the model should be validated regarding source validation and some measured total noise level such as stationary noise level for example
- The validation of the virtual vehicle should be fully described in a dedicated Validation Report
- A homologation process relying on virtual testing should take into account the uncertainties of the inputs used to compute the uncertainty level of the output. Final output uncertainty should be limited.
- Corridors will be defined to simplify the validation. The main principle is to assign frequency dependent error corridors for the reference cases defined.
- The adequacy of the person in charge of the validation of the virtual vehicle to perform calculations shall be reported as part of the Validation of the virtual vehicle report. This person shall be recognized as an expert (in the future, if accreditation process is developed for such activity, this person should be accredited).

- The candidate applications for which VT is foreseen concern the hybrid approach and Extension of Approval approach.
- Some candidate applications for which ACOUTRAIN consortium has to bring evidence have already been proposed. They are defined in the following chapter 7.

The preliminary recommendations will be validated and/or updated in the deliverable D1.8.

7. EVALUATION OF THE PROPOSED PROCEDURE

The ACOUTRAIN-procedure proposed in this deliverable requires some verification and validation activities to demonstrate that the simulation results are reliable (described in chapter 4.3). The idea is that certain evidence should be collected for each virtual vehicle assessment to show that the calculations correspond to reality.

Besides these V&V-activities, that are a part of the ACOUTRAIN-procedure, the complete procedure has to be validated as well. This is important for the new procedure to receive recognition in the whole railway sector. This means that this proposal has to be thoroughly tested within ACOUTRAIN before it can be presented as an alternative to the established methods currently available. A validation and demonstration of the recommendations in this deliverable will be performed in a dedicated workpackage of the project ACOUTRAIN (WP5). The definition of validation still applies with some small modifications. In this WP5, the term validation will have the following meaning:

> *the process of determining the degree to which a* virtual testing procedure *is an accurate representation of the* real testing procedure *from the perspective of the use within* the framework of a TSI Noise vehicle certification.

It will focus on demonstrating that the new procedure is accurate but also that it is user friendly, robust and practical. The methods and models that make up the total procedure are not completely new. Both sound power measurements of single sources, modelling of rolling noise and the use of simulation tools to calculate the total noise are techniques that are already widely used during the design-phase of new railway vehicles. The aim of Acoutrain is to develop these techniques further to suit the purpose of vehicle assessment within the framework of TSI Noise for which the requirements on reliability are high. It is the task of WP5 to demonstrate that this aim has been fulfilled.

During this work it has to be kept in mind that the general goal is to reduce both complexity and efforts needed for the certification procedure. That is why it has to be ensured during the validation that the procedure is transparent and well documented. User guides both for describing best practice methods for characterizing the noise sources used to create the virtual vehicle as well as for giving clear guidelines for the conformity judgement will be examined. They should be easy to follow and give reproducible results. It is important that the question of whether a vehicle is approved or not should neither depend on the operator performing the virtual tests nor the Notified Body evaluating them.

The results of the validation in WP5 will be an important input to deliverable D1.8 *A virtual certification process* at the end of the project.

Approach

The new ACOUTRAIN procedure will be validated by comparing it with established methods based on measurements. A number of application cases will be defined that can be used to demonstrate the new procedure step by step. These cases should be of different level of complexity and correspond to the recommended candidate cases for virtual testing described in chapter 6. Each case will be assessed both with the conventional procedure as described in the TSI Noise and the new ACOUTRAIN-procedure. This includes using the methods to characterize sound sources developed in WP2 and WP3 to obtain the inputs to a virtual vehicle that will be created with the tools that have been certified in WP4, but also to evaluate the framework around the testing activities that is needed for a complete certification process. The results of the two assessment procedures will be compared with each other.

Thanks to measurement campaigns performed in previous research projects, some experimental validation data are already available. Although these data will not allow fulfilling the approach presented here above (as they have not been obtained with the newly developed ACOUTRAIN-methods), they are still useful to demonstrate steps of the procedure. A comprehensive validation campaign will be carried out within ACOUTRAIN to be able to validate the whole procedure.

