Rail4Future

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Deliverable D1.1.5

Implemented and Tested Sub Model Environment

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Deliverable released

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1 Executive Summary

This deliverable provides comprehensive insights about the use cases that are considered and which of them were implemented, tested, validated and finally released for the R4F project by using the adapters and interfaces mentioned in Deliverable D1.1.4. Besides, the use cases, which were already implemented, are briefly described in this report. The description of the use case implementation methodology can be found in Deliverable D1.3.5.

2 Table of Content

3 Abbreviations and Acronyms

Abbreviations / Acronyms	Description
MBS	Multi-Body Simulation
MIVP	Maschinenbauinformatik und Virtuelle Produktentwicklung
R4F	Rail4Future
VTI	Vehicle Track Interaction
RLT	Residual Life Time
ViV	Virtual Vehicle Research GmbH
ML	Machine Learning
VRVis	Zentrum für Virtual Reality und Visualisierung Forschungs-GmbH
FMI	Functional Mock-up Interface
SSP	System Structure and Parameterization
FMU	Functional Mock-up Unit
PID	Proportional-Integrative-Derivative
AIT	Austrian Institute of Technology GmbH
ÖBB	Österreichische Bundesbahnen (Austrian Federal Railways Holding Company)
DT	Digital Twin
MBD	Multibody Dynamics

4 Problem Description / Objectives

4.1 Problem Description

Before the use case implementation into the R4F Platform, railway use cases are defined and concretized due to subsystem (e.g., rail vehicle, turnout) and requirements for condition monitoring and predictive maintenance of a railway infrastructure system. Then, the simulation models, associated with these use cases, are to be virtualized in order to successfully implement these models into the platform. After specifying adapters and interfaces (see Deliverable D1.1.4) for the implementation, railway assets belonging to these use cases are to be simulated in the platform. Besides, it is important to learn about the simulation raw assets of these use cases, because these help obtain simulation results directly from the default software tools, which are then compared to the results of the adapted version of these assets for validation purposes. Therefore, the implementation methodology of these raw assets is to be comprehended as well (see Deliverable D1.3.5).

4.2 Objectives

First, this deliverable aims to show and describe railway use cases successfully implemented into the R4F Platform, which are then listed with their critical data in a table. After that, all use cases considered for the R4F project are listed in a table as a general overview of the use cases and their current state.

5 Significance for the overall Project

Every physical domain generally has typical industrial use cases, which identify and highlight the domain itself. In our case, the railway domain has different use cases, which are essential for railway infrastructure managers and train operators for their monitoring and predictive maintenance tasks. Therefore, it was decided to implement these use cases into the R4F Platform, which has a significant part in glorifying the R4F project for those managers and operators. This deliverable provides an overview of the current status of these use cases as described, and thus, is expected to give insights about the usefulness and feasibility of the R4F project.

6 Description

6.1 Successfully Implemented Use Cases

6.1.1 MBS Model of a Railway Vehicle

This use case demonstrates the straight and/or curved drive of a railway vehicle on a designed track, which consists of two bogies, is modeled as an MBS model in a commercial simulation software tool Simpack from Dassault Systèmes, based on Manchester Benchmark [3] and provided from ViV. In Table 1, all the input parameters, outputs, simulation configurations and additional remarks, applied to the MBS model for its implementation into the R4F Platform, are listed.

