



Predicting wear of railway profiles

The approaches, mathematical models and corresponding tools used in the "Universal mechanism" software for predicting wear of wheel and rail profiles are considered

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16. Predicting wear of wheel and rail profiles

The evolution geometry of railway profiles due to wear has a deep effect on the vehicle dynamics. This, in turn, affects many performances, the main of which are vehicle stability, ride comfort and derailment safety.

Algorithms of predicting rail/wheel wear, implemented in Universal Mechanism software (UM), are based on the experimental relationship between the volume of removed material by wear and the frictional work in contact [1] [2]. The following wear models are implemented in UM: *Archard model* [3], *Archard model with wear coefficient map* [1] and *Specht model* [4].

- Archard model.

The Archard model uses a linear relationship between volume wear and the work of frictional forces:

$$W = k_V A, \quad (16.1)$$

where k_V is a wear coefficient, A is the friction work.

$$A = \int_0^t P dt, \quad (16.2)$$

where P is power of frictional forces.

$$P = \int_F \boldsymbol{\tau} s dF, \quad (16.3)$$

where $\boldsymbol{\tau}$ is tangential traction, s is sliding velocity, F is the contact patch area.

- Archard model with wear coefficient map

Volume wear is calculated as follows:

$$W = k_V \frac{Ns}{H}, \quad (16.4)$$

where N is the normal force, s is sliding distance, H is the hardness of the softest contacting surfaces. The wear coefficient k_V is determined by the map in Figure 16.1.

- Specht model.

In the Specht model also linear relationship between volume wear and the work of frictional forces is used. But it is assumed that there exist mild and severe wear regimes with different wear coefficients.

$$W = \begin{cases} k_V A, & p < p_{kp}, \\ k_V \gamma A, & p \geq p_{kp}, \end{cases} \quad (16.5)$$

where p_{cr} is a critical power density of frictional forces, γ is a jump coefficient.

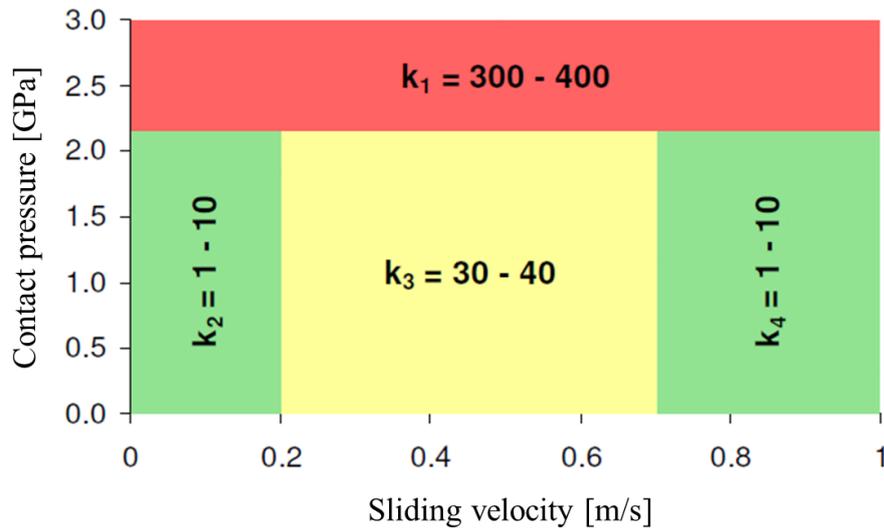


Figure 16.1. Wear coefficient map

The **UM Loco** module uses the FASTSIM algorithm to solve the tangent contact problem. In the FASTSIM algorithm, the contact patch is discretized into equal width strips parallel to the x -axis, which in turn are divided into an equal number of elements, Figure 16.2. Volume wear is calculated for each element according to expressions (16.1) and (16.4) as follows:

$$W_{ij} = k_v \tau_{ij} v w_{ij} \Delta F_{ij} \Delta t, \tag{16.6}$$

where v is the wheelset velocity, w_{ij} is the creep in the center of the element, ΔF_{ij} is the area of the element, Δt is the integration time step size;

$$W_{ij} = k_v \frac{p_{n_{ij}} \Delta F_{ij}}{H} |w_{ij}| \Delta x_j, \tag{16.7}$$

where $p_{n_{ij}}$ are normal pressures in the center of the element, Δx_j is the element size along the x -axis.

The total wear accumulated in the strip is obtained by summing all elements of the strip.

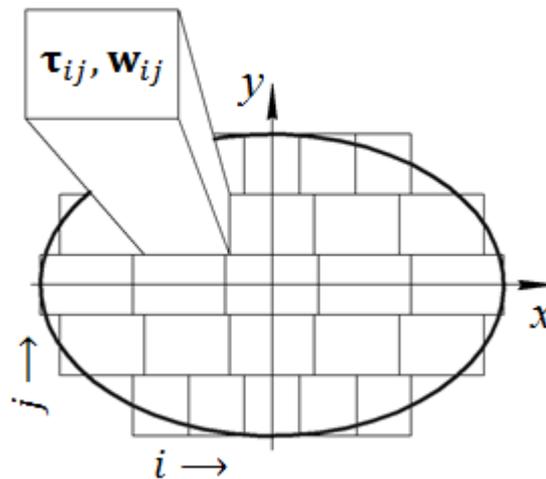


Figure 16.2. Discretization of the contact patch in the FASTSIM algorithm

The above ratios allow you to calculate the material removal at the points of the profile. Before starting the simulation, the profile is discretized along the arc-coordinate into n segments of equal length. In the simulation process of rail vehicle dynamics, a histogram of the volume wear distribution along the profile is built on this discretization, Figure 16.3. The resulting histogram is then approximated by a B-Spline.

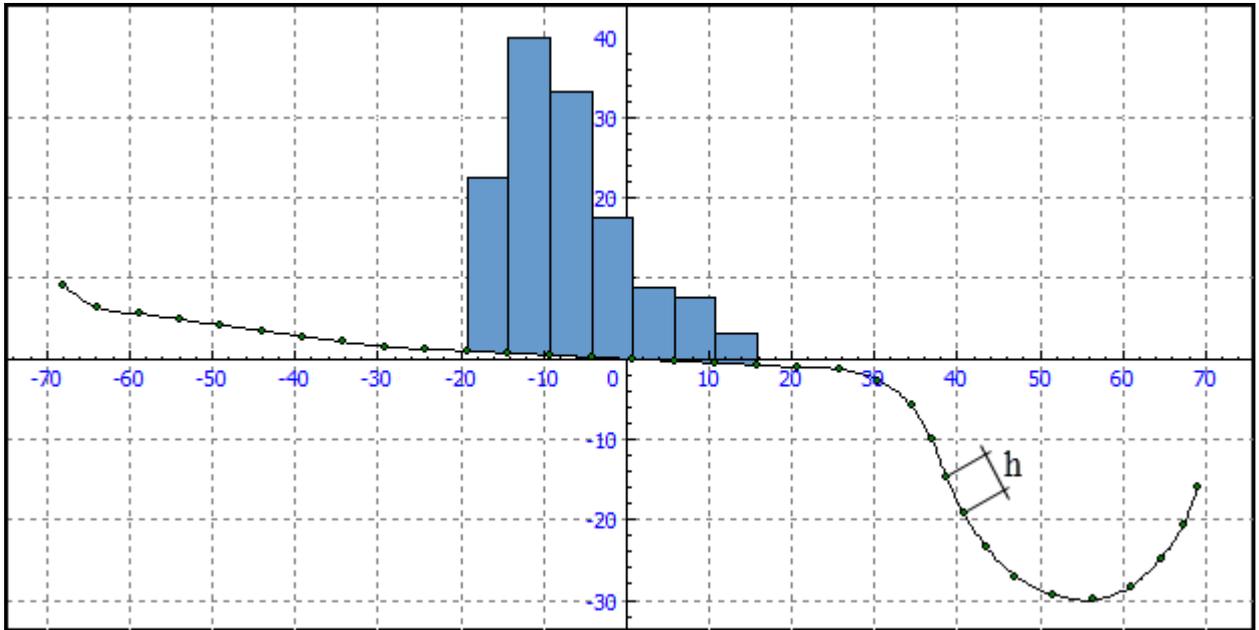


Figure 16.3. Histogram of the wear distribution along the wheel profile, h is the step of discretization the profile into segments

Wear depth for the wheel profile is defined by the expression:

$$\delta_w(s) = \frac{w(s)}{2\pi R(s)h} \quad (16.8)$$

where w is the volume wear, R is the wheel radius, s is the arc-coordinate.

When calculating the wear depth it is considered that a wheel in circumferential direction wears uniformly, i.e. remains an axisymmetric body.

Wear depth for the wheel profile:

$$\delta_r(s) = \frac{w(s)}{Lh}, \quad (16.9)$$

where L is the length of the wear section.

When calculating the rail profile wear, it is assumed that the rail wears evenly in the longitudinal direction, i.e. the rail profile does not change along the track length.

New coordinates of the profile points:

$$(x_i \ y_i)^T = (x(s_i) \ y(s_i))^T - \delta(s_i)\mathbf{n}(s_i), \quad (16.10)$$

where \mathbf{n} is the external normal to the wheel profile.

Note 1 The algorithms for predicting wheel and rail profile wear consider changing the profile geometry only due to abrasive wear. Changes related to pitting and plastic deformation are not taken into account.

Note 2 Results of wear simulation significantly depend on the used configurations and parameters of wear models. For reliable quantitative wear prediction all simulation parameters should be accurately measured and applied. To exclude the influence of unknown parameters and non-proved assumptions it is recommended to use wheel/rail profile wear simulation in qualitative sense with comparing different vehicles/profiles within the same working conditions.

Quantitatively, the wear of profiles is characterized by *wear control parameters*. Wheel profile control parameters are shown in Figure 16.4 and Figure 16.5.

