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DELIVERABLE D1.2

Description of the vibration prediction tool

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[1] PU: Public; CO: Confidential, only for members of the consortium (including Commission Services)

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

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10/03/2022	Sylvain Barcet	Vibratec	Modification of summary	Coordinator Task T1.3 Leader
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19/05/2022	Sylvain Barcet, Brice Nélain, Pascal Bouvet	Vibratec	Update of figures, according to new prototype version, update of processes	Coordinator Task T1.3 Leader
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Executive Summary

This report presents Deliverable D1.2 "Description of the vibration prediction tool" of the Collaborative Project SILVARSTAR that is funded under the European Union's Horizon 2020 Research and Innovation Program under the open call as part of the Cross Cutting Activities of the Shift2Rail Joint Undertaking.

The work on ground vibration within SILVARSTAR aims to provide the railway community a user-friendly prediction tool for ground vibration impact studies. This tool will be used for environmental impact assessment of new or upgraded railways on a system level. It will provide access to ground vibration predictions to a wider range of suitably qualified engineers.

SILVARSTAR Deliverable D1.1 explains the concept and methodology integrated in the SILVARSTAR prototype vibration prediction tool in detail. The vibration level in a building is expressed as the product of source, propagation and receiver terms, each of which is frequency-dependent and can be represented by either numerical predictions or by experimental data. This Deliverable D1.2 describes the prototype vibration prediction tool and constitutes also a user's guide to this tool.

The software is developed and compiled from matlab. The user must first install the software tool (see Appendix 1), and must plug the USB Dongle on their computer before starting. The installation executable generates the necessary folders for the use of the tools. Folders contain the integrated data.

To ensure that the prediction tool is capable of rapid calculations and is accessible to a wide range of users, it is built around an extensive database of both measured and pre-computed data. The initial database is described in SILVARSTAR Deliverable D2.1.

The user interface provides tools to manage the database: create new source from numerical models and import new experimental data. This is done through flexible excel files that are opened by clicking on buttons in the main user interface.

The interface allows the user to select sources, propagation terms and receiver terms, define combinations between them, and compute vibration and noise levels inside buildings.

After computations, specific simple interfaces are dedicated to plot the vibration and noise spectra obtained. All results (intermediate and final) are available in .mat format. Final results (noise and vibration inside buildings) are also made available in ASCII files (see Appendix 2 for description).

List of abbreviations, acronyms, and definitions

Abbreviation / Acronyms	Description
FINE-2	Furthering Improvements in Integrated Mobility Management (I2M), Noise and Vibration, and Energy (complementary Shift2Rail project)
FP7	European Union Framework Programme 7
GUI	Graphical User Interface
ICT	Intercity Train
RIVAS	Railway Induced Vibration Abatement Solutions (FP7 project)
WP	Work Package

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1. Introduction

The overall objective of the work on ground vibration in SILVARSTAR is to provide the railway community with a commonly accepted, practical and validated methodology, and a user-friendly prediction tool for ground vibration impact studies. This tool will be used for environmental impact assessment of new or upgraded railways on a system level. It will provide access to ground vibration predictions to a wider range of suitably qualified engineers.

The SILVARSTAR prediction tool is based on a hybrid approach that combines the advantages of both numerical and experimental methods. As with international standards, the general framework adopted expresses the vibration level in buildings as the product of terms describing a source, a propagation term and a receiver; each of these terms is frequency-dependent and can be represented by numerical prediction or by experimental data.

The prototype of this hybrid numerical / experimental prediction tool was developed and provided to all partners of the SILVARSTAR project. After partner feedback, improvements were added in a final version.

This document presents an overview of the underlying computation theory and provides support to those beginning to use the SILVARSTAR prototype software. This prototype is verified and validated (Deliverable D1.3) and will be fully integrated with the existing noise mapping software IMMI developed by Wölfel in WP3. The current excel format for the database will not be the same in IMMI, but the data and metadata will be the same. A specific user's guide will be written for IMMI.

2. Theory

The complete theory is presented in detail in Deliverable D1.1 [1]. This section gives an overview of the different computation schemes in the SILVARSTAR prediction tool.

2.1 Concept

The vibration level in a building is decomposed as the product of terms describing the source, the propagation and the receiver. Figure 1 illustrates the global concept with this decomposition.

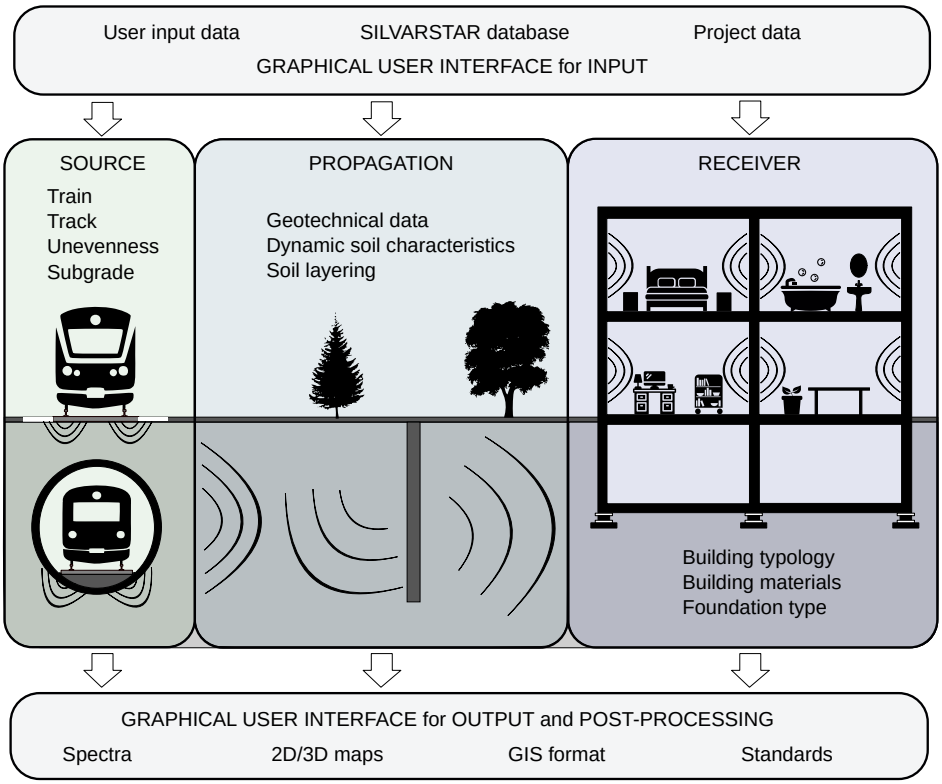


Figure 1 Ground vibration prediction process and integration of GUIs.

Each component (Source, Propagation or Receiver) may come from numerical or empirical results. The SILVARSTAR prototype deals with four computation scheme processes for combination of source and propagation:

- Fully empirical.
- Fully numerical.
- Hybrid model 1: numerical source model combined with an empirical propagation term.
- Hybrid model 2: empirical source term combined with a numerical soil model.

The receiver term (the building's coupling loss) is always calculated as a combination of adjustment factors [1]. These describe the transmission of vibration from free field to the building foundation, from the foundation to the various floors and the sound radiation into the rooms from the floor vibration.

2.2 Fully empirical computation

For the fully empirical computation, the source can be described by one of these terms:

- The force density at rail head, $L_F(X,x_1)$, with excitation on the track (rail head).
- The equivalent force density below (or next to) the track, $L_F(X_1,x_1)$ with excitation at positions X_1 under or next to the track.
- The vibration level next to the track, $L_v(x_{ref})$, at a reference distance x_{ref} from the track.

The soil propagation term has to be consistent with the source term:

- Line source transfer mobility from rail head, $TM_L(X,x_1)$.
- Line source transfer mobility from excitation below (or next to) the track, $TM_L(X_1,x_1)$.
- Difference in line source transfer mobility, $\Delta TM_L(x_{ref}, x_1)$.

The vibration levels are then computed using one of these equations, depending on the terms:

$$L_v(x_1) = L_F(X,x_1) + TM_L(X,x_1)$$
$$L_v(x_1) = L_F(X_1,x_1) + TM_L(X_1,x_1)$$
$$L_v(x_1) = L_v(x_{ref}) + \Delta TM_L(x_{ref}, x_1)$$

NB:

The user specifies the type of data when importing them, so that the tool automatically applies the appropriate combinations of source and propagation terms.

In the tool, measurements performed with impacts next to the track (force density or line source transfer mobility) are treated the same way as if they were measured below the track (i.e. where the track will be laid for new network project).

2.3 Fully numerical computation

The train-track-soil interaction problem is solved in the frequency-wavenumber domain, using train and track models, and pre-computed soil data.

The numerical source (train and track) is described by:

- a train composition and parameters (distance between axle and bogie, mass, spring and damping).
- a track composition and parameters.
- unevenness spectra for the rail and the wheel.

The numerical propagation term (soil) is described by pre-computed transfer functions and impedances. Several cases are included in the database: 5 homogeneous soils and 7 layered soils covering several types of soil in Europe [2].

Several assumptions are made:

- The track compliance is computed for a stationary load.
- The axle loads are applied at a fixed positions instead of moving along the track with the train speed. This corresponds to a low speed approximation for which the Doppler effect is neglected.
- The axle loads are assumed to be incoherent.

All assumptions were made to reduce the computation times without losing accuracy of the results. They are validated in Deliverable D1.3 [3].

2.4 Hybrid 1 computation: numerical source with empirical propagation term

For the hybrid 1 computation scheme, the same equations as for the empirical approach are used (section 2.2). The appropriate source term (force density L_F or vibration level L_v) is computed based on the same approach as in the fully numerical computation scheme (see section 2.3), and is subsequently combined with the measured propagation term (line source transfer mobility TM_L or ΔTM_L).

When importing an empirical propagation term, the user must specify several pieces of information (called metadata) to be able to combine it with an appropriate numerical model for hybrid computations.

2.5 Hybrid 2 computation: empirical source with soil numerical model

For the hybrid 2 computation scheme, the same equations as for the empirical approach are used (section 2.2). The propagation term (line source transfer mobility TM_L or ΔTM_L) is computed numerically based on the same approach as in the fully numerical computation scheme (see section 2.3), and is subsequently combined with the measured source term (force density L_F or vibration level L_v).

When importing an empirical source term, the user must specify several pieces of information (called metadata) to be able to combine it with an appropriate numerical model for hybrid computations.

3. User's guide

The installation procedure for the software is described in Appendix 1.

The prototype tool fits with the global theoretical decomposition, and is hence based on an architecture with three tabs (Source, Propagation, and Receiver).

For each term (source, propagation, or receiver), the element can be provided from the numerical or the empirical database. As presented in section 2, the SILVARSTAR prototype software is able to combine empirical and numerical databases.

Database management:

To ensure that the prediction tool is capable of rapid large-scale calculations and is accessible to a wide range of users, it was built around an extensive database of both measured and pre-computed data [2]. The database includes sets of data describing vehicles, tracks, unevenness, and soil and building transfer functions.

However, if a new element is needed, the user can augment the database with their own data following sections 3.1 to 3.4:

- Section "3.1 Create a new numerical source",
- Section "3.2 Create a new empirical source",
- Section "3.3 Create a new propagation term",
- Section "3.4 Create a new receiver".

NB: a new numerical receiver (transfer functions computed externally) can be added using the "new empirical" process.

Computations and plots:

The procedure to start a computation is described in section "3.5 Start a computation".

The section "3.6 Analysis – Velocity and Noise levels" explains all steps and functionalities to plot the results.

The sections are written as step-by-step procedures to enable any user to easily perform a computation.

3.1 Create a new numerical source

To create a new numerical source, click on “New Source Numerical” in the main Menu, in the “Source” tab.

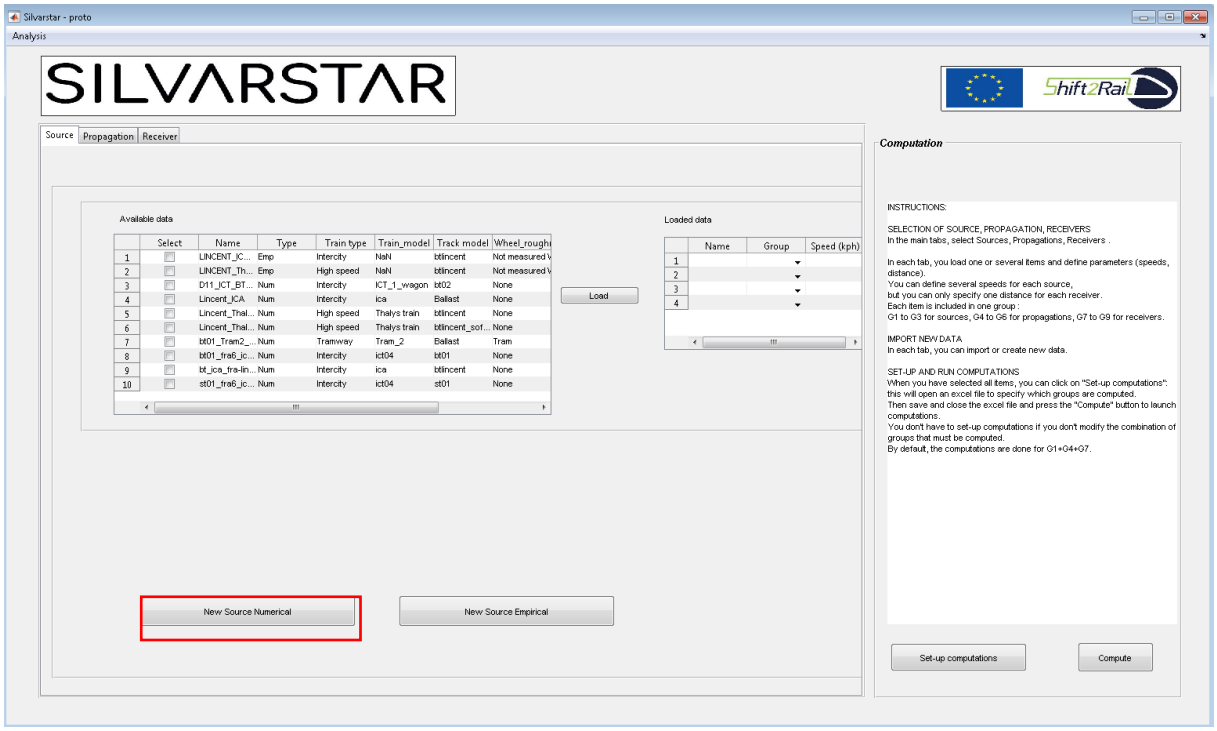


Figure 2 Main Menu – create a new numerical source.

The creation of a new numerical source requires the user to fill in the three new tabs “Train”, “Track” and “Unevenness” before clicking on “Validate” (or “Cancel”) at the end. These tabs are described in the following paragraphs.

Train information

Step 1: select the type of train to be used as the basis of your new train.

- "Unsprung mass" for an axle alone. The mass is editable (step 3).
- "Generic vehicles" is an open vehicle model, enabling to associate and combine several types of vehicle (e.g. 1 Loco, 5 Wagons, …, 1 Loco). Lengths, mass, stiffness and damping are editable (step 3). Some examples below describe this case in more detail.
- "ICT 1 wagon" for coaches carried by 2 bogies with 2 axles each. Lengths, mass, stiffness and damping are editable (step 3).
- "ICT 4 wagons" for 4 coaches carried by 8 bogies with 2 axles each. Lengths, mass, stiffness and damping are editable (step 3).
- "Tram 1" and "Tram 2" are complete train compositions with some suspended coaches. Lengths, mass, stiffness and damping are editable (step 3).
- "Metro 1 wagon" for coaches carried by 2 bogies with 2 axles each. Lengths, mass, stiffness and damping are editable (step 3).
- "Metro 5 wagons" for 5 coaches carried by 10 bogies with 2 axles each. Lengths, mass, stiffness and damping are editable (step 3).

Step 2: click on "1 - Load" to add the train type to be used as the base of the new train.

Step 3: clicking on "2 – Edit (Open Excel)" will open an Excel file called "SourceNumInit.xlsx (see Figure 4) to edit parameters (length, mass, stiffness and/or damping). Whenever you want to modify a parameter, you have to click on the "2 – Edit (Open Excel)" button.