Besides the ACOUTRAIN-tool that has been developed within the project (this tool corresponds to the deliverable D.4.2 of the project) two further tools will be tested and certified within the project. All three tools will be used to assess the application cases for the validation of the procedure. This makes it possible to compare the results of different tools but also of different operators. Further options that can be evaluated are:

- *Effects due to the level of detail for the directivity of sound sources.*
  How much will the results vary if you for instance choose a monopole-setting or if you have more information about the directivity of the source?

- *Effects due to the method used for the source characterisation*.
  In practice most source information will be provided by the supplier. Different suppliers may have varying possibilities to perform correct acoustic measurements. It can be due to missing equipment or suitable anechoic measurement rooms with low background noise. Is there any difference in the output results or accuracy if the sound power or the sound pressure level has been measured? If the measurement took place in a laboratory or if the source was built in and measured in-situ? If the characterisation has only been performed in a limited frequency range?

- *Effects due to lacking information concerning the position of sound sources or vehicle geometry.*

The validation will be performed for the total sound level of the stationary noise and pass-by noise as well as in one-third octave bands and as a time history. The uncertainty of both measured and simulated results will be evaluated for all application cases.

The candidate applications for which ACOUTRAIN consortium has to bring some evidence of the VT process reliability (WP5) are the following:

- Modification of equipment on EMU/DMU with an extension of approval approach
- EMU/DMU pass-by VT assessment with a hybrid approach based on stationary noise measurements
- Change of track conditions with a hybrid approach (e.g. transposition from non TSI-compliant track to TSI-compliant track
- Change of brake system for a freight wagon

These application cases will be selected so that they will correspond to different levels of complexity. They represent relevant cases where VT is expected to increase efficiency in the certification process.

8. VIRTUAL TESTING OUTSIDE THE SCOPE OF THE TSI NOISE

Virtual testing has been foreseen for activities that are outside the scope of the TSI certification such as:

- Evaluate the noise control solutions for situations when investments in noise control are needed
- Support the assessment of railway noise for END mapping

In fact, virtual testing requires an acoustic model of the studied rolling stock. As presented in the paragraph 5.5.1, uncertainties on the calculated noise level will be computed, for TSI certification specifications (TSI track compliant for example).

It is known that sound sources found in railway vehicles change over time. After years of operation, wear and dirt may lead to changes of the noise emission. One simple example is the wheel roughness, which is one important factor causing rolling noise. It depends on the brake type but also on the distance the wheels have run and on maintenance (reprofiling).

In a more general way, the noise lifecycle of a rolling stock can be modelled by taking into account the variations coming from the whole lifecycle of the different noise sources. This approach is relevant for carrying out a sensitivity analysis: output of such study can indicate which parameters have the most influence in term of noise increase due to ageing. For example, a representation such as the Sobol's index (7) allows to show in a simply way which parameters dominate the evolution of the noise.

In the DYNOTRAIN project, such representation with Sobol's index is used to illustrate the influences of different track and rolling stock parameters on the dynamic stability indicator Y/Q (8), as shown in the Figure 6.

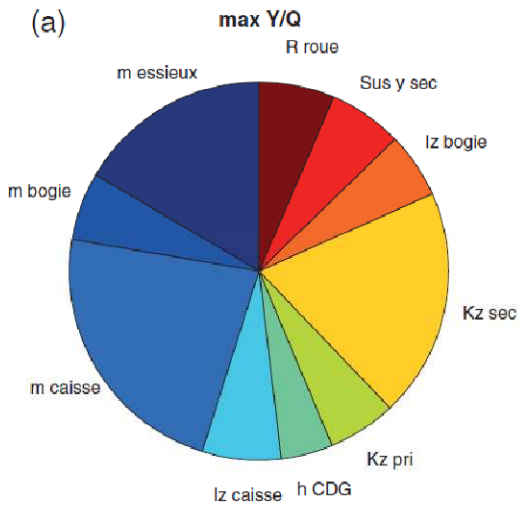

Figure 6: Sobol's indice representation to illustrate the influent parameters on the track dynamic indicator Y/Q, presented in (9)

Therefore, these data could be used at the design stage, to ensure a better lifecycle in terms of noise for the rolling stock.

