Universal Cost Model Bogie 2.0

Assessing Innovative Solutions on System Level

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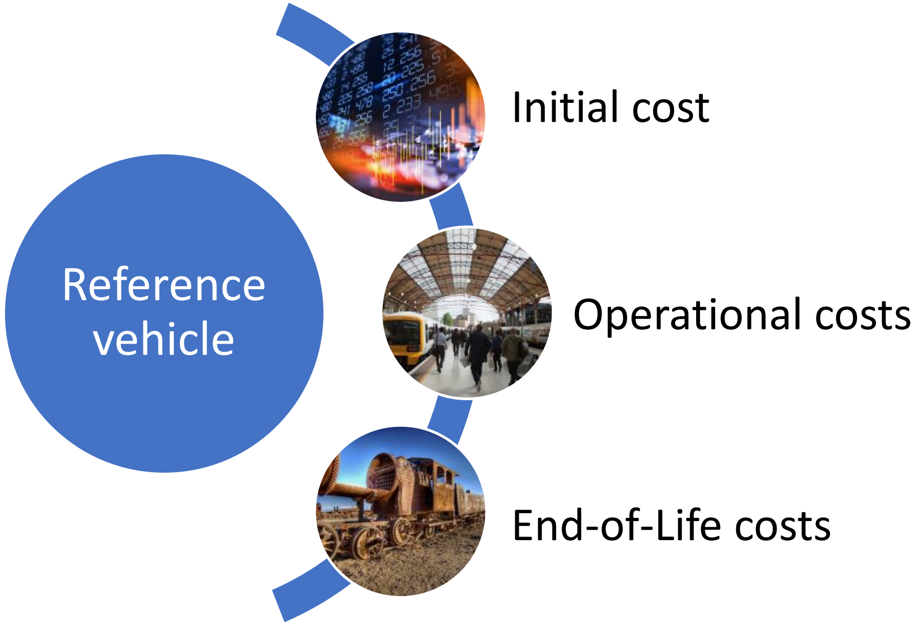
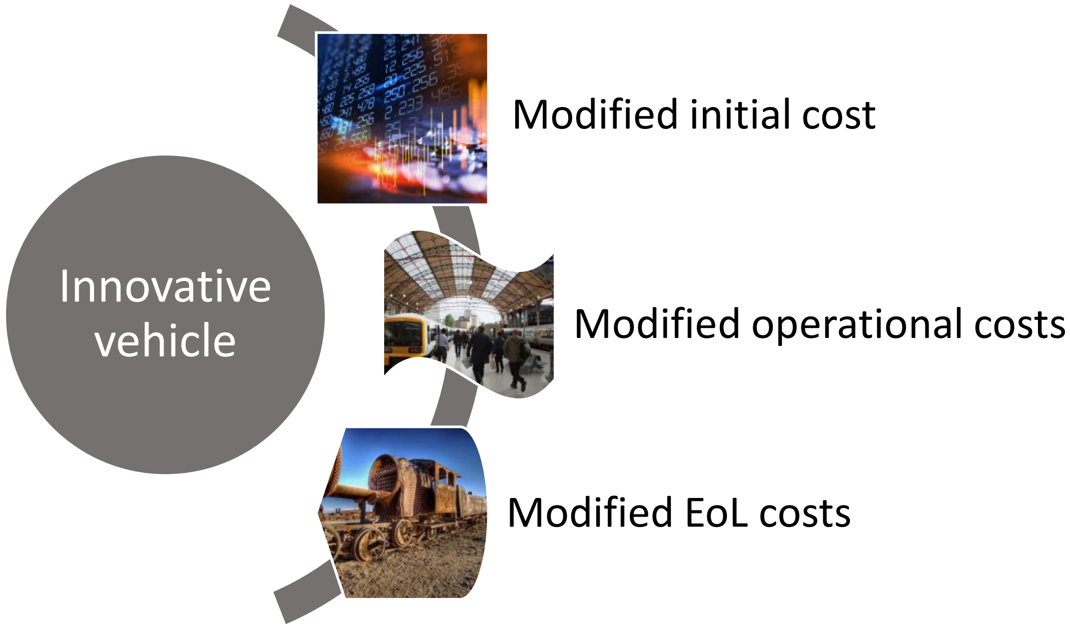
Assessing the Total Cost of Ownership for Bogies

In 2016, we presented ideas on how to assess the Total Cost of Ownership for Bogies on system level.

Today, we want to present what has happened in the follow-up and also the “result”.