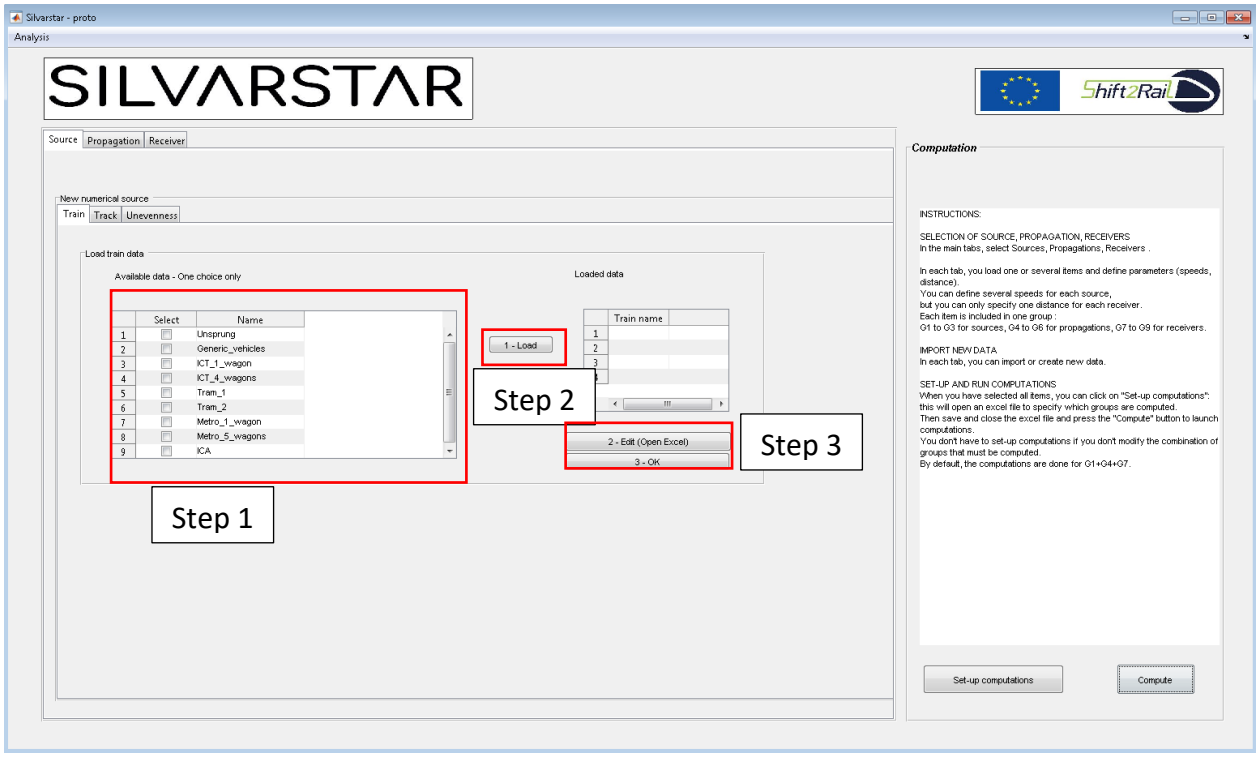
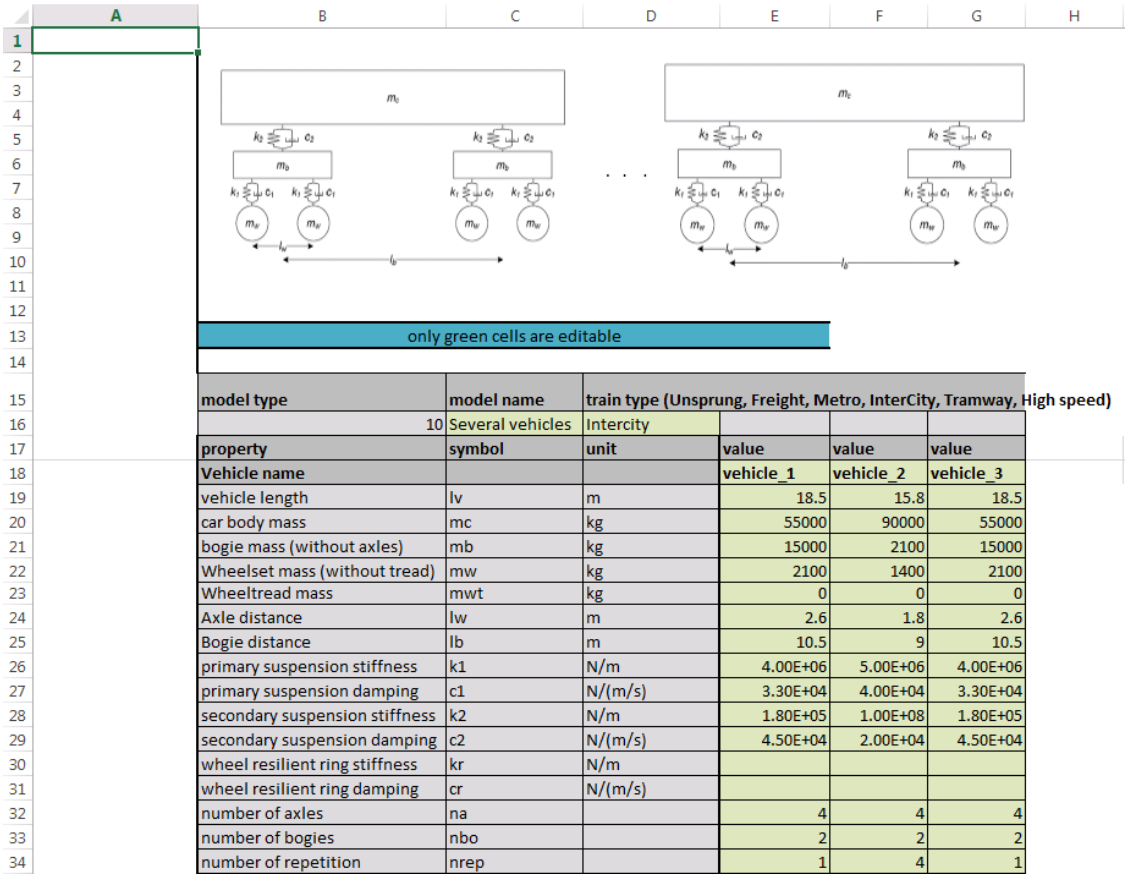


Figure 3 "New source numerical" interface – "Train" tab.

It is possible to change any of the values (green cells):

- Model name: name of the vehicle.
- Train type: select one of proposed terms.
- Mass, stiffness, damping, length, etc.



only green cells are editable

model type	model name	train type (Unsprung, Freight, Metro, InterCity, Tramway, High speed)			
10	Several vehicles	Intercity			
property	symbol	unit	value	value	value
Vehicle name			vehicle_1	vehicle_2	vehicle_3
vehicle length	lv	m	18.5	15.8	18.5
car body mass	mc	kg	55000	90000	55000
bogie mass (without axles)	mb	kg	15000	2100	15000
Wheelset mass (without tread)	mw	kg	2100	1400	2100
Wheeltread mass	mwt	kg	0	0	0
Axle distance	lw	m	2.6	1.8	2.6
Bogie distance	lb	m	10.5	9	10.5
primary suspension stiffness	k1	N/m	4.00E+06	5.00E+06	4.00E+06
primary suspension damping	c1	N/(m/s)	3.30E+04	4.00E+04	3.30E+04
secondary suspension stiffness	k2	N/m	1.80E+05	1.00E+08	1.80E+05
secondary suspension damping	c2	N/(m/s)	4.50E+04	2.00E+04	4.50E+04
wheel resilient ring stiffness	kr	N/m			
wheel resilient ring damping	cr	N/(m/s)			
number of axles	na		4	4	4
number of bogies	nbo		2	2	2
number of repetition	nrep		1	4	1

Figure 4 Train parameters for the new numerical source – example of a model with generic vehicles.

NB: The most important value is the unsprung (wheelset + wheeltread) mass. If there is no wheel tread, leave the value of "Wheeltread mass" as 0 kg.

When the train definition is finished, save and close the Excel file. Click on "3 - OK" (from the "Train" tab). The following pop-up message will appear to confirm train creation. Click on "OK".

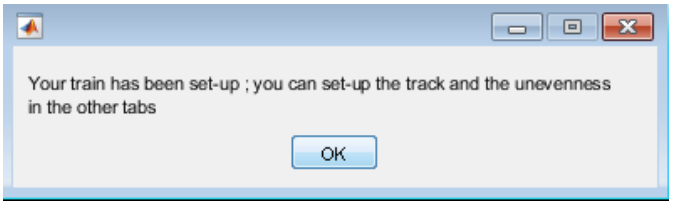
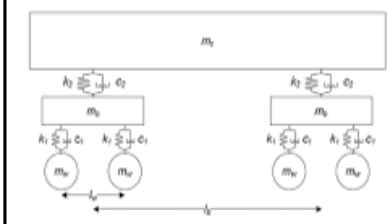


Figure 5 Pop-up message after train validation.

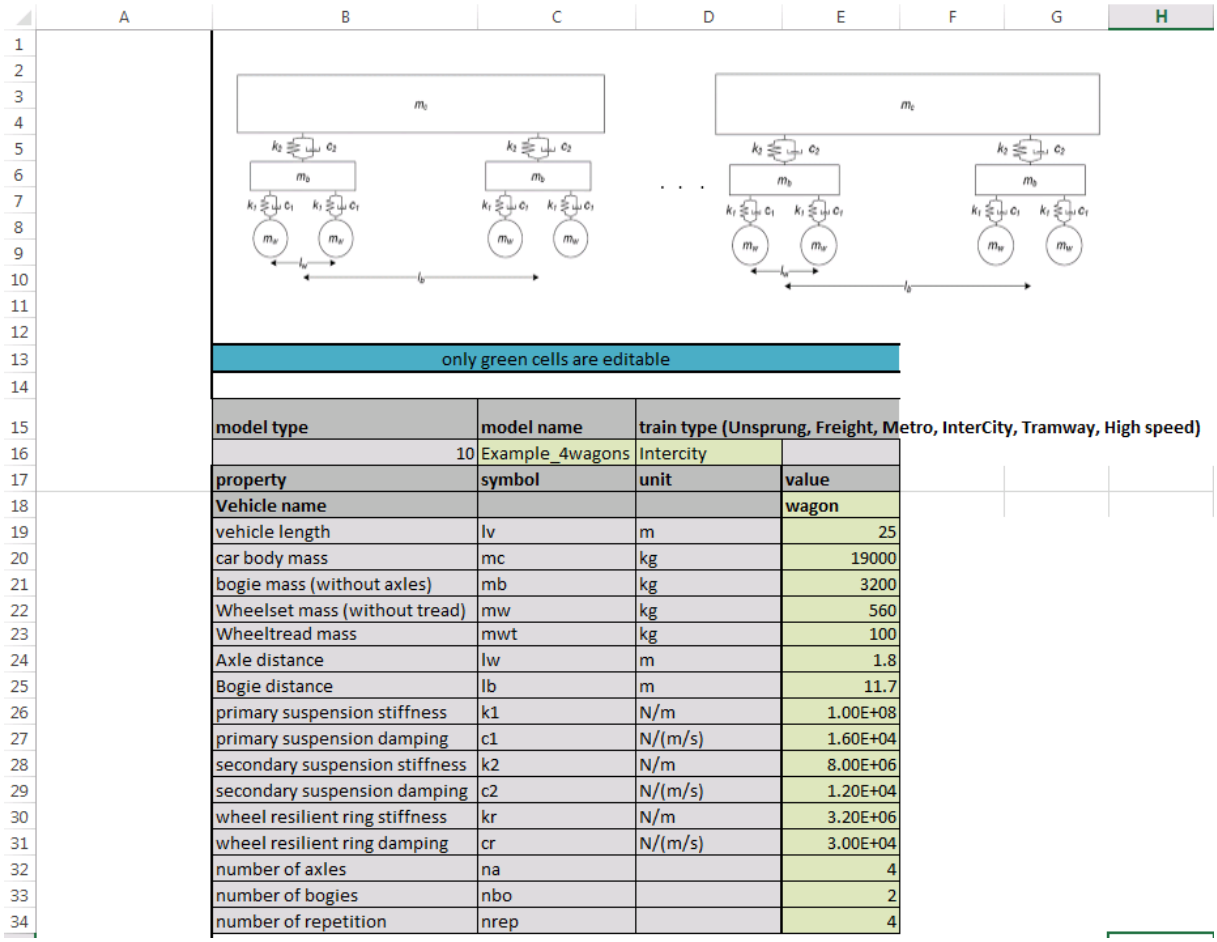
Some examples are presented in the following figures, based on the generic vehicle model.



only green cells are editable

model type	model name	train type (Unsprung, Freight, Metro, InterCity, Tramway, High speed)			
10	ica	Intercity			
property	symbol	unit	value		
Vehicle name			locoHLE13	centrall11	sidel11BDx
vehicle length	lv	m	19.11	26.4	26.4
car body mass	mc	kg	0	0	0
bogie mass (without axles)	mb	kg	0	0	0
Unsprung wheelset mass	mw	kg	2823	1500	1544
axle distance	lw	m	3	2.56	2.56
bogie distance	lb	m	10.4	18.4	18.4
primary suspension stiffness	k1	N/m	0.00E+00	0.00E+00	0.00E+00
primary suspension damping	c1	N/(m/s)	0.00E+00	0.00E+00	0.00E+00
secondary suspension stiffness	k2	N/m	0.00E+00	0.00E+00	0.00E+00
secondary suspension damping	c2	N/(m/s)	0.00E+00	0.00E+00	0.00E+00
number of axles	na		4	4	4
number of bogies	nbo		2	2	2
number of repetition	nrep		1	11	1

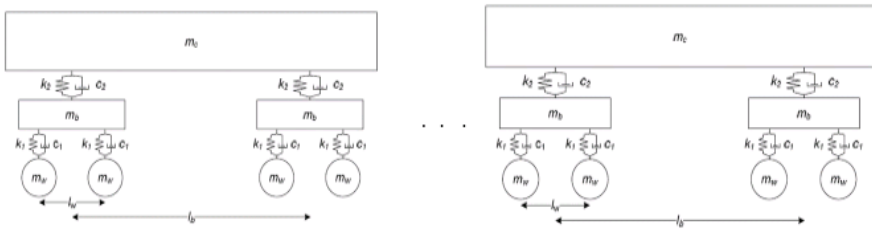
Figure 6 Example with an IC-A train composed of 1 locomotive, 11 intermediate vehicles and one side vehicle.



only green cells are editable

model type	model name	train type (Unsprung, Freight, Metro, InterCity, Tramway, High speed)	
10	Example_4wagons	Intercity	
property	**symbol**	**unit**	**value**
Vehicle name			**wagon**
vehicle length	lv	m	25
car body mass	mc	kg	19000
bogie mass (without axles)	mb	kg	3200
Wheelset mass (without tread)	mw	kg	560
Wheeltread mass	mwt	kg	100
Axle distance	lw	m	1.8
Bogie distance	lb	m	11.7
primary suspension stiffness	k1	N/m	1.00E+08
primary suspension damping	c1	N/(m/s)	1.60E+04
secondary suspension stiffness	k2	N/m	8.00E+06
secondary suspension damping	c2	N/(m/s)	1.20E+04
wheel resilient ring stiffness	kr	N/m	3.20E+06
wheel resilient ring damping	cr	N/(m/s)	3.00E+04
number of axles	na		4
number of bogies	nbo		2
number of repetition	nrep		4

Figure 7 Example with a 4 wagon train with resilient wheels.



only green cells are editable

model type	model name	train type (Unsprung, Freight, Metro, InterCity, Tramway, High speed)			
10	Several vehicles	Intercity			
property	symbol	unit	value	value	value
Vehicle name			loco_1	f_wagon	loco_2
vehicle length	lv	m	18.5	15.8	18.5
car body mass	mc	kg	55000	90000	55000
bogie mass (without axles)	mb	kg	15000	2100	15000
Wheelset mass (without tread)	mw	kg	2100	1400	2100
Wheeltread mass	mwt	kg	0	0	0
Axle distance	lw	m	2.6	1.8	2.6
Bogie distance	lb	m	10.5	9	10.5
primary suspension stiffness	k1	N/m	4.00E+06	5.00E+06	4.00E+06
primary suspension damping	c1	N/(m/s)	3.30E+04	4.00E+04	3.30E+04
secondary suspension stiffness	k2	N/m	1.80E+05	1.00E+08	1.80E+05
secondary suspension damping	c2	N/(m/s)	4.50E+04	2.00E+04	4.50E+04
wheel resilient ring stiffness	kr	N/m			
wheel resilient ring damping	cr	N/(m/s)			
number of axles	na		4	4	4
number of bogies	nbo		2	2	2
number of repetition	nrep		1	4	1

Figure 8 Example with a freight train composed of 1 locomotive, 4 freight wagons and 1 locomotive.

