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DELIVERABLE D4.3
AURALISATION AND VISUALISATION SOFTWARE: USER'S MANUAL

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[2] https://projects.shift2rail.org/s2r_matrixtd.aspx

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Executive Summary

This report represents Deliverable D4.3 "Final User Version as stand-alone VR Tool" of the Collaborative Project SILVARSTAR that is funded under the European Union's Horizon 2020 Research and Innovation Programme under the open call S2R-OC-CCA-01-2020 as part of the Cross Cutting Activities of the Shift2Rail Joint Undertaking.

This document describes the final user version of the VR railway pass-by noise auralisation tool developed within Work Stream 2 of SILVARSTAR. The tool consists of two parts: First the SILVARSTAR Auralisation Tool generates audio signals, which are then used in a second step by the SILVARSTAR VR Tool.

The work was performed within Work Package 4, where the frameworks described in Deliverable D4.1 were implemented in functional software tools within Task T4.3. The requirements and availability of the two software tools are described in Deliverable D4.2.

List of abbreviations, acronyms, and definitions

Abbreviation / Acronyms	Description
dB	Decibel
Empa	Swiss Federal Laboratories for Materials Science and Technology
EU	European Union
EULA	End-user license agreement
FINE-2	Furthering Improvements in Integrated Mobility Management (I2M), Noise and Vibration, and Energy in Shift2Rail - S2R-CFM-CCA-01-2019
GUI	Graphical Use Interface
HMD	Head Mounted Display
JSON	Human-readable, hierarchical text file format
L_{AE}	A-weighted, sound exposure level
L_{AFmax}	Maximum, A-weighted, FAST time-weighted sound pressure level
L_r	Rail roughness level rel. 1 µm
PC	Personal Computer
SILVARSTAR	Soil Vibration and Auralisation Software Tools for Application in Railways
TDR	Track Decay Rate
VR	Virtual Reality
WP	Work Package

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1   Introduction

The Virtual Reality (VR) Tool for railway noise, which has been developed in Work Stream 2 of the SILVARSTAR project, provides comprehensive demonstrations of railway noise mitigation to experts in the field and also to the general public. The tool consists of two parts, see Figure 1: first, the auralisation tool generates audio signals,see left side of Figure 1 and details in chapter 2. Second, these signals are fed to the SILVARSTAR VR Tool, see right side of Figure 1 and details in chapter 3.

The tools and further information are provided on https://www.empa.ch/web/silvarstar/.
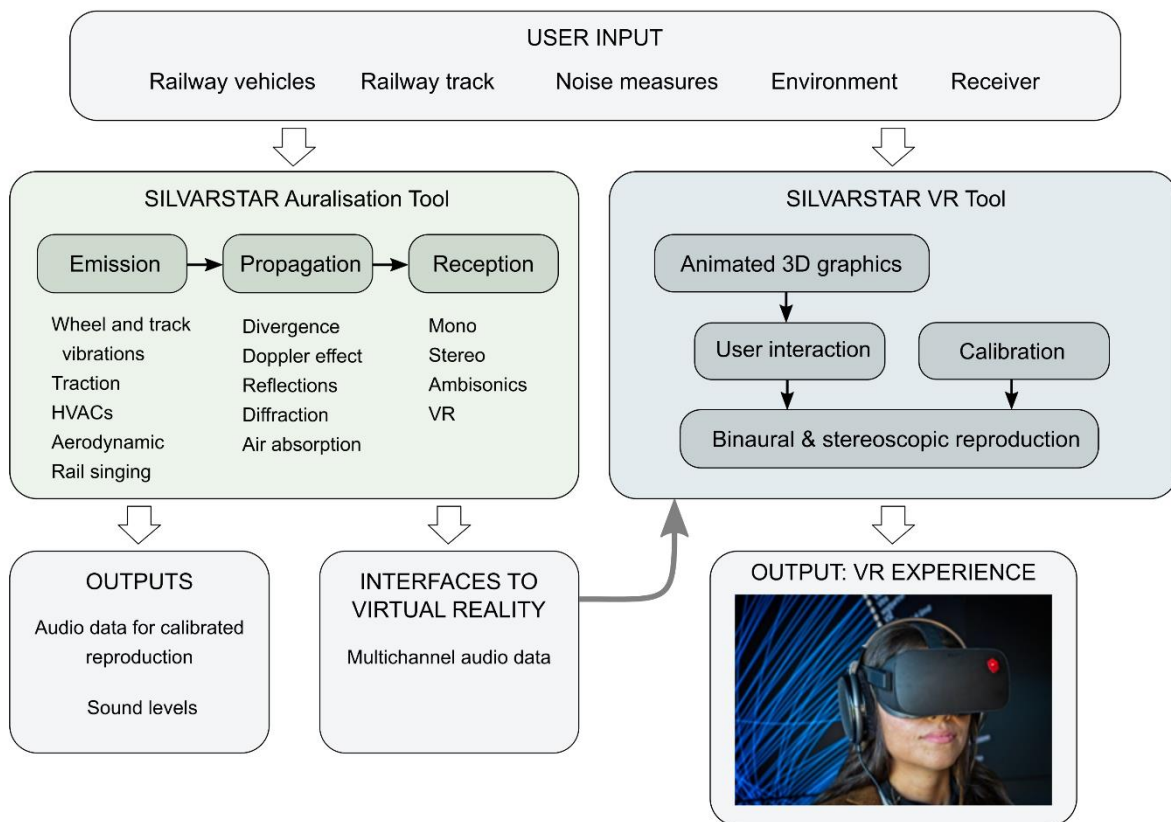
Figure 1: Software architecture of SILVARSTAR Auralisation & VR Tools.