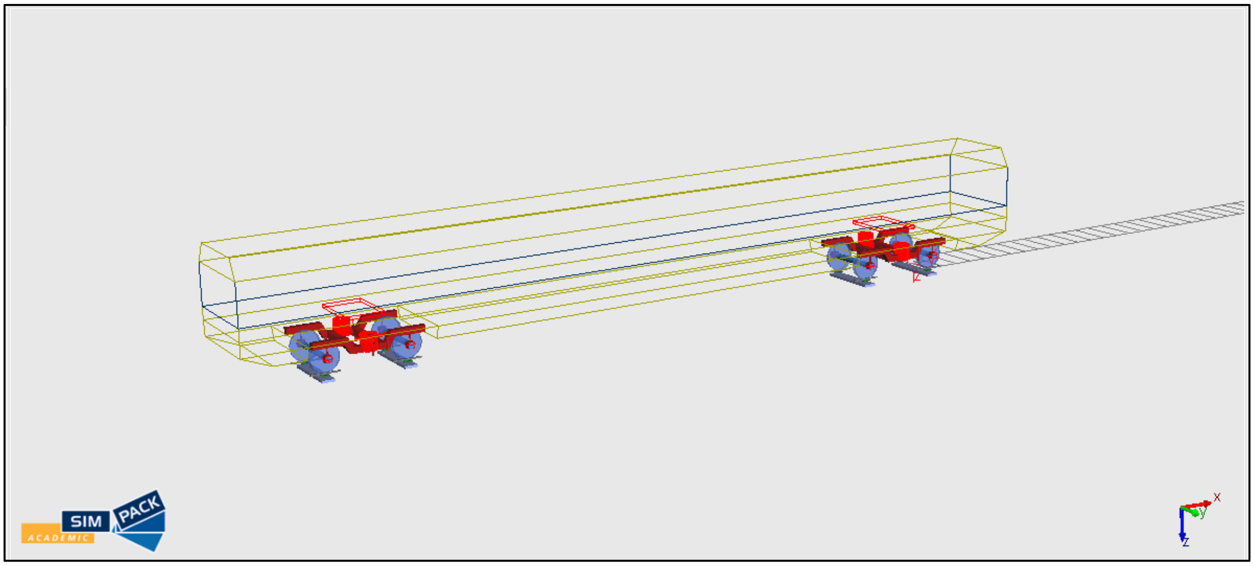

Figure 1: Simpack MBS Model based on Manchester Benchmark [3] and provided from ViV.

The model's vehicle speed, track curve radius, track superelevation, additional mass (passenger+luggage) and rail-wheel friction coefficient were configurable as input parameters according to the requirements from R4F stakeholders. Actual vehicle speed, track position, track excitation (left & right) and vertical deflection of primary springs implemented in the bogies come as outputs for further life time calculation of the MBS vehicle in the R4F Platform.

For this use case, the track was kept as short as possible, because we only wanted to succeed the implementation methodology out of large-scale simulation in this case. The MBS model is simulated with different scenario parameters to test the feasibility of various scenarios such as curved, straight or high-load drive. It was simulated both as a Simpack model and as FMU container. Table 1 shows the entire parameter variation, which is applied to the simulation test and created under ViV's assistance.

Scenario Parameter	Parameter Variation						
Track radius [m]	300	500	700	900	1200	1500	10.000 (straight drive)
Track superelevation [m]	0,15	0,15	0,10	0,10	0,05	0	0
Vehicle Speed [m/s]	$v = \sqrt{r \times (0{,}6 + 9{,}81 \times (u/1{,}5)}$						120/3,6
Additional mass [kg]	Crowded (approx. 200 passengers, ≈+15.000 kg		Few people (approx. 100 passengers, ≈+7.500 kg		None		
Rail-wheel friction coefficient [-]	0,10 (winter: rainy, wet)			0,35 (summer: dry)			

Table 1: Scenario parameter variation for the simulation test of the MBS vehicle

6.1.2 ML-based Surrogate Model of the MBS Vehicle

A holistic railway infrastructure DT platform is sophisticated and consists of a series of submodels (e.g., turnouts, tracks, vehicles, etc.) that are built through various methodologies and software. However, integrating these submodels into the DT platform is tremendously challenging due to considerable computational complexity, software, and interface restrictions. In this usecase, we propose to utilize a surrogate modeling approach to offer an effective solution by reducing the computation time and unifying the integration interfaces of different submodels. In this report, we designed a ML based surrogate modeling methodology for the submodel integration in the holistic railway infrastructure DT platform and illustrated the methodology through a case study. In this case study, an ML-based surrogate model for MBS of railway vehicle-track dynamics is created, which can replace the railway vehicle-track simulation executed with the MBD Simulation commercial software SIMPACK. The well-built ML model can accurately and quickly predict the vehicle-track system's dynamic responses to different track irregularities. Besides, we have validated the reliability of this methodology with input data of different dimensions and applied different algorithms used in developing the surrogate model. The developed surrogate modeling methodology shows great promise owing to its high fidelity, which is verified by the measurement data collected from the Austrian national railway track system. Furthermore, this approach can also be applied to other submodels and help to build the holistic railway DT platform collaboratively.

