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Virtual certification of acoustic performance for freight and passenger trains

D6.3 - Technical Recommendations

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PP	Restricted to other programme participants (including the Commission Services)	
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EXECUTIVE SUMMARY

The ACOUTRAIN FP7 European Research project, aims to develop procedures and calculation tools to simplify the TSI Noise test procedures. From October 2011 to December 2014, the fifteen ACOUTRAIN partners have cooperated for **introducing virtual certification for noise with a reliable simulation approach**.

Moreover the ACOUTRAIN project has also contributed to the progress of other railways noise research areas such as:

- ***Methods for separation of infrastructure and rolling stock noise contributions***: Three separation methods have been proposed and tested against measured data. These methods can be used either to transpose a vehicle to a different track or to transpose to another vehicle on the same track. The concept has been extended to a proposal for transposing measured results to a virtual reference track.

- ***Establishment of measurement procedures for new running conditions*** (e.g. braking and curving): A new procedure for type testing vehicles for curving noise has been proposed, including an on-board occurrence test procedure combined with trackside pass-by test.

- ***Development of procedures to obtain inputs for the European Noise Directive (END)***: A procedure to use ”virtual testing” models and data for the definition of equivalent noise sources for the END noise mapping has been established. This procedure leads to realistic vehicle source power allocation without costly testing for application of the END.

The objective of this deliverable was to propose a UIC/UNIFE technical recommendation based on the deliverables of the ACOUTRAIN Work Packages. A UIC/UNIFE Technical Recommendation serves as a common comprehensive standard, approved by UIC and UNIFE and therefore recognised as a voluntary sector standard aimed to facilitate the interoperability of and to improve the competitiveness of the European railway system.

However during the life of the project, the ACOUTRAIN project contacted the UIC/UNIFE TecRec Standards Steering Group to get their approval to deliver such a UIC/UNIFE Technical Recommendation. Even if, UNIFE gave its approval for working on such a technical recommendation, it was not possible to get the approval of UIC during the ACOUTRAIN project life to deliver such a UIC/UNIFE Technical Recommendation using ACOUTRAIN results. As the ACOUTRAIN partners considered that it would be worthwhile to have a project Technical Recommendation, it was decided to describe in this deliverable the objectives of such a ACOUTRAIN project Technical Recommendation and to highlight the ACOUTRAIN deliverables that would be the pillars of the ACOUTRAIN project Technical Recommendation. Indeed the ACOUTRAIN project Technical Recommendation is not one standalone document but is made of several deliverables coming from several Work Packages.

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1. INTRODUCTION

Noise pollution is an important concern. At a European level the Environmental Noise Directive (END) requires noise mapping of large agglomerations and major routes and the development of Action Plans. It is estimated that 14 million people in Europe are exposed to levels of railway noise above 55 dB Lden, compared with 125 million people for road traffic. In parallel, regulations controlling the noise emission from individual vehicles have been introduced. For the railway sector these were introduced from 2002 in the form of Technical Specifications for Interoperability (TSI) which limit the noise emission of new vehicles. The latest revision of the Noise Technical Specification for Interoperability (TSI) entered into force in January 2015.

Although the Noise TSI is strategically important in ensuring that the railway remains an attractive means of transport in the future and in allowing the sector to grow, it also means restrictions and increased costs to individual stakeholders. The conformity assessment required in the Noise TSI is mainly based on field tests, which is often a very expensive and time consuming process. Noise measurements are required under pass-by, stationary and starting conditions as well as inside the driver's cab.

The ACOUTRAIN FP7 European Research project aims **to develop procedures and calculation tools to simplify the Noise TSI test procedures**. From October 2011 to December 2014, ACOUTRAIN partners have cooperated for introducing virtual certification for noise with a reliable simulation approach.

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Moreover to implement the project results and promote the ACOUTRAIN project Technical Recommendation, the project has strengthened its relationships with standardisation and regulation bodies like the European Railway Agency and CEN/CENELEC. Several outputs of ACOUTRAIN have been considered or used by standardisation and regulation bodies.