2 SILVARSTAR auralisation tool

The SILVARSTAR Auralisation Tool generates a train pass-by audio signal at a certain observer (receiver) position based on a series of predefined scenarios/parameters, see Figure 2. The main purpose of the tool is to test virtually different noise mitigation measures.
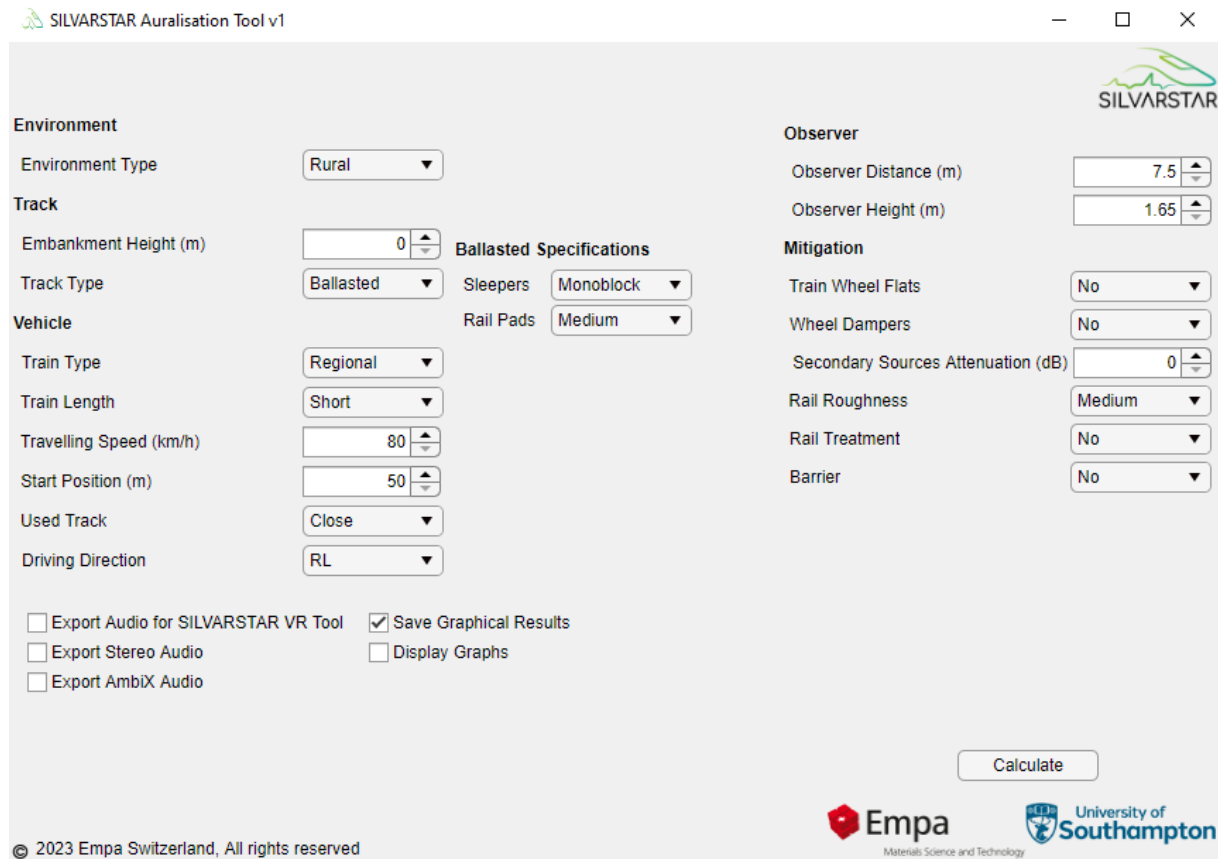
Figure 2: GUI of the SILVARSTAR Auralisation Tool.

2.1 Scenarios

The SILVARSTAR Auralisation Tool features a number of train pass-by scenarios, which are described in detail in [1] and summarized below. Figure 3 describes the track environment.
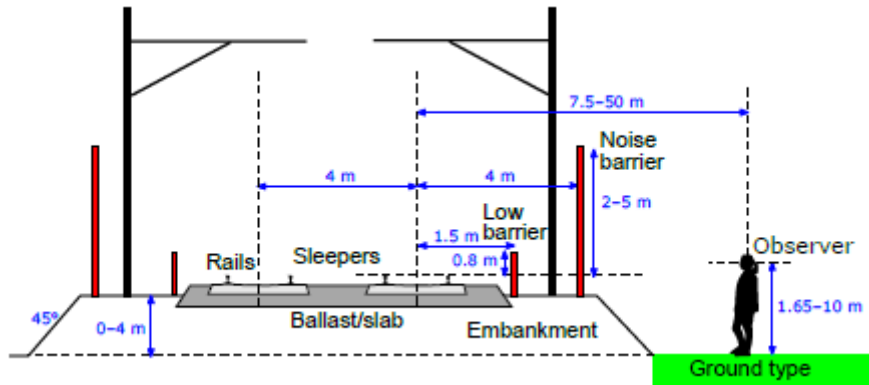
Figure 3: Track environment.

Environment
- Rural: A situation in free-field conditions with grass environment.
- Urban: A situation within a city with concrete and tarmac environment.

Track
- Embankment Height: 0-4 m
- Track type:
  - Ballasted
    - Sleepers: concrete monobloc or bibloc
    - Rail pads:

Type	Vertical stiffness [MN/m]
Soft	100
Medium	250
Hard	1000

Table 1: Rail pad types.

  - Slab

Vehicle

- Train type:
    - Regional
    - Intercity
    - Freight
- Length:
    - Short
    - Long
- Travelling speed:
    - 80-200 km/h for Regional and Intercity trains
    - 60-100 km/h for Freight trains
- Start position: Longitudinal distance (50-200 m) between the observer position and the train at the beginning of the simulation.
- Used Track: a double track is considered. The train can either be simulated on the close or far track relative to the observer.
- Driving direction: left to right or the reverse.

Observer

The observer position is defined in the horizontal direction relative to the centre of the nearest track (7.5-50 m for the Rural environment and 7.5-30 m for Urban environment) and in the vertical direction relative to the ground (1.65-10 m), see Figure 3.

Mitigation

- Train Wheel Flats: If yes, 2% of the wheelset have wheel flats.
- Wheel Dampers: If yes, an additional mode-specific wheel damping is applied.
- Secondary Sources Attenuation: Sources such as equipment, traction and aerodynamic noise are considered and can be attenuated by 0-99 dB.
- Rail Roughness:
    - Smooth: corresponds to acoustic rail grinding, L_r = -13 dB at 25 mm
    - Medium: about the TSI curve, L_r = -4 dB at 25 mm
    - Poor: above TSI curve, L_r = 9 dB at 25 mm
- Rail Treatment:
    - Shields: spectral insertion loss on the rail contributions is applied.
    - Dampers: rail dampers increase the track decay rates (vertical and lateral) in line with typical rail dampers measured in the Stardamp project [2].
- Barrier:
    - Type:
        - Standard barrier: variable height between 2-5 m.
        - Low barrier: fixed height at 0.8 m
- Ci-K-ratio: This parameter corresponds to the brake block type (Ci = cast iron, K = composite) and affects the wheel roughness of the freight wagons. Three different values can be defined: 0 / 50 / 100 % with 100 % corresponding to cast iron and thus the higher wheel roughness resulting in a higher pass-by noise levels compared to 0 % (all wheels equipped with composite brakes).

2.2 Validation

The auralisation model has been verified and validated against pass-by measurements of a rolling stock certification according to the ISO 3095 standard [3]. Very good agreement was found for time signals as well as sound pressure spectra. Further comparisons between simulated auralisation audio signals and measurements will be done by the parallel FINE-2 project.

2.3 User's manual

The requirements and availability of the SILVARSTAR auralisation tool are described in Deliverable D4.2.