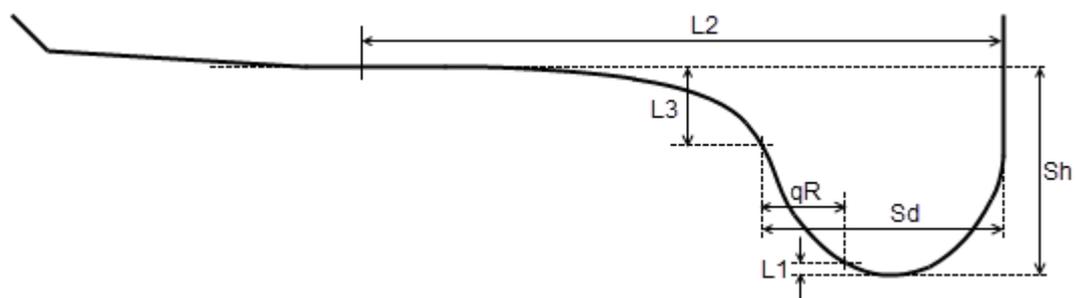


Figure 16.4. Wheel wear control parameters S_d , Sh and qR [5]

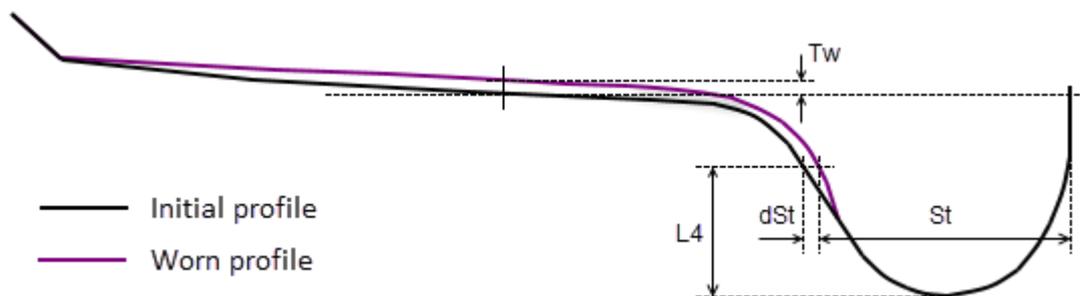


Figure 16.5. Wheel wear control parameters T_w , St and dSt [6]

Wheel wear control parameters:

- S_d is the flange thickness, measured from wheel tape-circle;
- Sh is the flange height;
- qR is the flange steepness;
- T_w is the tread wear;
- St is the flange thickness, measured from flange vertex;
- dS_d , dSt are difference of parameters S_d and St between worn and initial profiles.

Note Methods of determining of wear control parameters S_d and St are different in the selected reference point. S_d is measured in some distance from the wheel-tape

circle. Note that the wheel-tape circle wears during the simulation i.e. the reference point changes. On the other hand, St is measured from the flange vertex, where under normal operating conditions there should be no wear. The introduction of two concepts "flange thickness" is related to such features.

The rail profile wear control parameters are shown in Figure 16.6.

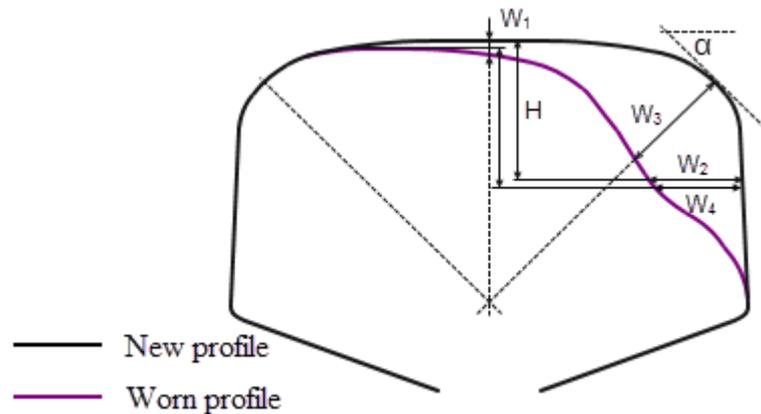


Figure 16.6. Rail profile wear control parameters: W_1 is the vertical rail head wear W_2 is the lateral rail wear, W_3 is the gauge corner wear, W_4 is the lateral wear measured from existing running surface

Parameters L1, L2, L3, L4, H and α parameters are set in options of **UM Simulation** program (**Main menu | Tools | Options... | Wear control parameters**), Figure 16.7.

General		Autosave		Format of numbers	
Export to MS Excel		Bug reports		Wear control parameters	
Parameter	Value				
L1, mm	5				
L2, mm	70				
L3, mm	10				
L4, mm	20				
Sd	Flange thickness				
Sh	Flange height				
qR	Flange steepness				
Tw	Tread wear				
St	Flange thickness (from flange vertex)				
dSd	Flange wear				
dSt	Flange wear (from flange vertex)				
H, mm	12				
a, °	45				
W1	Vertical rail head wear				
W2	Lateral rail wear				
W3	Gauge corner wear				

Figure 16.7. Settings for evaluating the railway profiles wear

16.1. UM Loco/Wheel Profile Wear Evolution tool: predicting wear of railway wheel profiles

Wheel Profile Wear Evolution tool of **UM Loco** module in UM software aimed at predicting wear of railway wheel profiles. The module is available in the UM configuration if the sign + is set in the corresponding line of the **About** window, the **Help | About...** main menu command, Figure 16.8.

Note. Note that **Wheel Profile Wear Evolution** tool is supported only by models of contact forces by W. Kik and J. Piotrowski (**UM Loco/Multi-point Contact Model** tool) and CONTACT. An interface for the CONTACT model is implemented in **UM Loco/CONTACT add-on interface** tool.

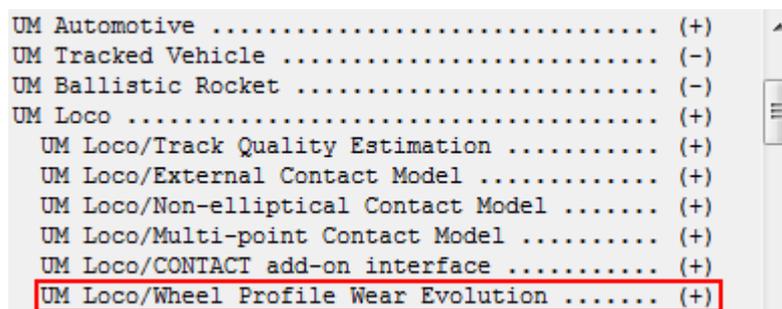


Figure 16.8. Current UM configuration in **About** window

Wheel Profile Wear Evolution tool has the following main features:

- predicting wear of railway wheel profiles;
- saving profiles and wear depth after each wear step;
- calculating wheel wear control parameters;
- creating source data sets for the simulation of accumulation of rolling contact fatigue damages in railway wheels in **UM Rolling Contact Fatigue** module ([Chapter 25](#)).

Wheel Profile Wear Evolution tool is not available for a model, if:

- number of vehicles exceeds one;
- model includes external subsystems;
- model includes FE subsystems;
- equations are generated in the symbolic form.

It is obvious that modeling of the wheel profiles wear when vehicle running along entire railway network requires a lot of simulation time. A possible solution is to wear simulation on a set of configurations (routes) than takes into account the general properties of the railway network. *The set of configurations should be a representative set of working conditions in which the rail vehicle is used.* Statistical analysis should be used to divide the railway network into a representative set of configurations, table 16.1.

Table 16.1

Example of statistical analysis of railway track

Curve radius range, m	Weighted average radius, m	Weighted average length, m	Weigh
<400	321	272.8	0.08
400-700	578	378.6	0.19
700-1000	847	344.1	0.06
>1000	1766	328.1	0.13
Tangent	-	-	0.54

In **Wheel Profile Wear Evolution** tool a parallel discrete approach for predicting wear of railway wheel profiles is implemented.

The "Parallel" means that different configurations of a rail vehicle are modeled in parallel, with the same wheel profiles for all configurations, Figure 16.9. Configurations differ in track geometry, track irregularities, vehicle mass and so on.

The "Discrete" means that the track length traveled by the vehicle during the simulation is divided into a sequence of intervals (wear steps). The number of intervals is the same for all configurations. Within each interval the wheel profiles are not changed. At the end of each wear step, a wear depth is scaled according to mileage assigned to one wear step. The scaling procedure is correct, since a small quantity of material removed due to wear depends almost linearly on the traveled distance (obviously only inside the wear step). After scaling, the wear depth is summarized for the respective wheels by taking into account the weight (statistical) factors of the configurations and the wear symmetry, if any. Then the profiles are updated according to accumulated wear depth, Figure 16.9. Contact forces are computed using the model by W. Kik and J. Piotrowski [7] or CONTACT library. In the model of W. Kik and J. Piotrowski, the FASTSIM algorithm modified for non-elliptical contact patches is used to compute the creep forces.

Parallel calculation of configurations on multithreading CPUs is implemented to speed up the simulation process.