Motivation for a Cost Model Tool

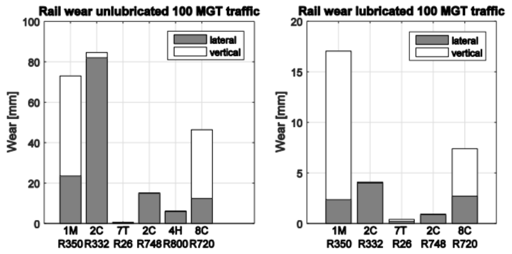




Development of the Universal Cost Model

- Delivered a high sophisticated modelling surrounding
- The model could calculate a lot – having access to the input data necessary
- The calculation “software” (excel-based) was complex according to the degree of details
- Not being fully into the UCM, it was hard to be used

The infrastructure module was a construction site even after the end of the project.



3.3.6 Vertical track settlement

Two validation case studies have included the calculation of vertical settlement; VC2 for a railway line in Sweden and VC8 for a railway line in the United Kingdom. From comparing the results from the two studies, it could be observed that there was a big difference in tamping frequency on the two lines: for VC2 tamping takes place every 8-9 years for a traffic load of 5 MT per year and for VC8, tamping takes place every 1.9 years with a traffic load of 7.8 MT per year. It can therefore be concluded that for the vertical settlement module, the calibration of the model with historical data is critical. Without a calibrated model, the results can differ too much from reality and even when used in a relative way, one should question the reliability.

2 examples:

The simulation of the wheel-rail-interface using different simulation approaches delivers very different results (e.g. rail wear in the diagram shown.
→ technical input to the UCM → financial output?

The calculation (simulation) of ballast settlement is in its infancy. We all know, there are (too) many aspects influencing the settlement → the approach couldn’t be verified or it is simply not reliable.

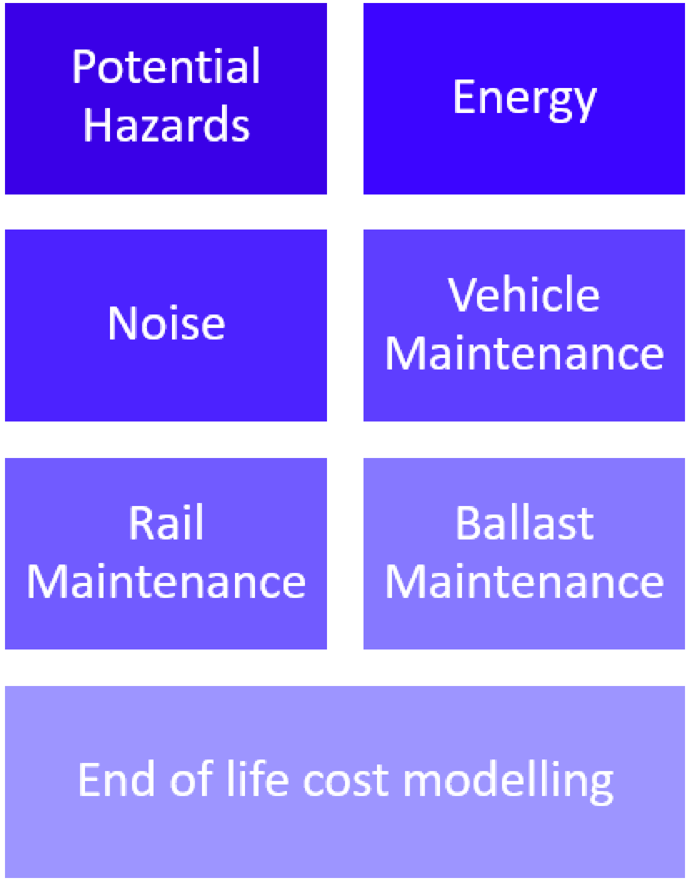
Development of the Universal Cost Model 2.0

The tasks for the overhaul of the UCM within the Next Gear project:

- A simplified damage prediction model for switches that is useful for cost calculations
- A simplified damage prediction model for track settlement that is useful for cost calculations
- A UCM that utilises the best aspects of engineering and economic approaches to cost calculations
- A UCM where simplicity and precision are balanced; easy to use and scientifically accurate. The modelling approach places user feedback and engagement at the heart of our approach
- A new user interface, default values to use in case input is missing and better explanations on how to use the UCM

Development of the Universal Cost Model 2.0 – the Plan

UCM tool modules and simulation of Performance Inputs (PI)



- Potential hazards
- Energy
  - CO2 cost modelling
- Noise
  - Accurate costs modelling
- Vehicle maintenance
  - New maintenance-based PI
  - Single method for damage calculation
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  - Rail damage simulation and costs
  - Switch damage simulation and costs
- Ballast maintenance
  - Ballast maintenance modelling and costs
- End of life cost modelling

UCM tool – Excel based

UCM 2.0 - Baseline Case Selection

UCM 2.0

The Universal Cost Model (UCM) is a comparison framework that accounts for all aspects of running gear innovations that influence the whole railway system's Life Cycle Costs (LCC). It is a simulation-based framework – and accompanying tools – that enable the comparison of a reference vehicle against an innovative one, showcasing the differential costs and benefits of said innovation in the railway system.