2.3.1 Starting the software

A license file, provided by EMPA, is required at the first start of the software, see Figure 4. Once the license is loaded and activated, this step is not required during the validity of the license. The license lasts for two weeks and afterwards the user can request for a new license file (more info here: https://www.empa.ch/web/silvarstar/).
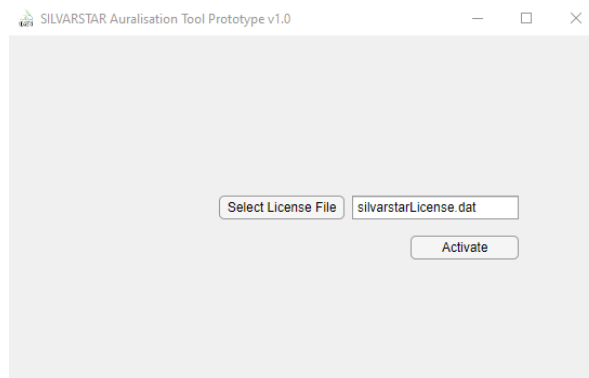
Figure 4: SILVARSTAR Auralisation Tool – License file selection.

2.3.2 Calculation

The calculation process, see Figure 5, takes between 5 minutes and 2.5 hours depending on the user's PC and the selected scenario. Figure 6 shows the message shown when the calculation is finished.
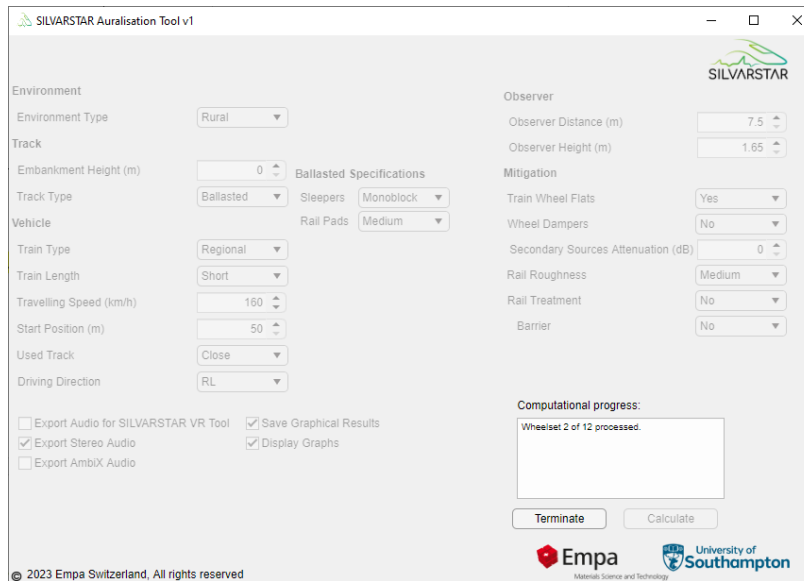
Figure 5: SILVARSTAR Auralisation Tool – example of calculation in progress.
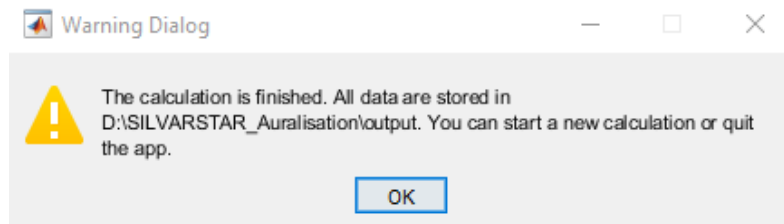
Figure 6: SILVARSTAR Auralisation Tool – Calculation finished message.

2.3.3   Results and output files

All the results are stored in the following directory C:\SILVARSTAR_Auralisation, which is created automatically when you start the tool. Note, that existing files from previous calculations are not overwritten. Every result filename has a unique name which is based on the date and time of the simulations. By default, the tool exports results (e.g. L_{AE} and L_{AFmax}) together with the simulation information in a log .txt-file and if the L_{AFmax} is less than 90 dBA a mono audio file of the auralisation is exported as well, see detailed list below. The user is also given the option to plot and store three extra results: the track decay rates (TDR), see Figure

7, the propagation situation in cross-section, see Figure 8, and the level-time history of the simulation, see Figure 9.
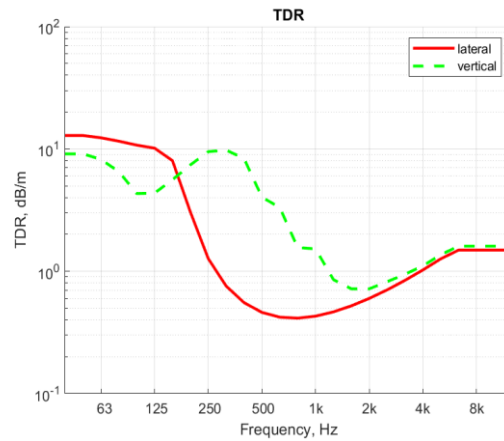
Figure 7: SILVARSTAR Auralisation Tool – example of the TDR output.
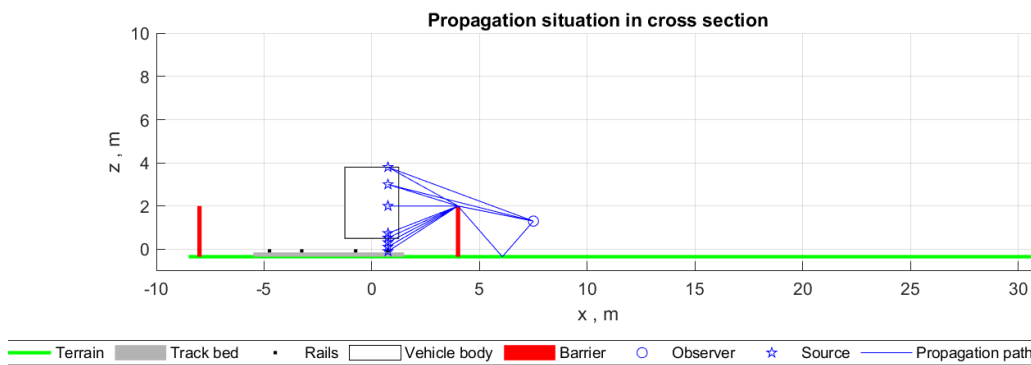
Figure 8: SILVARSTAR Auralisation Tool – example cross-section view of the propagation situation.
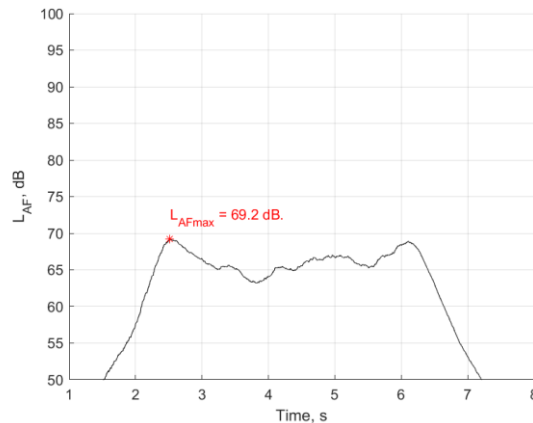
Figure 9: SILVARSTAR Auralisation Tool – example time level history with indication of maximum level.

Standard results are:

- […]_TDR.png: track decay rates, see Figure 6.

- […]_geometryCrossSection.png: cross-section view of the scenario, see Figure 7.