Track information

Step 1: select the type of track to be used as the basis of your new track, from the 9 possible choices (Table 1).

Table 1 Track database to create a new track

BALLAST	SLAB
bt01 (standard rail pads)	st01 (main line Rheda slab track with standard rail pads)
bt02 (soft rail pads)	st02 (tramway slab track with standard rail pads – level 0)
bt03 (very soft rail pads)	st03 (tramway slab track with soft rail pads – level 1)
bt04 (standard rail pads, stiff under sleeper pads)	fst01 (floating slab track – level 2)
bt05 (standard rail pads, soft under sleeper pads)	

Detailed parameters are listed in the deliverable D2.1. All parameters are editable (step 3).

Step 2: click on "1 - Load" to add the type of track to be used as the basis of the new track.

Step 3: clicking on "2 – Edit (Open Excel)" will open an Excel file called "SourceNumInit.xlsx (see Figure 4) to edit track parameters (track type, masses, stiffness and/or damping). Whenever you want to modify a parameter, you have to click on the "2 – Edit (Open Excel)" button.

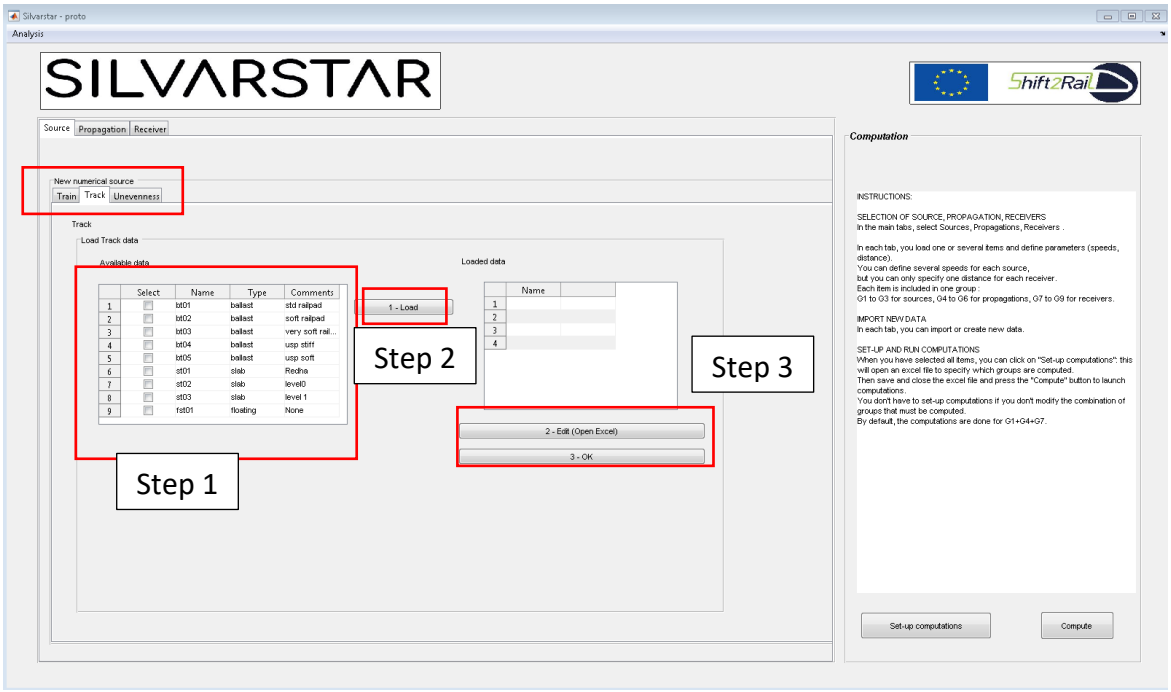


Figure 9 “New source numerical” interface – “Track” tab.

It is possible to change any of the following values (green cells): Young's modulus, mass, stiffness, damping, etc. to transform the existing track (used as a basis) into the new track. The shadowed cells are not editable, and depend on the type of track.

For ballast track, the soil width interface is needed (cell "D34"). For slab or floating slab tracks, the width of the slab is required (cell "D25")

	A	B	C	D
1				
2			Project:	name
3			Track name:	bt01
4			Track description:	ballast
5			Track type:	2
6			Track ID n°:	2
7			Comments	std railpad
8	RAIL		Type:	UIC60
9		E_r	Young modulus (GPa)	210
10		EI_r	Vertical bending stiffness (M.m^2)	6.4
11		M_r	Mass per unit length (kg/m)	60
12		η_r	Vertical damping factor	0.02
13		ν_r	Poisson's coefficient	0.3
14		ρ_r	Mass density per unit volume (kg/m^3)	7850
15		κ_r	Shear coefficient	0.4
16				
17	PADS			
18		d	Pad distance (sleeper distance) (m)	0.6
19		η_p	Vertical damping factor (C/Ccrit)	0.2
20		K_p	Vertical stiffness (MN/m = kN/mm)	300
21				
22	SLEEPER (half)	S_s	Surface (1/2 sleeper) (m²)	0.325
23		M_s	Mass (1/2 sleeper) (kg)	162.5
24				
25	SLAB	w_s	Width (m)	
26		H	Height (m)	
27		E	Young's modulus (MPa)	
28		EI_{vs}	Vertical bending stiffness (N.m^2)	
29		ρ	Density(kg/m^3)	
30		M_s	Mass per unit length (kg/m)	
31				
32	BALLAST or MAT	η_g	Vertical damping factor (C/Ccrit)	0.4
33		K_g	stiffness per unit area (MN/m3)	462
34		b	soil interface width(m)	3

Figure 10 Track parameters for the new numerical source.

When the track is finished, save and close the Excel file.

Click on "3 - OK". The following pop-up message appears to validate track creation. Click on "OK".

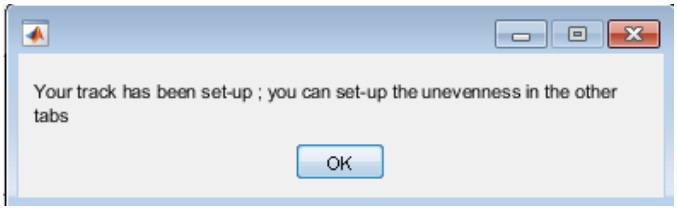


Figure 11 Pop-up message after track validation.

Unevenness information

Several unevenness spectra are selectable. **Rail and Wheel unevenness both have to be defined.** If necessary, a 'None' (wheel or track) unevenness is selectable. **However, something has to be selected for both components.**

The 'select' column accepts only one choice, which will be applied. The 'Display' column enables several choices to visualize different unevennesses.

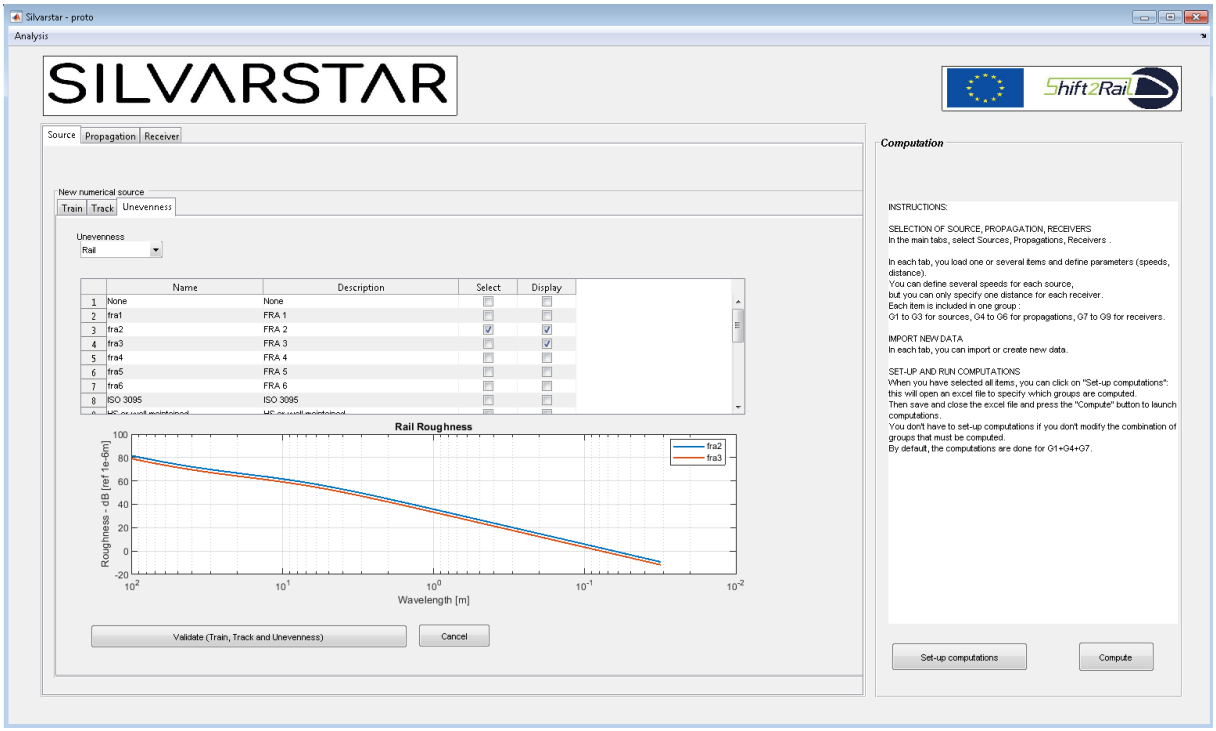


Figure 12 "New source numerical" interface – "Unevenness" tab.

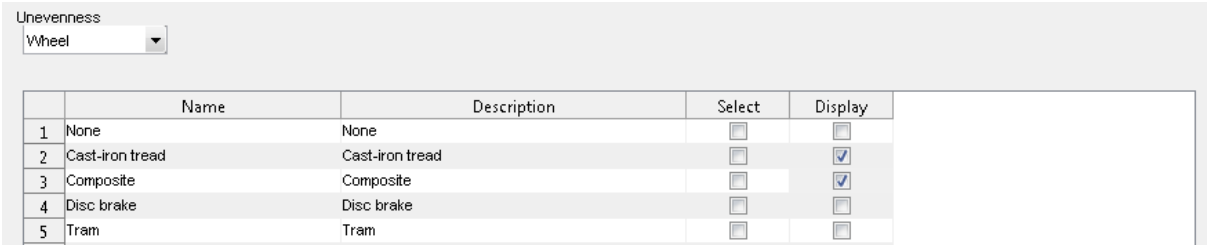


Figure 13 "New source numerical" interface – "Unevenness" tab – zoom.

Table 2 lists the unevennesses available in the pre-defined database. The database can be enriched by user inputs. The user will simply add a line in the corresponding excel file (\Database\Roughness_database.xlsx)

Table 2 Rail and wheel unevenness list in database

Name	Description	Type
None	None	Rail
fra1	FRA 1	Rail
fra2	FRA 2	Rail
fra3	FRA 3	Rail
fra4	FRA 4	Rail
fra5	FRA 5	Rail
fra6	FRA 6	Rail
iso3095	ISO 3095	Rail
bt_hs_or_well_maintained	HS or well maintained – ballasted	Rail
bt_normally_maintained	Normally maintained – ballasted	Rail
bt_not_well_maintained	Not well maintained – ballasted	Rail
bt_freight_line	Freight line	Rail
bt_tram_line	Tram line –ballasted	Rail
bt_normally_maintained_and_corrugated	Normally maintained and corrugated – ballasted	Rail
bt_not_well_maintained_and_corrugated	Not well maintained and corrugated – ballasted	Rail
st_hs_or_well_maintained	HS or well maintained – slab	Rail
st_normally_maintained	Normally maintained – slab	Rail
st_not_well_maintained	Not well maintained – slab	Rail
st_tram_line	Tram line (embedded) – slab	Rail
st_normally_maintained_and_corrugated	Normally maintained and corrugated – slab	Rail
st_not_well_maintained_and_corrugated	Not well maintained and corrugated – slab	Rail
fra-lincent	Fra lincent	Rail
None	None	Wheel
Cast_iron_tread	Cast-iron tread brake	Wheel
Composite	Composite brake	Wheel
Disc_brake	Disc brake	Wheel
Tram	Tram	Wheel

Creation of the new numerical source

When the three components (Train, Track and Unevenness) have been selected and edited, the new numerical source is ready to be validated. Click on the “Validate (Train, Track and Unevenness)” button. This will create and add the new numerical source to the “Current_project” folder. This source appears and is now selectable in the main tab “SOURCE”.

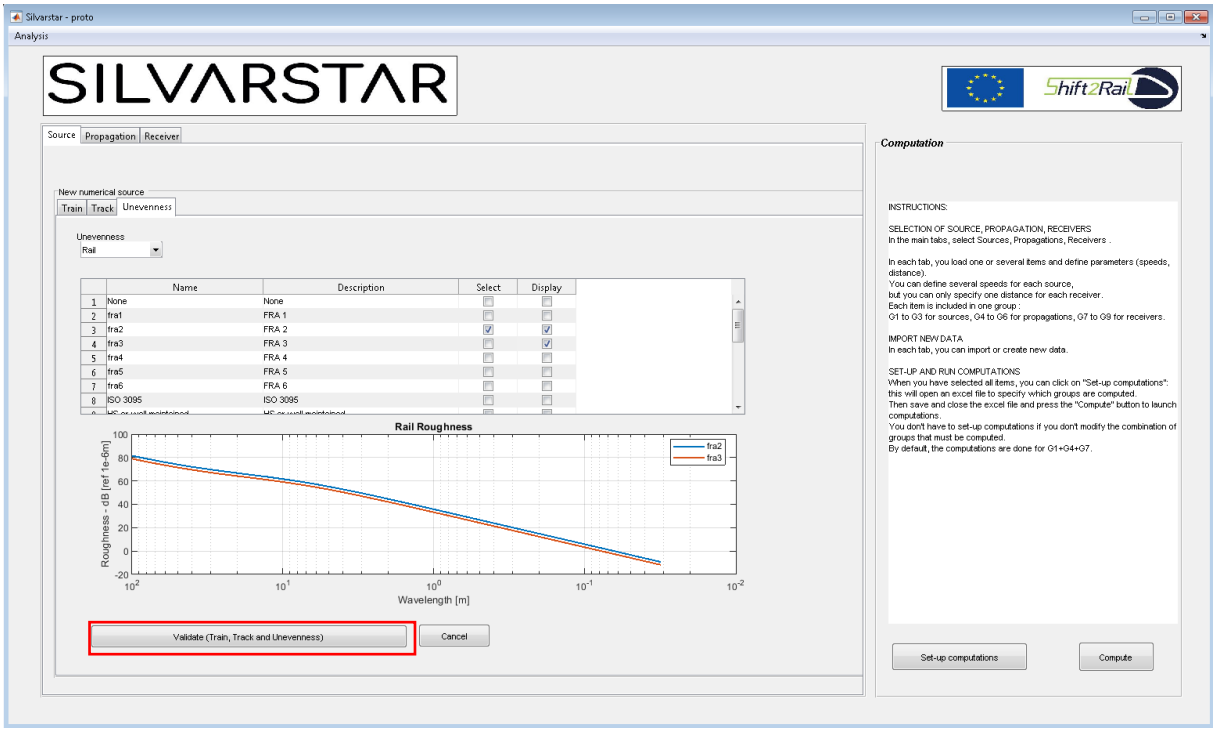


Figure 14 “New source numerical” interface – “Unevenness” tab – for VALIDATION.