This deliverable is mainly linked to three ACOUTRAIN public deliverables:

- D1.1 – Clarification of the simplified method in the partial revision of the TSI
- D1.2 – Recommendations for a future certification process
- D1.8 – A virtual certification process (validated)

Note: Those deliverables coming from Work Package 1 (Procedures for a virtual certification of acoustic performances of freight and passenger trains) are using outputs from all the ACOUTRAIN technical Work Packages:

- *Work Package 2 - Noise Sources: Rolling noise*
- *Work Package 3 - Characterisation of vehicle specific noise sources*
- *Work Package 4 - Methodology to certify tools for acoustic virtual testing*
- *Work Package 5 - Validation of the noise virtual certification*

2. Background - History

Today the growth of traffic on many railway lines in Europe is limited by the noise exposure of nearby residents. This implies that, if the foreseen traffic growth is to be contained within the environmental noise reception limits, each train must emit less noise. The Noise TSI should be seen in this light; it introduces limit values for the noise emitted by individual vehicles and is therefore an important instrument for reducing environmental noise levels in Europe. By gradually introducing lower limit levels in the Noise TSI, the supply industry is put under pressure to develop quieter products. A limited revision of the Noise TSI was then approved in 2010 and entered into force in 2011. In parallel, noise limits for the high speed rolling stock segment were introduced in the High Speed Rolling Stock TSI in 2008. The test procedures are based on ISO 3095.

The new designs of trains have to be certified for noise according to these TSIs. This requires running tests to be performed with a real train on a well-defined 'reference' track. The purpose of a reference track is to minimise the track contribution to the measured noise. Specified noise limit values have to be met for particular operational conditions, in particular 80 km/h and the maximum operational speed. For powered vehicles a starting test is also required and a measurement of noise in the driver's cab. The limit values differ for different types of rolling stock.

According to the Interoperability Directive, the applicant needs to get a conformity assessment report from a "Notified Body" to guarantee the conformity of the sub-system to all the applicable TSIs. The "Notified Bodies" are responsible for appraising the 'EC' procedure for verification of the subsystems, which for the Noise TSI consists in reviewing the measurement results and the quality of design and production to ensure that the tested vehicle is representative of the complete series of vehicles.

Besides the aspect of noise reduction, in common with the whole TSI portfolio, the Noise TSI is intended to promote interoperability. This means that once a vehicle has been authorized in one country this is sufficient to allow operation over the whole Trans-European Network.

This sounds appealing but, in reality, the Noise TSI conformity assessment process has introduced a layer of complexity and rigidity that limits its benefits.

The return of experience of using the Noise TSI has highlighted some problems related to the conformity assessment procedure, in particular in the use of "Reference Tracks" and also different possible interpretations of its requirement in different Member States. This led to the "limited revision" of the Noise TSI that offers more flexibility in the conformity assessment procedure but gives little guidance to the applicant and the "Notified Bodies" on the application of the text.

The most important aspects of the Noise TSI that require attention are:

- ***Reference Track***: Pass-by noise measurements have to be performed on a "reference track" which consists of a low noise track fulfilling criteria for railhead roughness and vibration decay rate defined in the Noise TSI. It has proved to be very difficult to locate and maintain such tracks due to these strict requirements on their acoustic performance. The

shortage of reference tracks has caused major cost increases and delivery delays. Moreover different “reference tracks” can lead to significant differences in the measured vehicle pass-by noise emission. Because there is only a one-sided limit for the track parameter criteria, reference tracks can vary from exceptionally quiet ones to well-maintained in-service tracks. The NoiseTSI revision gives more flexibility to that respect by allowing measurements on a track that deviates from the reference track definition. However, a method is still required to extrapolate the result obtained on a normal track to correspond to the one on the reference track.

- ***Simplified evaluation method***: The new ‘limited revision’ allows for a simplified method in certain cases:
    - Vehicle families: Very often variants of a vehicle type are produced to satisfy different requirements of end-users. This results in several similar vehicle types belonging to the same vehicle family;
    - Different formations of multiple units: often multiple units are produced with different combinations of powered and unpowered vehicles;
    - Retrofitted vehicles: it should be demonstrated that noise levels are not increased if a component is replaced on a vehicle (for instance an HVAC unit). In each case the difference in acoustic performance can be very minor but a Noise TSI conformity assessment is still needed for each type. Application of the simplified method to these cases requires further clarification to avoid unnecessary work on re-certification.

3. Aims/means and expected results

The ACOUTRAIN Technical Recommendation aims at simplifying and improving the acoustic conformity assessment process of new rolling stock, in particular relating to the Noise TSI. Today the need of conformity assessment for a new vehicle according to the Noise TSI represents a significant element of both cost and time to market due to the need to carry out expensive and time consuming tests.