- […]_LAF.png: A-weighted, fast time-constant sound pressure time signal, see Figure 9.

- […]_log.txt: log-file summarizing the input parameters.

- […]_mono.wav: single-channel (mono) audio file of the simulated pass-by.

Additional results are stored upon request before launching the calculation, see Figure 10:

- […]_AmbiX.wav: ambisonic audio file of the simulated pass-by.

- […]_stereo.wav: stereo audio file of the simulated pass-by.

- […]_VR.wav: audio file required for the SILVARSTAR VR Tool.

Figure 10: Output options for the SILVARSTAR Auralisation tool.

3   SILVARSTAR VR Tool

The SILVARSTAR VR Tool allows train pass-by scenarios to be experienced in an immersive virtual reality environment. The sound used in this tool is generated with the SILVARSTAR Auralisation Tool described in chapter 2. The overall software architecture including the link between the two tools is shown in Figure 1; details of the VR Tool architecture are shown in Figure 11.
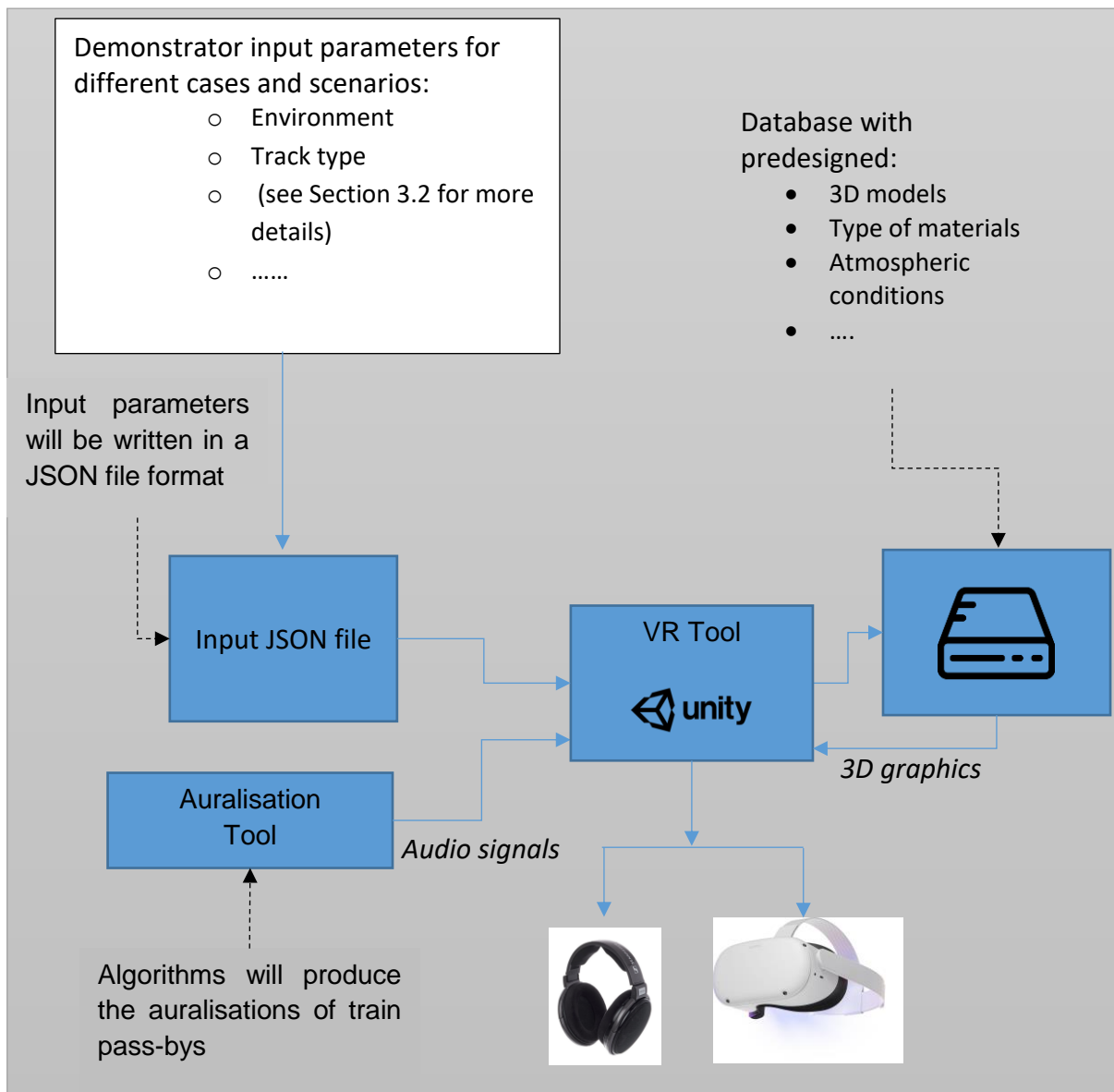
Figure 11: SILVARSTAR VR Tool architecture.

3.1 Scenarios

Several pass-by scenarios are provided with the SILVARSTAR VR Tool. Figure 12 shows a selection of different scenario options.

Rural environment with regional train and noise barrier	Urban environment with regional train and low noise barrier
Rural environment with freight train	Urban environment with Intercity train on 4 m high embankment
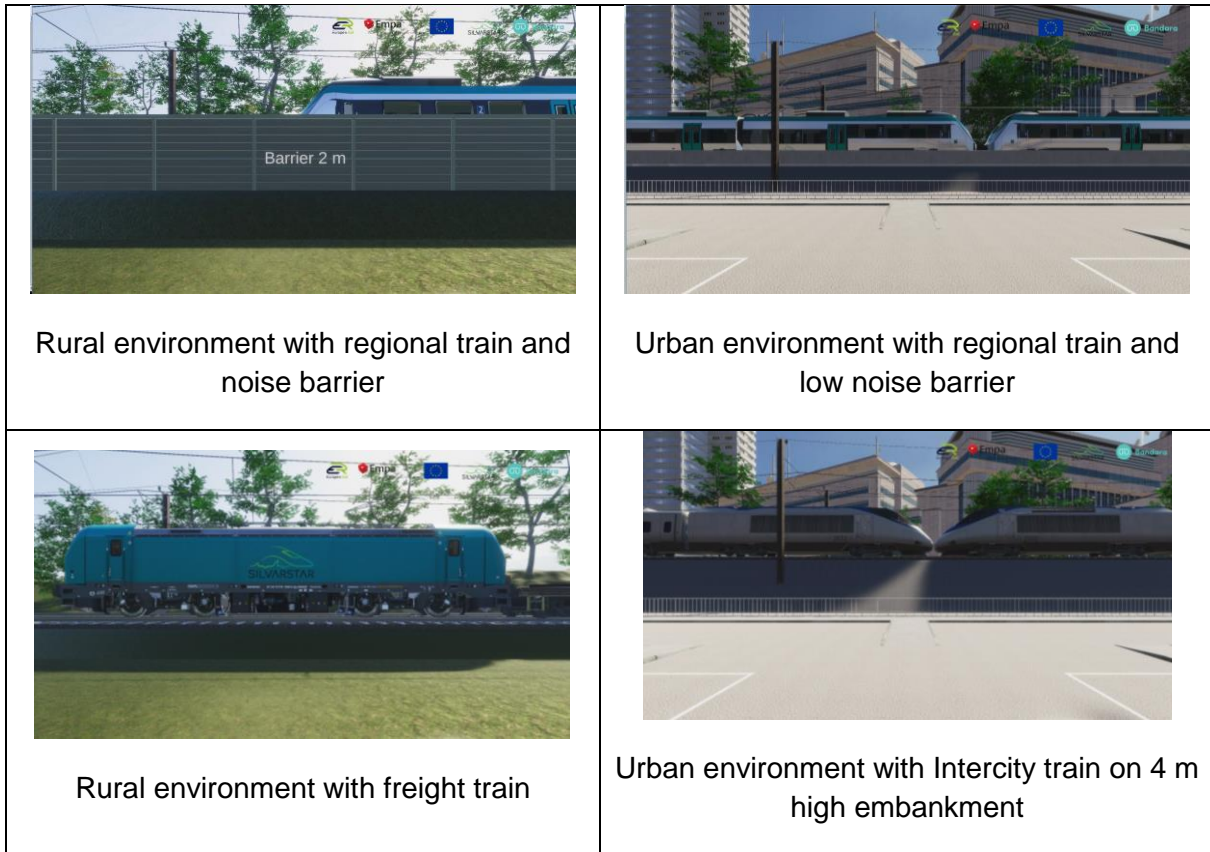
Figure 12: Selection of scenarios for the SILVARSTAR VR Tool.