The “Cancel” button goes back to the main menu without adding the new numerical source.

3.2 Create a new empirical source

To create a new empirical source, click on “New Source Empirical” in the main Menu, in the “Source tab”.

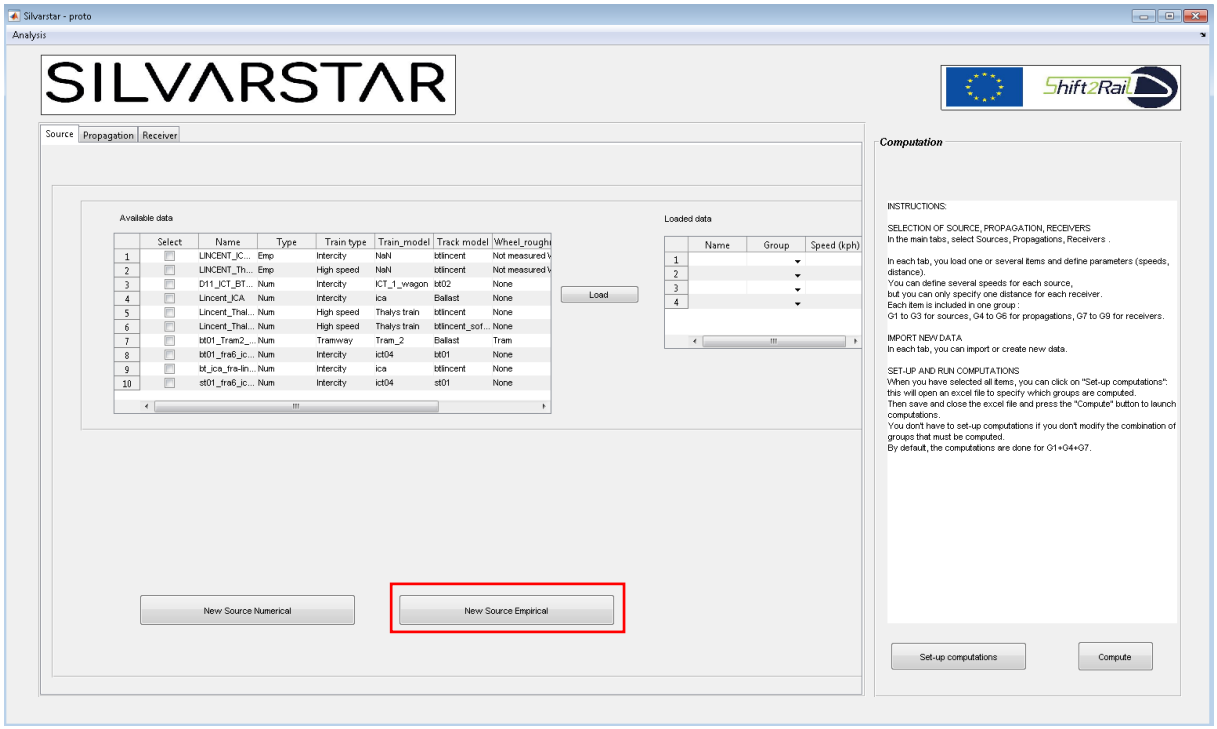


Figure 15 Main Menu – create a new empirical source.

An empirical source may be defined by:

- An equivalent force density at the rail head,
- An equivalent force density below (or next to) the track,
- A vibration level next to the track.

Depending on the type of new empirical source, click on the corresponding “Excel open” button.

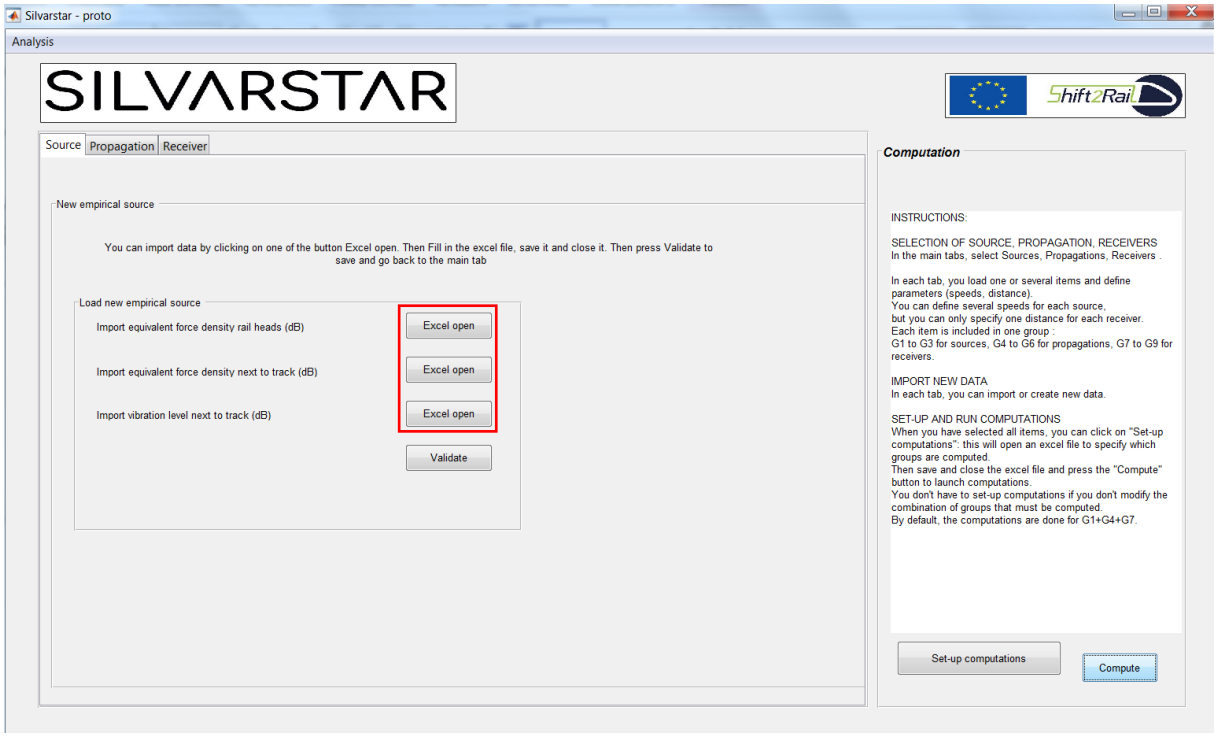


Figure 16 “New source empirical” interface.

To go back to the main menu without adding a new empirical source, click on “Validate”.

A new interface page is opened: fill in the new empirical source information (name and metadata), and click on “OK”. The metadata are presented in Figure **17**, and detailed in Table 3 below.

The Cancel button returns to the “new empirical source menu”.

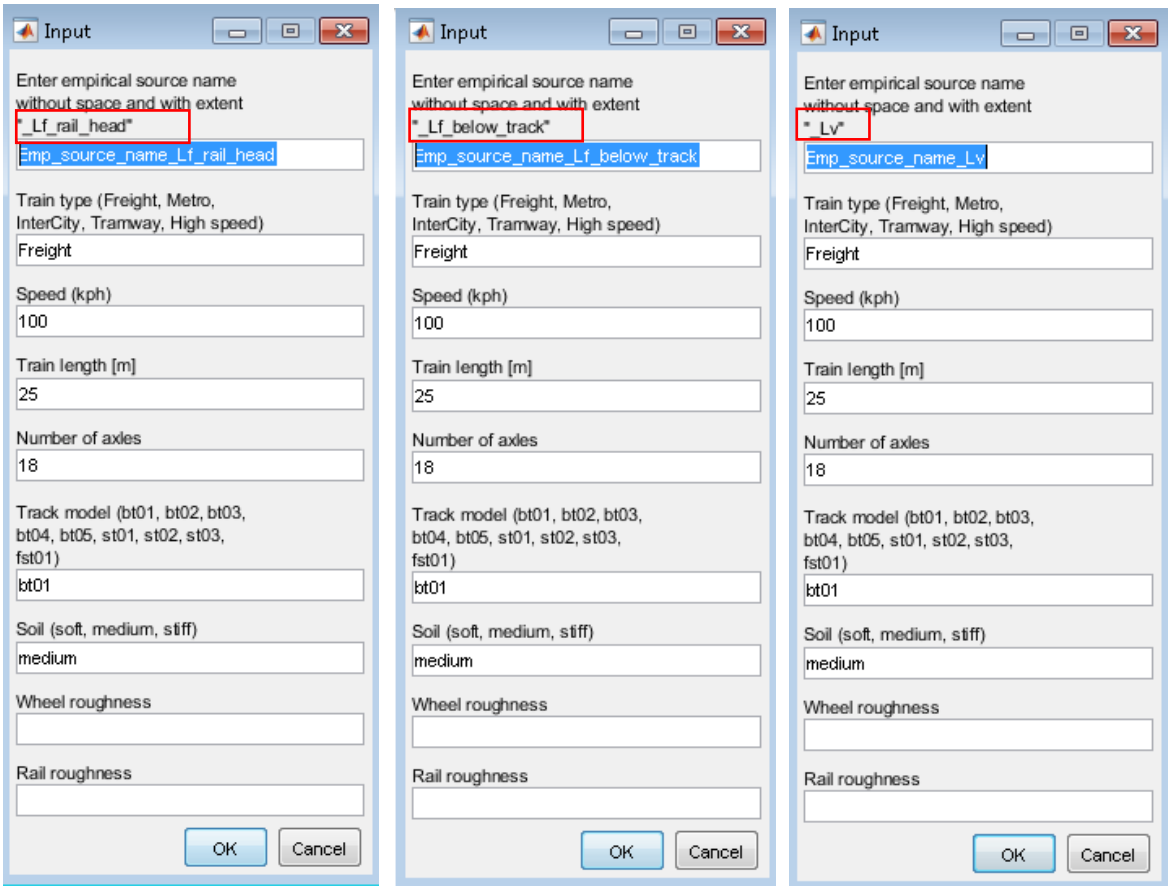


Figure 17 New source empirical” name and metadata.

NB: Be careful with the name length. The total maximum characters allowed is 31.
An equivalent force density measured next to the track can be imported as “Lf_below_track”.

After clicking on “OK”, the Excel file “Empirical_source.xlsx” is opened, and adds a new tab with the name and metadata on the left side based on the information provided (Figure **18**).

The metadata sets are described in Table 3. They are mostly important for hybrid computation, to ensure compatibility with the soil numerical model. If the user does not specify one of the metadata, the default value (if available) is used by the tool.

Table 3 Data and associated metadata for empirical source terms

Data type	Metadata (cell in excel file - Figure 18)	Possible values **Default value in bold**	Comments
$L_F(X,x_1)$, at rail head Or $L_F(X_1,x_1)$, below the track Or $L_v(x_{ref})$ next to the track	Train Type ("D9")	Freight / Tramway / Intercity / Metro / High speed	No default value, must be specified
	Train speed ("D10"), length ("D11") and number of axles ("D12")	Any number	No default value, must be specified
	Track model ("D15")	**bt01** /… /bt02 st01 …	btXX: ballasted tracks stXX: slab tracks See descriptions in the excel files when importing data, and in Table 1
	Soil model ("D16")	soft / **medium** / stiff	Based on the RIVAS project, this depends on the Cs wave of the main soil layer - Cs < 180 m/s => 'soft' - 180 < Cs < 360 m/s => 'medium' - Cs > 360m/s => 'stiff'
	Wheel unevenness ("D17")	**None** / Cast-iron tread / Composite / Disc brake / Tram	Choose one of the wheel unevenness in the excel database (extract in Table 2) (\Database\Roughness_database.xlsx)
	Rail unevenness ("D18")	**bt_normally_maintained** / bt_hs_or_well_maintained… **st_normally_maintained** / ….	Choose one of the rail unevenness in the excel database (extract in Table 2) (\Database\Roughness_database.xlsx)

NB: The default value for rail unevenness depends on the track form (ballast or slab).

As illustrated in Figure 18, enter the values (third octave band spectra in dB, the reference information is written in cell “D7”) in the green cells (column “J”).

	A	B	C	D	E	F	G	H	I	J
1										
2		Information						Measured data		
3										distance (m)
4			ITEM	VALUE	UNIT				frequency (Hz)	4
5			Type of source:	Lv					1	
6			Unit of measured data	dB					1.25	
7			dB ref.	5.00E-08	m/s				1.6	
8									2	
9			Train type						2.5	
10			Train speed		kph				3.15	
11			Train length		m				4	
12			Train number of axles						5	
13									6.3	
14			iated models in database (used for hybrid computa						8	
15			Track						10	
16			Soil						12.5	
17			Wheel roughness						16	
18			Rail roughness						20	
19									25	
20									31.5	
21			**Track model**						40	
22			see D1.2 and detail below						50	
23									63	
24			**Soil model**						80	
25			See D2.1 chapter 5.1 and detail below						100	
26									125	
27			**Roughness**						160	
28			- if not measured -> chose roughness in the database						200	
29			("Path" \Database\Roughness_database.xlsx). Otherwise, a						250	
30			default roughness data will be associated (normally						315	
31			maintained).							
32			- if measured : first add measurements in the database, then							
33			select the corresponding name here							

Figure 18 “New source empirical” values and parameters – example for source defined by measured vibration levels

NB: the input units cannot be changed. If the user has data in other units, they must convert it before importing.

For types “Lv” and “Lf below the track”, the distance parameters have to be added above the source values (cell “J4”).

When the data is complete, save and close the Excel file.

3.3 Create a new propagation term

To create a new propagation term, click on “New Propagation” in the main Menu, in the “Propagation tab”.

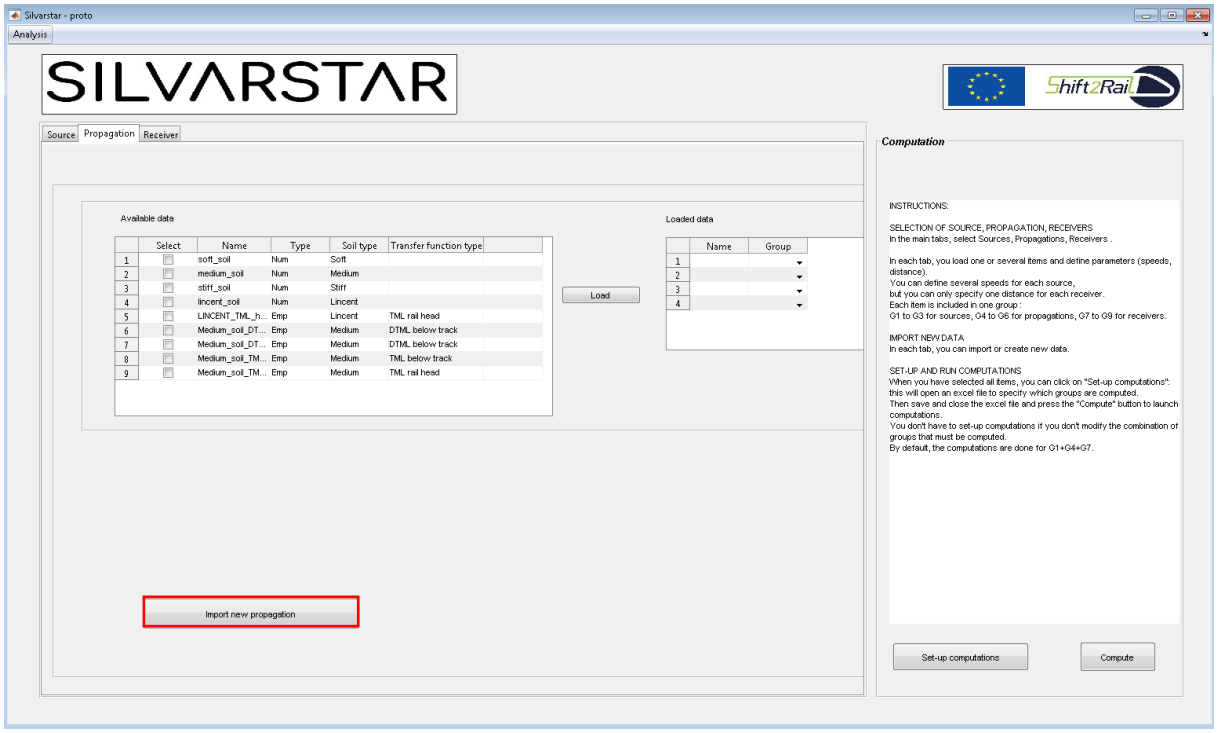


Figure 19 Main Menu – create a new propagation term.