6.1.3 Anti-Slip Traction and Vehicle Speed Control of the MBS Vehicle

In this use case, we succeeded to control the anti-slip traction and vehicle speed of the Simpack MBS vehicle by combining it with a PID-based controller model, which is manually modeled in MATLAB/Simulink. By this, we aimed to realize more different scenarios which the vehicle potentially encounters, such as uphill, downhill, curved drive, co-accelerating and co-breaking in train stations.

All the scenario parameters mentioned in the MBS Model of a Railway Vehicle subsection are given as inputs directly to the Simpack MBS vehicle. In addition, initial vehicle speed, acceleration, desired slip and wheel radius are entered directly to the Simulink PID controller model.

Four force elements (one per each wheelset) are additionally implemented into the MBS vehicle in order for the Simulink PID model to invoke the wheelsets of the vehicle mentioned in Deliverable D1.3.5. For this, four input channels are directly assigned to the force elements and then connected to four output ports, which are created in the Simulink PID model. These four ports come from the PID controller and contain output signals of the controller. Besides, output channels, containing the actual vehicle speed and four wheel speeds of all the wheelsets, are assigned to the MBS vehicle. These output channels are then manually connected to four input ports implemented in the Simulink PID model. As a result, a closed-loop co-simulation model, consisting of both the MBS vehicle and PID model, was created.

6.1.4 RLT Calculation of a Railway Steel Bridge

This use case aims to calculate the residual life-time and damage sum of a railway steel bridge. First, we worked with a dummy bridge use case, which is a prototypical version of real RLT bridge use cases and provided from AIT. The dummy use case is visualized by VRVis in the R4F Platform (see Figure 2). The RLT calculation of the bridge is succeeded with a Python code, which is simply executed and then results are generated.

As inputs, X, Y and Z coordinates of five detail points, detail categories, influence lines, frequencies of individual trains, axle loads and distances of the individual train configurations are entered. As outputs, residual life time (years) and annual damage sum (1/year) of the bridge due to these detail points are generated from the RLT calculation.