The goal of the proposed project is to speed up the product authorisation by introducing some elements of virtual testing while retaining the same degree of reliability and accuracy. A successful simplification of the Noise TSI conformity assessment process would result in a strengthening of the competitiveness of the European railway sector. The risk of not developing such a simplification would be that the expense of excessive certification of new products could hamper the introduction of new innovations.

The major contribution of the ACOUTRAIN Technical Recommendation is a **new certification process including some elements of virtual testing**.

By way of example, a number of possible scenarios where a simplified certification procedure could be applied are listed below:

- The pass-by noise emission of a vehicle has been measured on a track with known properties.

  → What would the noise emission be on a different track?

- A new HVAC unit is installed.

  → How is the exterior noise affected?

- A power pack encapsulation is installed.

  → What will be the noise reduction for the complete vehicle?

- A fan is replaced by a low noise fan.

  → How can it be shown that the exterior noise is not increased?

- The electric current fed to a traction motor is changed.

  → Does this affect the noise at all?

- The rotational speed of a cooling fan is increased.

  → How much does the noise increase?

- A pantograph is replaced by a new design.

  → Up to what train speed can the acoustic effect be neglected?

- The train speed is increased from 320 km/h to 350 km/h.

  → Can the aeroacoustic contribution be extrapolated?

This list comes from typical situations encountered in the field for the Noise TSI conformity assessment. In each of these cases a new certification test would be required under the current Noise TSI. The ACOUTRAIN Technical Recommendation proposes an approach based on virtual testing that will allow simplifying certification process for such cases.

4. Strategy

The ACOUTRAIN Technical Recommendation is mainly based on the work carried out in ACOUTRAIN project where a new certification procedure based on virtual testing has been developed, associated with a complete validation process: verification and validation of the numerical tool used for the simulation and validation of the virtual vehicle (defined as a set of noise sources) used in the simulation (criteria are established in ACOUTRAIN for common approval of the modelling and simulation approaches in accordance with TSIs and European standards).

These simulations are based on calculations or measurements (for example on a static train or component) or a combination of both. The objective is to establish a global simulation approach in which noise source data can be assembled and thereby avoid full scale line tests (the term simulation approach is used in this way in the remainder of the proposal). As the subsystem data can, in principle, be obtained in different ways (experimentally, theoretically or numerically), the method offers a high degree of flexibility. However, methodologies for noise sources characterization are prescribed, according to the tests carried out in ACOUTRAIN work packages dedicated to sources characterization.

Finally, in the virtual certification procedure, it is clearly identified when and where such approach can be used.

5. ACOUTRAIN Technical Recommendation

The paragraphs below describe the steps achieved in the ACOUTRAIN project to estanlish the entire virtual procedure for acoustic certification of rolling stock, including noise sources characterization methodologies, software certification procedure, validation criteria for the virtual vehicle, limits of use of a virtual certification (the “when and where such approach can be used” limits).

Indeed the ACOUTRAIN Technical Recommendation is based on key ACOUTRAIN deliverables being the backbone of the ACOUTRAIN project Technical Recommendation. The ACOUTRAIN project Technical Recommendation is not one standalone document but is made of several deliverables coming from several Work Packages.

The parts below will refer to these key deliverables.

5.1 First steps towards a virtual certification process

ACOUTRAIN was mainly dedicated to the conceptualization and the definition of the virtual certification procedure. For this purpose, the conditions of use of virtual testing within the scope of a Noise TSI certification process must be precisely defined, in such a way that it is as reliable as the real measurement procedures in use today.

In a first stage, a preliminary process that implies a reduced need for real measurements was elaborated by detailing **the simplified evaluation method** already mentioned in the Noise TSI (entered into force in 2011). In fact, this simplified evaluation method is not often used because there is no common agreement among TSI parties about its scope and process. A study was carried out to support the use of the simplified evaluation method by harmonizing its application.

Then, to enlarge the scope of alternative approaches, other than real measurement, within the context of certification, a global process based on virtual testing was defined, with two main global requirements:

- To reduce costs and time to market compared with the real measurement process;
- To be as reliable as the real measurement process.

5.2 Clarification of the simplified evaluation method

One part of the ACOUTRAIN project was dedicated to the clarification of the concept of “simplified method” mentioned in the TSI Noise published in 201. Nine flowcharts have been developed to propose a simplified approach within the TSI Noise certification procedure, under very specific conditions.