A new propagation term may be defined by:

- A line source transfer mobility at the rail head,
- A line source transfer mobility below (or next to) the track,
- A difference in line source transfer mobility.

Depending on the type of new propagation term, click on the corresponding “Excel open” button.

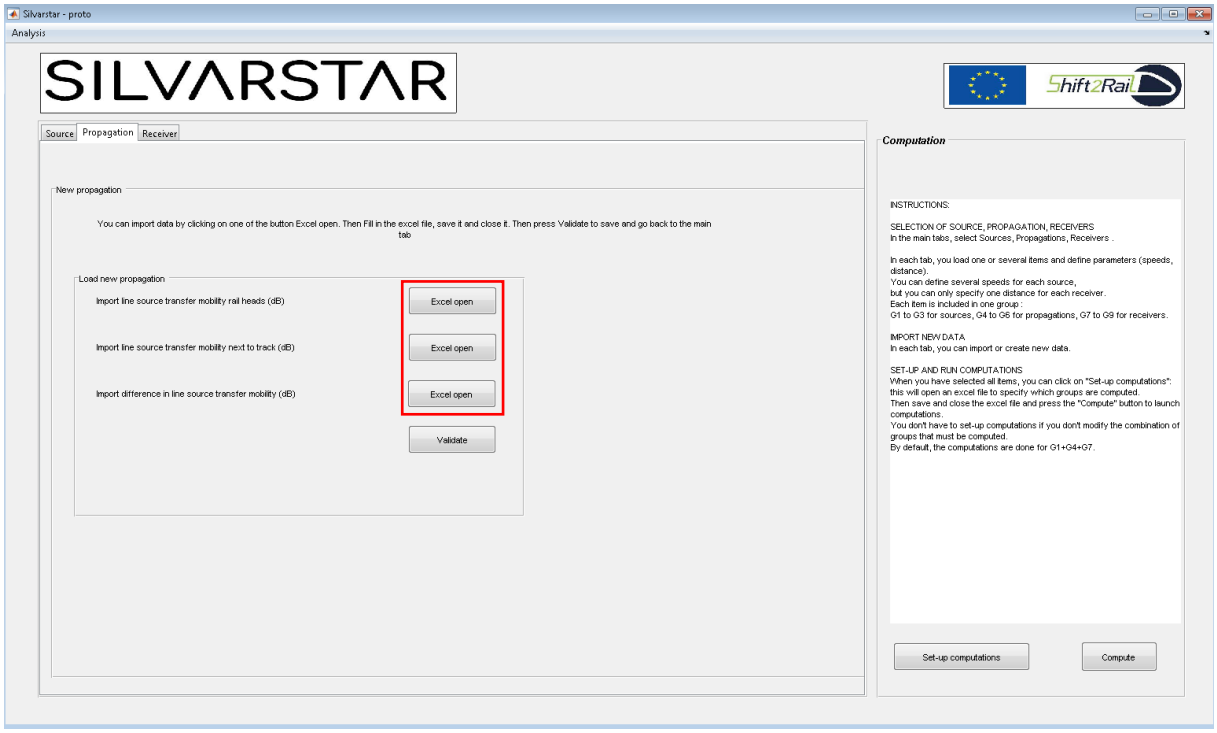


Figure 20 “New propagation term” interface.

To go back to the main menu without adding a new propagation term, click on “Validate”.

A new interface page is opened: fill in the new propagation term information (name and metadata), and click on “OK”. The metadata is described in Figure **21**, and detailed in Table 4.

The Cancel button returns to the “New propagation term” menu.

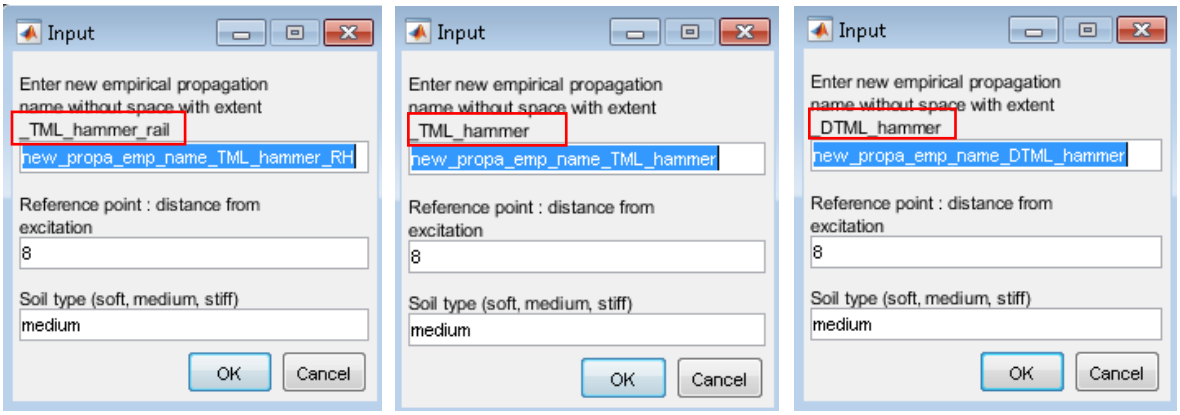


Figure 21 “New propagation term” name and metadata.

NB: Be careful with the name length. The total maximum characters allowed is 31.

After clicking on “OK”, the Excel file “Empirical_propagation.xlsx” is opened, and adds a new tab with the name and metadata on the left side based on the information provided (Figure 22).

The metadata sets are described in

Table 4. They are mostly important for hybrid computations to ensure compatibility with the source numerical model. If the user does not specify one of the metadata, the default value is used by the tool.

Table 4 Data and associated metadata for empirical propagation terms

Data type	Metadata (cell in excel file - Figure 22 "New propagation term" values and parameters – example for a line source transfer mobility measured with impact at rail head)	Possible values **Default value in bold**	Comments
TM_L and ΔTM_L	Reference point distance ("D8")	Any number	Must be set
	Soil type ("D9")	soft / **medium** / stiff	Based on the RIVAS project, this depends on the Cs wave of the main soil layer - Cs < 180 m/s => 'soft' - 180 < Cs < 360 m/s => 'medium' - Cs > 360m/s => 'stiff'
TM_L with impact at rail heads	Track model ("D10")	**bt01** /… /bt02 st01 …	btXX: ballasted tracks stXX: slab tracks See descriptions in the excel files when importing data (Figure 22), and in Table 1

As illustrated in Figure 22, enter the values (third octave band spectra in dB; the reference information is written in cell “D7”) in the green cells (column “J” to “ii”, depending on the distance).

	C	D	E	I	J	K	L	M
2	Information			Measured data				
3				TML (dB)	distance (m)	distance (m)	distance (m)	distance (m)
4	**ITEM**	**VALUE**	**UNIT**	frequency (Hz)	4	8	15	20
5	Type of transfer function:	TML rail head		1				
6	Unit of measured data	dB		1.25				
7	dB ref.	5.00E-08	(m/s)/(N/sqrt(m))	1.6				
8	Reference point : distance from excitation	4	m	2				
9	Soil type	medium		2.5				
10	Track model			3.15				
11				4				
12				5				
13	In the 'Soil type' value 3 possibility are expected :			6.3				
14	"Soft", "Medium", "Stiff".			8				
15	Based on the RIVAS project, this depend of the Cs			10				
16	wave on the main soil layer.			12.5				
17	- Cs < 180 m/s => 'Soft'			16				
18	- 180 < Cs < 360 m/s => 'Medium'			20				
19	- Cs < 360m/s => 'Stiff'			25				
20				31.5				
21				40				
22				50				
23				63				
24				80				
25				100				
26				125				
27				160				
28				200				
29				250				
30				315				

Figure 22 “New propagation term” values and parameters –example for a line source transfer mobility measured with impact at rail head

The distance parameters for each measurement point have to be added in line “4” (see examples in columns J, K, L, M in Figure 22). In the example, the measured distances are 4, 8, 15 and 20 m. The user can add any number of columns: one column per measured distance.

NB: the units (cells “D6” and “D7” in *Figure 22*) cannot be changed. If the user has data in other units, they must convert it before importing.

When the data is complete, save and close the Excel file.

3.4 Create a new receiver

To import a new receiver, click on “Import new receiver” in the main Menu, in the “Receiver tab”.

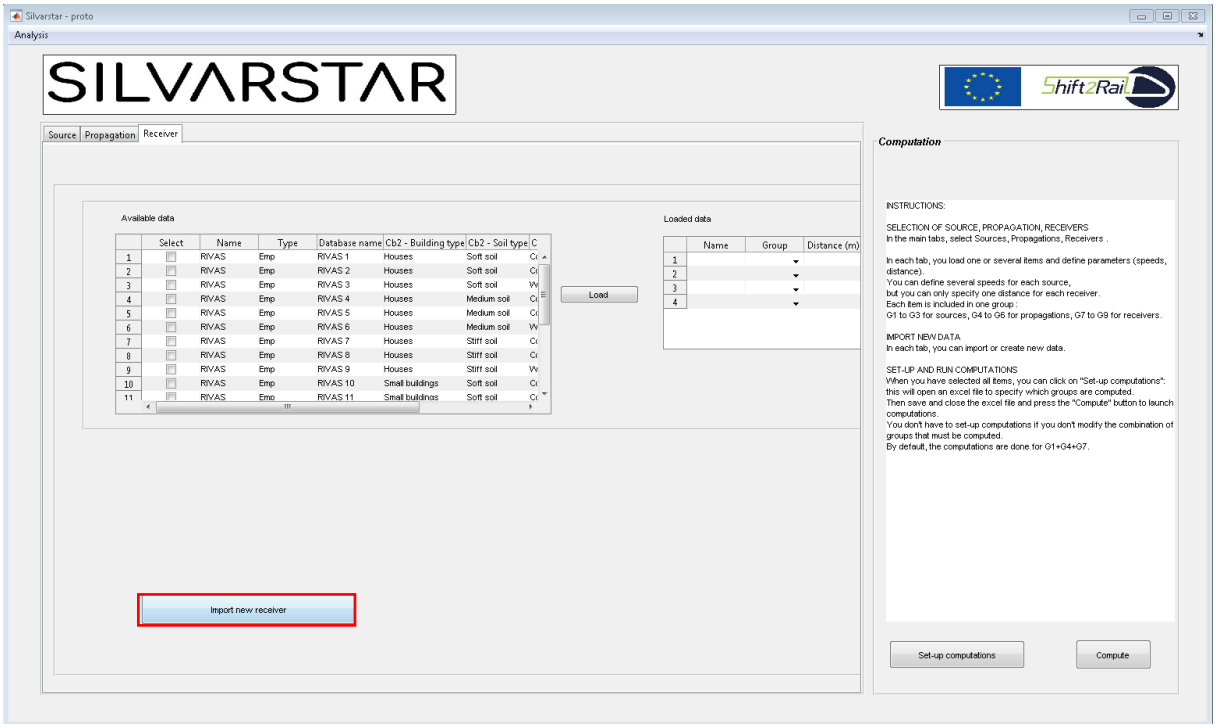


Figure 23 Main Menu – create a new receiver.

A new receiver may be added based on measurements or simulation. Click on “Excel Open” to add a new receiver database.

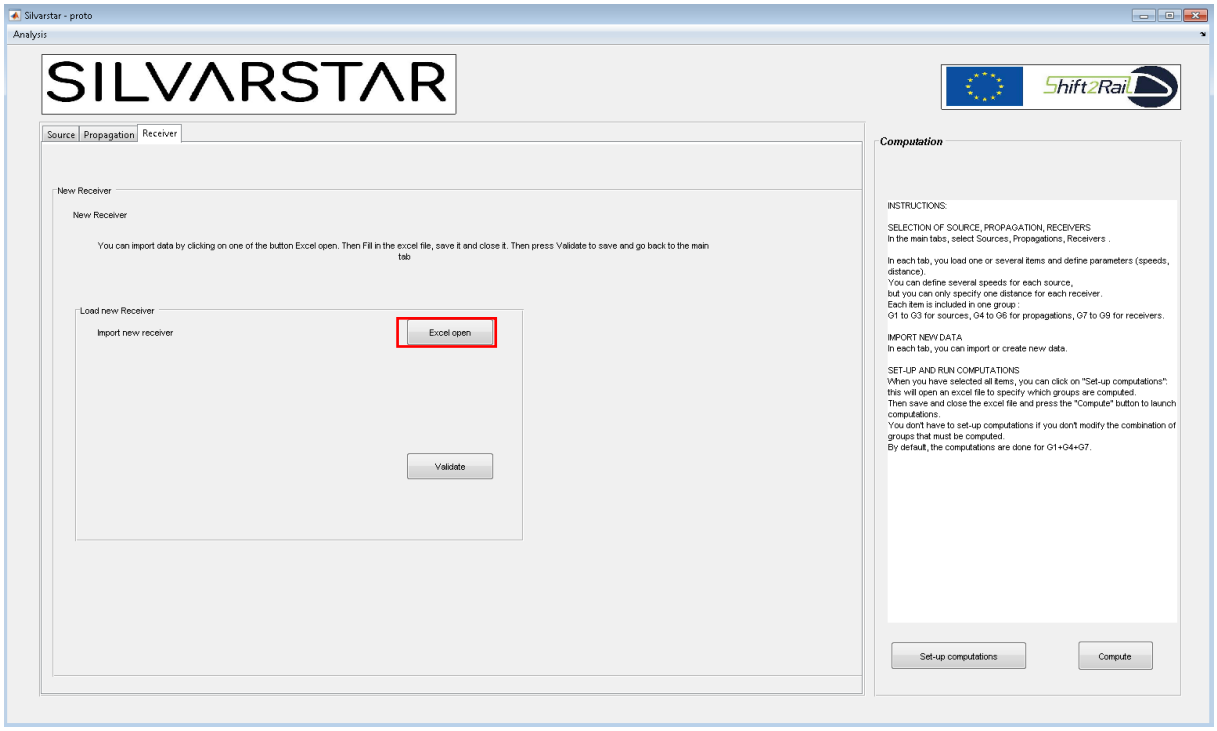


Figure 24 “New receiver” interface.

To go back to the main menu without adding a new receiver, click on “Validate”.

A new interface page is opened: fill in the new receiver database name and click on “OK”.

The receiver database can correspond to one measurement campaign on given sites for a line construction project. Several buildings can hence be included in the same database.

The Cancel button send back to the “new receiver menu”.

Figure 25 “New receiver” name and metadata.

After clicking on “OK”, the Excel file “Empirical_receiver.xlsx” is opened, adding a new tab with the input name.

As illustrated in Figure 26, Enter values (third octave band spectra in dB; the reference information is written in cell “D7”) in the green cells (from column “J”).

When creating a new receiver database, each new receiver needs to be added following the same process: Cb2, Cb3, Cb4 values in 3 columns ([J,K,L] for the first receiver, then: [M,N,O], etc.). Several new receivers may be added at the same time in the new receiver database. For example, the beginning of the RIVAS database is presented for illustration (Figure 27).

NB: The units cannot be changed.