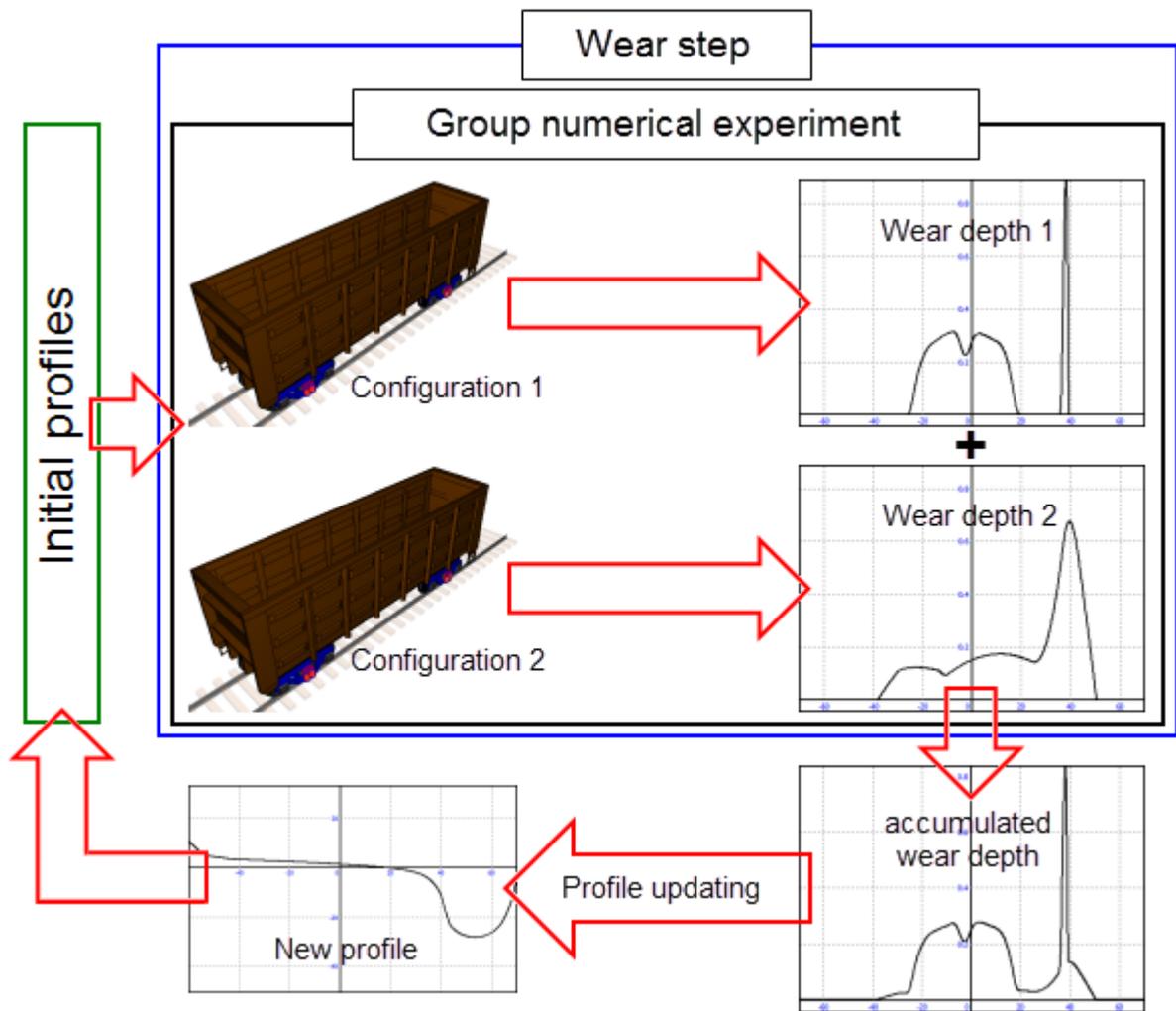


Figure 16.9. Scheme of wear simulation

16.1.1. Railway wheel profiles wear modelling

Run **UM Simulation** program. Open a model of a rail vehicle. Open **Object simulation inspector** and open **Wear** tab (**Wheel/Rail | Wear**), Figure 16.10.

For prediction of wear of railway wheel profiles turn on the **Wear profile evolution** option. Note that when you close the model, the state of the option is not saved. To load or save the evolution project, use the  and  buttons respectively.

The **Continue simulation** option is used to restart if the wear simulation has been fully or partially completed. The evolution project at restart cannot be changed. When you restart the calculation, it will be continued from the last calculated profiles found in the directory for saving results (Sect. 16.1.1.5 "Saving results", p. 16-16). Restart is not available if the result directory is empty or does not contain the *current.ecf* file.

When the option **Use threads** is turned on, calculation of configurations is performed in parallel threads on multithreading CPUs.

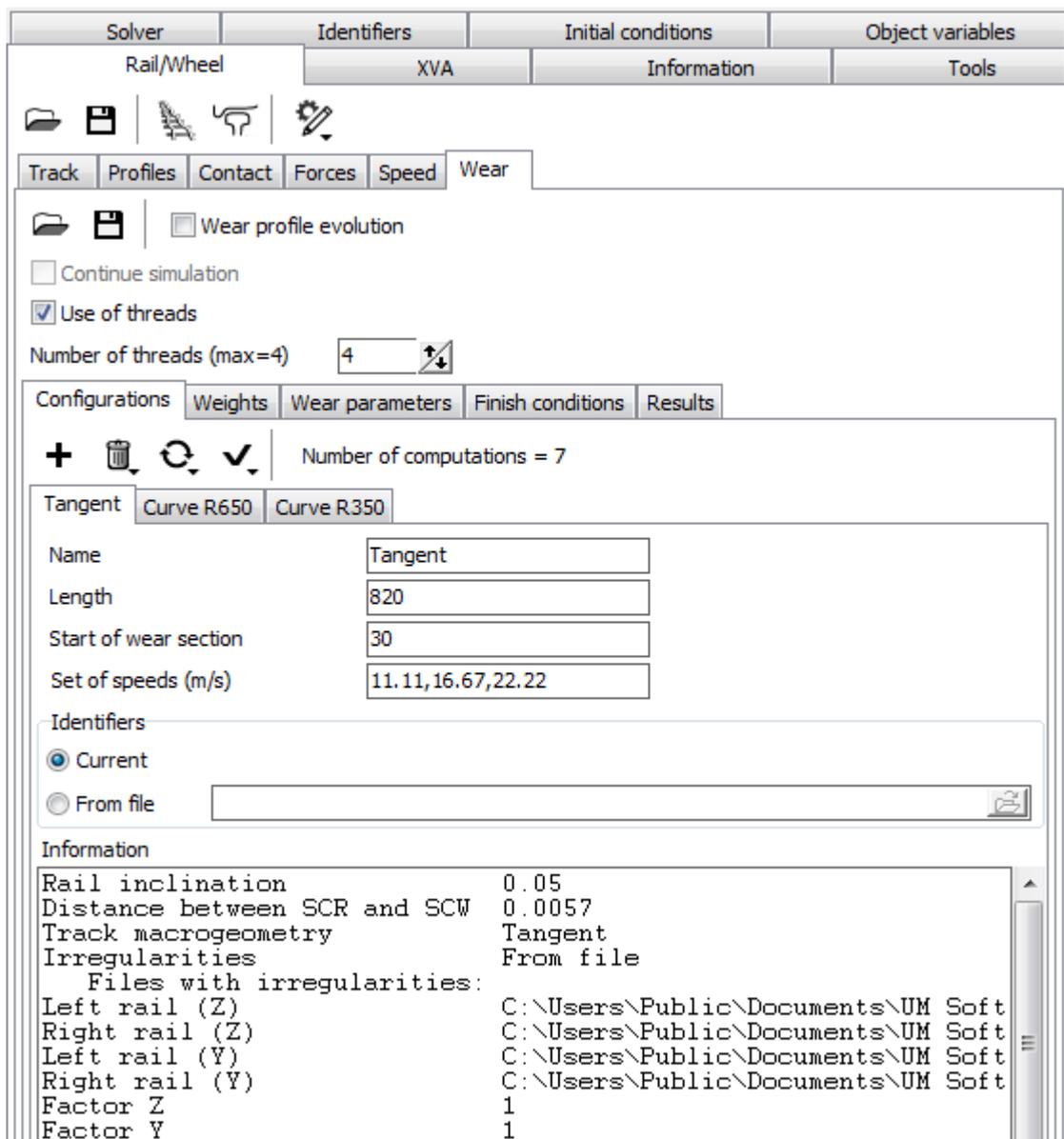


Figure 16.10. Wear tab

16.1.1.1. Creating configuration set

To edit a configuration set, open the **Configurations** tab, Figure 16.10. The tab contains buttons for working with configurations and tabs with configuration names. The **Add configuration** button **+** adds a configuration to the set with the current railway parameters. Under the current railway parameters we mean parameters set in the tabs **Track**, **Profiles**, **Contact**. For all configurations, the profiles assigned to the first configuration are used as the initial wheel profiles. Rail profiles can be different for different configurations.

The **Delete configuration** button  deletes the selected configuration from the set. The **Refresh configuration** button  sets the parameters of the selected configuration according to the current parameters, and the **✓** button sets the current parameters according to the parameters of the selected configuration.

After adding a configuration, complete the fields below.

Name is the name of configuration by which it is easy to identify.

Length (S_i) is the length of track traveled by the rail vehicle during the simulation.

Start of wear section (S_{b_i}) is the track distance on which wear calculation starts. This parameter is used to exclude from the simulation "smoothing irregularities" ([Chapter 8](#), Sect. *Track irregularities*), the length of a straight section before the curve ([Chapter 8](#), Sect. *Geometry of curve*) and so on.

Set of speeds is a list of vehicle speeds for the given configuration, for example: 15, 20, 25.

In **Identifiers** group, select the method of specifying identifiers values:

- **Current** option means that the configuration will use the current identifier values, that are specified on the **Identifiers** tab of the **Object simulation inspector**.
- **From file** option means that identifiers for this configuration will be read from the specified file. By assigning configurations of different files with the values of the identifiers you may simulate, for example, loaded or empty state of the vehicle.

The **Information** group provides general information about configuration parameters.

16.1.1.2. The weight coefficients of configurations and speeds

To assign weights of configurations and weight of speeds open the **Weights** tab, Figure 16.11.

