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Virtual certification of acoustic performance for freight and passenger trains

D5.2 Description of application cases

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EXECUTIVE SUMMARY

The main objective of this deliverable is to describe the application cases that have been chosen for the validation and demonstration of the virtual testing procedure in Acoutrain. These cases are real, commonly occurring cases in vehicle development and certification. They also correspond to the recommendations for virtual testing that have been elaborated in Acoutrain work package 1. These recommendations have been summarized in the first chapter.

This deliverable provides a first analysis of possible benefits as well as risks of acoustic virtual testing by proposing different aspects that should be examined during the validation with the application cases.

The validation will basically consist in assessing the application cases with a Virtual-testing approach and compare the output with measurement results. The methods and the tool that are required for virtual testing are being developed and partly validated in the work packages 2-4. Work package 5 makes a comprehensive view of all these methods and their integration in the total process. One important issue is to analyse the uncertainties and variables that influence the total result as well as documentation and practicability. Some of these issues will be evaluated analytically.

This deliverable can be seen as the starting point for the validation phase in Acoutrain and therefore it does not include any results. The results of the validation will be described in Deliverable 5.5 which will be an input to the D1.8 *"A virtual certification process (validated)".*

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1. INTRODUCTION

The main objective of Acoutrain is to develop procedures for acoustic virtual testing that can be introduced in the TSI Noise-certification procedure. These new tests based on simulation could replace some of the expensive field test measurements that are required today. In order to gain common recognition it is of great importance that the new procedures are validated. The validation should demonstrate that the required accuracy is reached for all cases covered by the method and that significant sources of error and uncertainty have been identified as well as the means how to control these.

The validation will be performed by comparing results achieved with the new virtual test procedure to measurement results. The comparison will be carried out for a number of application cases that correspond to typical scenarios that a certification procedure has to cover and for which a virtual testing procedure would be of advantage. These cases are defined for different levels of complexity and can be used to demonstrate different fields of application and operation of the new methods and tool that have been developed in Acoutrain.

The first step of the validation process was to summarize the existing measurement data that can be used for comparison with virtual testing results. This was the objective of Deliverable 5.1 [**1**]

The main objective of this deliverable D5.2 is to describe the selected application cases and list some of the aspects that can be validated by examining these. The application cases were chosen and defined according to virtual testing approaches that have been defined in Wp1. For this reason a short summary of these approaches and the corresponding requirements is given in Chapter 2 to provide the necessary background information.

In Chapter 3 it is described what the motivation for defining application cases is as well as which aspects they should cover in order to provide an adequate demonstration of the new virtual testing procedures. One section in this chapter addresses the measurement data that can be used for the validation. The descriptions of the six chosen application cases can be found in Chapter 4.

Altogether, this deliverable provides the basis for the validation that will be undertaken in Task 5.3. This means that at this point there are many questions that are still to be answered and one aim of this deliverable is to summarize these for the coming validation. The outcomes of the validation will be described in the deliverable D5.5 *“Results of validation”*

2. RECOMMENDATIONS FOR A FUTURE TSI NOISE HOMOLOGATION PROCESS- A SUMMARY

This deliverable contains the description of a number of cases that will be used within Acoutrain work package 5 to demonstrate the application of the new virtual testing procedure, which is being developed in the project for implementation in the framework of TSI Noise. These cases shall be real, commonly occurring cases in vehicle development and certification. They shall also correspond to the recommendations for virtual testing that have been elaborated in Acoutrain work package 1 and described in the deliverable D1.2 *"First recommendations for a future certification process"* [**2**]. This is the first proposal for a new virtual testing procedure and after the validation and demonstration in WP5 it will be further elaborated to be included in the deliverable D1.8 *"A virtual certification process (validated)".*

Some of the application cases described in this report correspond to procedures, based on the simplified method-approach, that have been described with flowcharts in deliverable D1.1 *"Clarification of the simplified method in the partial revision of the TSI"* [**3**]. Even though a validation of these procedures is not strictly necessary, a comparison with real measurement data can be useful to demonstrate the range of application and the possible use of simulation tools.

This chapter summarizes the first recommendations for the virtual testing procedure and the different approaches that could be applied.

2.1 VIRTUAL TESTING- THE FIRST PROPOSAL

The virtual testing procedures that are being developed in Acoutrain should provide an alternative to the real testing procedures (field tests) that are required today by the TSI Noise [**4**]. The indicators and the limiting values that are defined in the TSI should remain and be consistent for both real and virtual procedures. Consequently the general concept of virtual testing as proposed by Acoutrain is to simulate the measurement situation and set up with corresponding computations. This means that for instance a pass-by noise measurement is simulated considering parameters such as operating conditions, speed, and receiver positions as found in the description of the measurement method in the current TSI Noise.

Generally, in order to perform virtual testing a specifically for the purpose developed simulation tool is required. By defining the geometry of the vehicle in question and loading sound power levels of the individual noise sources in the tool, a virtual vehicle is created. The characteristics of the single sources can be assessed with laboratory measurements, numerical models or a combination of both. The tool takes physical effects like wave propagation, ground reflection and the Doppler effect into account. Such simulations are often done today by the manufacturers in advance of the certification measurements to manage the development of the vehicle in terms of noise control.

2.1.1 Simulation Tools

The tools that will be used for the demonstration of the application cases are the Acoutrain-tool that is being developed in Wp4, Vamppass developed by SNCF and Sitare developed by Alstom. The Acoutrain tool is specifically important for the work in Wp5 since it is public and the results can be analysed without restrictions. The Acoutrain-tool is a simplified tool that only includes the basic functions. One advantage is that improvements that might be suggested during the demonstration of the application cases could still be implemented.

All these tools are solely developed to simulate exterior noise and are therefore not suited for simulation of noise in the driver's cab. Further it was determined in Work package 4 (D4.1 -noise' of the trans-European conventional rail system.