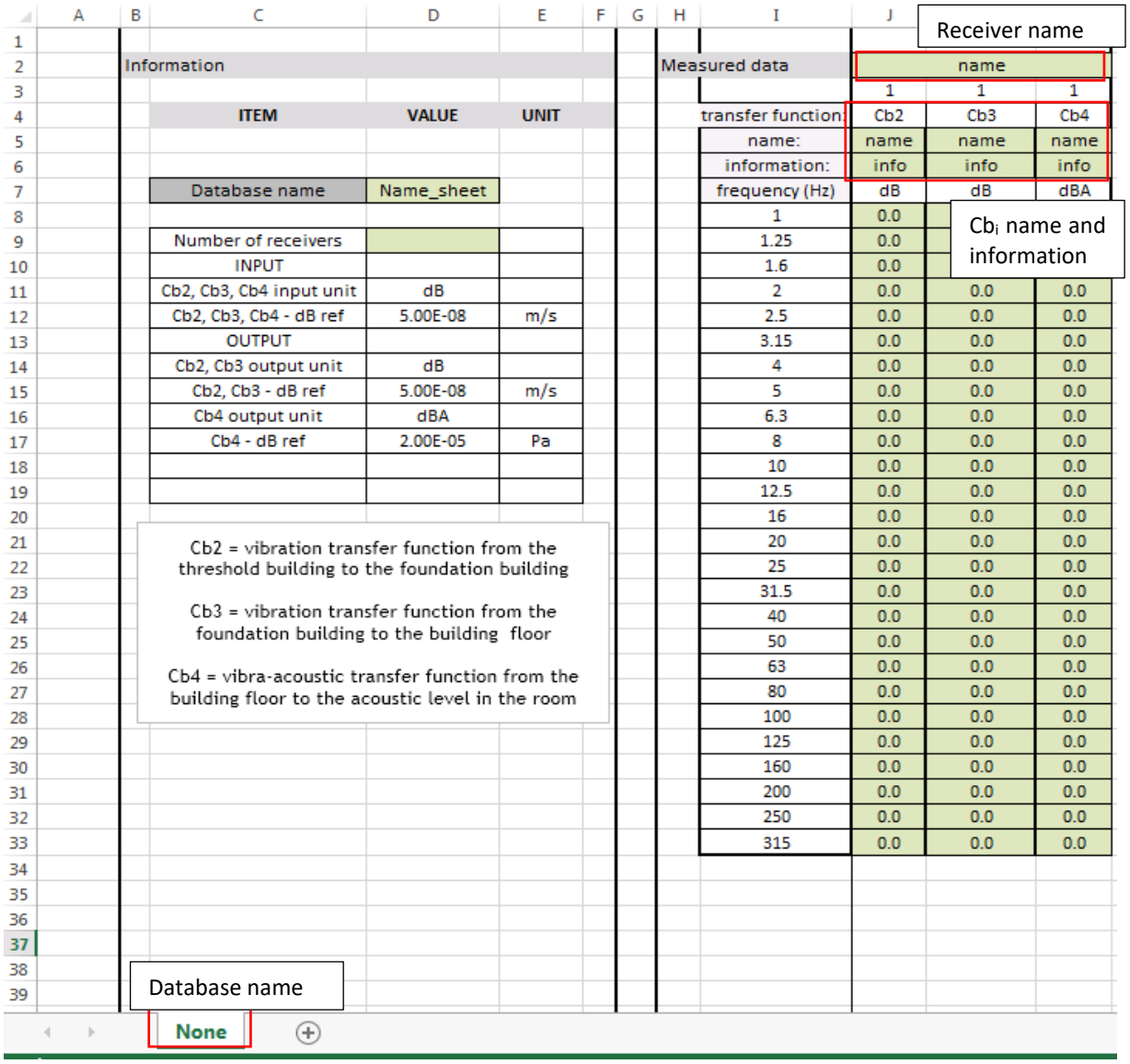
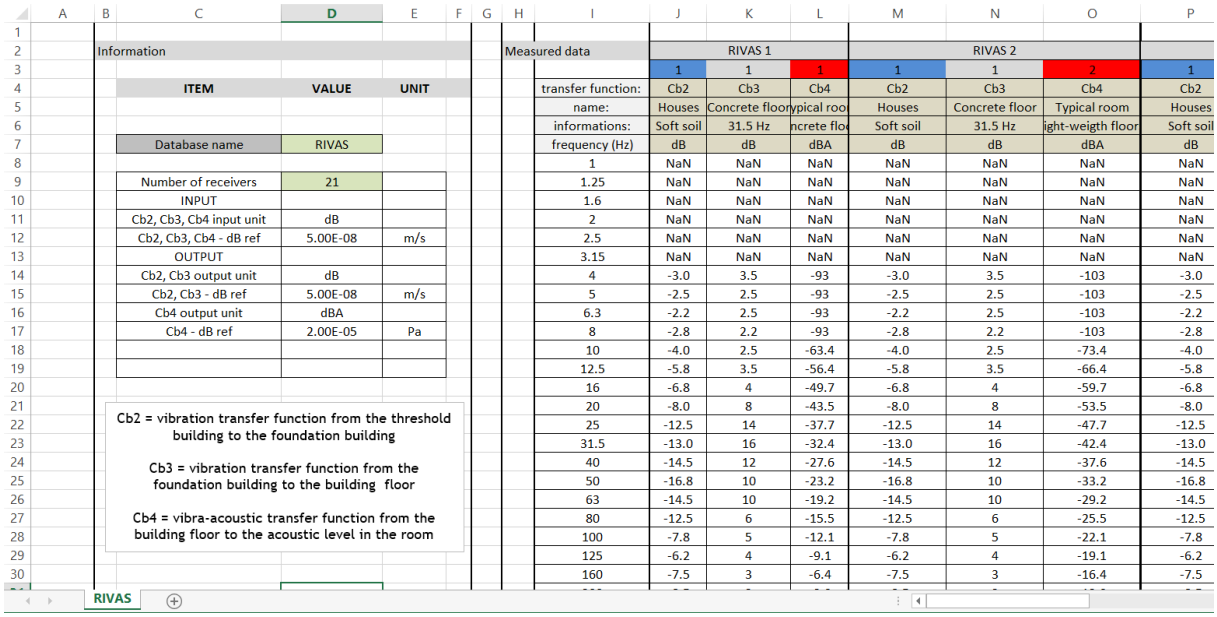


Figure 26 “New receiver” values and parameters.



Information

ITEM	VALUE	UNIT
Database name	RIVAS	
Number of receivers	21	
INPUT		
Cb2, Cb3, Cb4 input unit	dB	
Cb2, Cb3, Cb4 - dB ref	5.00E-08	m/s
OUTPUT		
Cb2, Cb3 output unit	dB	
Cb2, Cb3 - dB ref	5.00E-08	m/s
Cb4 output unit	dBA	
Cb4 - dB ref	2.00E-05	Pa

Cb2 = vibration transfer function from the threshold building to the foundation building

Cb3 = vibration transfer function from the foundation building to the building floor

Cb4 = vibra-acoustic transfer function from the building floor to the acoustic level in the room

Measured data

	RIVAS 1			RIVAS 2			
	1	1	1	1	1	2	1
transfer function:	Cb2	Cb3	Cb4	Cb2	Cb3	Cb4	Cb2
name:	Houses	Concrete floor	ypical roo	Houses	Concrete floor	Typical room	Houses
informations:	Soft soil	31.5 Hz	ncrete flo	Soft soil	31.5 Hz	ight-weigth floor	Soft soil
frequency (Hz)	dB	dB	dBA	dB	dB	dBA	dB
1	NaN	NaN	NaN	NaN	NaN	NaN	NaN
1.25	NaN	NaN	NaN	NaN	NaN	NaN	NaN
1.6	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2.5	NaN	NaN	NaN	NaN	NaN	NaN	NaN
3.15	NaN	NaN	NaN	NaN	NaN	NaN	NaN
4	-3.0	3.5	-93	-3.0	3.5	-103	-3.0
5	-2.5	2.5	-93	-2.5	2.5	-103	-2.5
6.3	-2.2	2.5	-93	-2.2	2.5	-103	-2.2
8	-2.8	2.2	-93	-2.8	2.2	-103	-2.8
10	-4.0	2.5	-63.4	-4.0	2.5	-73.4	-4.0
12.5	-5.8	3.5	-56.4	-5.8	3.5	-66.4	-5.8
16	-6.8	4	-49.7	-6.8	4	-59.7	-6.8
20	-8.0	8	-43.5	-8.0	8	-53.5	-8.0
25	-12.5	14	-37.7	-12.5	14	-47.7	-12.5
31.5	-13.0	16	-32.4	-13.0	16	-42.4	-13.0
40	-14.5	12	-27.6	-14.5	12	-37.6	-14.5
50	-16.8	10	-23.2	-16.8	10	-33.2	-16.8
63	-14.5	10	-19.2	-14.5	10	-29.2	-14.5
80	-12.5	6	-15.5	-12.5	6	-25.5	-12.5
100	-7.8	5	-12.1	-7.8	5	-22.1	-7.8
125	-6.2	4	-9.1	-6.2	4	-19.1	-6.2
160	-7.5	3	-6.4	-7.5	3	-16.4	-7.5

RIVAS

Figure 27 “New receiver” values and parameters - example.

Save and exit the Excel file and “Validate” to go back to the main menu, with the new receiver database available.

3.5 Start a computation

All computations will be saved into the folder “Projects\Current_project”. Results are written in the subfolder “\Results”, in the files “VelocityLevels.mat” and “Results.txt” (see Appendix 2 for description). The sub sub folder “\Results\Current_run” contains intermediate results in matlab format. All the results will be overwritten when a new computation is performed.

➔ **If you want to save results after each computation, copy the “Current_project” folder in a “new_name_project” folder in the “Projects” folder.**

Computation overview

Computations are performed on a combination of sources, propagation terms, and receivers, which are:

- Selected and loaded sources, propagation and receivers from the available data.
- A group is associated with each component (source, propagation or receiver):
  - G1, G2, G3 for Sources,
  - G4, G5, G6 for Propagation terms,
  - G7, G8, G9 for Receivers,
  - Several sources, propagations or receivers may be included in each group.
- Some information is needed, such as speed, distance, … in the right table (after loading the component):
  - Only one distance is permitted,
  - Several speeds are allowed.
- Set up the computation table by creating “Variants” (Vi).

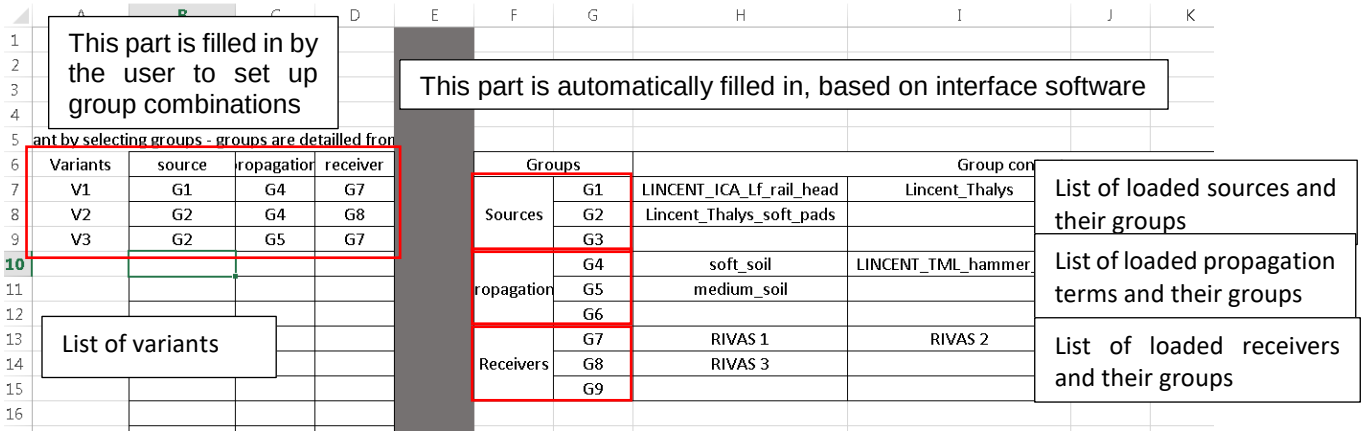


Figure 28 “Computation set-up” overview.

In this example:

- 3 sources are loaded; they are associated to two groups:
  - G1: “LINCENT_ICA_Lf_rail_head” & “Lincent_Thalys”,
  - G2: “Lincent_Thalys_soft_pads”.
- 3 propagations terms are loaded; they are associated to two groups:
  - G4: “soft_soil” & “LINCENT_TML_hammer_rail”,
  - G5: “medium soil”.
- 3 receivers are loaded, and associated to 2 groups:
  - G7: “RIVAS 1” & “RIVAS 2”,
  - G8: “RIVAS 3”.

Based on these groups, the user decided to create 3 variants:

- V1 = G1, G4, G7,
- V2 = G2, G4, G8,
- V3 = G2, G5, G7.

For each variant, all sources are combined with all propagation terms, and with all receivers, which can make a lot of computations.

The above example involves the following computations for each variant:

- V1: “LINCENT_ICA_Lf_rail_head”, “soft_soil”, “RIVAS 1”,
- V1: “LINCENT_ICA_Lf_rail_head”, “soft_soil”, “RIVAS 2”,
- V1: “LINCENT_ICA_Lf_rail_head”, “LINCENT_TML_hammer_rail”, “RIVAS 1”,
- V1: “LINCENT_ICA_Lf_rail_head”, “LINCENT_TML_hammer_rail”, “RIVAS 2”,
- V1: “Lincent_Thalys”, “soft_soil”, “RIVAS 1”,
- V1: “Lincent_Thalys”, “soft_soil”, “RIVAS 2”,
- V1: “Lincent_Thalys”, “LINCENT_TML_hammer_rail”, “RIVAS 1”,
- V1: “Lincent_Thalys”, “LINCENT_TML_hammer_rail”, “RIVAS 2”,
- V2: “Lincent_Thalys_soft_pads”, “soft_soil”, “RIVAS 3”,
- V2: “Lincent_Thalys_soft_pads”, “LINCENT_TML_hammer_rail”, “RIVAS 3”,
- V2: “Lincent_Thalys_soft_pads”, “soft_soil”, “RIVAS 3”,
- V2: “Lincent_Thalys_soft_pads”, “LINCENT_TML_hammer_rail”, “RIVAS 3”,
- V3: “Lincent_Thalys_soft_pads”, “medium_soil”, “RIVAS 1”,
- V3: “Lincent_Thalys_soft_pads”, “medium_soil”, “RIVAS 2”.

Sources

From the « Source » tab in the main menu, select the sources to be used for the computations from the available data, select the group to which sources will be associated, and select the speed (several speeds are allowed, separated by ‘;’).

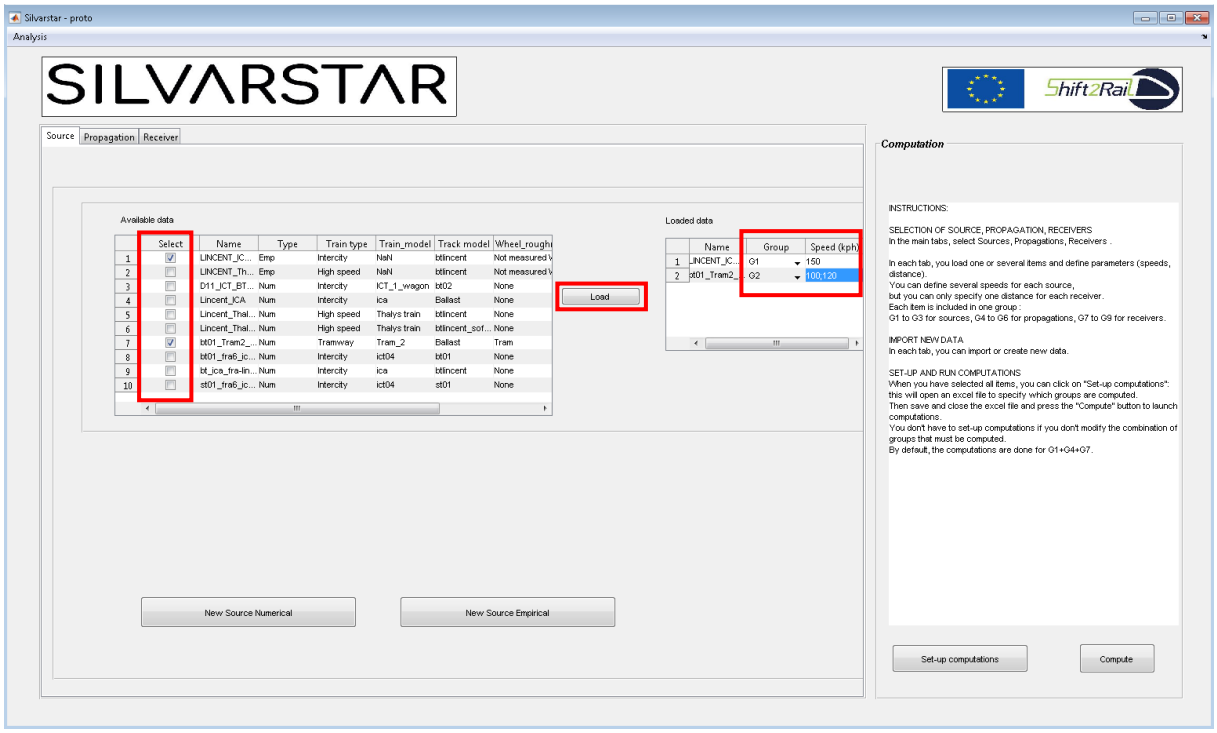


Figure 29 Load Sources.