This UCM2.0 is a new version of the previous UCM which was developed in the EU project Roll2Rail. As the previous version its framework and model is Excel based. The Case Selection is the landing page in which the user selects the System Platform Demonstrator (SPD) and is able to define two additional Cases (Case 1 and Case 2) which are then compared to it and quantified in the “Results and Visualization” sheet.

The rest of the tool excel sheets constitute the simulation framework which calculates the different cost drivers, or Performance Inputs. These are costs related to: Hazards, Energy, Noise, Vehicle Maintenance, Rail and Ballast Maintenance and calculated in the different modules (excel sheets). These modules r inputs for the calculations. Some of these inputs are called "Global inputs" when they are shared by different modules and therefore are taken directly from th "Case Selection Sheet". Others are called "module inputs" as they are specific to a certain module and require data from the user and in some cases some calculations to be carried out beforehand . There are guidelines on how to carry out the simulations in order to obtain the different module inputs summarised a specific document (see ref,)

Grant agreement ID: 881803
Call: H2020-EU.3.4.8.1. - Innovation Programme 1 (IP1): Cost-efficient and reliable trains
Topic: S2R-OC-IP1-02-2019 - Tools, methodologies and technological development of next generation of Running Gear

Case Selection

The UCM 2.0 is populated with all the necessary information for a baseline case.
These baseline cases are Urban, Intercity, and High Speed, based on the SPDs developed in S2R IMPACT-2 project [IMP2-WP4-D-DLR-008-02]

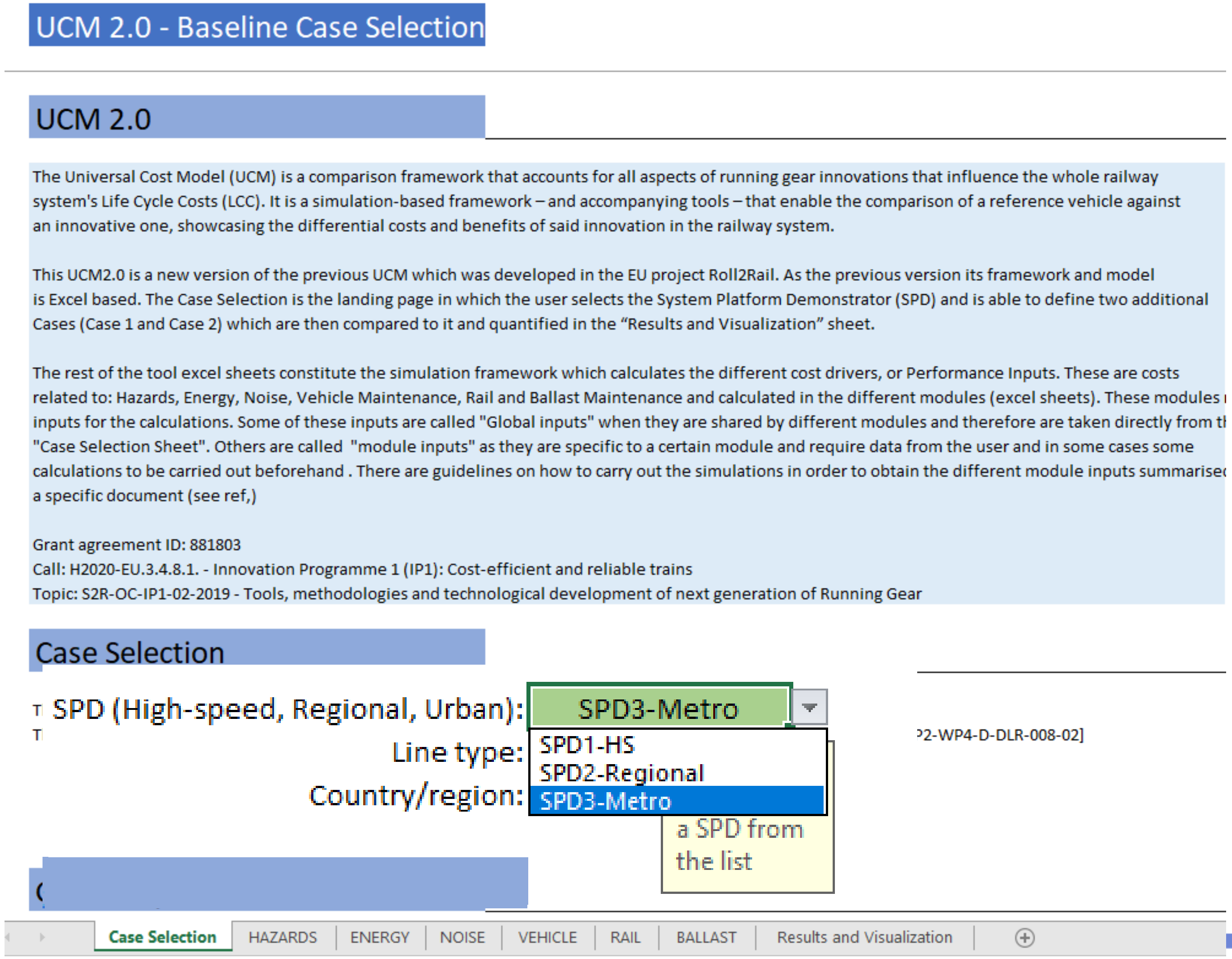
SPD (High-speed, Regional, Urban):	SPD3-Metro
Line type:	Straight
Country/region:	Sweden