For example, one flowchart proposes to deal with a modification of the maximum speed of a rolling stock without carrying out new measurements; another one proposes to numerically assess the

modification of the global pass-by noise for a change of brake system (provided that this change only affects the wheel roughness state and that the rolling noise is the only dominant source of the pass-by noise). These flowcharts are described in the ACOUTRAIN public deliverable ***D1.1 - Clarification of the simplified method in the partial revision of the TSI***, specifying the conditions of use and giving the technical background that ensure their reliability.

These flowcharts do not represent an exhaustive selection of what could be encountered within the framework of the Noise TSI application: they illustrate common and agreed strategies (among the ACOUTRAIN partners) for implementation of the simplified approach, to be used in conditions that are frequently experienced within the scope of the certification process. They propose some methodologies to carry out a certification with a simplified method. The type of rolling stock to which the method is applicable is mentioned in each dedicated flow diagram.

The certification cases described are the following:

Modification of	Stationary	Pass-by	Starting noise
Number of axles per unit length	Not relevant	Flow diagram n°1	
Maximum speed	Not relevant	Flow diagram n°2	Not re levant
Modification of wheels	Not relevant	Flow diagram n°3	Flow diagram n°3
Brake system	Not relevant	Flow diagram n°4	Flow diagram n°4
Formation of multiple single cars	Flow diagram n°5	Flow diagram n° 6 (addition of a single car) Flow diagram n°7 (removal of a single car)	
Same family / EMU-DMU (worst case selection)	Flow diagram n°8	Flow diagram n°8	Flow diagram n° 8
Equipment (i.e. traction equipment or auxiliary system) / installation of equipment	Flow diagram n°9	Flow diagram n°9	Flow diagram n° 9

The clarification of the simplified evaluation method is well defined in the public deliverable ***D1.1 - Clarification of the simplified method in the partial revision of the TSI***.

5.3 Recommendations for a future certification process

In parallel with the clarification of the simplified method, ACOUTRAIN partners have defined the preliminary recommendations for a TSI Noise certification procedure that allows Virtual Testing to be used.

These preliminary recommendations, gathered in the public deliverable ***D1.2 – Recommendations for a future certification process***, introduce the general principles of Virtual Testing. This presents the Verification and Validation methodology which defines the framework of a reliable virtual certification process (in addition, a vocabulary list specific to the acoustic virtual testing activity has been created). Then it exposes how the Verification & Validation process has been adapted to the framework of Noise TSI and the general approach applied in the most common simulation tools and virtual vehicles already in use: the conditions of application of a reliable virtual testing within the context of the acoustic certification are detailed (in particular, the documents that have to be produced are listed). A summary is then proposed to gather the most important points and recommendations for a new procedure: they form the starting point for the elaboration of a detailed procedure.

5.4 Dissemination workshop with ERA TSI parties

The definition of a new procedure for TSI Noise certification as well as the clarification of the simplified method have been worked out in close relation with the ERA working party in charge of the Noise TSI revision proposal. The ACOUTRAIN Advisory Group composed by standardisation and regulation bodies representatives was informed regularly about the project progress and advised the consortium on the implementation of the project results.

Moreover, a workshop was organised in September 2012 whose audience was made up of TSI parties: ERA representatives, NoBo representatives, CER and UNIFE representatives involved in the TSI Noise revision.

This workshop aimed at disseminating the flowcharts proposed in the public deliverable ***D1.1 - Clarification of the simplified method in the partial revision of the TSI*** and at agreeing with all the TSI protagonists about the preliminary recommendations for virtual testing implementation within the TSI certification process (public deliverable ***D1.2 - Recommendations for a future certification process***).

5.5 A virtual certification process (validated)

From the recommendations included in the public deliverable ***D1.2 - Recommendations for a future certification process***, methodologies for input characterization and procedures for verification and validation steps have been worked out. The results of these studies allow today final recommendations detailed in the public deliverable ***D1.8 - A virtual certification process (validated)***, detailing under which conditions and how virtual testing could be implemented in the acoustic certification process of the Noise TSI.

The present Noise TSI certification procedure requires measurements to be carried out to characterize the noise emitted from the rolling stock for several running conditions. The Noise tests are claimed to be costly and time consuming: 4 to 6 months of duration, 4 weeks of effective work.