Propagation terms

From the « Propagation » tab on the main menu, select the propagation terms to be used for the computations from the available data, and select the group to which the propagation terms will be associated.

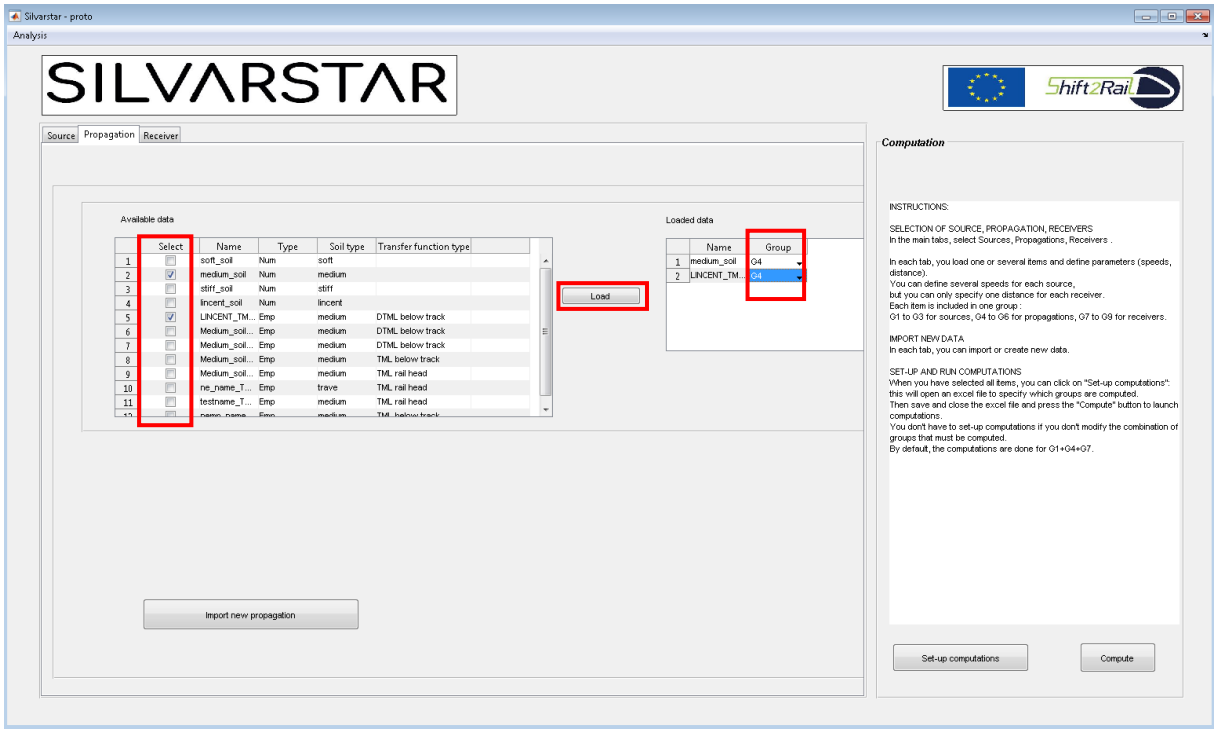


Figure 30 Load Propagation terms.

Receivers

From the « Receiver » tab on the main menu, select the receivers to be used for the computations from the available data, select the group to which receivers will be associated, and select the distance. The user can compute for several distances for one receiver, by writing for instance “10, 12, 14” in the “Distance” column. **In this case, the Analysis menu will not be available for post-processing**. The results can then be read from the ASCII file (see Appendix 2).

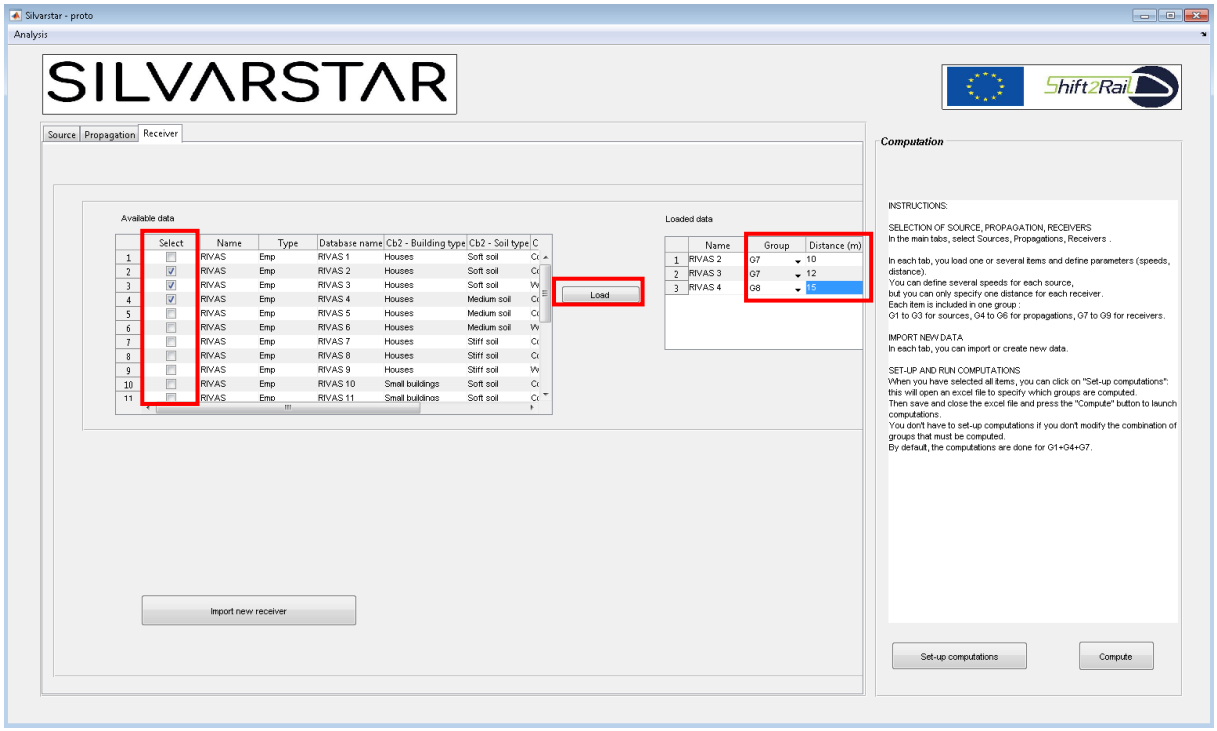


Figure 31 Load Receivers.

Set up computations

Click on “Set up the computations”: an Excel file is opened.
Fill in all variants in the corresponding table (variants list, based on the groups), see Figure 28 “Computation set-up” overview.

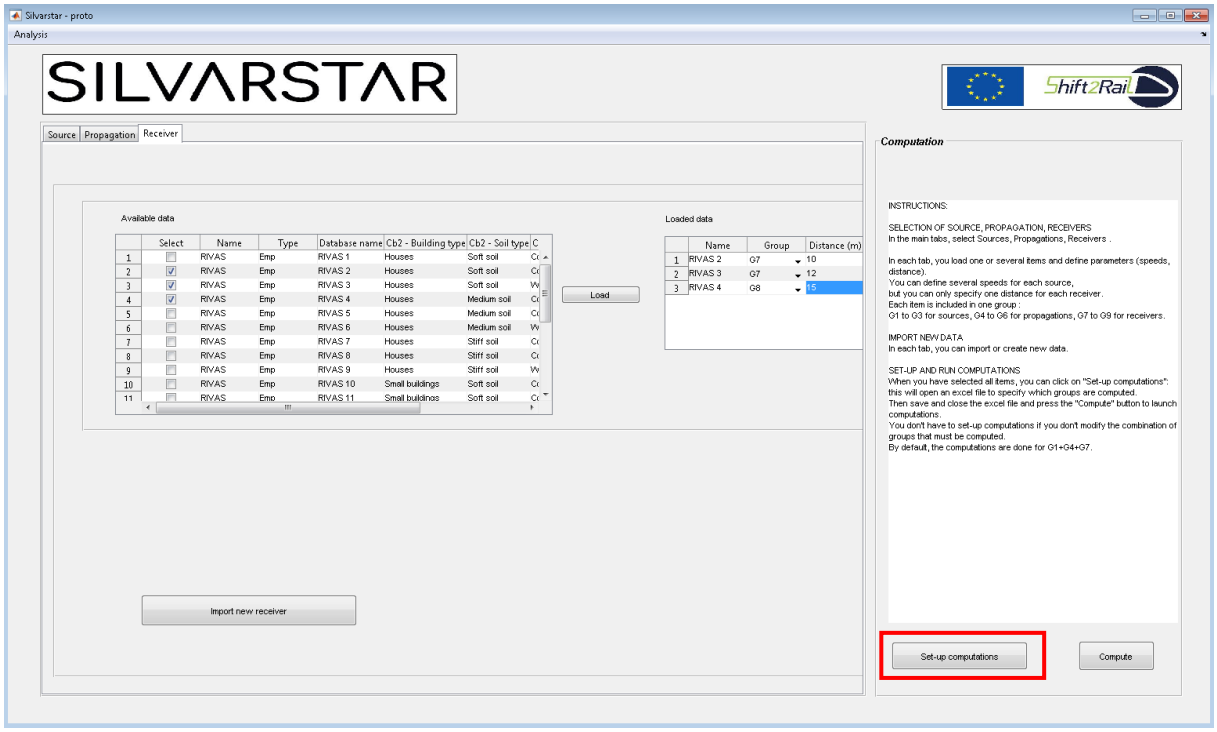


Figure 32 Main menu – “Set up computations”.

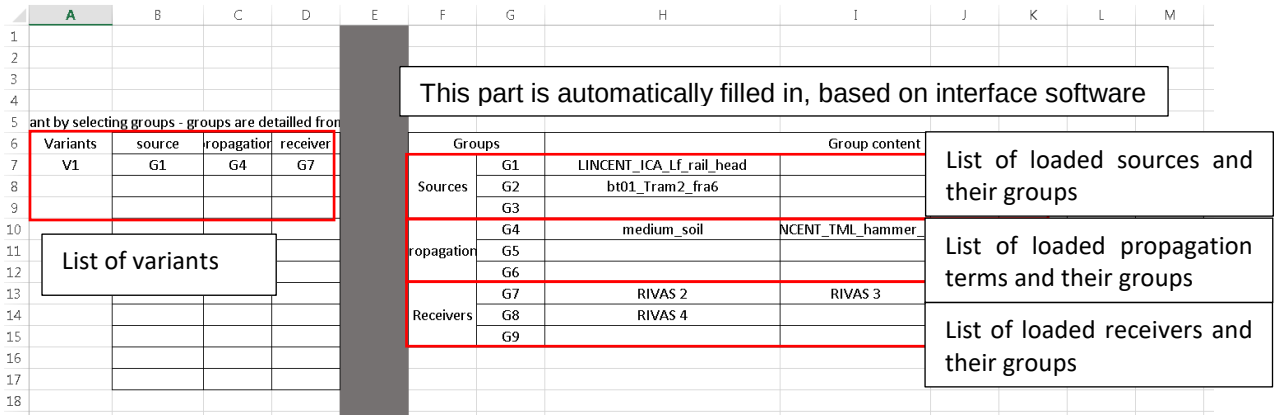


Figure 33 Set up computations Excel file

Computations

To start a computation, click on “Compute”; this launches the computations chosen in the “Set up computations” window.

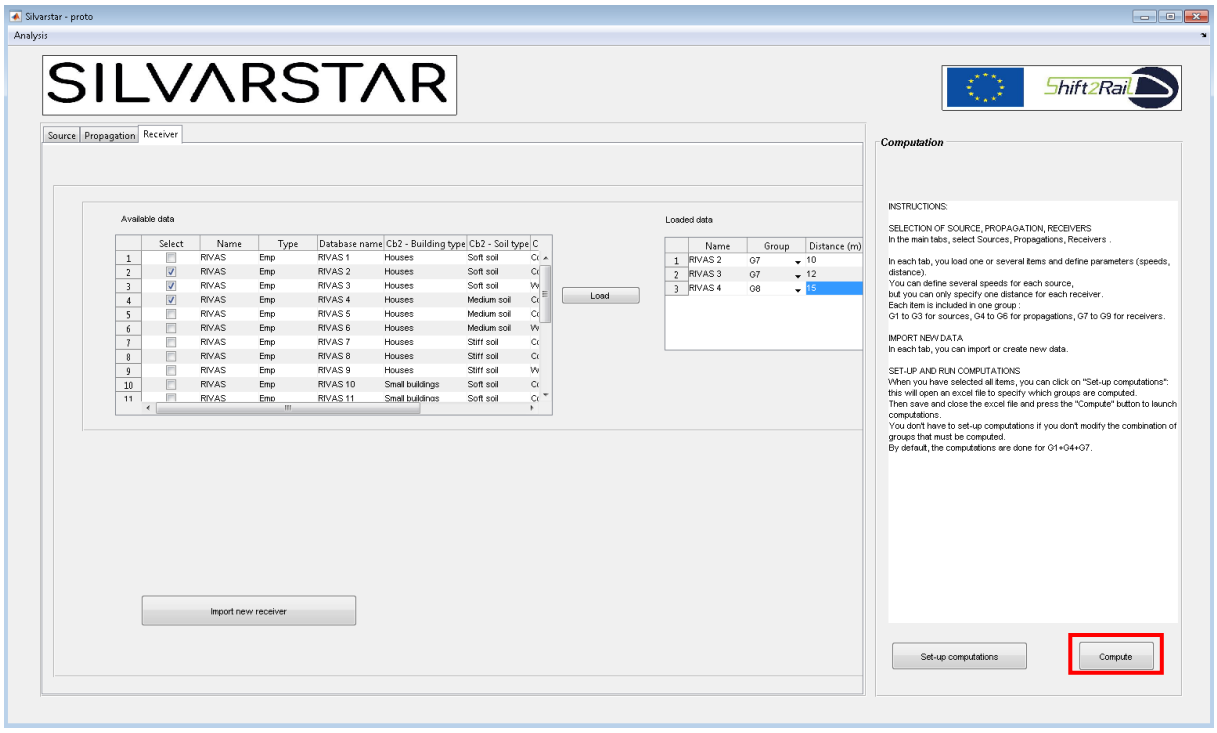


Figure 34 Main menu – start a computation.

A progress bar will appear to indicate the advancement of computation.

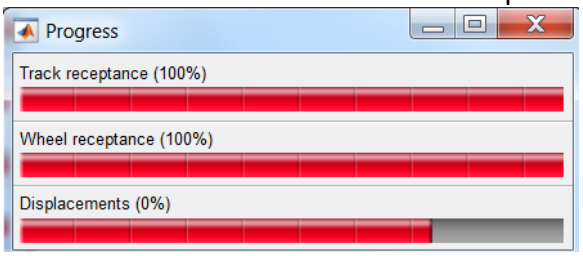


Figure 35 Progress bar for numerical sources.

When computations are finalized, a pop-up message appears.