Global Inputs

Case Selection | HAZARDS | ENERGY | NOISE | VEHICLE | RAIL | BALLAST | Results and Visualization

Landing Page!

UCM tool – Excel based



Landing Page!

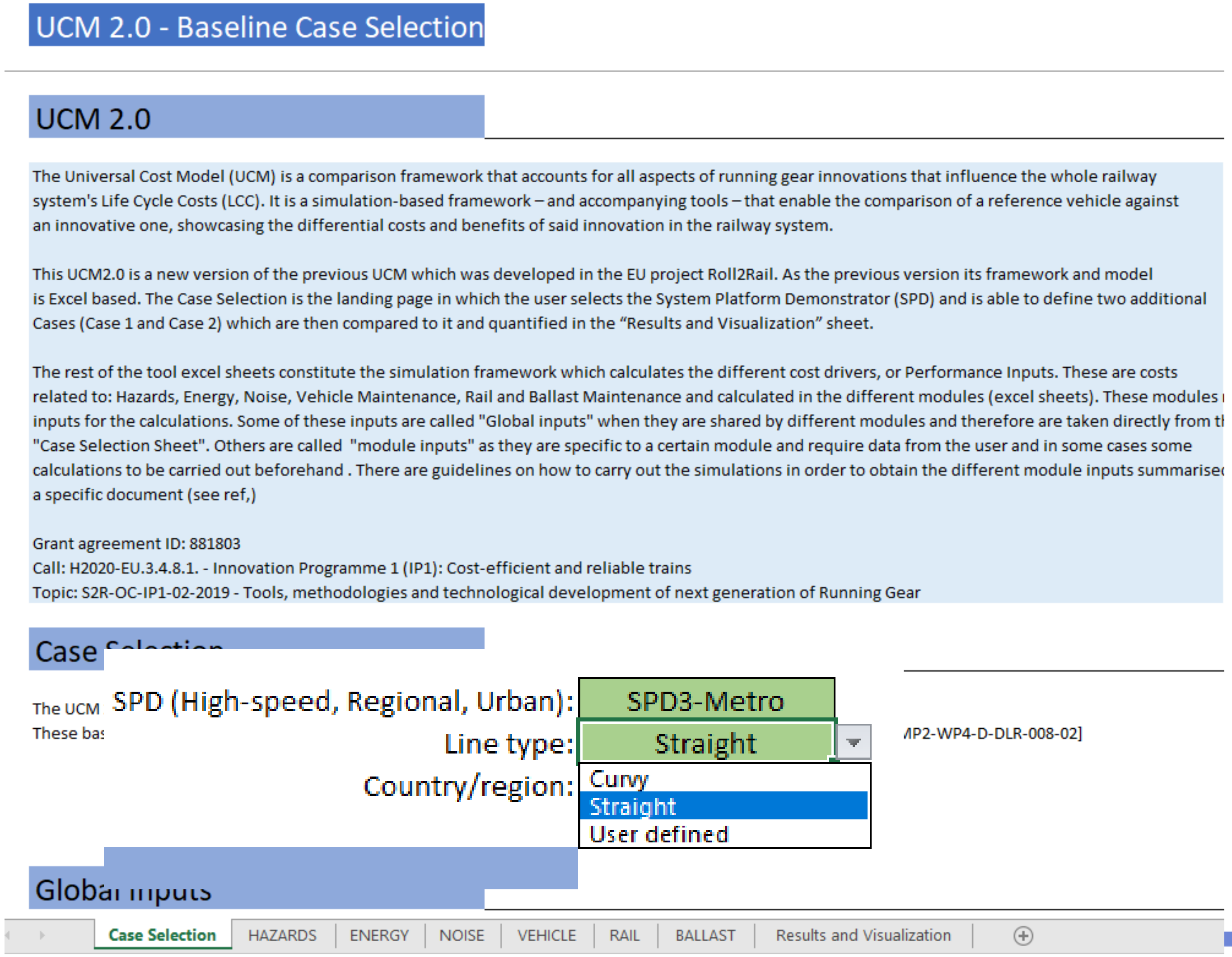
Case Selection

SPD System Performance Demonstrators

High-speed – Regional - Urban

SPDs define also a reference vehicle!