[5]) that it should not be required that a simulation tool can handle noise sources that change character with the vehicle speed. Consequently it is not possible to compute starting noise correctly and since no reference case has been defined to verify this function in Wp4, the accuracy cannot be guaranteed. In Acoutrain virtual testing procedures are mainly developed for stationary and pass-by noise.

2.1.2 Virtual Testing Approaches

Three different approaches have been proposed for the implementation of virtual testing in the framework of the TSI noise.

- Extension of Approval (EoA)
- Hybrid testing
- Full virtual testing

Extension of Approval and Hybrid testing are the two approaches that at this point are considered to be the most reliable ones. Both are a mix of well-known measurement procedures and computations. A full virtual testing approach could be conceivable for the long term. However, for the time being it is the general opinion that further research is necessary before the reliability of this approach can be ensured.

The Extension of Approval approach is to create a virtual vehicle of the type under assessment in the simulation tool by altering the inputs and settings of an already existing and validated reference virtual vehicle model. The reference vehicle should be similar to the type under assessment; ideally the two vehicles belong to the same rolling stock platform and are based on the same design with only a limited number of modifications.

A measurement campaign should be performed with the reference vehicle. This campaign will be comparable to today's TSI-measurements but it might be slightly extended to assess all necessary inputs for a virtual vehicle, for instance wheel roughness measurement. The measurement results of the noise emission in pass-by and/or stationary situations will be used to validate the correctness of the reference virtual vehicle. If it is approved it can be used for the homologation of further vehicles. For these succeeding vehicles it is only necessary to assess the modifications that would affect the noise emission in comparison to the reference vehicle.

The Hybrid approach is a combination of measurements and computations but unlike the Extension of Approval approach it does not necessarily rely on the comparison with a reference vehicle. Still the step of validating the virtual vehicle is required also with this approach. With the hybrid approach the NoBo receives two kinds of data from the manufacturer; test results and simulation results. It could for instance be useful to transpose pass-by measurements results from a normal track to correspond to a TSI compliant reference track, see application case 4 in Chapter 4.

The Full Virtual Testing approach is when the type testing is performed solely by computations in a simulation tool. Theoretically, for this approach no real assembled vehicle would be required for the certification, only the inputs to create a virtual vehicle. This can consist for instance, of measurements of individual sound sources. The Full Virtual-approach would mean a significant reduction in costs and can be seen as a long term objective that could be reached after more experience with virtual testing and the tools has been gained. It still has to be investigated how the results from this approach could be validated without having access to full scale measurements.

For each of these procedures there is a step that consists in validating the simulation results by comparing it to measurement data. It is very important and should guarantee a certain level of accuracy each time a virtual vehicle and computations are used to certify a new vehicle design.

This should however not be mixed up with the validation of the complete virtual testing procedure that is taking place in work package 5. In this report it is often also called demonstration of the procedure. The aim is to evaluate the reliability and feasibility of the methods that are being developed in Wp1-Wp4 in the context of a possible implementation in the framework of the TSI Noise.

2.1.3 Simplified Evaluation Method

The simplified evaluation method is not a new method but it was introduced in the latest revision of the TSI Noise in 2011 **[4]**. It is also not necessarily relying on virtual testing but since some of the application cases in this report could be assessed with the simplified evaluation method and it is mentioned several times in the following text, it was determined that a short summary of the method would be appropriate. The detailed description of the simplified method can be found in Section 6.2.3 of the TSI Noise and the quotations below are taken from there.

The simplified evaluation method is an option in the TSI Noise that can be applied to avoid some or all of the tests by "acoustically comparing the type under assessment to an existing type with documented noise characteristics compliant with the noise TSI". This approach consists of "providing evidence to show that the acoustically relevant systems and characteristics are either identical to those of the reference type, or such that they will not result in higher noise emission of the unit under assessment."

It is further stated that the evidence could include a calculation, simplified measurement or a combination of both. This implies that a simulation tool could be used to provide the evidence but it is not required. Up till now though no general procedure for testing and certifying the tools has existed and therefore it has been difficult to use this type of calculation for homologation purposes.

At the time of writing this report, the TSI Noise from 2011 is being revised. In this new version that is planned to come into force in the end of 2014 it will most likely be allowed to apply the simplified evaluation method also when the noise emission is increased in comparison to the reference as long as the TSI limiting values are respected.

There are some scenarios, for which both a simplified evaluation method as well as a virtual testing procedure could be conceivable but at different levels of complexity. One case is when a new unit is largely based on an existing design (same vehicle family). The main differences are:

- Because of the higher complexity of the assessment with virtual testing in comparison to the simplified evaluation it will demand higher requirements for the validation of simulations as well as the corresponding documentation as is the case for the simplified evaluation.
- A simulation tool will be necessary to calculate the virtual testing-cases whereas for the simplified evaluation other types of evidence could be accepted as well. If for instance a single sound source is modified, both methods require a characterisation of the new and the reference source under the same conditions. If it is found that the new source is less noisy than the older one, the case can be verified with the simplified method and probably the measurement results could be sufficient to prove that the total noise level won't be affected. If on the other side the new source proves to be noisier, it is important to evaluate the effect on the total noise and it could be done either by creating a virtual vehicle in a simulation tool or by performing field tests.

As was stated in the beginning of this chapter; some of the application cases described in Section Chapter 4 correspond to procedures, based on the simplified evaluation approach, that have been described with flowcharts in deliverable D1.1 *"Clarification of the simplified method in the partial revision of the TSI"* **[3]**. This deliverable provides examples how the simplified evaluation could be applied in different common cases. It was not considered necessary to validate the simplified evaluation method further but the cases that could be useful for demonstration of certain aspects of the virtual testing methods were chosen to be application cases, much because of the lower level of complexity.

2.2 Requirements for accuracy

When introducing a new alternative test procedure for the certification of vehicles it is not only required to develop new test methods but also to revise the verification procedure and to define suitable proof of conformity. It was determined in the beginning of the project that a prerequisite for introducing a virtual testing procedure as alternative to measurements is that the accuracy of both procedures is comparable.

