Virtual certification of acoustic performance for freight and passenger trains

 Deliverable 1.7: Global functional requirements of a virtual certification for the next revision of the TSI

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| PP | Restricted to other programme participants (including the Commission Services) |
| RE | Restricted to a group specified by the consortium (including the Commission Services) |
| CO | Confidential, only for members of the consortium (including the Commission Services) |

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Collaborative project
EXECUTIVE SUMMARY

ACOUTRAIN project global requirements have been defined along the first year of the project. They have been presented to a workshop where the partners of the Noise TSI could give their point of view.

This deliverable gathers the first global requirements presented during the workshop as well as the main remarks or questions raised by the audience. It will allow writing the first recommendations for a Virtual Testing implementation within the frame of the Noise TSI.
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1. INTRODUCTION

The global recommendations for the implementation of a Virtual Testing in a TSI certification process have been presented during a workshop dedicated to the ACOUTRAIN WP1 work.

The audience of this workshop was mainly made up TSI parties: ERA representatives, NoBo representatives, CER and UNIFE representatives involved in the TSI revision.

For the ERA: A. Shirmer, E. Godward, O. Martos
For the European Commission: M. Paviotti
For the manufacturers:
   UNIFE: A. Polo, N. Furio
   Alstom transport: J.M. Bodson (ACOUTRAIN Steering Board president), N. Cuny, A. Bistagnino, J. Sapena, Ch. Eichenlaub
   Bombardier Transport: S. Leth, U. Orrenius, L. Baures
For the operators / infrastructure managers:
   DB: M. Starnberg, N. Meunier, T. Tielkes
   SNCF: F. Margiocchi, P. Fodiman, F. Aubin, F. Letourneaux, F. Poisson, E. bongini
For the NoBos: B. Masson (Belgorail), J.L. Henriques (APNCF)
For the research center and the engineering consultants:
   ISVR: D. Thompson
   TNO: M. Dittrich
   ARUP: B. Fenech
   CIDAUT: R. Cordero, M. Morcillo
   Vibratec: B. Betgen, P. Delage

The following document gathers the presentation that was made during this workshop dedicated to the first recommendations for a virtual testing implementation within the scope of the Noise TSI as well as the different remarks and questions made by the participants. These comments will allow directing and focusing the next actions of the ACOUTRAIN partners’ work.
2. NOISE TSI BACKGROUND AND VIRTUAL TESTING

2.1 PRESENTATION

Virtual testing

- The VT process could be a combination between measurement and numerical simulation results.
- VT process should include elements of validation. ACOUTRAIN project is to assure reliability in the method with:
  - The verification of the numerical global tool
  - The validation of each vehicle global model of the vehicle under test

This is the V&V process

- Within ACOUTRAIN, this process will be validated
**Vocabulary**

- **Virtual Testing**: use of simulation models for the assessment of regulatory (enforced by law) essential requirements, e.g., Noise TSI in ACOULTRAIN.

- **Recommendations for Virtual Testing**: definition, by the ACOULTRAIN WP1 partners, of the action field for a Virtual testing implementation within the TSI frame. How could we use numerical simulation in a certification process? In which cases? Which numerical tool should be used? How can we make sure that the procedure is reliable enough to draw conclusions on the compliance of the vehicle according to TSI W01?

- **Numerical global tool**: software that allows to compute the global noise levels of a vehicle, defined as a set of acoustic sources.

- **Vehicle global model**: model of a vehicle as a set of acoustic sources, compiled in a numerical tool.

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**Noise TSI certification: background example**

Increase of the train traffic on the track Brussels – Playmobile city  
New rolling stocks have to be bought by the local railway operator.