This approach is also very useful in order to provide relevant data for the noise mapping required by the END (10): taking into account the variability of the different noise sources, according to time, will allow more realistic inputs to be defined for this mapping. Again, the uncertainty of the total pass-by noise will be obtained by combining variabilities of noise source either with a Monte Carlo approach or with the uncertainty propagation method.

Moreover, it will be useful also to compute actual noise level values with real track and wheel roughness and TDR. This will help understand cost/benefits on train emissions reduction versus wheel maintenance versus track maintenance versus track emissions reductions versus other approaches like barriers.

It could contribute to answering the following questions:

- Is it meaningful to keep reducing TSI targets if in the end tracks are very noisy?
- What approach will give the highest benefit with the lowest cost?

Currently, it is very difficult to carry out a cost-benefit analysis for the different noise mitigation measures: numerical systematic assessments of the impacts for different reduction solutions and their evolution with time could be, in this scope, very useful.

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ANNEX A: WHAT IS AN ACCREDITED ENTITY? HOW TO ACCREDIT AN ENTITY TO PERFORM VT IMPLEMENTATION STEPS?

During the continuous-ACOUTRAIN project, requirements for certification of simulation tools and validation of virtual vehicle models will be addressed. However even with the best tools mistakes can be made by analysts when building virtual vehicle models. It is recognised that a contribution to testing uncertainty, regardless the test, is the influence of technicians or operators. In the same way, there is an unavoidable influence of the person in charge of developing simulation models in the simulation results. Nevertheless it is not easy to assess how relevant this contribution can be to simulation uncertainty. As shown in previous cases (section 2. of (5) “Code dependency assessment”), different analysts performing virtual vehicle models may lead to different outcomes, even if the same simulation tool is used.

To minimise this discrepancy in the use of simulation tools a possible solution can be to establish a certification process for simulation tool users, which can guarantee that analysts performing noise calculations can demonstrate a minimum level of skill and experience in the subject.

What is accreditation, what is certification?

This is already a requirement for laboratories performing measurements for conformity assessment and described in the standard EN ISO 17025:2005 General requirements for the competence of testing and calibration laboratories.

If such a certification of analyst’s skills would be put into effect, then a certification body would be needed. Moreover, any certification body (responsible for certifying adequacy of analysts, in particular for ACOUTRAIN in acoustic simulation) would require a reference standard describing which aptitudes to evaluate and how to quantify them. Even more, establishing a parallelism between testing laboratories and VT, there should be also an accreditation body, which should be in charge of accrediting certification bodies, and again requirements for the assessment of certification bodies would have to be defined in a standard that would be followed by the accreditation body. The aforementioned standards for certification and accreditation, as well as certification bodies and accreditation body do not exist for VT. It is expected that in the future such standardised framework will be developed at CEN (or maybe ISO), but at the time being there is a lack of legal framework for the assessment of VT capabilities.

An alternative and more practical approach (less burdensome for simulation tool users like railway rolling stock manufacturers) is to rely on the fulfilment of ISO 9001 requirements. In particular we can mention section “6.2 Competence, Training and Awareness”. According to this quality standard, certified companies shall include as part of their Quality Management System (QMS) the following:

- Define the essential abilities:

The first requirement says that the organization must: “Determine the necessary competence for personnel performing work affecting conformity to product requirements (ref. 6.2.2 a)”. All work done as part of the QMS directly or indirectly affects the company's ability to satisfy its customers and meet requirements. This shall remain true in particular for the use of simulation tools in VT. Therefore, the job functions related to VT must be staffed by qualified people.