The accuracy or uncertainty of the simulation output is directly related to the uncertainty of the inputs that were used for the computation. There are many different variables that may cause these uncertainties. Most inputs are based on some kind of measurements which are always afflicted with uncertainties caused by variables such as the measurement equipment, environment and set up. These are normally quite small as long as the correct methods and suitable equipment have been used. Post processing of measurement data such as filtering can also be a source of uncertainty.

It is more difficult to control uncertainties or errors that stem from lack of information or inadequate assumptions. For instance, if the operational mode of a single component is not fully known it is hard to reproduce it in a laboratory. It could also concern the possible use of database or default values as input which might not correspond to the actual but unknown value.

Most simulation tools are deterministic which means that repeated calculations give the same output without spread as long as a certain input has been used. The certification procedure of simulation tools that is being developed in WP4 will ensure that all tools are comparable by giving the same output for a number of reference cases **[6]**. The simulation tools will be further tested and used in WP5 during the validation and demonstration phase but after the tool certification has been passed they will not be considered as a source of uncertainty.

Further it also has to be ensured that the new procedure has a certain level of transparency and that it is objective in the sense that it should be independent of the person setting up the virtual vehicle as well as the person evaluating the results.

The measurement procedures described in the current TSI Noise **[4]** are based on well-established standards and are relatively easy to apply for all kinds of vehicles. For the conformity assessment and verification it is checked that the measurements have been performed according to the specifications.

In the case of virtual conformity assessment, instead of an actual vehicle there will be a simulation of a vehicle. As a consequence, not only the results but also the models used will have to be verified. In order to check the conformity more documentation may be necessary, especially when tools and numerical models are used that are not available on the market or for NoBos.

There is a wide range of cases that can be assessed with a simulation tool, each using specific inputs and approximations and it is important that a practicable method for the validation of the simulation is developed. Something like a general step-by-step procedure with check lists and flow charts could be conceivable. It should include an analysis of the uncertainties of both the simulation results as well as of the data used for the verification. Subjective decisions should be excluded.

The key issues for achieving an accurate virtual testing procedure are:

- Development of general procedures for an accurate assessment of the inputs (WP2-3).
- Analysis of the influence parameters and their corresponding effect on the total result. (WP1-5)
- Definition of a certification process to ensure the reliability of simulation tools (WP4).
- Development of a method to validate the virtual vehicle (WP1, WP5).

All these issues are addressed in Acoutrain in different work packages and the requirements regarding accuracy can be seen as the starting point for the validation phase in WP5. They provide the basis for the definition of application cases. How to handle uncertainty in comparison to the TSI Noise limiting value will not be determined in Acoutrain since this question lies outside the scope of the project.

3. DEMONSTRATING THE VIRTUAL TESTING PROCEDURE

The introduction of a new procedure in the TSI Noise can only be successful if all parties are convinced that it complies with the requirements for reliability that are set on vehicle conformity assessment. On the other hand it is also important that the new procedure is practicable and does not cause a higher level of complexity and effort. A new virtual conformity test procedure could become a challenge for notified bodies that would need to examine the simulation results from the tools and judge whether these have been computed with the correct settings and inputs. There is a risk that notified bodies refuse to accept simulated results if they are not well acquainted with the new virtual procedure or the simulation tools.

Many of the methods anticipated for a virtual testing procedure are already used today for the development of new rolling stock. Up till now though there have been only a relatively small group of people that have the right expertise to perform such acoustic simulations. This since it is only in the last decade that the concern about environmental noise as well as the railway traffic have increased and made it necessary to manage and control noise sources when developing rolling stock. The simulation tools that are used by rolling stock manufacturers today are in-house developments that are not available for external users. Even though simulation tools and methods already exist, it is the objective of Acoutrain to provide the framework for using these reliably in a conformity assessment procedure.

The demonstration of the new procedure, that is to take place in work package 5, is necessary both to show how virtual testing can be used to assess common cases and the capacities of the simulation tools as well as validating the reliability and practicability of the procedure. The demonstration will be done by comparing virtual testing with the established methods based on measurements for the different application cases described in this deliverable. It should as far as possible cover the developments of the project but will partly consist of summarizing the findings of the different work packages and analysing them in the context of type conformity testing.

Different aspects should be addressed during the demonstration, some examples are:

- Which indicators are required to prove conformity of a virtual vehicle model? Will the limit value indicator (e.g. Lp_{AeqT}) be sufficient or is a frequency analysis required for proving the reliability of the virtual vehicle?
- Which sources of error and uncertainty could occur? For each application case the variables that could influence the results should be analysed. Besides the uncertainties inherent to a method, e.g. for providing the inputs of a virtual vehicle, there could be other errors that are due to wrong assumptions or different interpretation of results. Such errors are more related to the practicability of the method and can be identified by letting different persons test application cases in varying tools.
- When comparing the test vehicle to a reference vehicle, how many and to which extent modifications should be allowed? At what point is it necessary to define a new reference vehicle in order to sustain the reliability?
- What type of documentation will be required in a TSI Noise conformity process based on virtual testing? Which background knowledge can be expected from the notified body that will evaluate the results?
- How can the proposed procedure and possibly the tool be improved?

The results of the demonstration and validation will be an important input for the development of a final proposal for a virtual certification process in deliverable D1.8.

3.1 Measurement Data

The demonstration and validation of the virtual testing procedure will be performed by comparing computed results with measurement results. The main part of the measurement data that will be used for this purpose is already existing measurement results from earlier research projects that have been provided by the project partners. This data can provide the inputs for a simulation tool and is of use for demonstrating different aspects of assessing railway rolling stock with simulations. It is especially suitable for analysing the variability of inputs stemming from measurements.