The new rolling stock design is greatly based on an existing RS design, already certified, with small differences:  
- A new cooling system  
- New brake systems have been installed, to reduce squeal noise

How to minimise the certification cost (duration and costs) and at the same time ensure the acoustic quality of the new rolling stocks?
The NOI TSI issues

NOI TSI tests are costly and time consuming:

- 4 to 6 months of duration, 4 weeks of effective work
- Around 70k€ for a EMU/DMU certification (classic speed), from 65k€ to 90k€ for high speed train certification, depending on the network where the measurements take place
- For 1 manufacturer, 2 to 4 TSI certifications are required per year
- In many cases where certification is required, we talk about an extension to approval: the design of new vehicle is closely based on the design of a reference vehicle, already certified
- This “heavy” process could hamper the development of innovative solutions and the consequence could be that no noise reductions are implemented

Noise TSI: Virtual testing implementation example

- Standstill measurement of the reference RS
  → Characterization of the noise sources on the reference train

- In lab or numerical assessment of the cooling and the rolling noise:
  → $\Delta L_W^{cooling}$ & $\Delta L_W^{rolling}$

Between the reference RS and the new RS configurations

- Global vehicle model implementation in a certified global numerical tool:
  Validation of the reference RS global model by comparison with measurements
Noise TSI: Virtual testing implementation example

• Numerical simulation of the pass-by noise of the new rolling stock, versus the reference rolling stock
  → assessment of $\Delta L_p^{\text{global}}$, on the global pass-by noise

• the new rolling stock global pass-by noise is defined by:
  $$L_p^{\text{mat new}} = L_p^{\text{mat ref}} + \Delta L_p^{\text{global}}$$

$L_p^{\text{mat new}}$ is compared to the NOI TSI limiting values

Virtual testing

• The VT process could be a combination between measurement and numerical simulation results.

• VT process should include elements of validation. ACOUTRAIN project is to assure reliability in the method with:
  - The verification of the numerical global tool
  - The validation of each vehicle global model of the vehicle under test

  This is the V&V process

• Within ACOUTRAIN, this process will be validated
ACOUTRAIN adopts the Verification and Validation method described in the ASME "Guide for Verification and Validation in Computational Solid Mechanics". Virtual vehicles reliability is assessed at two levels, first with a verification process focused in two aspects; verification of code and calculation verification. Then virtual vehicle predictions are compared to equivalent test results in the Validation phase.
Verification and Validation activities apply to virtual vehicles, while certification applies to simulation tools.

Implementation of VT includes the main steps listed in slide 14.
In particular for validation purposes, test methods described in the ISO3095 are taken into account, but not only. WP4 is dedicated to simulation tools certification.

It is proposed that reliability of simulation tools shall be assessed before starting the VT process according to some certification requirements, which will are being defined in the project. Certification of simulation tools would be based on the comparison of simulation tools outcomes in simple scenarios against a set of reference cases (including analytical and numerical solutions).
Numerical global tool certification / report

Our proposal is that a certification report will be produced, including:

- Information about the numerical global tool: ground model used, source model used...
- The computed results for the reference cases tested, to be compared to the corresponding reference values
- Reference corridors will be defined: they correspond to interval of confidence in which the numerical global tool results should be

Information created during the certification process would be reported.

Vehicle global model validation

The Validation phase would be applied to virtual vehicles, each time a new vehicle is developed, while simulation tools certification would only be required once, unless modifications are implemented in it. New versions of simulation tools would have to be certified.
Three different VT approaches are proposed. An example is proposed which would fit in the so named Full VT approach.

In a Full VT approach only simulation predictions would be used in the assessment of NOI TSI requirements after V&V.
In the Full VT approach, effort is focused on the validation of the virtual vehicle. If validation requirements are met, then no tests would be conducted in the assessment of NOI TSI requirements. The train certification with respect to noise requirements would only rely on simulation results.

An example is given for a second VT approach named Hybrid VT.
In this case Hybrid stands for the use of both test and simulation results in the assessment of NOI TSI requirements.

The use of calculation can save tests in the assessment of noise emission performance from new trains, while still taking advance of simplest tests, according to the Hybrid VT approach.
A third VT approach is also identified. In this case it would address virtual vehicles that have been already validated in a previous certification process, and are used as a reference in which small modifications or changes are implemented. This approach is named Extension of Approval based on VT.

Virtual vehicle A is the base in which small modifications are introduced to derive Virtual vehicle B. NOI TSI requirements would be assessed only with the Virtual vehicle B.
Reliability of predictions in the Extension of Approval based on VT approach relies on the validation of Virtual Vehicle A and the assessment of modifications introduced.

As with simulation tools certification and virtual vehicle verification, a report would compile all validation outcomes.
3.2 QUESTIONS, REMARKS, COMMENTS FROM THE AUDIENCE

3.2.1 VT approaches
Extension of approval approach uses an existing validated model which is modified with the new equipment. Therefore, it is the least risky approach.