As with other ISO 9001 requirements, it is left to the organization to define what "competence" means in their specific context. But it would be desirable that a common set of competences be defined to be observed by the industry. To define requirements for VT related job positions we might ask:

- "What VT-specific knowledge area(s) must be well understood by someone involved in railway stock homologation?"
- "What manual, mental or interpersonal skills must an employee have to do VT well?"
- "What natural abilities or talents must someone possess to be effective in VT?"

Within the consortium a list of competencies for VT that can be used for hiring purposes and subsequent training and development plans will be drafted, based on the experience of project partners.

Required competency areas for VT, will be translated into a training and development plan for acoustic technicians and analysts. This can be done by evaluating or assessing employees' current knowledge, skills and abilities against the requirements for VT. This may consist in each employee rating themselves in each VT competency area, identifying strengths and weaknesses, then reviewing the rating with their immediate supervisor. Or, the supervisor could do the employee ratings on their own. A more in-depth approach would be to develop a formal certification to evaluate employee competencies. Regardless of the method chosen, any competencies that fall below the required performance level become the development needs for the employee. For new employees, the same process would be followed when hired resulting in a similar list of needs for competency development.

- Provide a process for competency development

Once the competency needs for VT are identified this should be followed by an appropriate intervention to close the "learning gap". In the words of the standard ISO9001, the organization must: “Where applicable, provide training or take other actions to achieve the necessary competence (ref. 6.2.2 b)”

Again, it is left to the organization to determine the appropriate method. This can be in the form of on-the-job or off-the-job training, job shadowing, mentoring, public seminars, educational courses or any other suitable method.

- Follow-up to ensure the competency was learned

Following the training in VT (whether it is related to testing or simulation) or other intervention, an appropriate evaluation of the employee's competency level should be completed. The standard requires the organization to:

- Evaluate the effectiveness of the actions taken (ref. 6.2.2 c)

Once more, the organization can determine a method that works in their specific context. It could include:

  - Special inspection of the technician's work until the needed quality level is reached
  - Written test following the training
  - Formal certification process

- Supervisor follow-up 60 days (or so) following the training or intervention
- Formal performance review

- Ensure quality awareness

The fourth requirement requires that the organization: “Ensure that its personnel are aware of the relevance and importance of their activities and how they contribute to the achievement of the quality objectives (ref. 6.2.2 d)”

- Keep records

As with most required quality processes in the ISO 9001 standard, records of VT must be kept. Specifically, the company must: “Maintain appropriate records of education, training, skills and experience (ref. 6.2.2 e)“. These records relate to both pre-hiring requirements and competency development that occurs once the employee is on board. Many job positions have prerequisite requirements that must be met in order to be considered for employment with the company. Complete records of education, training, competency evaluations and skill-development job experience and assignments that were completed after hiring must be maintained. These records are considered quality records and must be kept according to the requirements of section 4.2.4 in the standard ISO 9001.

Independently of how ability of technicians for VT is demonstrated by companies, more important VT tasks developed by manufacturers shall be witnessed by Notified Bodies, e.g.: calculations of noise prediction at company offices, development of validation tests, etc.

ANNEX B: FIRST RECOMMENDATIONS FOR THE VIRTUAL TESTING CERTIFICATION – VIRTUAL TESTING SCOPE

As first stage for the writing of this deliverable, the partners of the ACOUTRAIN consortium have been questioned about the scope of the virtual testing implementation within the rolling stock acoustic TSI certification. The following tables summarize their answer and therefore the various cases for which virtual testing is foreseen.