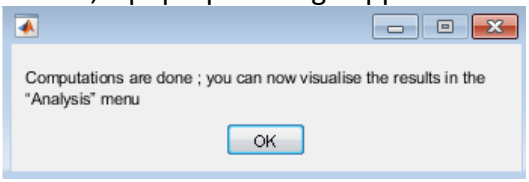


Figure 36 End computation message.

Results are written in Matlab using the following structure / nomenclature:

- Calcul_input: Input parameters used for the computation,
- Lp_building: Noise level inside the building in dB(A),
- Lv_building_floor: Vibration level on the building floor (dB),
- Lv_building_fondation: Vibration level on the building foundation (dB),
- Lv_soil: Vibration level at the soil surface (free-field) (dB).

3.6 Analysis – Velocity and Noise levels

To plot the results, click on the “Analysis” menu:

- “Velocity levels…” for vibration analysis,
- “Noise levels…” for acoustic analysis.

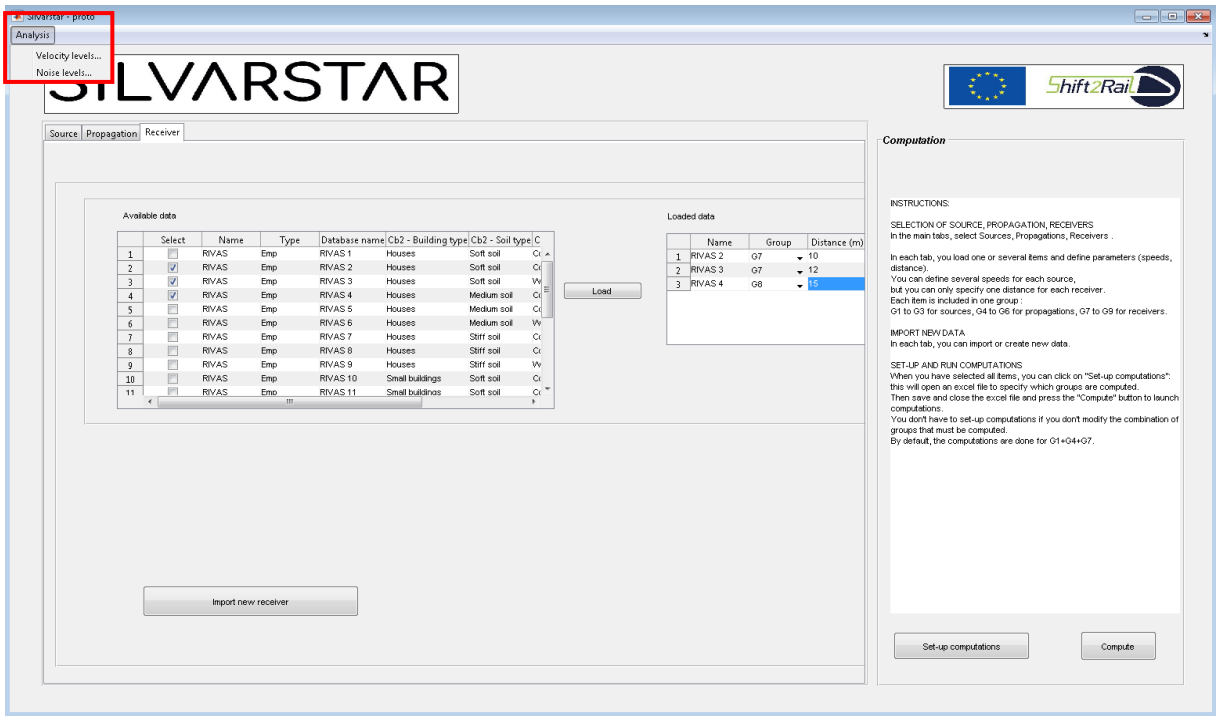


Figure 37 Main menu – Analysis.

Velocity levels

The file “VelocityLevels.mat” is automatically loaded from the “Current_project” folder (corresponding to the last run).

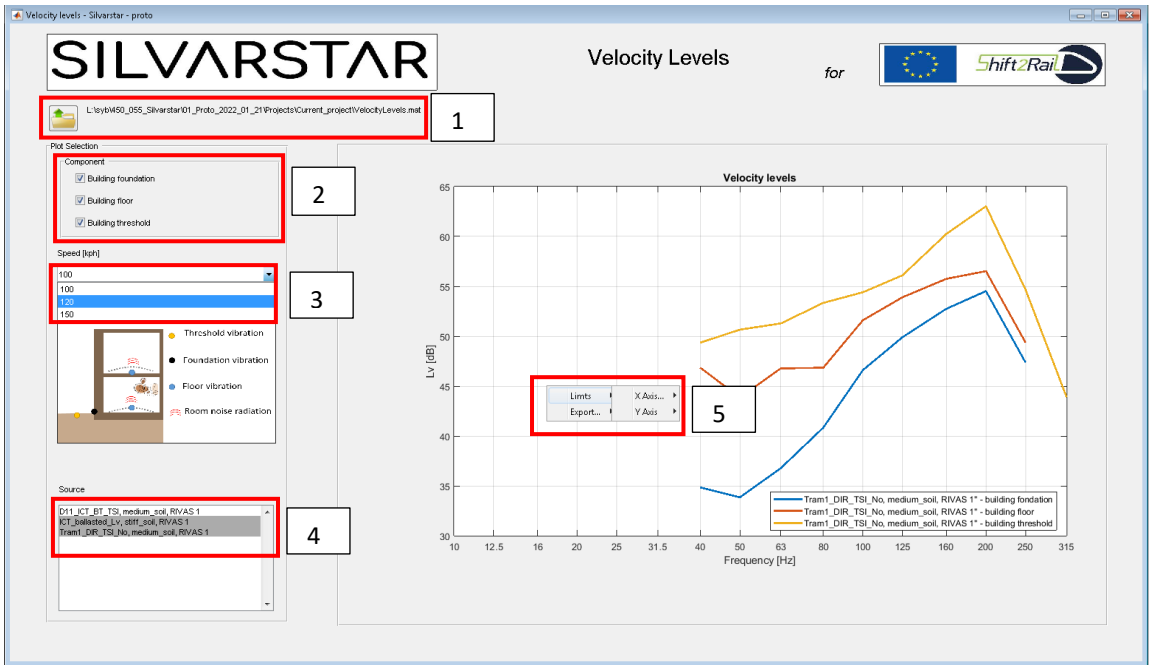


Figure 38 Velocity analysis window.

1- Open results “VelocityLevels.mat” file (to view another saved result).
2- Select where vibrations have to be analysed (Threshold, Foundation, Floor).
3- Select the speed (depending on the input parameters given by the user, some speeds may not be available for each source).
4- Select sources to visualise.
5- Right click on the figure to modify limits or export the figure.

Acoustic analysis

The noise analysis window is very similar to the velocity analysis window.
Only the noise (inside the building) is selectable.

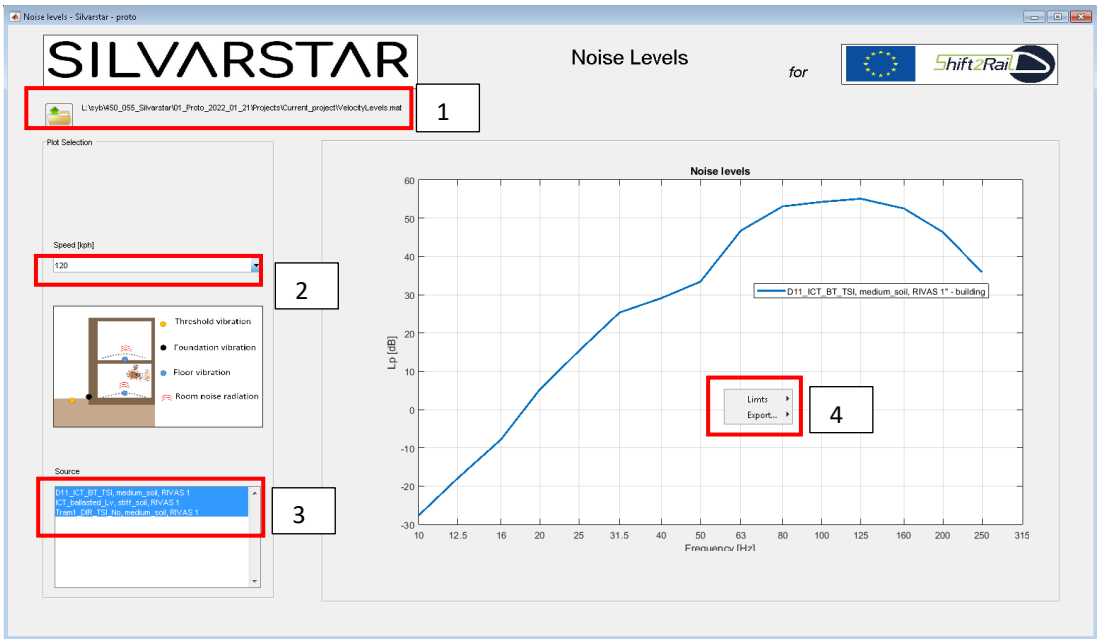


Figure 39 Acoustic analysis window.

1- Open results “VelocityLevels.mat” file.
2- Select the speed (depending on the input parameters given by the user, some speeds may not be available for each source).
3- Select sources to visualise.
4- Right click on the figure to modify limits or export the figure.

4. References

[1] G. Degrande, G. Lombaert, E. Ntotsios, D. Thompson, B. Nélain, P. Bouvet, S. Grabau, J. Blaul, A. Nuber. State-of-the-art and concept of the vibration prediction tool. SILVARSTAR Deliverable D1.1, May 2021.

[2] D. Thompson, E. Ntotsios, G. Degrande, G. Lombaert, G. Herremans, T. Alexiou, B. Nélain, S. Barcet, P. Bouvet, B. Fröhling and A. Nuber. Database for vibration emission, ground transmission and building transfer functions, SILVARSTAR Deliverable D2.1, January 2022.

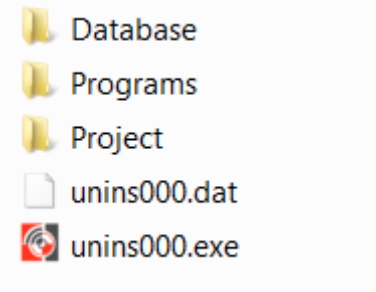
[3] P. Reumers, G. Degrande, G. Lombaert, F. Seyfaddini, G. Herremans, E. Ntotsios, D. Thompson, B. Nélain, P. Bouvet, A. Nuber. Validation of the prototype vibration prediction tool against documented cases, SILVARSTAR Deliverable D1.3, June 2022.

APPENDICES

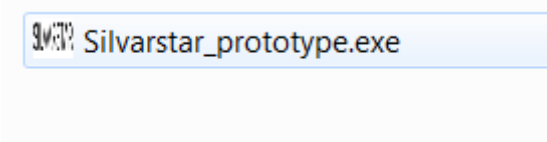
APPENDIX 1: Installation procedure

A set-up file “Silvarstar_setup_1.1.exe”, is dedicated to the set-up. During installation, the user may install the software in any Windows path. However, the user must have access to this folder with administrator rights.

The following architecture will be implemented at the designated location:



The application to start the software is in the “Programs” folder.



The user must plug the USB Dongle provided by VIBRATEC in order to use the software tool.

To uninstall the tool, simply double-click on the unins000.exe file.

APPENDIX 2: Description of result file “Results.txt”

The results are written in ASCII, and can be opened with excel. It is located in the folder \Project\Current_project\Results
Figure 41 shows an example, with 10 results (line 2). Only the first result is presented in the figure.

The data for result 1 is listed from line 5 to line 51.
Metadata sets are listed from line 6 to 20, and the data values are listed from lines 24 to 51.
The data consists in the building vibration and noise levels.

The file can be opened in excel for plotting or post-processing, as illustrated in Figure 40.

	A	B	C	D	E
1	Comma separated file	csv			
2	number of results =	10			
3					
4					
5	RESULT	1			
6		SOURCE description			
7	1	1			
8	source name	LINCENT_ICA_Lf_rail_head			
9	train speed	100			
10	wheel unenvenness	None			
11	track name	btlincent			
12	rail unenvenness	Ballasted track - Normally maintained			
13		PROPAGATION description			
14	1	1			
15	propagation name	LINCENT_TML_hammer_rail			
16		RECEIVER description			
17	1	1			
18	database name	RIVAS			
19	receiver name	RIVAS 3			
20	receiver distance	10			
21		DATA			
22	freq(Hz)	Lv (dB re 5	Lv (dB re 5e-	Lv (dB re 5e-	Lp (dBA re 2e-5 Pa)
23		free field	building fou	building floc	building room
24	1	10.58	NaN	NaN	NaN
25	1.25	12.54	NaN	NaN	NaN
26	1.6	14.55	NaN	NaN	NaN
27	2	18.02	NaN	NaN	NaN
28	2.5	22.4	NaN	NaN	NaN

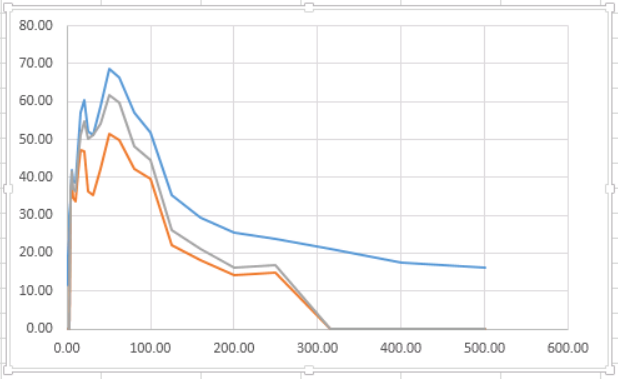


Figure 40 result file opened in excel

```
    ├---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8----+---
  1 Comma separated file, csv
  2 number of results = ,10
  3
  4
  5 RESULT,1
  6  ,SOURCE description
  7 1,1
  8 source name ,LINCENT_ICA_Lf_rail_head
  9 train speed  ,100
 10 wheel unenvenness ,None
 11 track name ,btlincent
 12 rail unenvenness ,Ballasted track - Normally maintained
 13  ,PROPAGATION description
 14 1,1
 15 propagation name ,LINCENT_TML_hammer_rail
 16  ,RECEIVER description
 17 1,1
 18 database name ,RIVAS
 19 receiver name ,RIVAS 3
 20 receiver distance,10
 21  ,DATA
 22 freq(Hz),Lv (dB re 5e-8 m/s),Lv (dB re 5e-8 m/s),Lv (dB re 5e-8 m/s),Lp (dBA re 2e-5 Pa)
 23  ,free field,building foundation,building floor,building room
 24 1,10.58,NaN,NaN,NaN
 25 1.25,12.54,NaN,NaN,NaN
 26 1.6,14.55,NaN,NaN,NaN
 27 2,18.02,NaN,NaN,NaN
 28 2.5,22.4,NaN,NaN,NaN
 29 3.15,28.55,NaN,NaN,NaN
 30 4,32.01,29.01,36.51,-66.49
 31 5,33.92,31.42,38.42,-64.58
 32 6.3,39.87,37.67,44.17,-58.83
 33 8,36.31,33.51,40.51,-62.49
 34 10,36.22,32.22,43.22,-30.18
 35 12.5,46.1,40.3,56.3,-10.1
 36 16,55.81,49.01,69.01,9.31
 37 20,59.93,51.93,65.93,12.43
 38 25,53.5,41,51,3.3
 39 31.5,53.48,40.48,47.98,5.58
 40 40,60.67,46.17,52.17,14.57
 41 50,71.74,54.94,60.94,27.74
 42 63,70.69,56.19,61.19,31.99
 43 80,62.96,50.46,56.46,30.96
 44 100,60.4,52.6,56.1,34
 45 125,43.37,37.17,39.17,20.07
 46 160,34.47,26.97,24.97,8.57
 47 200,29.83,21.33,17.83,3.93
 48 250,25.24,17.94,12.94,1.34
 49 315,21.71,NaN,NaN,NaN
 50 400,16.92,NaN,NaN,NaN
 51 500,14.79,NaN,NaN,NaN
 52
 53
 54 RESULT,2
 55  ,SOURCE description
```

Figure 41: example of result file in ASCII format, to be opened by excel