Hybrid approach: could be used in a Delta configuration, that means to compute the Delta between a reference RS and a new RS.

ACOUTRAIN will define which approach(es) is the most appropriate (simple and reliable) depending on the application case in concern. It will be clearly defined in the recommendations written at the end of the project, also depending on the results of the validation process, WP5.

Estimation of uncertainties: it is required whatever the VT approach is. The way the uncertainty level will be taken into account is not fixed (definition of corridors?)

3.2.2 Sources/inputs characterization
WP2 and WP3 are dedicated to defining methods for the assessment of input values, the use of tools (TWINS). Guidelines will define harmonized methodologies for characterizing each kind of noise source.

What about the characterization of the pantograph source?
The case of pantograph source can be included even if the contribution to TSI noise limit is low. The definition of aeroacoustic sources is very complex. That is why high speed cases are not really foreseen for a VT certification procedure. Nevertheless, aeroacoustic sources models are under development, for a use in a distant future.

Which level of accuracy for the sources characterization? Does the characterization have to be carried out by an accredited laboratory?

ACOUTRAIN will provide clear guidelines on the methodologies to characterize sources. The project is not delegated to define by who/how these methodologies will be carried out. This point relies on standardization bodies decisions.

ACOUTRAIN aims at developing new methods for the source characterization that could then be used in standards. These methods also deal with sources variability assessment.

3.2.3 Numerical tool
A tool is under development for an access to the process for everyone. ACOUTRAIN tool will be available on the market and could be an interesting tool for small manufacturers that do not have an in-house developed tool.

There is no clear decision about the availability of the tool as an executable file (.exe) or a Matlab program? Who is the owner? Who is going to manage the licences? These questions will be cleared at the end of the project.
Who is going to certify the software? Like for the measurement, the company who has developed the numerical tool (the measurement system) is responsible to prove that the software works properly. Reference cases defined for the tool are simple cases, implementable in any laboratory / company.

The complete process of the tool certification will be based on the reference values developed in ACOUTRAIN but it should be under the responsibility of a standardization group. This standardization group will define a proper certification process, and particularly, it will define how to elect an accredited person who will be able to evaluate the results and hands out a certification by a positive result.

There is one standard which could provide useful methodology for the numerical tool certification: ISO 25051
4. VIRTUAL TESTING IMPLEMENTATION IN NOISE TSI

4.1 PRESENTATION

TSI certification with VT: reference cases

- Remark: the application cases for VT will depend on global tool capabilities/limits to be detailed in the global VT procedure depending on WP4 conclusions.

- Virtual testing is considered for stationary and pass-by noise assessment:
  - Reference cases are available for numerical global tools certification for such running conditions.
  - These scenarios mostly include time-independent noise sources that could be assessed numerically or by tests.

- Virtual testing application could be considered for starting noise assessment if:
  - The noise sources are characterized at the different speeds they will reach for this scenario or fixed to an upper limit noise level.
  - The numerical global tool can handle noise sources whose characteristics can evolve with time.
  - No reference case is available for numerical global tools certification for such a running condition.

![TSI certification with VT: reference cases diagram]

ALSTOM products

DISTANCE

SPEED

Tramway

Métro

Train

Suburban

Régional

Locomotives

Très grande vitesse

Grande vitesse

FPT – ACOUTRAIN Collaborative Project
TSI certification with VT: reference cases

- Complete new “acoustic” design (sources configurations): where the boundary between EoA and hybrid approach?
  - Each of the families (tramway, metro, regional trains, high speed and very high speed trains) consist of several members, to match Customer’s needs and the market’s evolution. At the same time, they share the main acoustic source architecture and solutions.
  - Completely different architectures are sometimes developed for some customers, which may give rise to unique trains or new families.

Virtual testing for a complete new design of a rolling stock is considered with a **hybrid approach**. This allows a V&V procedure to be performed from a complete set of measurements carried out for one vehicle type of a complete fleet.