-
- **Freight wagon**
- The acoustic certification for a Freight wagon is mandatory in case of:
  - Change of APL
  - Change of the max speed
  - Wheel modification
  - Brake system modification
  - Change of auxiliary system
  - Complete new design
  -

Is virtual testing foreseen in this case?	Stationary noise	Pass-by noise	Starting noise *General remark: Beware of the sources characterization (speed-dependent behaviour of the sources, with the appropriate loads (mechanical and electrical)) and the management of the speed change over the time*
a change of APL		Y see flow diagram n°1 Or **Extension to approval** approach: numerical estimation of the increase of the pass-by noise with new APL to widen the scope of the diagram n°1	Y see flow diagram n°1 Or **Extension to approval** approach: numerical estimation of the increase of the starting noise with new APL to widen the scope of the diagram n°1
Change of the max speed		Y widen the scope of the flow diagram n°2 **Extension to approval** process	
Wheel modification		Y See flow diagram n°3 Implementation of EN ISO 13979-1 (2004), **Extension to approval**	Y See flow diagram n°3 Implementation of EN ISO 13979-1, **Extension to approval**
Brake system modification		Y See flow diagram n°4 **Extension to approval** process: assessment of the	Y See flow diagram n°4 **Extension to approval** process: assessment of the

		impact on the wheel roughness + TWINS estimation of the increase of rolling noise	impact on the wheel roughness + TWINS estimation of the increase of rolling noise at several speeds reached during the starting phase
a change of equipment	Y See flow diagram n°9 **Extension to approval** process: sources characterization with WP3 methodologies (+ installation effects) + numerical simulation of stationary noise with a certified global tool	Y See flow diagram n°9 **Extension to approval** process: sources characterization with WP3 methodologies (+ installation effects) + numerical simulation of pass-by noise with a certified global tool	Y See flow diagram n°9 **Extension to approval** process: sources characterization with WP3 methodologies (+ installation effects) + numerical simulation of starting noise with a certified global tool
Change of the super-structure		Extension to approval	
complete new design	Hybrid approach	Hybrid approach Full virtual testing: if we consider only the rolling noise	

Locomotive

- The acoustic certification for a locomotive is mandatory in case of:
  - Change of APL
  - Change of the max speed
  - Wheel modification
  - Brake system modification
  - Change of auxiliary system
  - Modification of traction system (traction engine, powerpack, cooling system) and/or change of its installation
  - Complete new design
  -

Is virtual testing foreseen in this case?	Stationary noise	Pass-by noise	Starting noise *General remark: Beware of the sources characterization (speed-dependent behaviour of the sources, with the appropriate loads (mechanical and electrical)) and the management of the speed change over the time*
Change of APL		Y see flow diagram n°1 Or **Extension to approval** approach: numerical estimation of the increase of the pass-by noise with new APL to widen the scope of the diagram n°1	Y see flow diagram n°1 Or **Extension to approval** approach: numerical estimation of the increase of the starting noise with new APL to widen the scope of the diagram n°1
Change of max speed		Y widen the scope of the flow diagram n°2 **Extension to approval** process	
wheel modification		Y See flow diagram n°3 Implementation of EN ISO 13979-1 (2004), extended to powered wheel **Extension to approval**	Y See flow diagram n°3 Implementation of EN ISO 13979-1, extended to powered wheel **Extension to approval**
brake system modification		Y See flow diagram n°4 **Extension to approval** process: assessment of the impact on the wheel roughness + TWINS estimation of the increase of rolling noise	Y See flow diagram n°4 **Extension to approval** process: assessment of the impact on the wheel roughness + TWINS estimation of the increase of rolling noise at several speeds reached during the starting phase