The existing data is however not suitable for validating the complete virtual testing procedure that is being developed in Acoutrain. The reason for this is of course that this procedure is new and has not been applied in earlier projects. For this purpose an additional validation measurement campaign is planned in Acoutrain. It should as far as possible cover the methods that are being developed in the different work packages of Acoutrain.

The validation measurement campaign will include characterisation of the most important noise sources and measurements at stand-still and pass-by. Since a virtual vehicle should be created with this data, all required inputs need to be assessed according to the methods that are being developed in the work packages 2 and 3. Besides the acoustic characterisation of the most significant noise emitting components this also includes for instance wheel roughness and track parameters.

At the time of writing, this campaign is being planned and all details have not yet been fixed. The vehicle that has been chosen for the campaign is the Bombardier developed EMU “NAT”. It is being produced for regional operation in France for SNCF. Previous tests have identified the following systems as the most relevant contributors at standstill and/or running at constant speed

- Transformer
- HVAC
- Drive unit
- Traction motor cooling
- Converter cooling

It was considered to be of advantage to perform the measurements with a vehicle that is coming straight from the production because it is representative for the typical situation of type testing. The alternative would have been to use a vehicle that is already used in normal operation. The EMU is a common rolling stock type with components that are being dealt with in WP3.

Here follows a short description of some earlier research project in which measurements of both inputs and corresponding outputs have been performed and that are available for demonstration purposes in Acoutrain:

- **Stairrs** (Strategies and Tools to Assess and Implement noise Reducing measures for Railway Systems) was a research cooperation project that was funded by the European Commission's Transport and Energy Directorate and co-financed by the UIC. The project started in January 2000 and lasted for 3 years. The consortium consisted of 11 European Partners and the focus was on comparing different noise mitigation measures and to simplify the process of finding cost effective solutions.
- **Silence** was a research project in the years 2005-2008 that was funded by the European Commission. It dealt with noise from both road and rail traffic and focused on noise

perception especially in urban areas. The consortium consisted of 45 partners from both railway and automobile industry. The global tool Vamppass was developed by SNCF during the Silence-project and several rail measurement campaigns were carried out to assess different noise reduction solutions

- **Nicobb** (Noise Impact of Composite Brake Blocks) was a cooperation project between DB and SNCF and sponsored by the UIC. It started in year 2007 and a measurement campaign was performed by DB to test different types of brake blocks for freight trains. The test train was the same one as the one used in one of the Silence-measurement campaign but at another test section and the analysis considered different wagons.

Which measurement data could be made available for demonstration in Acoutrain is an important factor for the selection of the application cases. This will be further described below in Section 3.2. Consequently one important step when selecting application cases was to link the existing data to each case to see which aspects could be demonstrated. This link can be found in the description of each proposed application case in Section 4.

3.2 Selection of Application Cases

The application cases described in this report will be used to validate and demonstrate the new virtual certification procedure. The purpose of defining application cases is to provide a structure for the comparison between the new virtual testing procedure and the established measurement procedure as well as to create user examples. It also makes it easier to focus on different aspects of the validation of the procedure.

The application cases should correspond to real and commonly occurring scenarios in vehicle development and certification for which a virtual test procedure could be profitable. They should cover the whole proposed virtual testing procedure and as far as possible include the methods that are being developed in the different work packages of Acoutrain.

The basis for selecting application cases was the prioritisation that was made in work package 1 by questioning the partners about the typical cases where virtual testing could be useful and how to implement it. The response from the partners together with further discussions both within work package 5 and a Wp1-workshop led to a selection of candidate applications for virtual testing. It was agreed that one priority for instance was to propose a reliable alternative to pass-by noise measurements in field due to the high costs. It was also determined not to include a specific case for train speeds above 250 km/h for one thing because high-speed train certifications are not that common but also because aero acoustic sources were considered to be a field of research that was not yet sufficiently explored.

The next step was to compare the candidate applications with the existing measurement data that was available for the validation and demonstration. As already stated in Section 3.1 it was found that the existing data is useful to create inputs for the simulation tools and compare the output to the measured results. It could however not cover all the methods that are being developed in Acoutrain. It was determined that the measurement campaign that will be performed in Acoutrain should focus on the methods for characterizing sources and assessing modifications that could not be covered by existing data, see Section 3.1. This case was considered to be of high priority. Other cases for which not sufficient data was available had to be disregarded.

In the end, six application cases were chosen. These are described in the next chapter. The definition of each case is in line with the recommendations and requirements defined in the deliverable 1.2. The application cases should represent the whole range of possible applications of the new procedure. But taking the modification of a sound source as an example there are probably as many different applications as there are vehicles. Therefore the demonstration will be performed in a general way and not focus on what specific sources or design changes. Some validation aspects will be evaluated analytically.

4. CHOSEN APPLICATION CASES

Six application cases have been chosen for the validation in Wp5, see Table 1. This chapter gives a detailed description of each case along with the aspects that can be validated by examining these. For each case a proposal has been made for how the validation could be performed and which data from the Acoutrain measurement campaign or the deliverable D5.1"Database with existing measurements" could be suitable for that purpose.

The selected cases have been divided into different categories of relevance and importance for the case that practical circumstances make it difficult to carry out a complete validation for all of them. The priority categories are the following:

I: Very important case, should be validated in any case

II: Interesting case, should be validated

III: Can be neglected if necessary

The application cases that falls under the third category are also extensively treated in other work packages.