3.2 User's manual

The requirements and availability of the SILVARSTAR VR Tool are described in Deliverable D4.2 and on https://www.empa.ch/web/silvarstar/.

3.2.1 Setup of the VR system

The following steps need to be taken before starting up the tool the first time:

1. Setup the Oculus Quest 2:
   a. It is no longer required to have a Facebook/Meta account. An account can be created using an email address.
   b. Update the Quest 2 to the latest software version
   c. Set up the guardian:
      i. Choose *Roomscale* mode
      ii. Set the up the guardian while standing. Ensure that the floor height is correct (it should be set at the same height as the real floor is)

2. Connect the external audio interface to the PC and install all the required drivers:
   a. Connect the HD650 headphones to the audio interface.
   b. Set the audio interface as the audio output device on the Windows sound settings.

3. Install the Oculus-App on the PC.

4. Connect the Quest 2 to the PC via the Oculus-Link cable: Ensure that the Quest 2 is turned-on. Be careful with the Oculus link cable because it is very sensitive and slight movements can cause a connection disruption. It is recommended to fix it on the headset using cable ties.

5. Launch the Oculus-App and then select *Devices*, and then *Add Headset*. Follow the instructions on the Oculus-App and make sure that you select *Link (cable)* as connection method.

6. Set Audio Device in Oculus-App
   a. Open the Oculus-App then select *Devices* then *Quest 2* and open the device settings.
   b. On the *Audio settings* click on the dropdown menu and select *Use Windows Settings.* That way you ensure that the audio will be played back via the external headphones (type Sennheiser HD650) and not from the Quest 2's integrated headphones (see Figure 13)

7. Wear the Quest 2 and click with the Oculus controller the *Quest link* option on the headset's menu and link the Quest 2 with the PC. **Important Note:** Once you connect the Quest 2 to the PC a pop-up window will appear which it prompts you to "*Allow access to data*", select *Deny.* If you allow access, you'll need to physically disconnect the cable from your headset and plug it in again and repeat this step.

After following the above steps, you are ready to launch the VR Tool. Not all the mentioned steps need to be followed every time before the user wants to launch the tool. Assuming that all steps have been implemented successfully once, then the user will only have to perform Step 7. If the headset is moved to another location then the Quest 2 will recognize this with its front cameras and will request to setup the *Guardian* (Step 1b). If connection issues occur it is recommended to first turn off and on the Quest 2, then plug and unplug the link cable before restarting the PC if the problem persists.
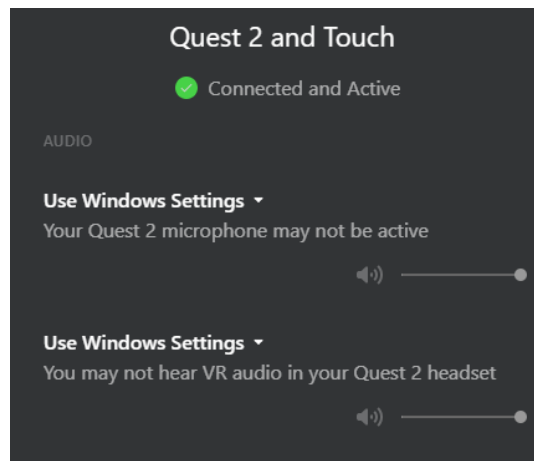
Figure 13: Quest 2 Audio settings.

3.2.2 Operation of the VR Tool

The following steps should be followed in order to operate the VR Tool:

1. Calibrate the audio by clicking the *Calibrate Audio* button shown on Figure 14. A new window will open which will ask the user to play an audio signal and instructions are given on how to perform the level calibration with the Voltage meter. As long as the gain settings on the audio interface are not modified after the first level calibration this step does not need to be implemented every time the user launches the tool. However, it is recommended to perform this on regular basis. Details about the calibration are given in subsection 3.2.3.

2. Load the scenario file by clicking the *Load JSON* button, see Figure 14. You need to ensure the JSON file and all the audio files required for the playback are in the same folder. Depending on the settings of your computer, you might encounter a parsing error upon loading the .json-file, see Figure 19 in subsection 3.2.4.

Figure 14: VR Tool startup page (operator view).

3. Select a case to start the VR playback (Figure 15). Before selecting a case, the subject who is wearing the head mounted display (HMD) needs to stand still and look forward since this position is used as a reference by the VR tool when the operator selects a case. If the operator forgets to notify the user, he/she can later correct this by clicking the *Calibrate HMD* button shown on Figure 16.

Figure 15: Case selection window (operator view).