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TSI certification with VT: application cases

- Most of the time, the cases where VT is foreseen concern **extension to approval** procedure:
  - Change of APL (for Freight wagon, locomotive, coach, EMU/DMU and high speed train)
  - Change of the max speed (for Freight wagon, locomotive, coach, EMU/DMU and high speed train)
  - A different formation of multiple units (for EMU/DMU and high speed train)
  - Wheel modification (for Freight wagon, locomotive, coach, EMU/DMU and high speed train)
  - Brake system modification (for Freight wagon, locomotive, coach, EMU/DMU and high speed train)
  - a modification of traction system (traction engine, powerpack, cooling system) and/or change of its installation (for locomotive, EMU/DMU and high speed train)
  - a change of auxiliary system (for Freight wagon - change of the super-structure, locomotive, EMU/DMU and high speed train)
Virtual testing implementation: Input characterization

- Methodologies to be developed and tested in the WP2 (rolling noise source) and the WP3 (vehicle specific noise sources)
- For the rolling noise computation:
  - the rail roughness is considered as equal to the TSI limit rail roughness
  - The wheel roughness: mean value of a wheel roughness after 1000 km of running ± uncertainties (?)

- For the vehicle specific sources, methodologies developed for measurements at standstill or in lab + methodologies to assess the attached uncertainty level
  A priori:
  - Directivity of each source should be characterized (there is a need of guidelines and standards to measure the directivity of extended sources)
  - Uncertainty levels should be characterized
  - Installation effect has to be taken into account (needs of guidelines and standards to characterize it)

→ Information about the sources / input characterization should be provided to the NoBo (as it is today in the module B with sub systems description).

Virtual testing implementation: output computation

- At least, the output corresponding to the TSI limiting values will be computed:
  - For stationary noise @ 7.5m / 1.2m, number of points around the vehicle:
    - $L_p(A)_{eq, T(1)}$
  - For pass-by noise @ 7.5m / 1.2m, @ 80 km/h and max speed:
    - $L_p(A)_{eq, T(0)}$
  - Outlook: for starting noise @ 7.5m / 1.2m, from 0 to 30 km/h:
    - $L_p(A)_{eq, T(max)}$
      (requires temporal source data... or can we assume the source to be time-independent equivalent to the time of most noise generation)

- Signature of the pass-by will also be available
Virtual testing implementation / report

- Our proposal is that this report will gather the results of:
  - The experimental certification tests if some are carried out
  - The numerical tests carried out with a model which has passed the V&V procedure.
  - The numerical tests results will be compared to NOI TSI limit levels or limit corridors.

TSI certification with VT / complete folder

- In the future, the complete folder will gather:
  - The verification of the numerical global tool report
  - The validation of the numerical global model report
  - A complete description of all the sub-system of the vehicle + the test reports for the noise sources / input characterization
  - The test report
4.2 QUESTIONS, REMARKS, COMMENTS FROM THE AUDIENCE

4.2.1 Scenarios

VT will be used for stationary and pass-by noise. The starting case is much more complicated and is not foreseen for the reference cases of the VT application.

Starting noise measurement: Are the measurement process and the limit value as defined in the TSI Noise today a good way of assessment? If it is not easy to model, it might not be the most suitable indicators.

The CEN group is working on this issue; two indicators could be used: a maximum noise value, to assess annoyance and also a mean value at 25m from the track to smooth the effect of time-variation of the noise during the started phase.

4.2.2 Reference cases

Extension of Approval is the VT approach that has the highest potential: the platforms approach can be useful, but when there are new technologies everything needs to be reassessed.

Full experimental measurement shall be performed for a new vehicle design, which implies a new production platform and that significantly differs from previous designs regarding the acoustic sources.
5. VALIDATION OF THE NEW PROCEDURE

5.1 PRESENTATION

Validation of the new procedure

- Numerical computations is a common mean in the development of new vehicles to predict the noise level.
- Can virtual testing be as accurate as measurements and is it suitable for rolling stock certification?
- The aims of introducing virtual testing are:
  - Reduce costs
  - Reduce the time and expenses
  - Maintain the accuracy of the results
- Every new method has to be validated in order to receive recognition
- What will it take for you to be convinced?
- In Acoutrain the validation will be based on a comparison between the new method (VT) and the established method

Accuracy of results – Pass-by measurement

There is a natural variation between the vehicles in a production line. One vehicle is chosen for the measurements.