Nr	Application case	Category
1	Modification of a brake system that influences the roughness of the wheels	III
2	Exchange or modification of a sound source	I
3	Adding encapsulation or shielding	III
4	Transposing measurements made on any track to a TSI conforming track	I
5	Measuring stationary noise and calculating pass-by noise	II
6	Different formation of multiple units	II

Table 1: The selected application cases

APPLICATION CASE 1: MODIFICATION OF A BRAKE SYSTEM THAT INFLUENCES THE ROUGHNESS OF THE WHEELS

Simplified evaluation method, Pass-by noise

The exchange of brake system of a vehicle is one modification that requires a new certification according to TSI Noise. One way to do this is by using the simplified method that is proposed in Flowchart 3.4 in Deliverable 1.1, see Annex 1. It applies to brake types that only influence the wheel roughness (block brakes) and consequently the excitation amplitude of rolling noise. It is based on the idea that the assessment of the new braking system at pass-by could be reduced to the measurement of wheel roughness. This does not apply to disc brakes that do not influence the condition of the wheel surface. The type of disc brakes may also have an effect on the rolling noise. A disc brake mounted on the wheel can increase the wheel damping, reducing emission with up to 2 dB which is not the case when mounted on the wheel axle. Consequently a change of disc brake type also requires a new assessment of the vehicle but it cannot be done with this particular procedure.

It will be common in the coming years that freight wagons with cast iron brake blocks are upgraded by equipping them with composite brake blocks. In case that it is the only change made on the wagon in question, it is already stated in the current TSI Noise (point 7.6.1**[4]**) that no further acoustic measurements are necessary in order to certify the vehicle. In the future there may be new developments of brake block materials that do not have that obvious effect on the wheel roughness. A reliable method is necessary for this case.

There are some different aspects of the proposed simplified method that should be evaluated and demonstrated in Wp5:

- **The development of wheel roughness**

  Only after running a certain distance in normal traffic the wheel roughness develops and it is characteristic for the brake block material. After the run-in, the wheel roughness stays approximately constant. The TSI Noise requires that the unit under test should have run for at least 1000 km before the measurements are performed. It should be evaluated whether this distance is sufficient for all types of brake material and to which extent the development of roughness deviates between different wheels of a vehicle as well as between different vehicles with the same brake type.

- **Measuring the wheel roughness and associated uncertainty**

  For a calculation procedure with measured roughness data as an important input it is essential to have knowledge of the measurement uncertainty. This is also necessary when measured data is to be compared as described above.

  A measurement procedure for measuring the wheel roughness has been developed in D2.4 *"Proposed analysis method for wheel roughness"***[7]**. A benchmark test was made where different partners performed the wheel roughness measurements on one unit according to this procedure. The result of the test can be found in D2.8 **[8]** and should be the basis for determining the uncertainty of this application case. One influence factor that should be evaluated is the number of wheels that should be included in a mean value calculation. Another question is whether it is necessary to reprofile the wheel tread before the brakes are modified and the wheels run in?

- **Usage of wheel roughness database**

In this application case, expensive pass-by noise measurements can be avoided by performing wheel roughness measurements instead. However, such measurements can be quite costly as well and the vehicle still has to run for at least 1000 km with the new brakes before the measurement can take place.

The Flowchart 3.4 in D1.1 opens up for the possibility to use roughness data from a database, which could make this application case become more profitable. This would mean that if the typical roughness spectrum of a specific brake block system is already known from earlier measurements, it does not have to be repeated for each vehicle certification. Still it has to be clarified under which circumstances the usage of a database is reliable and valid.

This application case can also be used for demonstrating the use of wheel, rail and combined roughness in the simulation tools and its influence on the output.

How to validate this application case:

This is a relatively simple case that can be validated with the results from Wp2 and existing measurement data.

The method to apply in this application case is described in the flow chart and it requires the quantification of U^{RN}_{calc}. It denotes the total uncertainty of the rolling noise that has been modified with the new wheel roughness. In this case it is composed of the uncertainty of the measurement method and the source variability. The uncertainty of the pass-by noise level measurement is excluded by calculating the delta between the reference level and the modified level.

As mentioned above the work in Wp2, in particular D2.8, will provide information regarding the uncertainty of the measurement method. The source variability concerns the variation in roughness level between wheels of one type. The uncertainty stems from the selection of samples. If the variation is high a larger sample size may be required in order to accurately represent the whole type. The variation between wheels can also be extracted from the Wp2-wheel roughness measurement campaign.

However for the validation of this case also pass-by noise measurements are required. This data can be taken from earlier measurement campaigns. For instance in the Nicobb-project the wheel roughness of a freight vehicle consisting of wagons with both CI-, K-, and LL-block brakes was measured. Altogether 72 wheels were measured. The pass-by noise was measured according to EN3095 [**9**] at 80km/h and 120km/h. It can be compared with other freight train measurements where the same block brake types have been installed.

Another interesting measurement campaign for validating this application case is a Dutch measurement of freight car transport wagons. They were equipped CI block brakes as well with LL block brakes of different types. Pass-by and indirect roughness measurements were performed regularly over a period of 15 months and can provide information concerning the development of wheel roughness.

Moreover, the deliverable D2.3 “Variability of rolling noise” will provide an important input for the validation of this case.

APPLICATION CASE 2: EXCHANGE OR MODIFICATION OF A SOUND SOURCE

Extension of Approval approach, Stationary- and Pass-by noise

In the development of railway vehicles it is common to base the new design on already existing vehicles. Often there are a number of variants of one vehicle design that together make up a vehicle family. All new vehicles have to be certified according to TSI independent of the extension of the modifications. The possibility to apply a simplified evaluation for vehicle families for instance, is already implemented in the latest version of the TSI Noise **[4]**. The prerequisite is that evidence must be provided to show that the modifications of the different vehicle variants do not cause higher noise emission than the corresponding TSI Noise limiting value.

In some cases this evidence can be quite simple, but for more complex cases it might even be impossible to prove the effect of modifications without using simulations. One goal of Acoutrain is to develop a virtual testing procedure based on simulations that could be used in such cases. In order to assure that this procedure is reliable, the exchange or modification of a sound source is chosen to be one of the application cases that should be validated and demonstrated in Wp5. Because of the high occurrence this case is considered to be of high priority.