UCM tool – Excel based



Landing Page!

Case Selection

SPD System Performance Demonstrators

High-speed – Regional - Urban

SPDs define also a reference vehicle!

Line type:

Curvy – Straight – User defined

Country:

Cost level

UCM tool – Excel based

UCM 2.0 - Baseline Case Selection

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Case Selection | HAZARDS | ENERGY | NOISE | VEHICLE | RAIL | BALLAST | Results and Visualization

Landing Page!

Case Selection
SPD System Performance Demonstrators
High-speed – Regional - Urban

SPDs define also a reference vehicle!

Line type:
Curvy – Straight – User defined

Country:
Cost level

UCM tool – Excel based

UCM 2.0 - Baseline Case Selection

Global Inputs

This section gets populated once an operational case and a Country are selected in the previous section.
The user can modify the input information by adding their own values to the cells for Case 1 and Case 2.
If the cells for Case 1 and Case 2 are left empty, the default value defined in the SPD is used for the calculations.

Simulation Inputs

Global inputs - Vehicle	***I***	***SPD3-Metro***	***Case 1***	***Case 2***
Number of units per vehicle (-)	u_V	6		
Number of seats per train (-)	seats	1000		
Wheelsets per vehicle (-)	N_w	24		
Vehicle mass (ton)	M_v	192		

Global inputs - Operation	***I***	***SPD3-Metro***	***Case 1***	***Case 2***
Number of vehicles in the case study (-)	N_v	24		
Distance run per vehicle per year (km)	D_y	120000		
Percentage of track usage by the studied vehicles (-)	V_per	1		
Years of use for the case study (-)	Y	30		

Global inputs - Infrastructure	***I***	***SPD3-Metro***	***Case 1***	***Case 2***
Track length A-B (km)	tr_leng	21,5		
Type of track, single (1) or double (2)	T_t	2		
% length of curves (-)	C_per	0,292		

Case definition data

In this section the information needed for the definition of the baseline cases is introduced. The user cannot enter own data here.

System Platform Demonstrators input

Case Selection | HAZARDS | ENERGY | NOISE | VEHICLE | RAIL | BALLAST | Results and Visualization

Global Input
Vehicle
Operation
Fleet

Modules

Results and Visualization

UCM tool – Excel based

LCC RESULTS	€ 14 026 518	€ 14 015 907	€ 14 017 450
	SPD3-Metro	Case 1	Case 2

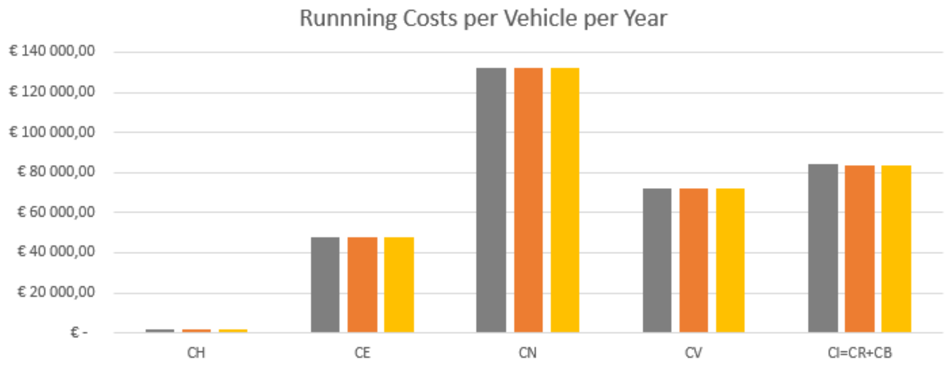
€/fleet/year

Costs

The costs for the whole life cycle of the vehicle are the sum of three concepts: the initial investment costs, the end-of-life costs, and the running costs.