a change of a equipment and/or change of its installation	Y See flow diagram n°9 **Extension to approval** process: sources characterization with WP3 methodologies (+ installation effects) + numerical simulation of stationary noise with a certified global tool	Y See flow diagram n°9 **Extension to approval** process: sources characterization with WP3 methodologies (+ installation effects) + numerical simulation of pass-by noise with a certified global tool	Y See flow diagram n°9 **Extension to approval** process: sources characterization with WP3 methodologies (+ installation effects) + numerical simulation of starting noise with a certified global tool
a modification of traction system (traction engine, powerpack, cooling system) and/or change of its installation	Y **Extension to approval** process: sources characterization with WP3 methodologies (everything should be tested at a realistic load – electrical as mechanical loads) + installation effects + numerical simulation of stationary noise with a certified global tool	Y **Extension to approval** process: sources characterization with WP3 methodologies (everything should be tested at a realistic load) + installation effects + numerical simulation of pass-by noise with a certified global tool	Y **Extension to approval** process: sources characterization with WP3 methodologies (everything should be tested at a realistic load) + installation effects + numerical simulation of starting noise with a certified global tool
2/3 modifications listed above in the same time: Depends on the contribution of each source on the global noise level	**Extension to approval** process	**Extension to approval** process	**Extension to approval** process
a complete new design / radical changes	Hybrid approach?	Hybrid approach?	Hybrid approach?

Coach

- The acoustic certification for a coach is mandatory in case of:
  - Change of APL
  - Change of the max speed
  - Wheel modification
  - Brake system modification
  - a change of auxiliary system
  - complete new design

Is virtual testing foreseen in this case?	Stationary noise	Pass-by noise	Starting noise *General remark: Beware of the sources characterization (speed-dependent behaviour of the sources, with the appropriate loads (mechanical and electrical)) and the management of the speed change over the time*
a change of APL		Y see flow diagram n°1 Or **Extension to approval** approach: numerical estimation of the increase of the pass-by noise with new APL to widen the scope of the diagram n°1	Y see flow diagram n°1 Or **Extension to approval** approach: numerical estimation of the increase of starting noise with new APL to widen the scope of the diagram n°1
Change of the max speed		Y widen the scope of the flow diagram n°2 **Extension to approval** process	
wheel modification		Y See flow diagram n°3 Implementation of EN ISO 13979-1 (2004), extended to powered wheel **Extension to approval** process	Y See flow diagram n°3 Implementation of EN ISO 13979-1, extended to powered wheel **Extension to approval** process
Brake system modification		Y See flow diagram n°4 **Extension to approval** process: assessment of the impact on the wheel roughness + TWINS estimation of the increase of rolling noise	Y See flow diagram n°4 **Extension to approval** process: assessment of the impact on the wheel roughness + TWINS estimation of the increase of rolling noise at several speeds reached during the starting phase
a change of an equipment (air conditioning system for	Y See flow diagram n°9 **Extension to approval** process: sources	Y See flow diagram n°9 **Extension to approval** process: sources	Y See flow diagram n°9 **Extension to approval** process: sources

example) and/or change of its installation	characterization with WP3 methodologies (+ installation effects) + numerical simulation of stationary noise with a certified global tool	characterization with WP3 methodologies (+ installation effects) + numerical simulation of pass-by noise with a certified global tool	characterization with WP3 methodologies (+ installation effects) + numerical simulation of starting noise with a certified global tool
Complete new design	Hybrid approach	Hybrid approach	

EMU / DMU

- The acoustic certification for an EMU / DMU is mandatory in case of:
  - Change of APL
  - Change of the max speed
  - A different formation of multiple units
  - Wheel modification
  - Brake system modification
  - a modification of traction system (traction engine, powerpack, cooling system) and/or change of its installation
  - a change of auxiliary system
  - complete new design
  -