Most rolling stock consists of a large number of components that all emit noise that may contribute to the total emitted sound pressure level. It would be impossible to validate all kinds of possible modifications of these components by comparing it with measured results in Wp5. There is not enough existing measurement data available and the necessary effort would be much too high. For this reason, the validation and demonstration of this application case should be performed in a general way, focusing on the basic principles and influence parameters of the proposed method. Still the accuracy of the method is dependent on the type of source that has been modified, its complexity and its contribution to the total noise.

There are a couple of aspects of this application case and the virtual testing approach Extension of approval that should be validated and demonstrated:

- **Influence of the method to characterize sources**
  Different methods are possible for the characterisation of sound sources. Some sources can be dismantled and measured in an acoustic laboratory. Others require a special a test bench which may be situated in a noisy environment. In some cases it can be more practical or even necessary to measure the noise emission of a source installed in the vehicle. This is the case if the source causes structure-borne noise. Furthermore, some simulation tools allow source

input data both as sound power level as well as sound pressure level. It should be evaluated in which situation the different methods can be used and how the choice influences the output. One important question is how to determine the operating conditions for single components and set these in a laboratory environment. This evaluation will be based on the results from work package 3.

- **Representation of sources in the simulation tool**

The basic way of representing sound sources in a simulation tool is to define one or more point sources. This is a kind of simplification and especially for sources with a large area it can be a factor that contributes to errors in the simulation result. Another question is how the results are affected from the settings of the directivity of the sound sources in the tool. It is quite difficult to measure the directivity of a source and it is easier to assume a standard directivity such as monopole, but which errors may such an assumption cause?

- **Method for quantifying measurement uncertainty of source characterisation**

The methods for quantifying measurement uncertainties of source characterisation should be described in the deliverable D5.4 *"Report on validation methodology"*. The measurement uncertainty is depending on the method for the characterisation including measurement equipment but also on the type of source and the measurement environment.

The measurement uncertainty can be determined specifically for each measurement set-up but it can also be determined once and generally for one method. The latter alternative implies less effort but the uncertainty level is generally higher since a larger number of variants have to be considered. A combination of both approaches is often applied in measurement standards where some variables are determined generally whereas other should be determined specifically. It should be evaluated which approach is the most practical in the context of source characterisation to be used in a type testing procedure.

- **Comparison with measurements to validate the reference virtual vehicle**

The virtual testing approach Extension of Approval includes a validation step in which measured and calculated data from one reference vehicle is compared. If the results show a good agreement the virtual reference vehicle model is accepted and can be used to assess other similar vehicle designs. It should be evaluated which parameters are to be compared and the level of agreement that should be required.

Since many influence parameters of field tests are difficult to assess (for instance ground impedance) it is quite probable that the first comparison between measured and calculated results shows non-acceptable deviations. If this is the case it could be possible to allow tuning or calibration of the simulated results in order to achieve a better agreement. The methods for doing so have to be evaluated in Wp5. The risk that it is actually the virtual reference vehicle that is incorrect (for instance wrong number of sources or mistakes made in the characterisation) has to be avoided. The analysis of this requires a lot of experience and knowledge of the vehicle in question. It would be the task of the Notified Body to judge whether the two results are comparable, a procedure is necessary, limits for which parameters are allowed to change and how much..

- **How many modifications of sound sources are allowed in comparison to the reference vehicle?**

The concept of Extension of Approval is that the reliability of the simulated results can be increased by comparing the test vehicle with a reference vehicle. For this to work, the two vehicles have to be of similar design and have several important components in common. It should also not be allowed to use a vehicle that has been certified by using the Extension of Approval-approach as a reference vehicle for a third vehicle. The first and completely measured reference vehicle should always be the basis. At some point it has to be determined that the differences between reference vehicle and test vehicle are of such an extent that the EoA-approach cannot be applied without performing new validation measurements. It has to be evaluated what this limit should be.

- **Documentation**

As described in chapter 5.7 of the deliverable D1.2 [**2**] the documentation required for a virtual certification procedure would be a folder of different reports. The content of these reports should be detailed and tested e.g. regarding practicability.

- **Starting noise**

The proposed virtual testing procedure is primarily intended to assess pass-by and stationary noise. In the TSI Noise however also the starting noise and driver's cab interior noise levels required. Many simulation tools cannot calculate sound pressure levels that evolve with time which would be the case for some sound source during acceleration. They are also not developed to handle interior noise. Since the virtual testing approach Extension of Approval is based on a reference vehicle that has been completely measured, including starting noise, it could be considered to certify the test vehicle also for starting noise provided that it can be proved that the modifications of the test vehicle do not have an effect.

How to validate this application case:

This case represents a typical application for the Extension of Approval-approach and is considered to be of high priority because of its expected usefulness in type testing and potential regarding cost reduction. Since this is a new approach that is being developed within Acoutrain there is hardly any existing data available for its validation. It was determined that the Acoutrain measurement campaign should primarily provide data for validating this case.

The most significant noise sources should, as far as possible, be assessed with methods developed in WP2 and WP3. Due to practical aspects and budget restriction it might not be possible in each case, this is something that will be detailed in the further planning of the campaign. If aberrations are shown to be unavoidable, the effect that they may have on the final result needs to be analysed.

A virtual vehicle will be defined with the measured inputs in the Acoutrain-tool as well as in the other tools that are undergoing the certification procedure in WP4. The stationary noise and the pass-by noise will be calculated in the tools and the output will be compared to the corresponding measurement results. So far this process corresponds to the one that will be required for a reference vehicle. It provides the opportunity to demonstrate the basic element of virtual testing; the representation of a real vehicle with a virtual vehicle in a simulation tool. Moreover it may be validated to which extent a calibration of the calculated data should be permitted and which input parameters this should concern. The documentation should be performed as proposed in D1.2.

The estimation of the influence parameters that may contribute to uncertainties should be provided from the tasks in Wp2 and 3 that deal with the noise source in question. The estimation of the total uncertainty as well as a sensitivity analysis will be performed within the validation of the application case. For the comparison between simulation- and measurement results it is also necessary to quantify the uncertainty of the field tests. This will be based on the recommendations of the measurement standard EN3095 **[9**].