In the preliminary phase of ACOUTRAIN, a survey was made to assess the costs of applying the Noise TSI. According the different answers received, the Noise TSI process costs around 70k€ for an EMU/DMU certification (classic speed), and from 65k€ to 90k€ for a high speed train certification, depending on the network where the measurements take place. For one manufacturer, 2 to 4 TSI certifications are typically required per year. This “heavy” process could hamper the development of innovative solutions and the consequence could be that the state of the art noise control measures are not implemented.

Furthermore, many cases where certification is required correspond to an extension of approval: the design of new vehicle is closely based on the design of a previous vehicle, already certified. Thus, virtual testing in the Noise TSI certification process should allow speeding up the product authorisation while retaining the same degree of reliability and accuracy.

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 measurements, 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.

To meet the fundamental environmental requirements covered by the Noise TSI (control of noise emission) without decreasing railway industry competitiveness, the Noise TSI process should be regularly examined to detect possible improvements. The ACOUTRAIN project was launched in this context, to examine if virtual testing (VT) could be a “good” alternative for real testing within Noise TSI:

- “Good” in this context means that the same degree of reliability is obtained with a reduction of costs.

- VT is an alternative to real tests: VT implementation does not imply any modification in Noise TSI certification criteria, as it is introduced as an alternative to conventional rea tests based rolling stock certification: the user could decide whether to use VT or not. The introduction of VT does not mean that experimental tests are eliminated. VT should allow complicated and expensive test procedures to be replaced by simpler and better focused test methods, dedicated to the virtual vehicle (VV) development. These new tests method are mainly based on measurement process already used by the manufacturers within the design and development phase.

Some research needs were identified, particularly related to implementation of current VT theory into rolling stock certification:

- Development of VT implementation approaches;
- Assessment of existing simulation techniques and development of an open tool;
- Application of standard and non-standard test methods for noise sources characterization.

Virtual testing in the context of the Noise TSI means that the tests required for the certification are partially carried out with numerical simulations. Thus, it requires a model to be built representing acoustically the vehicle. This model is called a virtual vehicle (VV) and consists in a set of noise sources that represents the total noise emission of the vehicle (vehicle = set of noise sources). The virtual vehicle is a central part in the concept of the ACOUTRAIN virtual testing procedure. It is the model of the real vehicle set up in a simulation tool that is used for calculating the noise levels that can be compared to the Noise TSI limit values. It is composed of data describing the vehicle noise sources that are the most important inputs to the tool.

In the ACOUTRAIN project, as a first step, the focus is on stationary and pass-by noise simulation. The starting noise and the cab noise tests require specific numerical approaches (handling sources evolving with time on the one hand and interior noise assessment on the other hand) that were not studied further within the 3 years of the project.

Virtual testing for noise certification deals with:

- Simulation tools with specific numerical approach to account for ground reflection etc.
- Noise source modelling: noise source characterization and representation
- Integration of noise sources within the train: integration effect

For validation of the VV that is based on comparison of real test and virtual test, other inputs have to be assessed carefully:

- Parameters that influence the propagation of noise in a complex environment (ground effect, topology effect)

- Track and wheel (wheel roughness) characterization

These issues were partly solved during the project with:

- Definition of Hybrid VT, Extension of Approval (EoA) and transposition techniques;
- Development of certification methods for simulation tools and a specific ACOUTRAIN tool;
- Demonstration of an application case, including the experimental characterisation of a real vehicle at a level of detail not addressed before.

In the public deliverable ***D1.8 - A virtual certification process (validated)***, many results come from the so-called “NAT case”: this is one application case studied in work package 5 for which a large measurement campaign has been carried out.

The final technical recommendations described in the public deliverable ***D1.8 - A virtual certification process (validated)*** gather the process to be followed for creating the input parameters for any virtual testing process: how to create a virtual vehicle and how to validate it. It also details how to choose the most appropriate approach for virtual testing, depending on the available input data and previous models (such as reference virtual vehicle). It is important to note that all these methodologies are proposals: indeed **the validation of the all process could not have been carried out in this project as not enough input data (complete set for compiling, validating and testing some virtual vehicles) were made available**. Therefore, the public deliverable ***D1.8 - A virtual certification process (validated)*** also proposed a list of research needs and recommendations for future measurement campaigns to come out onto a fully validated virtual testing certification process.

For each of these steps, technical recommendations have been studied and proposed in ACOUTRAIN as detailed in the public deliverable ***D1.8 - A virtual certification process (validated).***