Is virtual testing foreseen in this case?	Stationary noise	Pass-by noise	Starting noise *General remark: Beware of the sources characterization (speed-dependent behaviour of the sources, with the appropriate loads (mechanical and electrical)) and the management of the speed change over the time*
a change of APL		Y see flow diagram n°1 Or **Extension to approval** process: numerical estimation of the increase of the pass-by noise with new APL to widen the scope of the diagram n°1	Y see flow diagram n°1 Or **Extension to approval** process: numerical estimation of the increase of the starting noise with new APL to widen the scope of the diagram n°1
Change of max speed		Y widen the scope of the flow diagram n°2 **Extension to approval** process	
Change of vehicles / single cars in a fixed formation	Y See present TSI Or **Extension to approval** process: possible numerical computation of different formations of single cars in a fixed formation	Y See flow diagrams n°5, 6 & 7 Or **Extension to approval** process: possible numerical computation of different formations of single cars in a fixed formation	Y See flow diagrams n°5, 6 & 7 Or **Extension to approval** process: possible numerical computation of different formations of single cars in a fixed formation
wheel modification High priority		Y See flow diagram n°3 Implementation of EN ISO 13979-1 (2004), extended to powered wheel **Extension to approval** process	Y See flow diagram n°3 Implementation of EN ISO 13979-1, extended to powered wheel **Extension to approval** process
Brake system modification		Y See flow diagram n°4 **Extension to approval**	Y See flow diagram n°4 **Extension to approval**

High priority		process: assessment of the impact on the wheel roughness + TWINS estimation of the increase of rolling noise	process: assessment of the impact on the wheel roughness + TWINS estimation of the increase of rolling noise at several speeds reached during the starting phase
modification of traction system (traction engine, powerpack, cooling system) and/or change of its installation High priority	Y See flow diagram n°9 **Extension to approval** process: sources characterization with WP3 methodologies (everything should be tested at a realistic load – electrical as mechanical loads) + installation effects + numerical simulation of stationary noise with a certified global tool	Y See flow diagram n°9 **Extension to approval** process: sources characterization with WP3 methodologies (everything should be tested at a realistic load) + installation effects + numerical simulation of pass-by noise with a certified global tool	Y See flow diagram n°9 **Extension to approval** process: sources characterization with WP3 methodologies (everything should be tested at a realistic load) + installation effects + numerical simulation of starting noise with a certified global tool
modification of an auxiliary system and/or change of its installation High priority	Y See flow diagram n°9 **Extension to approval** process: sources characterization with WP3 methodologies (+ installation effects) + numerical simulation of stationary noise with a certified global tool	Y See flow diagram n°9 **Extension to approval** process: sources characterization with WP3 methodologies (+ installation effects) + numerical simulation of pass-by noise with a certified global tool	Y See flow diagram n°9 **Extension to approval** process: sources characterization with WP3 methodologies (+ installation effects) + numerical simulation of starting noise with a certified global tool
complete new design	Hybrid approach	Hybrid approach	

High speed train

The acoustic certification for a high speed train is mandatory in case of:

- Change of APL
- Change of the max speed
- A different formation of multiple units
- Wheel modification
- Brake system modification
- a modification of traction system (traction engine, powerpack, cooling system) and/or change of its installation
- a change of auxiliary system
- complete new design

Is virtual testing foreseen in this case?	Stationary noise	Pass-by noise	Starting noise *General remark: Beware of the sources characterization (speed-dependent behaviour of the sources, with the appropriate loads (mechanical and electrical)) and the management of the speed change over the time*
a change of APL		Y see flow diagram n°1 Or **Extension to approval** process: numerical estimation of the increase of the pass-by noise with new APL to widen the scope of the diagram n°1	Y see flow diagram n°1 Or **Extension to approval** process: numerical estimation of the increase of the starting noise with new APL to widen the scope of the diagram n°1
Change of max speed		Y widen the scope of the flow diagram n°2 **Extension to approval** process	
wheel modification		Y See flow diagram n°3 Implementation of EN ISO 13979-1 (2004), extended to powered wheel **Extension to approval** process	Y See flow diagram n°3 Implementation of EN ISO 13979-1, extended to powered wheel **Extension to approval** process
brake system modification		Y See flow diagram n°4 **Extension to approval** process: assessment of the impact on the wheel roughness + TWINS estimation of the increase of rolling noise	Y See flow diagram n°4 **Extension to approval** process: assessment of the impact on the wheel roughness + TWINS estimation of the increase of rolling noise at several speeds reached during the starting phase
a change of a traction system (including traction engine, powerpack and cooling system)	Y **Extension to approval** process: sources characterization with WP3 methodologies	Y **Extension to approval** process: sources characterization with WP3 methodologies (everything	Y **Extension to approval** process: sources characterization with WP3 methodologies (everything