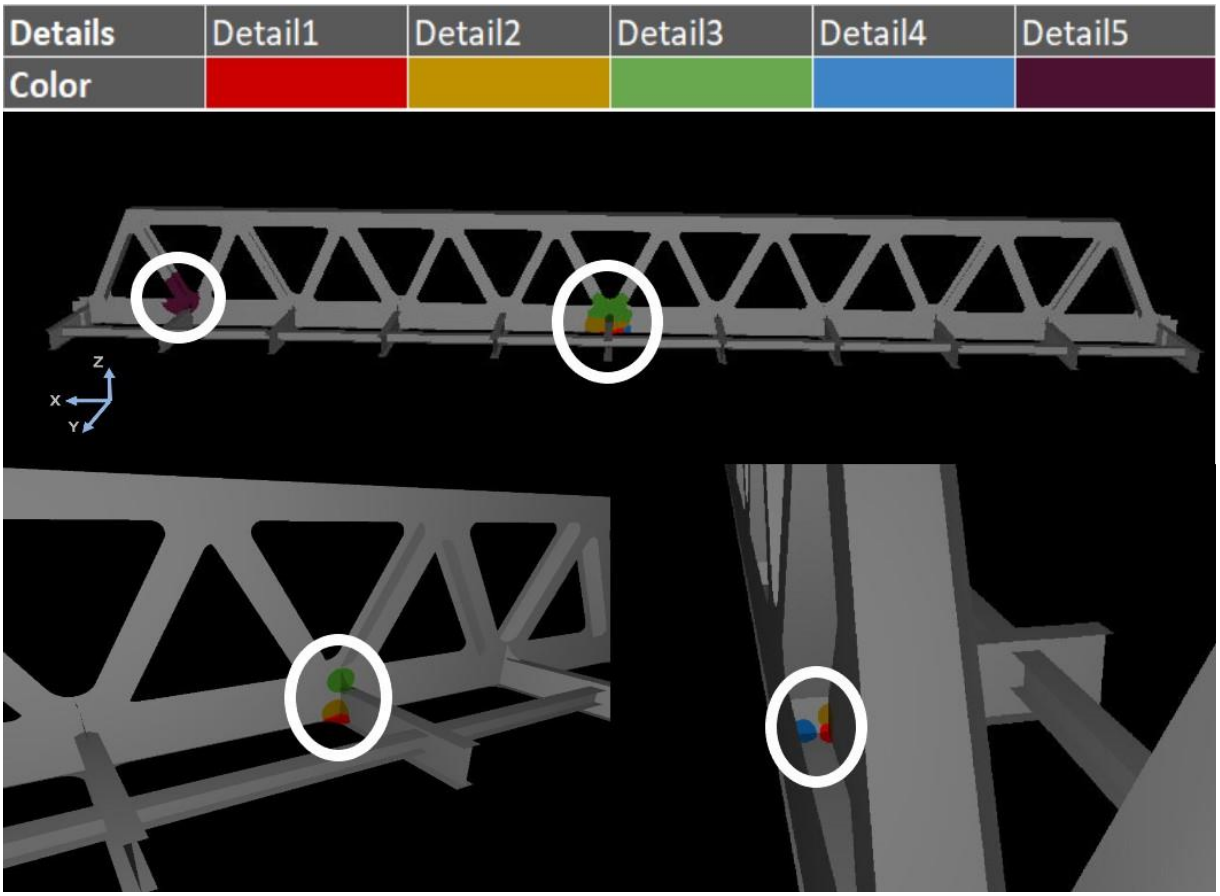

Figure 2: RLT bridge dummy use case with highlighted detail points provided from VRVis. [2]

After implementing the dummy version of the bridge, Eschenau bridge, ÖBB Mürzbrücke and Schellhammergasse bridge from Wiener Linien are implemented into the R4F Platform. In addition to the dummy use case, a boolean variable is given as an input in the Schellhammergasse use case, because simplified fatigue damage curve can be activated or deactivated by configuring this variable in this use case. Besides, there are two kinds of influence lines used for the real use cases: initial (uncalibrated) and calibrated. Except for these differences, the input and output types of the real use cases are the same as the ones of the dummy use case, only the values of the inputs and outputs are different.

6.1.5 VTI Use Case

Ballasted tracks represent the most common used type of railway tracks. Vertical track stiffness and its variation as well as the variation of vertical track geometry along the track are one of the main sources for the dynamic wheel-rail contact forces. These dynamic forces are responsible for the development of the track geometry. Thus, models predicting the evolution of vertical track irregularities are of high interest e.g. investigations regarding vehicle dynamics, to assess the track-friendliness of vehicles or for better designing and maintaining railway tracks. Therefore, the vehicle-track interaction (VTI) model was developed to study the long-term behavior of railway tracks. [4]