The operator is the only person who can switch between the different cases. The scenarios (e.g. barrier height) of each case can, however, be switched both by the operator (using the mouse) and the subject wearing the HMD (using the Quest 2 controllers, see Figure 17). The operator can mute the audio by clicking the *Mute Audio* button. The window on the top left shows what the subject wearing the HMD is viewing. This window can be maximized by clicking on it.
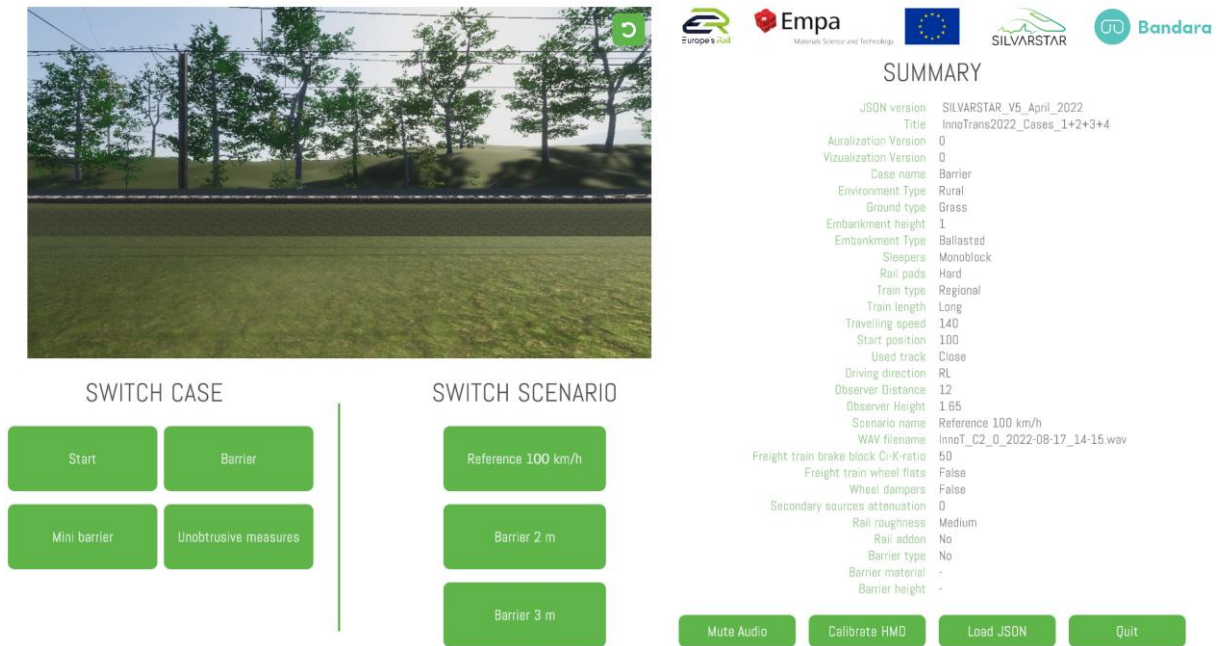
Figure 16: Main operator view while the VR Tool is playing back the audiovisual stimuli to the subject.
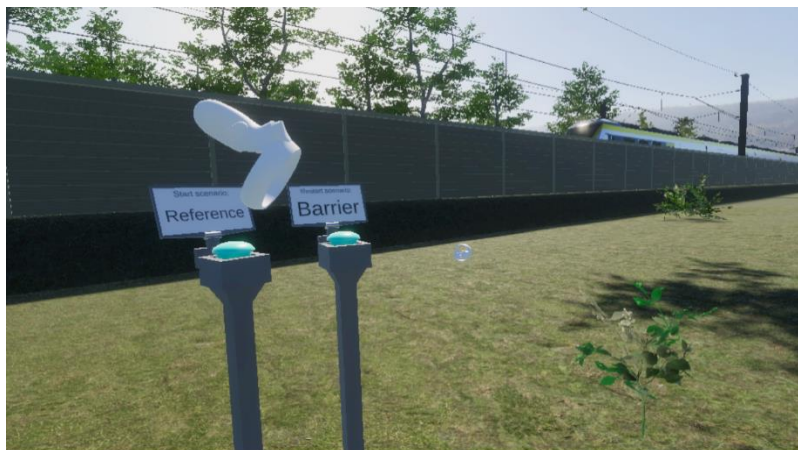
Figure 17: VR view example (user view).

3.2.3 Calibration of the audio system

To reproduce the audio at the correct level, the following steps need to be performed:

1. Connect the voltmeter to the soundcard's headphone output as shown in Figure 18. It is recommended to measure the output voltage with the headphones connected.

2. Play the calibration signal.

3. Measure the output voltage between one channel and the ground and adjust the output gain till the voltage reaches 60 mV AC.

4. Exit calibration.

Warning: Always check that the level is not too high before wearing the headphones and only then start the playback.
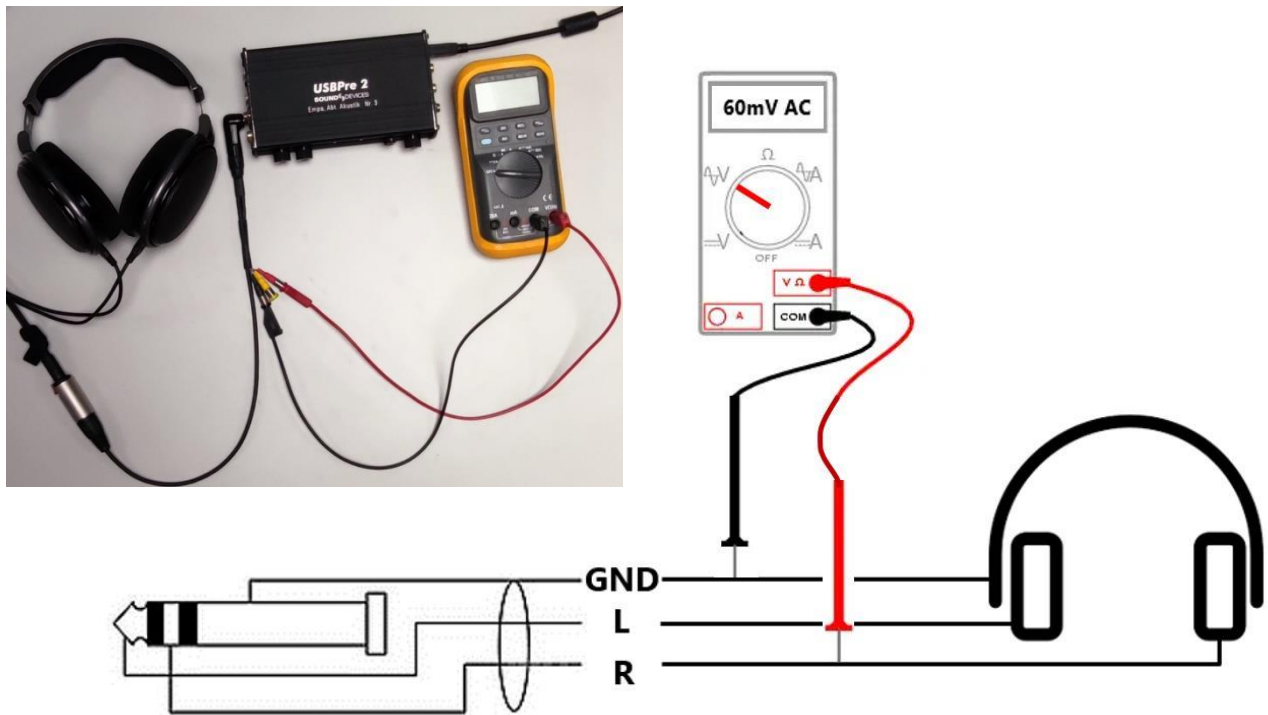
Figure 18: Calibration of the audio system