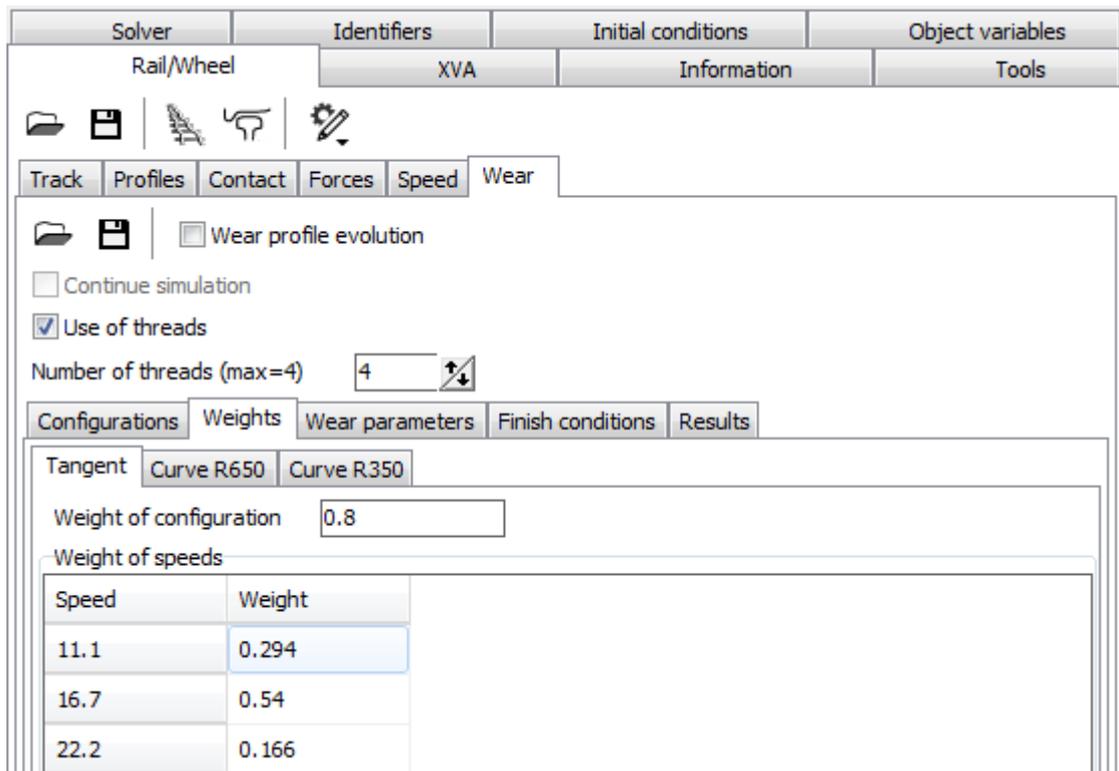


Figure 16.11. **Weights** tab

Weight of configuration (α_i) represents the frequency with which the parameter that separates the configuration (for example, the radius of the curved track or rail profile: new or worn) appears on the considered railway network, table 16.1. **Weight of speeds** (β_{ij}) determine a histogram of the speeds of the vehicle for this configuration.

16.1.1.3. The wear simulation settings. The profile-updating procedure

The wear simulation settings and the wear model are set on the **Wear parameters** tab, Figure 16.12. The wear simulation settings include **Number of iterations**, **Number of wear steps**, **Mileage**, **Width of wear accumulation interval** as well as the following options: **Symmetrical wear of wheelsets** and **Symmetrical wear of wheel profiles of same wheelset**.

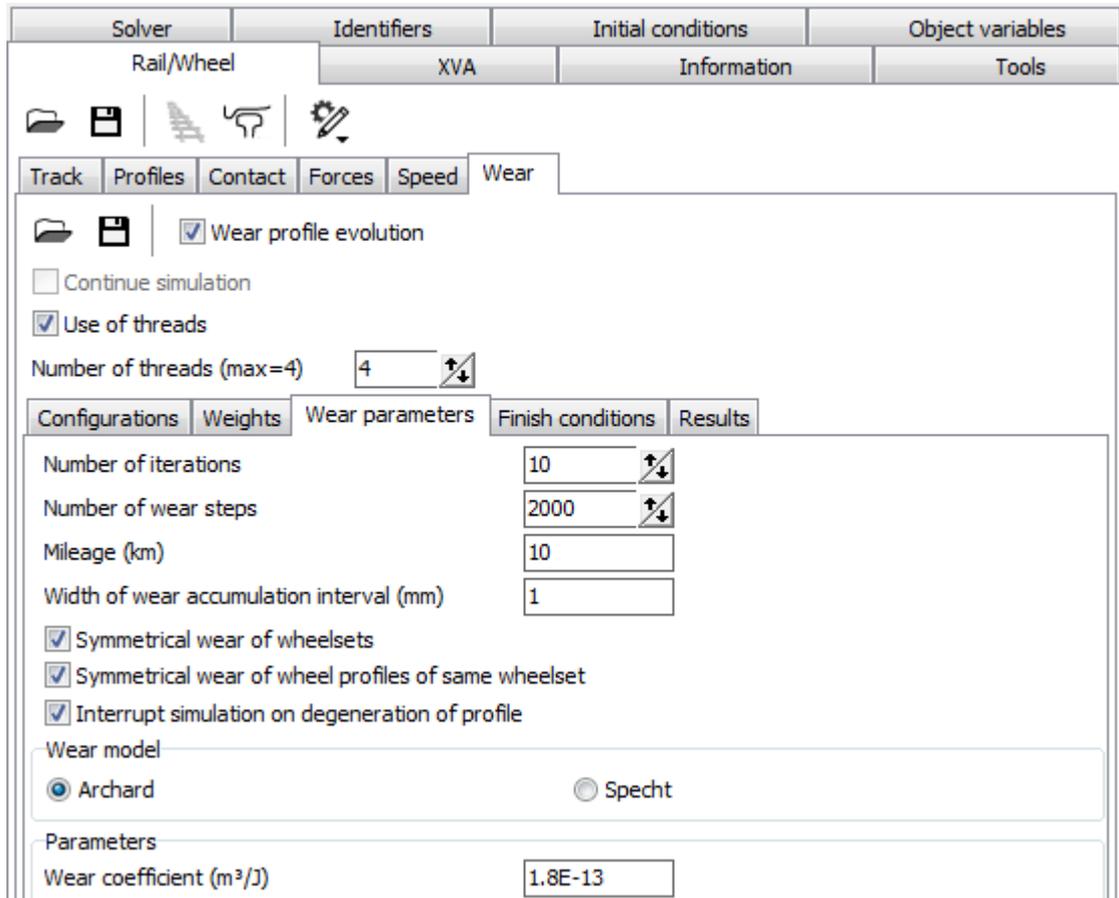


Figure 16.12. **Wear parameters** tab

Number of iterations (N_{it}) is the number of repetition of the wear simulation. Wear iterations are series of calculations of the same structure that differ only in the initial profiles. One iteration is a single calculation of a set of configurations. If finish conditions are specified (Sect. 16.1.1.4. "*Finish conditions*", p. 16-15), iterations will be executed until the finish condition is completed.

Number of wear steps (N_{ws}) is the number of profile-updates in one iteration. The more the number of steps and the less mileage (see below), the more realistic the profile evolution, but also modeling time is longer;

Mileage (km_{step} , km) is the mileage assigned to one wear step. The mileage value is used to scale the wear depth at the end of each wear step. The purpose of scaling procedure is to amplify the small wear with a short traveled distance. In fact, the wear depth is multiplied by the scale factor:

$$c_{scale} = \frac{N_{ws} km_{step}}{S_i - S_{b_i}}, \tag{16.11}$$

where i is the configuration index.

The scaling procedure is correct, since a small quantity of material removed due to wear depends almost linearly on the traveled distance, which is true within one wear step.

Total mileage (km_{tot}) is calculated using the formula:

$$km_{tot} = N_{it} N_{ws} km_{step}; \tag{16.12}$$

Width of wear accumulation interval (h) is the discretization step along the arc-coordinate of the wheel surface on the circumferential stripes. It is used for creating a histogram of the wear distribution on the wheel profile, Figure 16.3.

When the option **Symmetrical wear of wheelsets** is on, the wheel profiles of wheelsets, placed symmetrically relative to the center of the rail vehicle, have the same wear, i.e. profiles of the corresponding wheels of the first and last wheelsets wear equally. You should turn on this option if the rail vehicle moves in forward and backward directions without 180° turn of the vehicle.

You should turn on the option **Symmetrical wear of wheel profiles of same wheelset** if on the researched road network the shares of left and right curves of the considered radius are the same. In this case, to study motion in curves, use right curves only.

Interrupt simulation on degeneration of profile option is responsible for processing the degeneration of the profile. Degeneration of profile is the transition of profile from the single-valued function of the x-coordinate to a multivalued, Figure 16.13. If the option is on, the calculation will be interrupted with the output of the corresponding message. When the option is off, the roll back of the degenerated section of the profile to the previous state with the continuation of the simulation will be done. A typical reason for profile degeneration is large value of the **Mileage** parameter.

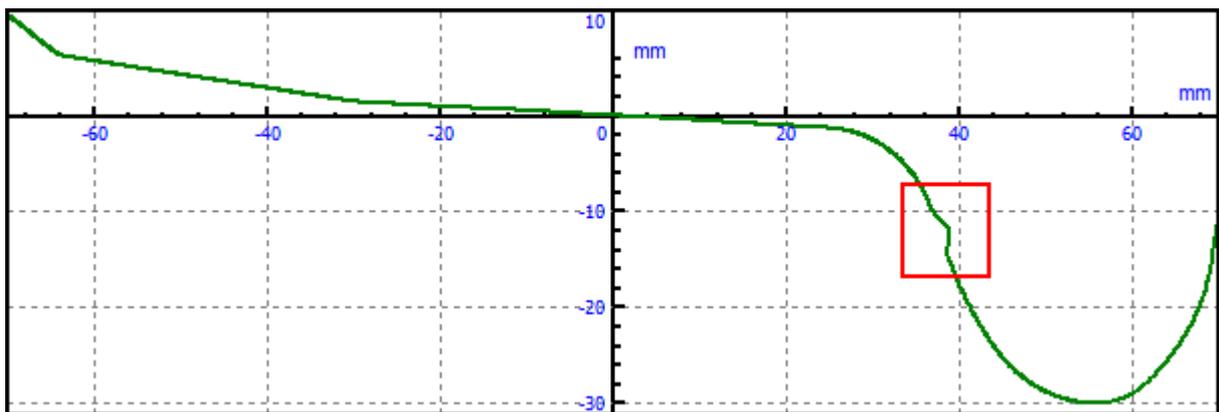


Figure 16.13. Degeneration of profile

Let us consider a method of updating a profile. Let $w_{ijk,l}$ and $w_{ijk,r}$ be volume wear for left and right wheels of the wheelset k calculated for configuration i with the running speed v_{ij} .

In case of symmetrical wear of wheel profiles of same wheelset, volume wear for the left and right wheels of the wheelset k are averaged:

$$w_{ijk,l} = w_{ijk,r} = \frac{1}{2}(w_{ijk,l} + w_{ijk,r}). \quad (16.13)$$

In the case of symmetrical wear of wheelsets, volume wear for the wheels of wheelsets placed symmetrically relative to the vehicle center are averaged:

$$w_{ijk,m} = w_{ij(N-k+1),m} = \frac{1}{2}(w_{ijk,m} + w_{ij(N-k+1),m}), \quad m = l, r, \quad (16.14)$$

where N is a number of wheelsets.