and/or change of its installation	(everything should be tested at a realistic load – electrical as mechanical loads) + installation effects + numerical simulation of stationary noise with a certified global tool	should be tested at a realistic load) + installation effects + numerical simulation of pass-by noise with a certified global tool	should be tested at a realistic load) + installation effects + numerical simulation of starting noise with a certified global tool
a change of an auxiliary system and/or change of its installation	Y **Extension to approval** process: sources characterization with WP3 methodologies (+ installation effects) + numerical simulation of stationary noise with a certified global tool	Y **Extension to approval** process: sources characterization with WP3 methodologies (+ installation effects) + numerical simulation of pass-by noise with a certified global tool	Y **Extension to approval** process: sources characterization with WP3 methodologies (+ installation effects) + numerical simulation of starting noise with a certified global tool
modification of the shape of the train (aeroacoustic effects)		Extension to approval?	
a complete new design	Hybrid approach?	Hybrid approach?	?

ANNEX C: FIRST RECOMMENDATIONS FOR THE VIRTUAL TESTING CERTIFICATION – INPUT CHARACTERIZATION

Noise source characterization is the scope of the WP2 and WP3: both work packages will propose dedicated methods to characterize the noise sources that should be implemented in a global noise simulation tool.

The following table gathers the existing methodology that could be foreseen to define the different noise sources:

Source characterize with:	Numerical simulation	Methods	Test bench	Methods / standards	In-situ meas.	Methods
Traction equipment (motor + fan) Beware of applying the real LOAD	?	If fan is the main contributor, CFD methods; for electrical noise there are some FE methods but still in research approach.	Y	ISO 9614-2 ISO 3745 / ISO 3744	Y	
Powerpack compartment Beware of applying the real LOAD	?	FEM/BEM	Y	ISO 9614 / ISO 3745 / ISO 3744 or in situ	Y	
Exhaust Beware of applying the real LOAD	?	SIDLAB Several methods FE/Matrix	Y	ISO 9614 / ISO 3745 / ISO 3744 / ISO 5135	Y	
Cooling systems Beware of applying the real LOAD	?	CFD, semi empirical formulas	Y	ISO 9614 / ISO 3745 / ISO 3744	Y	
Inlets	?		Y	ISO 9614, SWL in situ measurements	Y	
HVAC	?	CFD, semi empirical formulas	Y	ISO 9614 / ISO 3745 /	Y	

				ISO 3744 or in situ		
Compressor	?	FEM/BEM	Y	ISO 9614 / ISO 3745 / ISO 3744	Y	
Rolling noise	Y	TWINS	N		Y (running)	No standardized method
Aeroacoustic noise from the pantograph	Y	CFD methods	Y	No standard Wind tunnel, scale model?	Y	array measurement during pass-by, which give qualitative information
Aeroacoustic noise from the bogie	Y	CFD methods	Y	No standard Wind tunnel, scale model?	Y	array measurement during pass-by, which give qualitative information
Aeroacoustic noise from the nose	Y	CFD methods	Y	No standard Wind tunnel, scale model?	Y	array measurement during pass-by, which give qualitative information
Aeroacoustic noise from the inter-coach	Y	CFD methods	Y	No standard Wind tunnel, scale model?	Y	array measurement during pass-by, which give qualitative information
Shielding effect	Y	Ray-tracing & BEM Various TL tools + FEM/BEM/raytracing	Y	No standard Wind tunnel, scale model, mock-up	Y (static)	
Car body / structure-borne noise	Y	FEM + BEM, & SEA in high frequencies	Y	No standard available. Measurement of the radiation of any structure	Y	array measurement during pass-by, which give qualitative information