Operational costs

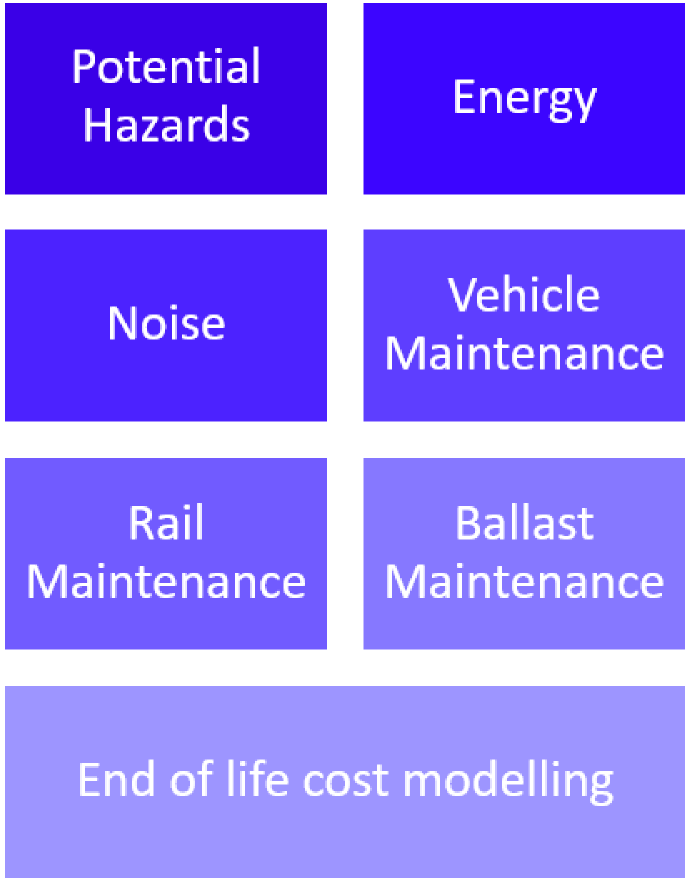
Cost Description	*C*	*SPD3-Metro*	*Case 1*	*Case 2*
Hazards	CH	€ 1 800,00	€ 1 800,00	€ 1 800,00
Energy	CE	€ 47 837,73	€ 47 837,73	€ 47 837,73
Noise	CN	€ 132 227,77	€ 132 227,77	€ 132 227,77
Vehicle	CV	€ 72 000,10	€ 72 000,10	€ 72 000,10
Rail	CR	€ 21 119,97	€ 20 698,91	€ 20 760,12
Ballast	CB	€ 63 011,12	€ 63 011,12	€ 63 011,12



Case Selection | HAZARDS | ENERGY | NOISE | VEHICLE | RAIL | BALLAST | **Results and Visualization**

Results modules: €/vehicle/year

UCM tool modules



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UCM tool modules and simulation of Performance Inputs (PI)

RAIL MAINTENANCE MODULE

	SPD3-Metro	Case 1	Case 2	
	€ 21 120	€ 20 699	€ 20 760	€/vehicle/year

Performance Inputs

Cost due to different types of Vehicle Damage is calculated based on the following Performance Inputs:

Performance Input Description	*PI*	*SPD3-Metro*	*Case 1*	*Case 2*
Rail grinding interval, curves (MGT)	PI_GIC	15,00		
Rail grinding interval, straight track (MGT)	PI_GIS	45,00		
Average rail grinding depth, curves (mm)	PI_GDC	3,00		
Average rail grinding depth, straight track (mm)	PI_GDS	2,00		
Switch reprofiling/grinding (MGT)	PI_SwIG	110,00	254,17	217,86
Switch rail replacement (MGT)	PI_SwIR	392,00	508,25	508,25
Switch Deburring (MGT)	PI_SwID	36,00	46,81	46,81
Crossing weld repair (MGT)	PI_XgIW	201,00	192,02	189,59
Crossing rail replacement (MGT)	PI_XgIR	252,00	240,03	236,99

The user can input their own simulated Pis for Case 1 and Case 2 in order to compare different vehicle designs.
See the *Simulation Guidelines* document for further information on the simulation of Pis.

separate Simulation Guidelines

Cost calculation

The module calculates the costs of Rail Grinding based on the number of actions, depth of each grinding action, and grinding costs.
It considers how many times the rail can be grinded before needing a rail replacement.
It is simplified so that decimal values are used.
For a full description of the calculation procedure refer to the User Manual.

$$CG = CRgr * N^{gr} + CRrepl * N^{repl} \quad \text{(R.1)}$$

$$N^{G} = \frac{MGT_y}{PI\_GIC} * \frac{1}{V_{per}} \quad \text{(R.2)}$$

$$N^{repl} = N^{G} * \frac{PIGDC}{dMat_{max}} \quad \text{(R.3)}$$

Case Selection | HAZARDS | ENERGY | NOISE | VEHICLE | RAIL | BALLAST | Results and Visualization

9 Performance Indicators

5 PIs as default values

Simulation!