3.2.4 .json parsing error - Microsoft Windows regional settings

The VR-Tool was tested on different computers with Windows 10 operating system. In some computers which had French Windows regional settings a parsing error upon loading the .json file appeared, see Figure 19. This error is related to Windows regional settings. The problem could be solved by changing the Windows regional settings to US as shown in Figure 20. Another workaround is to replace all parameter values using decimals by integers, e.g. put the observer height from 1.6 m to 2 m, but in this case the auralisations need to be implemented again using the new parameters in order to reproduce the correct audio output.
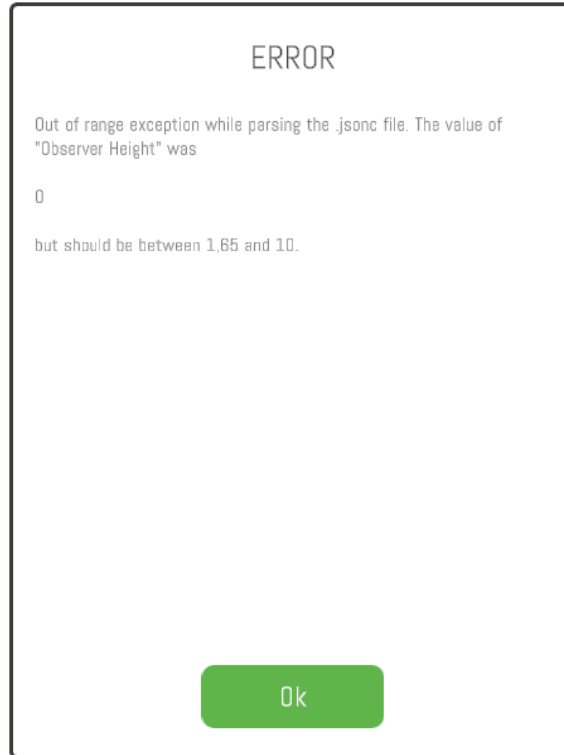
Figure 19: .json parsing error.
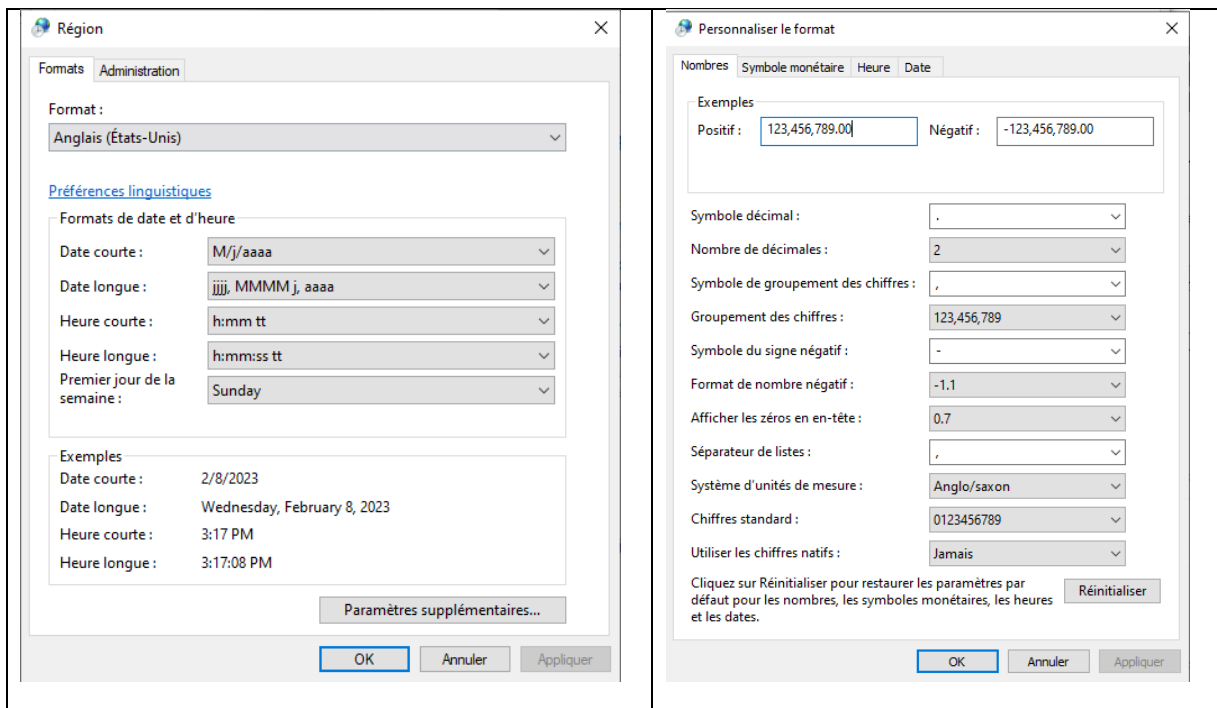
Figure 20: Microsoft windows regional settings (here on a computer in French language).

3.2.5 Creation of a new scenario

A .json file with some standard scenarios is provided with the SILVARSTAR VR Tool. This file can be used as a basis for a new scenario. Creating a new scenario requires the following steps:

1. Create a new VR audio file with the SILVARSTAR auralisation tool, see chapter 2. The "export to SILVARSTAR VR Tool" needs to be activated.

2. Once the calculation has finished, put the .wav-file with the "_VR" suffix and the log .txt-file in one folder. Add an existing .json-file to this folder and modify it by setting all the parameters to the ones in the corresponding log-file, see example in Figure 21.