Accumulated volume wear is found using the follows formula:

$$w_{k,m} = \sum_{i=1}^{N_C} \alpha_i \sum_{j=1}^{N_{v_i}} \beta_{ij} w_{ijk,m}, \quad m = l, r. \quad (16.15)$$

Then volume wear is smoothed with the help of the B-spline.

The wear depth in the center of each circumferential strip is calculated as follows:

$$\delta_{k,m}(s_i) = \frac{\tilde{w}_{k,m}(s_i)}{2\pi R_{k,m}(s_i)h}, \quad m = l, r, \quad (16.16)$$

where s_i is an arc-coordinate of the center of the strip, $\tilde{w}_{k,m}$ is a smoothed volume wear, $R_{k,m}$ is a wheel radius, h is a width of a strip.

When calculating the wear depth it is considered that a wheel in circumferential direction wears uniformly, i.e. remains an axisymmetric body.

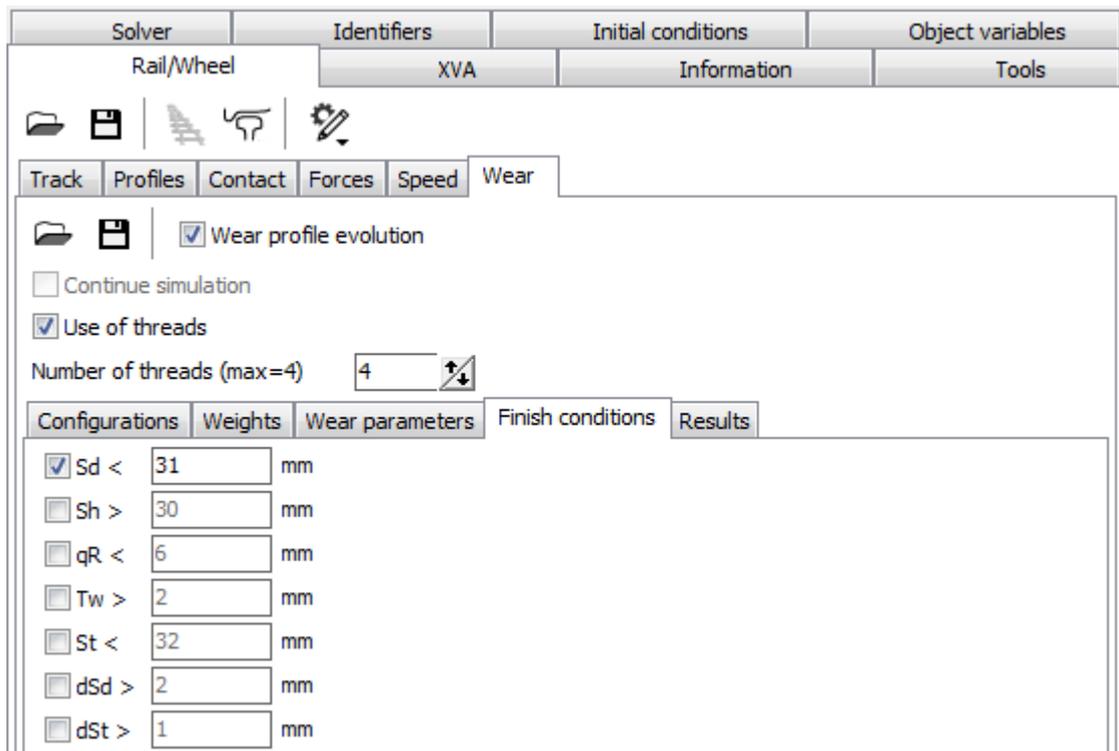
New coordinates of the profile points are as follows:

$$(x(s_i) \quad y(s_i))^T_{k,m} = (x(s_i) \quad y(s_i))^T_{k,m} - \delta_{k,m}(s_i) \mathbf{n}_{k,m}(s_i), \quad m = l, r, \quad (16.17)$$

where $\mathbf{n}_{k,m}$ is the external normal to the wheel profile.

16.1.1.4. Finish conditions

Finish conditions are set on the **Finish conditions** tab, Figure 16.14. In **Wheel Profile Wear Evolution** tool the wheel wear control parameters are used as stopping criteria (Figure 16.4 and Figure 16.5).

Figure 16.14. **Finish conditions** tab

A numerical experiment will be interrupted when one of the finish conditions is satisfied (the logical operator OR). If no finish conditions are selected, the simulation will be completed when the specified number of wear iterations is reached.

16.1.1.5. Saving results

Wheel Profile Wear Evolution tool allows saving the following calculation results:

- wheel profiles;
- wear depth;
- source data sets for the simulation of accumulation of rolling contact fatigue damages in railway wheels.

To customize the results saving, open the **Results** tab, Figure 16.15. In the **Directory for saving results** field, specify the path to the directory where the calculation results will be saved. The wheel profiles are saved by default. Wear depth are saved when the option **Save wear depth distribution along profile** is turned on.

In **Rolling contact fatigue** group in wheels tree check the wheels for which simulation of accumulation of contact fatigue damages should be performed. To simulate the accumulation of damage data about distribution of normal pressure and tangential traction in the wheel-rail contact is used.

In the field **Number of records per wheel revolution** (N_r) specify how many times data should be saved per one wheel revolution. The larger the number of records, the more representative the dataset, but also the longer the simulation time in the **UM RCF** module.

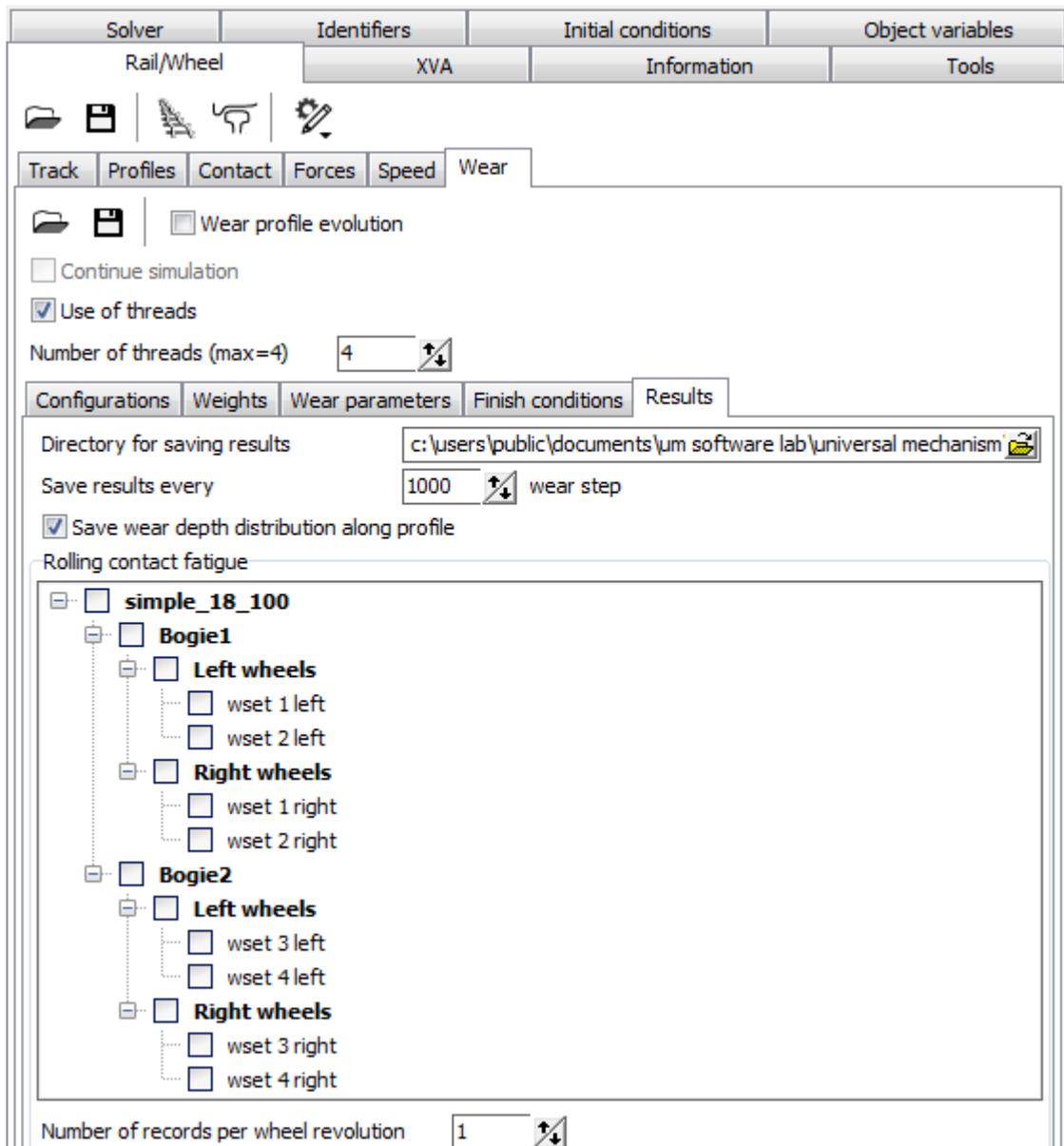


Figure 16.15. Results tab

16.1.1.6. Wear simulation process

Run the simulation by clicking the **Integrate** button in the **Object simulation inspector** window. After clicking the button, the **Monitor of wear of railway wheel profiles** window appears (Figure 16.16), in which it is possible to monitor the progress of the modeling process, or view the results obtained at the moment. The following results are available:

- wheel profiles at the corresponding wear step (menu item *Profiles*);
- distribution along the wheel profile of losses of material accumulated for one wear step, see the formula (16.16) (menu item *Wear depth*);
- distribution of total (accumulated) losses of material of wheel profile for all wear steps to the corresponding step inclusively (menu item *Accumulated wear depth*).