The pass-by measurement is repeated three times

Decision rule

\[ L_{\text{p,eq}}, T_p < \text{TSI limiting value} \]
\[ L_{\text{p, max}} - L_{\text{p, min}} < 3 \text{dB} \]

There are several uncertainty sources:
- Changes in environmental conditions
- Test equipment
- Varying sound emission of sources
- Small variations in speed etc.

When validating a new method by comparing it with an established one, it is necessary to know what uncertainty can be applied to the respective results. Also the TSI-field test measurement
procedure is afflicted with uncertainties. These variations stem from measurement uncertainties during the type testing due to changing environmental conditions, measurement equipment amongst other things. As TSI field measurements are carried out on a single vehicle, these uncertainties are not due to to differences between single vehicles in the production line. This presentation slide shows an example of a pass-by measurement that according to TSI Noise has to be repeated three times. The deviation between the different runs may not exceed 3dB. This is called a decision rule. It does however not describe the measurement deviation that would be found if the measurement were to be repeated in different days, at different temperature or at a different track.

Every quantity can be considered to have a real value, which we cannot know. By performing a measurement or a calculation it is though possible to achieve an estimation of the real value of the quantity. The estimation value may deviate from the real value because of errors that can be of systematic or random character. An uncertainty interval describes a range of values attributed to the quantity in which there is a high probability that the real value can be found.

All measurements or calculations are afflicted with uncertainties and when comparing the estimated value against a limiting value there is always a risk to make a false acceptance or a false rejection. This risk should be evaluated for the established method and by defining a new decision rule for virtual type testing methods it should be made certain that the risk for the new method is corresponding or even lower.
When repeating a measurement several times under the same conditions, there will be small unavoidable fluctuations causing a range of values. Most calculations are deterministic which means that there are no random errors in the output results. When repeating a calculation with one specific input one will always achieve the exact same output each time.

Also the calculations in a simulation tool are deterministic (except for Vammpass that includes a randomly changing variable). This does not mean that there are no errors or uncertainties in a calculated value. The accuracy of the results is highly depending on the uncertainties of the inputs, which in this case mainly are the different measured or calculated sound levels of the sources. A model is also a sort of estimation of the real world and includes approximations and simplifications. There is an additional risk when no vehicle is used that errors when making the model due to lacking competence.
A target was set in the beginning of the project, that the new procedure including virtual testing should be as accurate and reliable as the established method based on measurements. It was seen as necessary to reach this target in order to achieve the confidence in the procedure of the users. This will be dealt with in work package 5 that is dedicated to the validation of the new procedure. Several cases at different levels of complexity will be assessed with both methods and the results will be compared. But how can the two values be compared to show that the target is reached? A decision rule will have to be defined, both for the maximum range of the result and for the coverage of both results.
When validating the results it is necessary to look at the frequency analysis even though the limiting value only considers the total noise level. The frequency analysis could give a better indication whether the correct model is being used for a specific vehicle. One could also consider bigger variations in a frequency range that is not dominating in the total level.
5.2 QUESTIONS, REMARKS, COMMENTS FROM THE AUDIENCE

5.2.1 Sources uncertainty

We should categorize source and propose uncertainty limit for the different categories, because the different spectra discrepancies presented could or could not have an influence on the global pass-by noise.

5.2.2 Methodology for the comparison

There might be different requirements depending on the VT approach (Full, hybrid or EoA).

For example, in the case of EoA approach, we only talk about delta between reference and new RS and in this case uncertainty combination is not a big issue.

How to compare the VT approach with a full experimental approach?

Not a common agreement has been found during the workshop. Several proposals:

- On the total noise level: not necessary to look on the overall spectrum uncertainty. The spectrum analysis should only be done for the certification of the tool and not for the global vehicle model, because in the end the results from the model will be compared only to global level.
- On the spectrum of both signals: if only total noise levels are compared, risk that a complete different spectra shape could result in the same global level and so the model is valid only for one scenario, at one speed.
- On the total level but for different speeds, different configurations so that it could bring enough evidence about the model validity.
- Use statistical analysis to test the model and the procedure reliability, to back setup the validation of the model.
- The time level history could also be a good indicator to check the accuracy of the model. Beware that the start and ending times of your pass-by will have a big influence on the global noise level.

Look on the requirements of the measurement systems: it can orientate the validation in the same trends.