One limitation of the measurement campaign is that it will not be possible to make any modification to the noise sources of the "NAT". In order to reproduce this situation it is planned either to run one component in another operational mode with different acoustic characteristics or to mount an additional sound source, like for instance a loud speaker, on the train. The virtual vehicle should be correspondingly adjusted and the new output compared to stationary- and pass-by measurements that will be repeated after the modification.

The questions concerning the number of modifications should be allowed will be dealt with analytically be estimating the corresponding increase in uncertainty. This should be performed on a component level. The same approach will be applied to estimate the possibility of using the EoA-approach for assessing starting noise.

APPLICATION CASE 3: ADDING ENCAPSULATION OR SHIELDING

Extension of Approval approach, Stationary- and Pass-by noise

As the TSI-limiting values are lowered in the future, the addition of shielding or encapsulation could become a useful noise reduction measure to reach the certification limits. This could be for instance the shielding due to fairings on the roof or skirts to reduce rolling noise and emission from other bogie mounted equipment.

The reduction of noise due to encapsulation or shielding is only one effect that is referred to by the term "geometrical integration effects" This covers all types of local integration effects on a sound source that is installed in a vehicle in comparison to the dismounted source. Such effects are specific for the vehicle design and the position of the source and have to be taken into account by defining equivalent sound sources for the setting up of a virtual vehicle in a simulation tool. It can be done directly in the simulation tool with a specially developed module (for instance ray-tracing) or included in the characterisation of the source. The Acoutrain-tool requires equivalent sound sources as input for which the integration effects are already taken into account

Different methods to assess the effect of integration including shielding and encapsulation will be examined in task 3.4 "*Geometrical integration effects".* These methods include measurement of transfer functions as well as numerical methods (ray tracing, and energy BEM). The examined methods have different levels of complexity and reliability and the focus for the validation in WP5 will be to analyse the influence on the total sound pressure level and the corresponding uncertainty.

Besides the addition of shielding or encapsulation it should be examined how the methods for assessing integration effects can be applied with the EoA-approach in a case similar to application case 2 but with the difference that sources of the test vehicle aren't modified in regard to the reference vehicle but only the positions have been changed.

How to validate this application case:

The basis for the validation of this application case will be the results from task 3.4. In this task both measurement and calculation results will be compared and with that the methods for geometrical integration effects will be validated. These results will be further analysed in Wp5 in regard to practicability and reliability of the methods as an integrated step of a future virtual vehicle certification procedure.

Moreover it should be evaluated how the methods can be used to determine the insertion loss of added shielding or encapsulation and how a virtual vehicle can be modified correspondingly. This analysis will be performed analytically.

Measurements will be performed in task 3.4 and it will also use measurement data from the Silence project for the validation. Moreover Alstom has performed measurements with a DMU at stand-still with real and artificial sources at different positions of the vehicle and with different shielding configurations. This campaign was performed in 2001 with the purpose of validating the module for integration effects in Sitare. The measurement set up differs from the one proposed in Acoutrain. Still it can be provide useful information for the validation activities both task 3.4 and Wp5.

Hybrid approach, Pass-by noise

Noise from the track can contribute significantly to the total noise emission of a railway vehicle at pass-by. For the assessment of vehicles the influence of the test track should be limited and such that measurements are comparable. For this reason reference track conditions have been defined in the TSI Noise to which the test track of the pass-by measurement has to correspond. It includes requirements for free sound propagation and minimum curvature radius but also for minimum vertical and lateral track decay rates and maximum rail roughness level. Even though such constraints are necessary it often contributes to increasing the costs and efforts of type testing since it can be hard to find tracks that comply to these relatively high requirements. When a suitable test track is found regular work may be required in order to maintain the high track quality.

With the introduction of the small deviation method in the TSI Noise 2011 more flexibility in the choice of track was made possible. The roughness of test track may exceed the maximum level of a TSI reference track but the deviations have to be that small that they only cause a difference in sound pressure level of maximum 1 dB. The small deviation method requires calculation of a corrected sound pressure level (Appendix B **[4]**). With a simulation tool, more complex calculations could easily be performed and it could be possible to transpose measurement results from any track to correspond to results of a TSI compliant track.

Because of the big cost-saving potential and already high level of experience in calculating rolling noise it was determined that transposing measurements made on any track to a TSI compliant track should be an application case to be evaluated in work package 5. The procedures for such a transposition are being developed in task 2.4. This procedure has to be evaluated in the context of a certification procedure and the required accuracy. The influence of the track parameters on the total result and the measurement uncertainties will be evaluated. One aspect that will be considered is whether the quality of the measurement track still needs to be of a certain level so that the difference to a TSI-track is not too large. It should also be evaluated if it is necessary to distinguish between a track that does not comply to TSI requirement because of too high rail roughness levels and one that does not comply because of too low track decay rates.

The transposition should be done between two track conditions; the track where the measurement took place and a track that complies with the TSI limit curves for decay rate and rail roughness. However, the latter has not been defined. Theoretically, by using a virtual test procedure the influence of the track could be removed and only the vehicle considered. But since calculations should only be an alternative to measurements the two methods have to correspond. The limit curves for decay rate and rail roughness defined in the TSI Noise are theoretical and do not correspond to real tracks. When a TSI reference track is found it is possible that for instance roughness is significantly lower than the limit values. It would mean a certain disadvantage for the calculated results. Since the definition of a reference virtual TSI track would be directly connected to the TSI limiting values, this issue will be analysed but cannot be fully resolved in Acoutrain.