UCM tool modules

Potential Hazards	Energy
Noise	Vehicle Maintenance
Rail Maintenance	Ballast Maintenance
End of life cost modelling	

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UCM tool modules | ballast maintenance modelling

BALLAST MAINTENANCE MODULE

	€ 63 011	€ 63 011	€ 63 011	
	SPD3-Metro	*Case 1*	*Case 2*	€/vehicle/year

Performance Inputs

Cost due to different types of Ballast Maintenance is calculated based on the following Performance Inputs:

Performance Input Description	*PI*	*SPD3-Metro*	*Case 1*	*Case 2*
Unsprung mass [kg/wheel]	PI_UM	620,00		

Cost calculation

The module calculates the costs of ballast maintenance of track and S&Cs (tamping, ballast cleaning, and small maintenance).
Also Ballast cleaning/renewal at the time of re-investment can be considered (optinal, pre-setting = "no")

There are no Performance Indicators needed. The vehicle input is the static wheel load plus a speed dependent dynamic supplement. The P2-force as defined in the GB Railway Group Standard GMRT2141 (Issue 4, 2019) is used, in which only static wheel load, unsprung mass per wheel, and speed are variables. (See Deliverable 1.1)

$$P_{2V} = Q + (A_z \times V_m \times \left[\frac{M_v}{M_v + M_z}\right]^{0.5} \times \left(1 - \left(\frac{\pi \times C_z}{4 \times [K_z \times [M_v + M_z]]^{0.5}}\right)\right) \times (K_z \times M_v)^{0.5})$$

P2-forces are calculated for 8 speed ranges and 4 radii ranges. For the cost calculation every single axle counts. The damage mechanism is approached by a power of 3.
The P2-forces are reference loadings. They are calculated using the values underlayed for this approach.
With inserting vehicle weight, number of axles and unsprung mass per wheel, the UCM calculates the reference loads.
The cost increments (c0 for ballast renewal and c1 for ballast maintenance, both in €/kN³km) are pre-calculated with a reference loading.
Maintenance frequencies are pre-set for a standard concrete sleeper track with 60E1 rails on medium ballast quality and good subsoil and drainage condition. These track properties can be varied.
Costs of unavailabilty of track can be addressed optional.
The costs per vehicle-kilometre is a weighted average according to the speed and radii distribution of the line.

$$CB = D_y \cdot \sum \frac{\%_v}{R} \cdot N_w \cdot \frac{P2_V}{R^3} \cdot (c_{0R} + c_{1R})$$

Case Selection | HAZARDS | ENERGY | NOISE | VEHICLE | RAIL | **BALLAST** | Results and Visualization

No Simulation!

1 Performance Indicator

Simulating ballast behaviour is in its infancy!

Simulation of settlement needs input on ballast material, subsoil quality, drainage functionality, sleeper type, rail profile, maintenance machinery, …

↓

Modelling!

UCM tool modules | ballast maintenance modelling

BALLAST MAINTENANCE MODULE

	SPD3-Metro	Case 1	Case 2	
	€ 63 011	€ 63 011	€ 63 011	€/vehicle/year

	Cost Increments	c0	c1
R>1,000m	1,96692E-09	0,000E+00	1,967E-09
600m<R<1,000m	1,98361E-09	0,000E+00	1,984E-09
400m<R<600m	2,66173E-09	0,000E+00	2,662E-09
250m<R<400m	3,81584E-09	0,000E+00	3,816E-09
R<250m	7,2931E-09	0,000E+00	7,293E-09

		SPD3-Metro	Case 1	Case 2
	48%	0,42	0,42	0,42
	5%	0,03	0,03	0,03
	7%	0,02	0,02	0,02
	30%	0,05	0,05	0,05
	0%	0,00	0,00	0,00
	6%	0,00	0,00	0,00
	0%	-	-	-
	3%	0,00	0,00	0,00
	0%	0,00	0,00	0,00
	0%	0,00	0,00	0,00
	0%	-	-	-
	0%	-	-	-
Line	100%	0,53	0,53	0,53

Case Selection | HAZARDS | ENERGY | NOISE | VEHICLE | RAIL | BALLAST | Results and Visualization

Maintenance frequencies are pre-set for a standard concrete sleeper track with 60E1 rails on medium ballast quality and good subsoil and drainage condition. These track properties can be varied.

Costs of unavailabilty of track can be addressed optional.

The costs per vehicle-kilometre is a weighted average according to the speed and radii distribution of the line.

$$CB = D_y \cdot \sum \frac{\%_v}{R} \cdot N_w \cdot \frac{P2_V}{R^3} \cdot (c_{0R} + c_{1R})$$

Case Selection | HAZARDS | ENERGY | NOISE | VEHICLE | RAIL | BALLAST | Results and Visualization

Based on previous works (Swiss Wear Factor, tamping demand modelling for High-speed and heavy-haul), we use as reference load the P2-force with the power of 3.