Several scenarios can be created in a single .json-file. Each scenario requires a corresponding log and .wav file.

```
Input parameters:
  Environment:
    Environment type: Rural
  Track:
    Embankment heigth in m: 0
    Track type: Ballasted
    Ballasted specifications:
      Sleepers: Monoblock
      RailPads: Soft
  Vehicle:
    Train type: Regional
    Train length: Short
    Travelling speed in km/h: 80
    Start position in m: 50
    Used track: Close
    Driving direction: RL
  Observer:
    Observer distance to near track center in m: 7.5
    Observer height above ground in m: 1.65
  Mitigation:
    Freight train brake block Cast iron to K-block ratio (Ci-K-ratio): 0
    Wheel flats: No
    Wheel dampers: No
    Secondary sources attenuation in dB: 0
    Rail roughness class: Smooth
    Rail treatment: No
    Barrier type: No
    Standard barrier height above rail in m: 2
```

```
{
  "JSON version": "SILVARSTAR_V5_April_2022",
  "Title": "MAR",
  "Cases": [ // Minimum: 1 / Maximum: 2 cases per json \\
    {
      "Case 1": {
        "Case name": "MAR",
        "Environment": {
          "Type": "Rural", // [Rural, Urban] \\
          "Ground type": "Grass" // [Grass, Asphalt] \\
        },
        "Track": {
          "Embankment height": "0", // In meters (decimal numeral) [Minimum: 0 Maximum: 4] \\
          "Type": "Ballasted", // [Ballasted, Slab] \\
          "Ballasted specifications": {
            "Sleepers": "Monoblock", // [Monoblock, Biblock] \\
            "Rail pads": "Soft" // [Soft, Medium, Hard] \\
          }
        },
        "Vehicle": {
          "Train type": "Regional", // [Regional, Intercity, Freight] \\
          "Train length": "Short", // [Short, Long] \\
          "Travelling speed": "80", // In kmh (whole number) [Minimum: 50, Maximum: 160] \\
          "Start position": "50", // In meters (whole number) [Minimum: 50, Maximum: 200] \\
          "Used track": "Close", // [Close, Far] \\
          "Driving direction": "RL" // [LR, RL] \\
        },
        "Observer": {
          "Distance": "12", // In meters [Minimum: 7.5, Maximum: 50] \\
          "Height": "2" // In meters [Minimum: 1.65, Maximum: 10] \\
        },
        "Scenarios": [ // Max 3 scenarios per case [A, B, C] \\
          {
            "Scenario A": {
              "WAV filename": "Regional_2023-02-08_15-04.wav",
              "Scenario name": "Regional train 80km/h",
              "Mitigation": {
                "Freight train brake block Cast iron to K-block ratio (Ci-K-ratio)": "0", // In % [0, 50, 100] \\
                "Train wheel flats": "No", // [Yes, No] \\
                "Wheel dampers": "No", // [Yes, No] \\
                "Secondary sources attenuation": "0", // In dB (whole number) \\
                "Rail roughness": "Smooth", // [Smooth, Medium, Poor] \\
                "Rail treatment": "No", // [No, Shields, Dampers] \\
                // Set "Barrier type" to "No" for scenarios without Barrier \\
                "Barrier": {
                  "Barrier type": "No", // [No, Standard, Low] (Low = height 0.8 m) \\
                  "Standard barrier specifictions": {
                    "Barrier material": "Absorptive", // [Absorptive, Reflective] --> if the barrier Type is "None"
                    "Barrier height": "2" // In meters (decimal numeral) [Minimum: 2, Maximum: 5] --> if the barrier
                  }
                }
              }
            }
          }
        ]
      }
    }
  ]
}
```
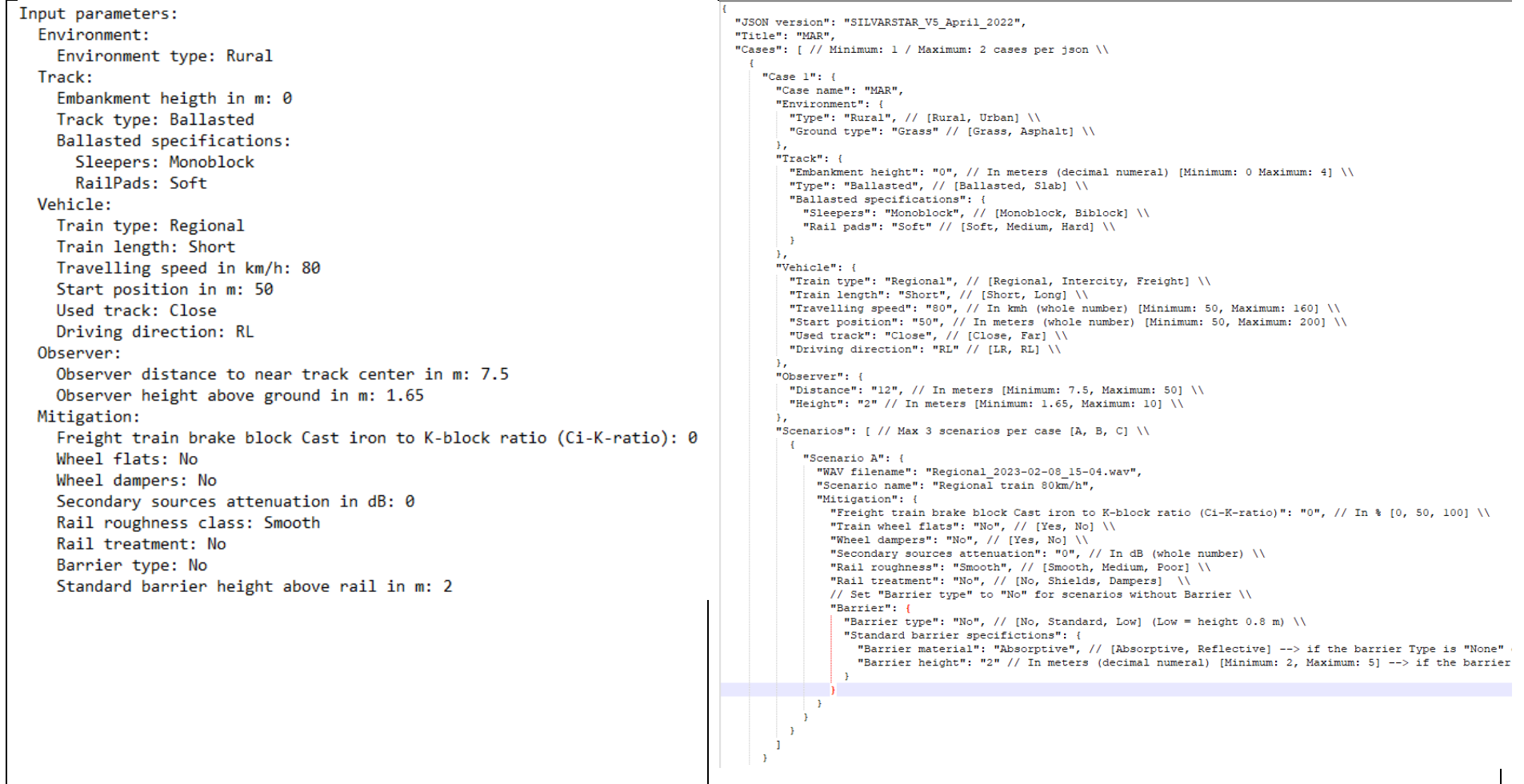
Figure 21: Left: Extract from the log file with input parameters. Right: .json file for one scenario.

4   Public demonstration

A version with a limited number of scenarios of the SILVARSTAR VR railway pass-by noise auralisation tool has been demonstrated with great success at the international railway fair INNOTRANS 2022, see Deliverable D4.2.

The Final User Version as stand-alone VR Tool was presented to the public at the final SILVARSTAR workshop, which was held on the 15th of February 2023 in Brussels.

Finally, the tool was provided to Europe's Rail and FINE-2 member Deutsche Bahn for use in public demonstrations, noise mitigation projects, etc.

5 References

[1]   R. Pieren, G. Squicciarini and D. J. Thompson, "Auralisation of combined mitigation measures in railway pass-by noise", *Internoise*, Glasgow, 2022.

[2]   STARDAMP, "Standardisation of damping technologies for the reduction of rolling noise - Final report", 2013.

[3]   R. Pieren, D. Lauper and K. Heutschi, "Demonstrator for rail vehicle pass-by events", *Proceedings of Euronoise 2018,* pp. 1409-1414, 2018.