How to validate this application case:

The validation of this application case will be based on the work in task 2.4. Experimental data from earlier measurement campaigns can be used to demonstrate the new transposition methods. For instance in the LZarG-project pass-by measurements were made with a freight train running over three different track sections with varying dynamic properties. This data can be used to demonstrate how the transposition between two tracks can be handled in the simulation tools and to evaluate the influence of the track parameters on the total result and the corresponding uncertainties

APPLICATION CASE 5: MEASURING STATIONARY NOISE AND CALCULATING PASS-BY NOISE

Hybrid approach

The pass-by noise measurement is the most expensive part of the noise certification process. If it could be avoided by performing simulations instead, a significant reduction of costs could be achieved. The application case measuring stationary noise and calculating pass-by noise will be evaluated in work package 5 by using the hybrid approach. It could be an alternative to the Extension of Approval-approach in the case that no suitable reference vehicle is available.

For this application case all sound sources of the test vehicle should be characterised and listed for both operation conditions; stationary and pass-by. A virtual vehicle is created and the stationary noise calculated. The results are compared to a measurement of the stationary noise according to TSI. It should be evaluated if this, in some cases, could be a sufficient validation of the virtual vehicle for it to be used for pass-by noise calculations as only means for the certification.

Such a validation would not be as complete as the validation that is possible with a reference vehicle for which also pass-by measurement results are available. It would however still reduce the risk of modelling mistakes such as erroneous characterisation of sources, missing sources, wrong position or unknown installation effects. However some unknowns would remain. It would not be possible to validate the computed rolling noise and it is in many cases the dominating sound source at pass-by. Many sources change character and noise emission level in running operation in comparison to stationary which means that the virtual vehicle for pass-by may differ significantly to the virtual vehicle for stationary noise.

This application case has many evaluation factors in common with other application cases described in this report. The procedures of characterising sources and the way they are represented in a simulation tool are the same as for case 2; Modification or exchange of sound sources. For both cases the main part of measurement data for the demonstration will come from the Acoutrain measurement campaign. The aspects concerning wheel roughness measurements are shared with application case 1 and the problems of simulating rolling noise at a virtual reference TSI-track are described for application case 4.

Moreover, it should be evaluated if there are other possibilities to validate the calculated rolling noise besides measurements of the pass-by. Because of the limited validation and consequently lower level of confidence it is possible that the variety of cases conceivable for this procedure should be more restricted than for the Extension of approval approach. This could for instance concern types of wheels with a common design that can be modelled reliably. One complication is that the vehicle still has to run for at least 1000 km in order to make a reliable wheel roughness measurement.

How to validate this application case:

The measurement campaign that is being planned in Acoutrain could be used to validate this application case. It covers both stationary and pass-by noise and the sound sources will be characterised for both scenarios. For this case it is important to consider the contributions of each source to the total noise of stationary noise respectively pass-by noise.

Possibly measurement data from the project Silence could be used for the demonstration of this case. In this measurement campaign the sound sources of an AGC were characterised for different operations and speed. The used assessment methods do not fully correspond to the ones proposed by Acoutrain but still the results can be used to analyse the variation in noise emission of different sources at stationary in comparison to pass-by at different vehicle speeds.

APPLICATION CASE 6: DIFFERENT FORMATION OF MULTIPLE UNITS

Simplified evaluation method or Extension of Approval- approach, Pass-by noise

It is common that multiple units are designed in a way that different formations of vehicles are possible for an increased flexibility of the trains in operation. Each of the possible formations needs to be certified according to TSI. In Section 6.2.3.1 of the TSI Noise 2011 **[4**] it is stated that the simplified evaluation can be used for different formations of multiple units. In deliverable 1.1 “Clarification of the simplified method”**[3**] four different cases concerning formation of units were developed as Flowcharts. These were

- Flowchart 3.5: Train with different single cars formation, stationary case,

- Flowchart 3.6 Addition of single car,
- Flowchart 3.7 Removal of single car.
- Flowchart 3.8 Selection of the noisiest formation of different single cars

For the stationary noise which is measured and energy averaged at a number of microphone positions around the unit, it is easy to see how microphone results representing one vehicle can be added or removed in the calculation. The other cases address pass-by noise. The procedure is that all the vehicles of the multiple unit should be individually acoustically characterised. If the least noisy vehicle is added to a formation it would mean less noise over a longer measurement time and an increase of noise level is impossible. The same argumentation is valid for the removal of the noisiest vehicle. The restriction of flowchart 3.1 that the APL may only increase with 10% has to be observed. These three cases are quite evident and don't need further validation in work package 5.

The fourth flowchart 3.8 describes a more complex case for which a simulation tool could be of use. As in the cases described above, each vehicle of a multiple unit should be characterised individually. Further, a list of all possible formations should be compiled and the noisiest of these formations is determined. Only this vehicle has to be measured according to TSI and if it complies with the limit value, the whole platform can be certified.

The determination of the noisiest formation can be performed with a simulation tool and it has the advantage compared to other calculations that it provides clear and visual evidence for the documentation and communication with Notified Bodies. Since the need of certifying different formations of a multiple unit is a common case, it was determined that it should be one of the application cases to be validated in Wp5. One important aspect is to define the necessary documentation. Other questions could be the procedure when two formations are about as noisy or how to proceed when the noisiest formation does not comply with the TSI limits?

How to validate this application case:

There is one set of measurement data that could be used for the validation of this case. It consists in pass-by noise measurements of an EMU in two different unit formations: A-A and A-B-B-A. Since the rolling noise was dominating in this case it is strictly seen not necessary to set up a virtual vehicle in a simulation tool to calculate the differences in total noise emission. Still this data could be used to create a user example of the application case and evaluate important aspects like documentation. At the time of writing it could not yet be clarified whether all inputs that are required to set up a virtual vehicle can be made available for the project. Some of the validation aspects mentioned above will be analysed analytically.

5. REFERENCES

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ANNEX 1:

Flowchart 3.4 Modification of the brake system (that does not influence anything else than the roughness of the wheel) from the deliverable D1.1 *“Clarification of the simplified method in the partial revision of the TSI.”* The procedure described by this flowchart is addressed in application case 1.