The cost increments (= €/kN³km) are precalculated from a mixed-traffic vehicle collective.

The % of curves and speed levels are taken from the landing page.

UCM tool modules | ballast maintenance modelling

Calculation Options

The following inputs are are used for the calculation of the Module costs.

Global Inputs

These are defined in the ***Case Selection*** page and cannot be modified here as they affect different Modules.

Global inputs				
Track Properties		Standard		
		SPD3-Metro	***Case 1***	***Case 2***
Distance run per vehicle per year (km)	D_y	120 000,00	120 000,00	120 000,00
Vehicle weight [t]	Pl_UM	192,00	192,00	192,00
Number of axles [-]	N_w	24,00	24,00	24,00

Module Options

In order to adjust the module to User needs, the following options are available:

Include costs of reinvestment (ballast cleaning)	no
Include costs of track un-availabilty	yes

Track Characteristic active						
Track Radius	**Ballast**	**Subsoil**	**Drainage**	**Sleeper**	**Rail Profile**	**Rail Steel Grade**
R>1,000m	medium	good	good	concrete	60EX	R260
600m<R<1,000m	medium	good	good	concrete	60EX	R260
400m<R<600m	medium	good	good	concrete	60EX	R260
250m<R<400m	medium	good	good	concrete	60EX	R260
R<250m	medium	good	good	wooden	54EX	R260

Case Selection | HAZARDS | ENERGY | NOISE | VEHICLE | RAIL | BALLAST | Results and Visualization

Track properties are set to “Standard” in the tool.

Heavy superstructure on good subsoil and proper drainage.

UCM tool modules | ballast maintenance modelling

Calculation Options

Track Characteristic						
active						
Track Radius	**Ballast**	**Subsoil**	**Drainage**	**Sleeper**	**Rail Profile**	**Rail Steel Grade**
R>1,000m	medium	good	good	concrete	60EX	R260
600m<R<1,000m	medium	good	good	concrete	60EX	R260
400m<R<600m	medium	good	good	concrete	60EX	R260
250m<R<400m	medium	good	good	concrete	60EX	R260
R<250m	medium	good	good	wooden	54EX	R260
Standard						
Track Radius	Ballast	Subsoil	Drainage	Sleeper	Rail Profile	Rail Steel Grade
R>1,000m	medium	good	good	concrete	60EX	R260
600m<R<1,000m	medium	good	good	concrete	60EX	R260
400m<R<600m	medium	good	good	concrete	60EX	R260
250m<R<400m	medium	good	good	concrete	60EX	R260
R<250m	medium	good	good	wooden	54EX	R260
Generic - CHOOSE FROM THE DROP-DOWN LIST | CELL D67 must be on "Generic"						
Track Radius	Ballast	Subsoil	Drainage	Sleeper	Rail Profile	Rail Steel Grade
R>1,000m						R260
600m<R<1,000m						R260
400m<R<600m						R260
250m<R<400m						R260
R<250m						R260

good
poor
good
poor
good
concrete
concrete
crete
crete USP
den
wooden

Track Radius						Rail Steel Grade
R>1,000m	good	good				R260
600m<R<1,000m	medium	poor	poor	concrete USP	54EX	R350HT
400m<R<600m	poor			wooden	49EX	R400
250m<R<400m						
R<250m						

Case Selection | HAZARDS | ENERGY | NOISE | VEHICLE | RAIL | **BALLAST** | Results and Visualization

Changing to "User-defined", we can change the track properties.

The user can change the superstructure components and substructure issues by drop-down menus to these options.

UCM tool modules | ballast maintenance modelling

Other options included:

- Consider the cost of ballast cleaning (end of life) as well
- Insert cost figures for ballast maintenance works
- Consideration of costs of non-availability of track

Note: ballast maintenance costs for S&Cs are included (input: number and size of S&Cs → Case definition)

The calculation of the PI's incremental costs is performed automatically.

In this way, we ensure that simplicity and precision are balanced and a tool that is easy to use and scientifically accurate.

Universal Cost Model 2.0 – Summary & Outlook

Simulation framework

- S&C simulation procedure has been developed
- Balance between accuracy and simplicity is challenging
- Normalised damage calculation package provided with the UCM 2.0
- Simulation Guidelines for consistency in the simulations

UCM tool

- Integration of all the proposed costs in an excel-based tool
- Simplicity and user friendliness systematically pursued, e.g. no macros
- SPD-based baseline cases with a complete set of default values, including references

Further work

- Extensive peer-review of the tool is needed
- Simulation-based add-on for ballast settlement damage
- Pursue the validation of a non-iterative wheel damage calculation method

Thank you

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