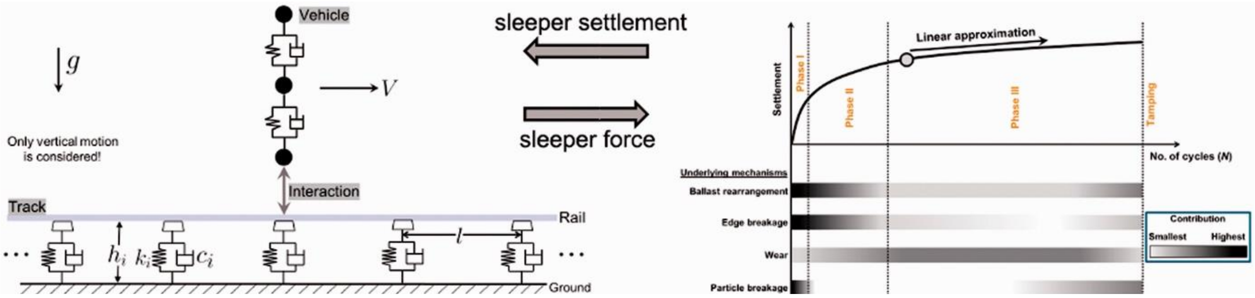

Figure 3: The modelling approach. On the left side the Vehicle-Track-Interaction (VTI) model and on the right side the sleeper settlement model. [4]

Figure 3 shows the modelling approach. The vehicle and track system are shown in the left part. The track model considers the discrete support of the elastic rail, where each sleeper support can have its own stiffness, relative height and settlement behavior. The vehicle model represents an 8th of a car and considers only vertical dynamics. The initialization of the track model is done using the measured vertical static track deflection and track geometry. If these measurements are not available, assumptions need to be made. On this initialized track, an 8th vehicle runs with constant speed. After the vehicle pass, a load history is obtained for each sleeper due to dynamic interaction between vehicle and track. The peak sleeper force is used as an input in the right part of Figure 3 to obtain the incremental sleeper settlement dependent on the number of vehicle passes (load cycles). This loop is repeated to obtain the track geometry evolution for the considered track and is visualized in a flowchart in Figure 4. [4]

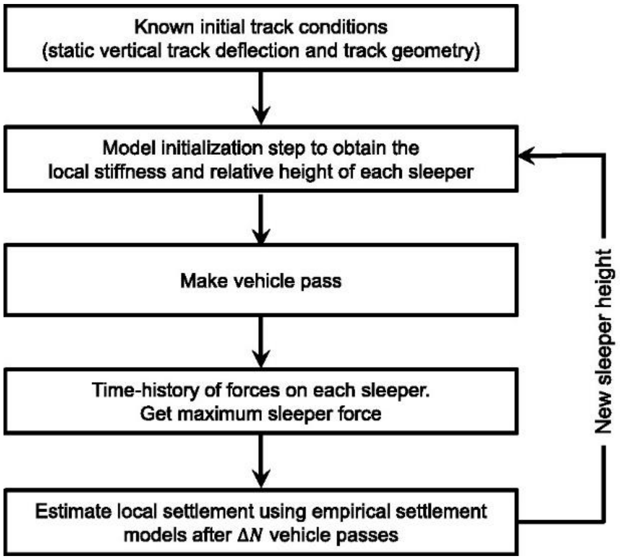

Figure 4: Flowchart of the VTI model simulation methodology for calculating the evolution of track geometry. [4]

6.2 General Information and Status of all Use Cases

In Table 2 and 3, all the input parameters, outputs, simulation configurations and additional remarks (e.g. simulation runtime, additional modeling), applied to the successfully implemented use cases, are listed.

Use Case	**Input [Unit]**	**Output [Unit]**
MBS Vehicle	* Initial Vehicle Speed [km/h] * Additional Mass (passenger+luggage) [kg] * Track Curve Radius [m] * Track Superelevation [m] * Rail-Wheel Friction Coefficient [-]	* Vertical Deflection [m] * Actual Track Excitation [m] (left & right)
ML-based Surrogate Model for MBS Vehicle	* Track Irregularities [m] (vertical, horizontal, cross-level) * Speed [km/h] * Curvature [Degree]	* Actual Wheelset Forces [N] * Vehicle Acceleration [m/s^2]
Anti-Slip Traction and Vehicle Speed Control	* The same as the MBS Vehicle + * Desired Slip [-] * Vehicle Acceleration [m/s^2] * Wheel Radius [m] * P-, I-, D- and N-Constants [-]	* Wheel Speed [1/s] * Actual Vehicle Speed [m/s] * Actual Slip [-] * Controller Signal [-] * Vertical Deflection [m]
RLT Bridge	* X, Y and Z Positions of Detail Points [m] * Influence Lines [N/mm^2/kN] * Detail Category [N/mm^2] * Distances and Axle Loads of Individual Trains [m, N/mm^2] * Frequencies of Individual Trains [-/year]	* Life Time [years] * Damage Sum [-/year]
VTI Use Case	* Vertical deflection measurement [mm] * Vertical track geometry measurement [mm] * 1/8th vehicle parameters (masses [kg], spring [kN/m] and damping coefficients [kNs/m]) * Vehicle speed [km/h] * Sleeper properties (dimensions [m], type [-], spacing [m], density [kg/m³] * Rail properties (young’s modulus [N/m²], area moment of inertia [m^4], cross-sectional area [m²], density [kg/m³], damping coefficients [s] and [1/s]	* Vertical track geometry development including settlement [mm] * Forces on the simulation components [N] * Displacements [m], velocities [m/s] and accelerations [m/s²] of the simulation components * Rail deflection [mm] and [°]