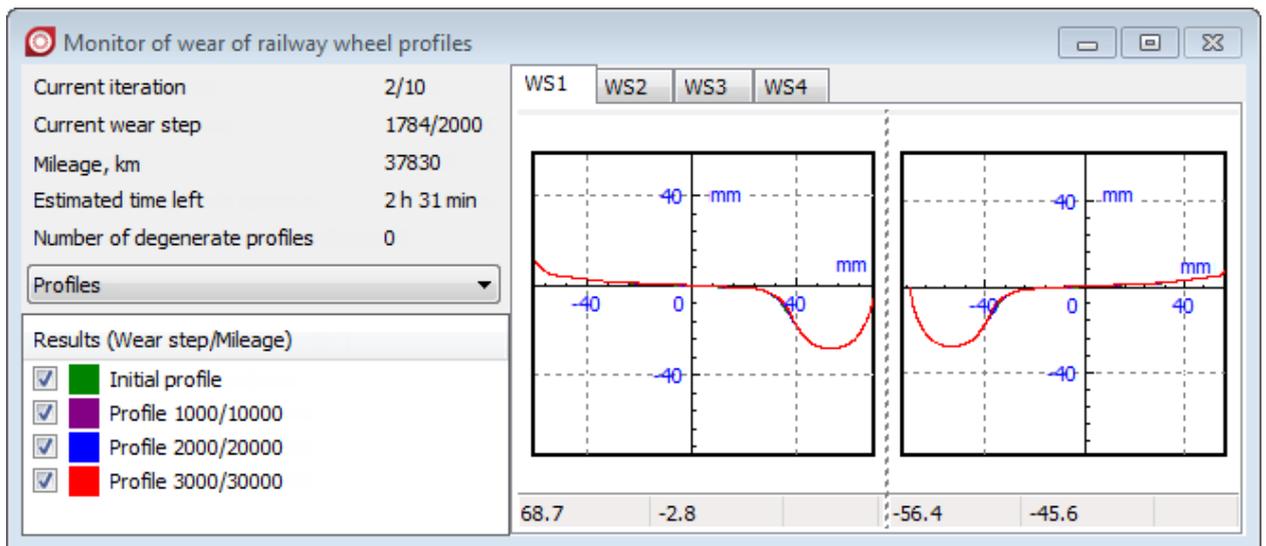


Figure 16.16. Monitor of wear of railway wheel profiles window

The **Pause mode** button  on the information panel **Process parameters** allows to suspend the simulation process.

In the single threading mode (when the option **Use threads** is turned off) in the animation windows you can monitor the animation of the movement of the rail vehicle and the animation of the wheel-rail contact for various calculation options. To select a calculation variant in the **Animation window** and in the **Contact animation window**, open the context menu and in **Variants of wear calculation** submenu choose one of the calculation variant, Figure 16.17. The active variant is marked. To select a calculation variant in the **Contact patch viewer** window, move the mouse cursor to the right border of the window, wait for the panel with calculation variants to appear and select one of them, Figure 16.18.

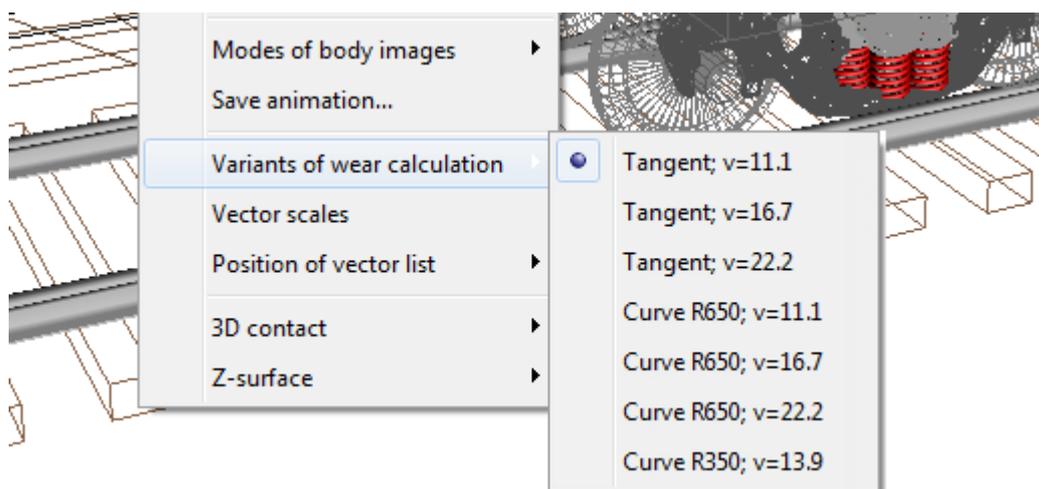


Figure 16.17. Choosing variant of wear calculation in the **Animation window**

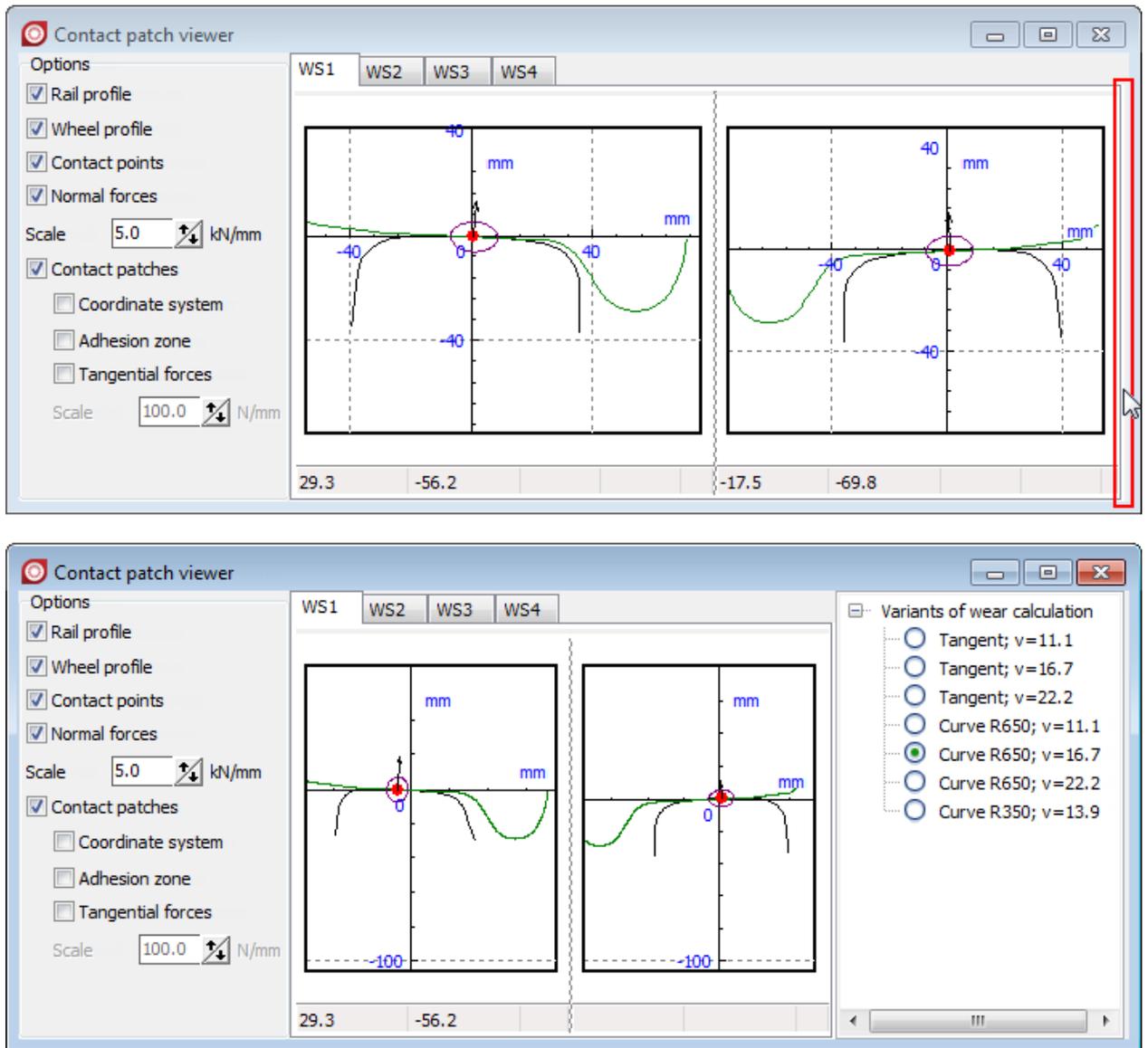


Figure 16.18. Choosing variant of wear calculation in the **Contact patch viewer** window

16.1.2. Creating a sample project of the evolution of wheel profiles

16.1.2.1. Project description

As an example let us consider the creation of a project of the evolution of wheel profiles (GOST 10791-2011) freight car with three-piece bogie 18-100. The model of the railcar is in the [{UM Data}\samples\Rail_Vehicles\simple_18_100](#) folder. The wear project will contain 3 configurations.

1. Motion in a tangent track with speeds 40, 60 and 80 km/h.
2. Motion in a curve $R = 650$ m with speeds 40, 60 and 80 km/h.
3. Motion in a curve $R = 350$ m with the speed 50 km/h.

The rails in the tangent and the inner rail in the curves have a new profile R65, the outer rail in the curves is a worn profile R65. The track irregularities for all configurations correspond to the track of a good quality according to the UIC standard.

Note Preliminary prepared file of evolution configuration of wheel profile "*Wheel Wear Test.ecf*" is available in the model folder.

16.1.2.2. Creating a set of configurations and assigning weight coefficients

1. Run **UM Simulation**. Open the railcar model from the [{UM Data}\samples\Rail_Vehicles\simple_18_100](#) folder. Open **Object simulation inspector** and select **Rail/Wheel** tab.

2. Creating the first configuration:

1. Open the **Track | Model and parameters** tab and set the following values for parameters:

- **Rail inclination (rad)** = 0.05;
- **SCR-SCW distance (mm)** = 5.7;
- **Track model** = *Inertial rail*.

2. Open the **Track | Macrogeometry** tab and set **Track type** to **Tangent**.

3. Open the **Track | Irregularities** tab, set **Track type** to **Uneven**, set **Type of irregularities** to **From file**. Using button  **Load group of irregularities from file** assign to the rails a group of irregularities *uic_good_1000m.tig* from the [{UM Data}\rw](#) folder.

4. Open the **Profiles | Wheels | Profiles** tab and assign for all wheels the *newwagnw.wpf* profile from the [{UM Data}\rw\prf](#) folder. For more detailed information see [Chapter 8](#), Sect. *Assignment of wheel profiles*.