5.2.3 Levels of accuracy

At the end, validation corridors have to be related to the uncertainty of the experimental tests. The critical point here is to assess the uncertainty related to a test method, which is not the same thing than the variability.

We should not try to go to a perfect assessment; we need something good enough, so the question of the frequency content can be questioned.
The validation process should be defined according to what is needed to convince the sector that the VT is relevant? Is accuracy the only issue? Beware that traceability and quality management is also the same between experimental test and VT approach.

A programmatic approach should be preferred: we should start to define validation according to what is available today.

5.2.4 Application cases for the validation availability of data

The collection of the measurement data has shown that we do not have a complete set of input data to validate the process. A measurement campaign is planned but maybe the manufacturers have this kind of data or use a certification process under development to do extra measurements.
6. VIRTUAL TESTING OUTSIDE THE SCOPE OF THE NOISE TSI

6.1 PRESENTATION

Noise Virtual Testing out of the scope of TSI certification

**European Noise Directive noise mapping**
- Characterization of inputs (vehicles models) for noise mapping required by the END is costly and time consuming.
- Certification process with virtual/numerical approach can easier supply the input for the mapping calculations required by the END to provide the main noise sources to define the rolling stock.
- A procedure has therefore to be developed to transpose certification output data to required input for the END mapping.
- Firstly, the procedure has to define “END noise sources” that means noise sources that correspond to commercial running conditions. These END noise sources have to take into account:
  - for each rolling stock fleet, specific noise sources variability;
  - the rolling noise in commercial running conditions, that means the wheel and the track noise contributions with their variability, depending on wheel and track parameters, provided by the WP2.

**Sensitivity analysis, classification**
- Optimization of conception/maintenance

Parametric method, with inputs corresponding to noise sources characteristics over the lifecycle of a vehicle, allow computing very efficient indicators for an acoustic optimization of vehicles
- Estimation of the importance of the inputs on the outputs

Classification: Sobol’s indices
For the train dynamic indicator Y/Q DINOTRAIN project
7. CONCLUSION: MAIN DECISIONS FROM THE WORKSHOP

The following remarks are the main outcomes from the workshop discussions: they will be used to adjust the scope and the actions for the next steps of the project.

1- Virtual Testing procedure cannot be mentioned in the next revision of the Noise TSI: only validated and fully defined methods can be mentioned in a TSI. Omnibus procedure could be used to ensure a monitoring of ACOUTRAIN by the ERA.

2- Starting noise is not foreseen for a virtual testing approach in a close future.

3- Virtual Testing is mainly foreseen in case of an Extension of Approval. The noise levels / indicators of the reference rolling stock should always be assessed by a full experimental measurement campaign.

Hybrid approach can be used for assessing the Delta on noise between one reference rolling stock and a new one, or for building a reference vehicle that will then be used in an EoA approach for example.

4- Full experimental measurement shall be performed for a new vehicle design which implies a new production platform and that significantly differs from previous designs regarding the acoustic sources.

5- Uncertainty of the calculated global level has to be assessed. It requires to determine uncertainty of all the input i.e. uncertainty on the different noise source models.

6- Certification of the global numerical tool should, at the end, be standardized; ACOUTRAIN will define the methodology and the reference cases that could be used for such a certification.

The certification process by itself should be defined, after the end of ACOUTRAIN, by a standardization group. The standard EN ISO 25051 could be a good starting point to define the complete process of software certification.

7- Guidelines will be provided by ACOUTRAIN about the methodologies to characterize the sources for an implementation in a global numerical tool. Some of these guidelines should in the future be turned into standards.

8- The following tasks are required in a Virtual Testing process:
   - the source characterization
   - the model computation
- and the calculations

At the end, after a proper definition of the certification process according to standardization group, these tasks should be carried out by certified institute which gets its certification from an accreditation body. Meanwhile, they will be carried by the different companies involved in the TSI process, according to the recommendations of the ACOUTRAIN project.

9- No common agreement on the criteria that should be used for the validation of the procedure. Several criteria have been mentioned: comparison of global levels, comparison of spectra, or comparison of time-signal.

10- Application cases for the validation: precise description of what is needed will be sent to the manufacturers so that they can check if available sets of data could be provided to ACOUTRAIN consortium?