Table 2: Configuration table showing the input and output data of the use cases.

Use Case	Model Structure	Simulation Configurations	Additional Remarks
MBS Vehicle	Simpack MBS Model	* FMI 2.0 for Co-Simulation * Solver: SODASRT 2 * Simulation Step Size: variable	* Track Length: 900 m * Simulation Runtime in Jenkins Pipeline: 5-6 Min.
ML-based Surrogate Model for MBS Vehicle	Python Code	* FMI 2.0 for Co-Simulation * Simulation Solver Integration Method: SODASRT 2 * Sampling Rate: 2000 Hz	* Track Length: 900 m * Simulation Runtime in Jenkins Pipeline: 3 Sec
Anti-Slip Traction and Vehicle Speed Control	Simpack MBS Model + Simulink PID-based Model	* FMI 2.0 for Co-Simulation * SSP 1.0 * Dormand-Prince Solver, simulation step size 10^-3 variable * Simulation Step Size: 10^-4 fixed (for SSP Simulation)	* Track Length: 180 m * Simulation Runtime in Jenkins Pipeline: 5-10 Min. (10^-3 Step Size) 15-20 Min. (10^-4 Step Size)
RLT Bridge	Python Code	* FMI 2.0 for Co-Simulation * Simulation Step Size: 10^-2, fixed	* Simulation Runtime in Jenkins Pipeline: max. 5-10 Sec.
VTI Use Case	Matlab Model	* Requires optimization and signal processing toolbox	* Requires settlement parameter tuning for proper track geometry and settlement predictions

Table 3: Implementation table showing the successfully implemented use cases with key data.

In Table 4, the current status of all the use cases considered for the R4F project is summarized as an overview.

Use Case	Applied to the R4F Platform	Visualized
MBS Vehicle	Yes	Not planned
ML-based Surrogate Model	Yes	Not planned
Anti-Slip Traction and Vehicle Speed Control	Yes	Not planned
RLT Bridge	Work in progress	Work in progress
VTI Use Case	Yes	Yes
Tunnel	Work in progress	Not planned
Track Wear	Yes	Yes
Track Crack Formation	Work in progress	Yes
Plasticity Turnout Centerpiece	Not planned	Not planned
Turnout	Not planned	Not planned

Table 4: Status table showing all the use cases considered for the R4F Project.

7 Conclusion

This deliverable aimed to show and describe use cases successfully implemented into the R4F Platform by using the interfaces and adapters specified in Deliverable D1.1.4. Even if not all defined use cases are completely implemented (e.g. because of lack of visual description), the use cases achieved so far show a lot of the feasibility and applicability of the railway use case implementation in the platform. Furthermore, even without visualization tools the implemented use cases are still useful for engineers which can export the data for further analysis.

In the deliverable 1.1.6 we will present simulation deployment results and their validated version coming from the use cases successfully implemented in the R4F Platform. This will help to ensure the reliability of the use case implementation in the platform. Surely, it will assist infrastructure managers and train operators to get comprehensive insights into the virtual environment of the railway infrastructure for their condition monitoring and predictive maintenance work.

8 References

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