5. Open the **Profiles | Rails** tab and assign to both rails the *r65new.rpf* profile from the [{UM Data}\rw\prf](#) folder. For more detailed information about assigning rail profiles see [Chapter 8](#), Sect. *Assignment of rail profiles*.

Open the **Contact | Contact forces** tab. Select Kik-Piotrowski contact model and set the following values for contact parameters:

- **Young's modulus** = $2.1 \cdot 10^{11}$;
- **Poisson's ratio** = 0.27;
- **Width of strip (mm)** = 5;

- **Minimum number of strips** = 20;
- **Number of elements** = 20;
- **Interpenetration factor** = 0.55;
- **Damping ratio** = 0.001.

This completes the preparation of the first configuration.

6. Open the **Wear** tab and add the configuration to the set (Sect. 16.1.1.1. *Creating configuration set*, p. 16-11). Set the following values for the parameters of added configuration (Figure 16.19):

- **Name** = *Tangent*;
- **Length** = 820;
- **Start of wear section** = 30;
- **Set of speeds** = 40, 60, 80 (11.11, 16.67, 22.22, if speed units are m/s);
- **Identifiers** = *Current*.

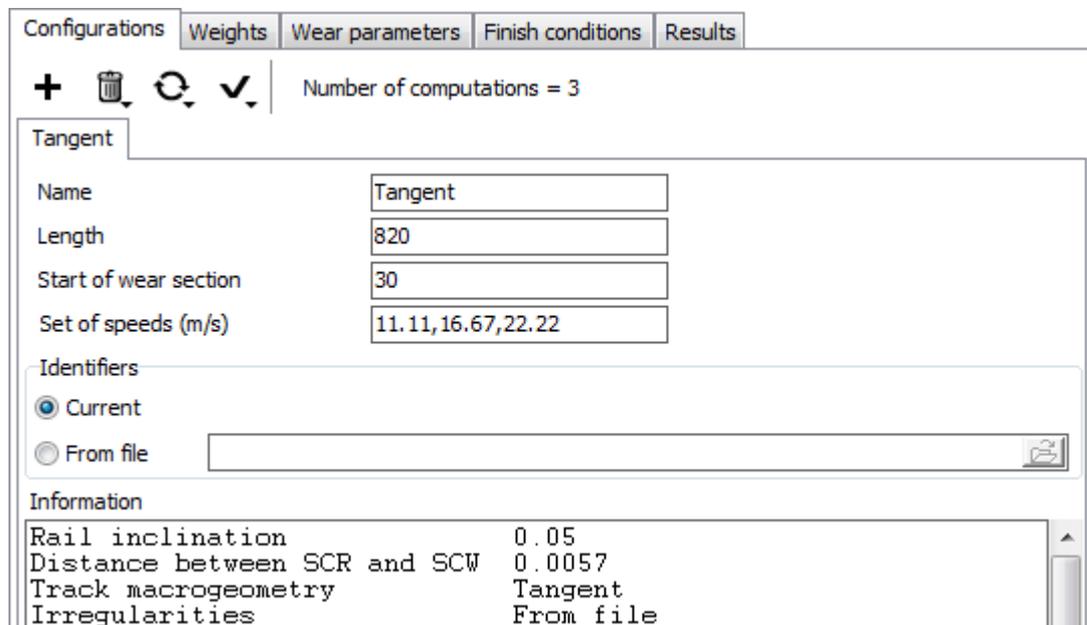


Figure 16.19. Configuration *Tangent*

Open the **Weights** tab. Set weight of configuration to **0.8** and weight of speeds to **0.294**, **0.54** and **0.166** respectively, Figure 16.20.

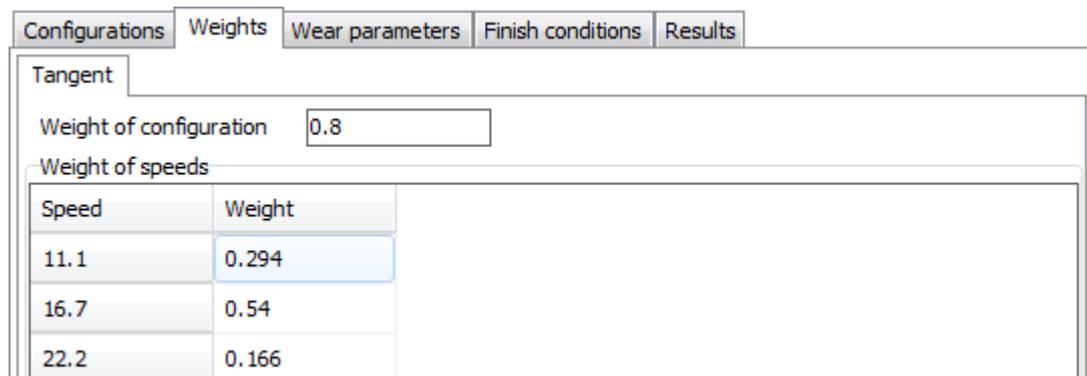


Figure 16.20. Weight of configuration and weight of speeds

3. Let us create the second configuration:

1. Open the **Track | Macrogeometry** tab and set track **Track type** to **Curve**. Set the following values for the curve parameters:

- **L1** = 10;
- **P11** = 50;
- **S1** = 300;
- **R1** = 650;
- **H1** = 0.1;
- **R12** = 50;
- **dY1** = 0;
- **Smoothing** = 8.

2. Open the **Profiles | Rails** tab and set for the left (outer) rail the *r65worn.rpf* profile from the [\[UM Data\]\rw\prf](#) folder. For the right rail leave the *r65new.rpf* profile.

Leave the rest data without changes.

3. Add a configuration to the set. Set the following values for the configuration parameters:

- **Name** = *Curve R650*;
- **Length** = 410;
- **Start of wear section** = 60;
- **Set of speeds** = 40, 60, 80 (11.11, 16.67, 22.22, if speed units are m/s);
- **Identifiers** = **Current**.

4. Open the **Weights** tab. Set for the weight of configuration 0.15 and weight of speeds 0.294, 0.54 and 0.166 correspondingly.

4. Let us create the third configuration:

1. Open the **Track | Macrogeometry** tab and set **Track type** to **Curve**. Set the following values for the curve parameters:

- **L1** = 10;
- **P11** = 50;
- **S1** = 300;
- **R1** = 350;
- **H1** = 0.1;
- **R12** = 50;
- **dY1** = 0.01;
- **Smoothing** = 8.

Leave unchanged all other parameters.

2. Add the configuration to the set. Set the following values for the configuration parameters:

- **Name** = *Curve R350*;
- **Length** = 410;
- **Start of wear section** = 60;
- **Set of speeds** = 50 (13.89, if speed units are m/s);

- **Identifiers = Current.**

3. Open the **Weights** tab. Set for the weight of configuration to 0.05 and weight of speed to 1.

16.1.2.3. Wear parameters setting

Open the **Wear parameters** tab and set the following values for the wear parameters (Figure 16.21):

- **Number of iterations** = 10;
- **Number of wear step** = 2000;
- **Mileage (km)** = 10,

i.e. total mileage will be $km_{tot} = N_{it}N_{ws}km_{step} = 10 \cdot 2000 \cdot 10 = 200,000$ km;

- **Width of wear accumulation interval (mm)** = 1;
- **Symmetrical wear of wheelsets** = on;
- **Symmetrical wear of wheel profiles of same wear** = on;
- **Interrupt simulation on degeneration of profile** = off;
- **Wear model** = Archard;
- **Wear coefficient (m^3/J)** = $1.83 \cdot 10^{-13}$.

Configuration	Value
Number of iterations	10
Number of wear steps	2000
Mileage (km)	10
Width of wear accumulation interval (mm)	1
Symmetrical wear of wheelsets	<input checked="" type="checkbox"/>
Symmetrical wear of wheel profiles of same wheelset	<input checked="" type="checkbox"/>
Interrupt simulation on degeneration of profile	<input type="checkbox"/>
Wear model	<input checked="" type="radio"/> Archard <input type="radio"/> Specht
Parameters	
Wear coefficient (m^3/J)	1.8E-13

Figure 16.21. Wear parameters

16.1.2.4. Finish conditions setting

Select the **Finish conditions** tab and turn off all options, i.e. in the project will not use the finish conditions on wear control parameters. The simulation will be completed when the specified number of wear iterations is reached.

16.1.2.5. Saving results setting

Select the **Results** tab. In **Directory for saving results** assign the path to the folder in which the calculation results will be placed. Assign the next values for parameters for saving results (Figure 16.22):

- **Save result every N wear step** = 2000, i.e. results will be written every 2000 wear step;
- **Save wear depth distribution along profile** = on.

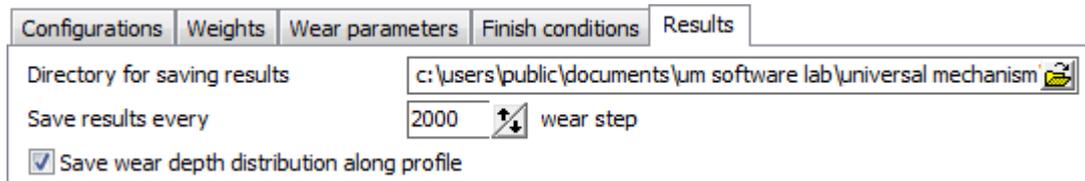


Figure 16.22. Saving results

Wear project is completed. Turn on **Wear profile evolution** option (Figure 16.10) and run simulation by clicking **Integration**.

16.1.3. Analysis of the results

The calculation results are processed using the specialized tool **Analysis of wear of railway wheel profiles** (**Main menu | Tools | Analysis of wear of railway profiles | Wheel profiles...**), Figure 16.23. To load calculation results click the **Browse...** button and specify the folder with results or choose the corresponding path from the reopen list.

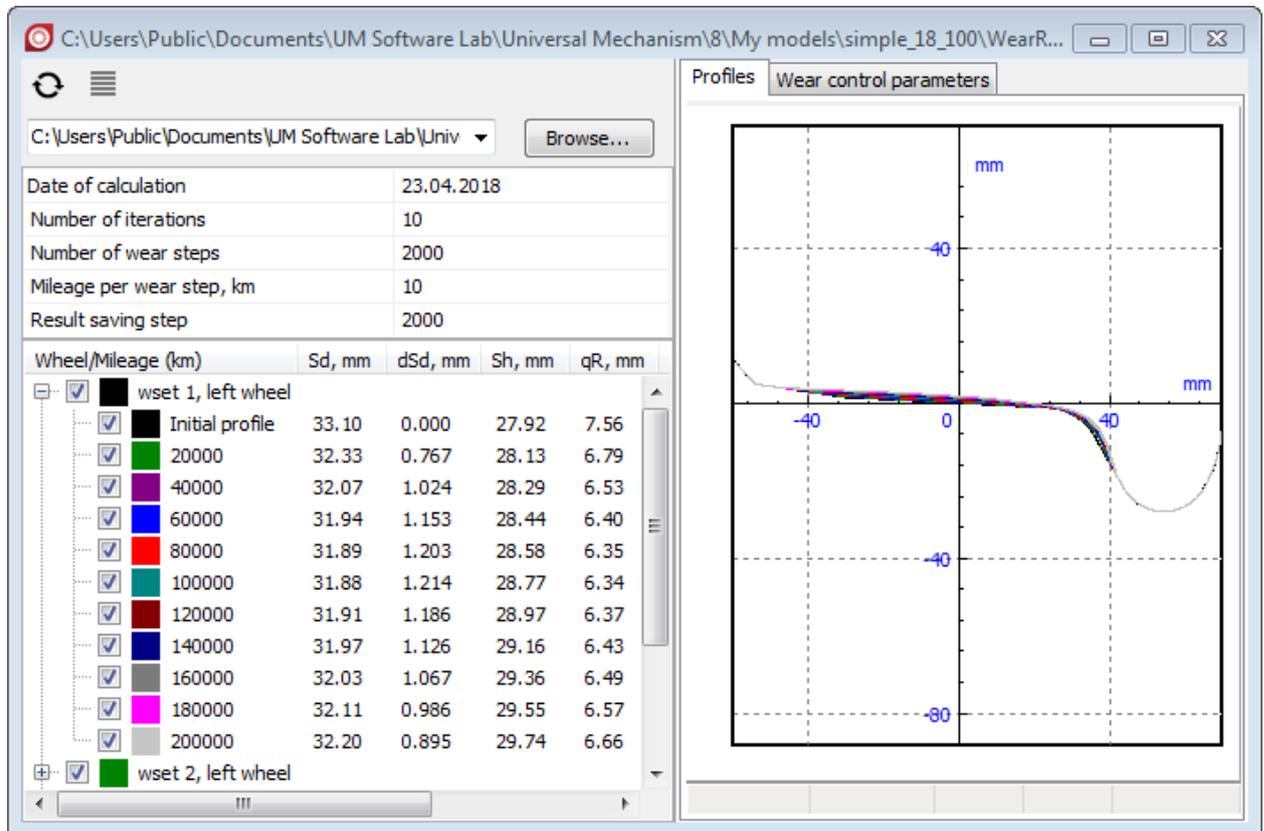


Figure 16.23. Analysis of wear of railway wheel profiles tool

In the result tree for each mileage value in the columns there are numerical values of wheel wear control parameters (Figure 16.4, Figure 16.5). Use right mouse button click on the result tree to open the context menu. Context menu commands provide additional features for processing results: open a profile in the profile editor and copy wear control parameters to the clipboard. On the **Profiles** tab there are profiles obtained at the corresponding mileage, Figure 16.24. On the **Wear control parameters** tab graphs of dependence of wear control parameters vs mileage are available, Figure 16.25. Use button to set visibility of wear control parameters graphs and columns of result tree.

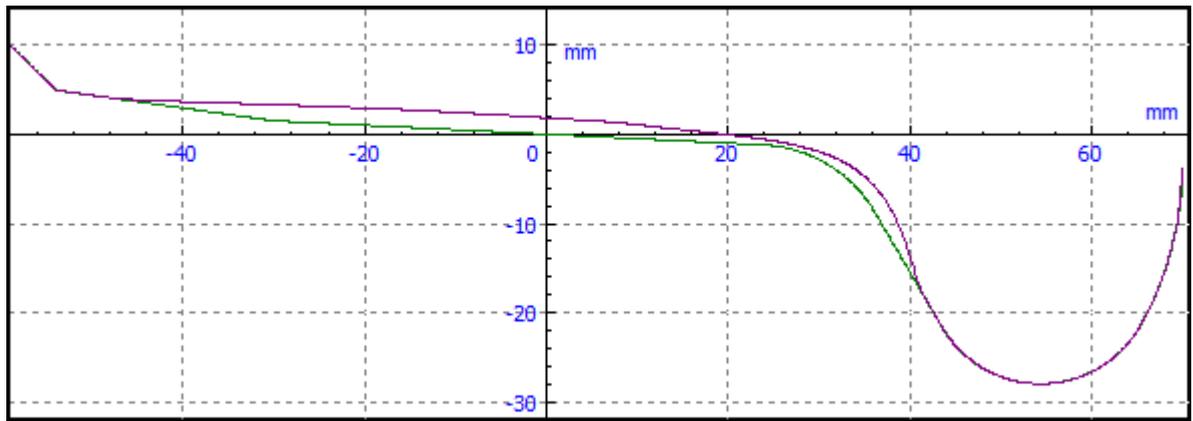


Figure 16.24. Profile of left wheel of the 1st wheelset in new state and after a mileage of 200 thou. km

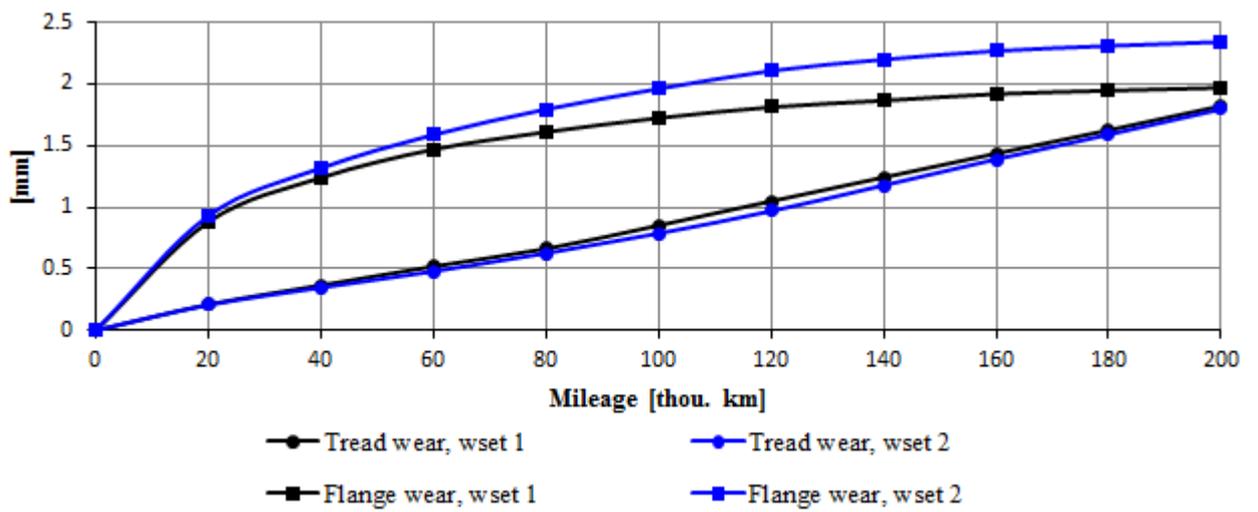


Figure 16.25. Tread and flange wear of left wheels of the 1st and the 2nd wheelsets

16.2. UM Loco/Rail Profile Wear Evolution tool: predicting railway profiles wear

Rail Profile Wear Evolution tool of **UM Loco** module in UM software aimed at predicting wear of railway rail profiles. The module is available in the UM configuration if the sign + is set in the corresponding line of the **About** window, the **Help | About...** main menu command, Figure 16.26.

Note. Note that **Rail Profile Wear Evolution** tool is supported only by models of contact forces by W. Kik and J. Piotrowski (**UM Loco/Multi-point Contact Model** tool) and CONTACT. An interface for the CONTACT model is implemented in **UM Loco/CONTACT add-on interface** tool.

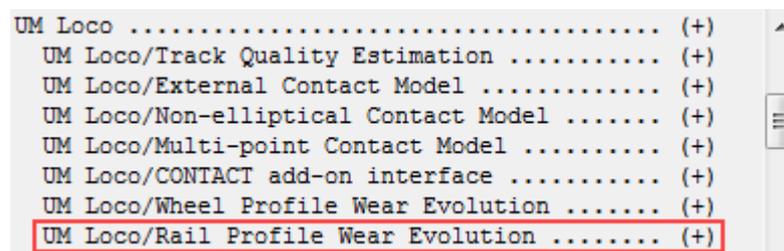


Figure 16.26. Current UM configuration in **About** window

The **Rail Profile Wear Evolution** tool is an add-on for the **UM Experiments** module, which has been supplemented by the concept of *evolution*. Evolution refers to a series of multivariate calculations of the same structure which are the wear *iterations* that differ from each other only in rail profiles. The rail profiles do not change during the iteration. The profiles are changed after the end of the iteration, taking into account the weight coefficients of numerical experiments and the scale factor.

Rail Profile Wear Evolution tool has the following main features:

- predicting wear of railway rail profiles;
- saving profiles and wear depth after each iteration;
- calculating rail wear control parameters;
- creating source data sets for the simulation of accumulation of rolling contact fatigue damages in rail in **UM Rolling Contact Fatigue** module ([Chapter 25](#)).
- saving list of variables for each wear iteration.

It is assumed that the user is already familiar with the concepts and structure of the **UM Experiments** module and has experience of working with it.

16.2.1. Rail profile wear simulation

Run **UM Simulation** program. Create a new rail profile wear prediction project select the **Scan | New project – rail profile wear...** main menu command. A standard scanning project window appears in which the **Rail profile wear** tab is added. Open **Alternatives** tab and add to the project the models of rail vehicles that are used on the track section under consideration. Use the  button to assign weight coefficients to the vehicles, Figure 16.27. The weight coefficient of the vehicle is the specific weight (percentage) of the vehicle in the vehicle fleet, operated on the considered track section.

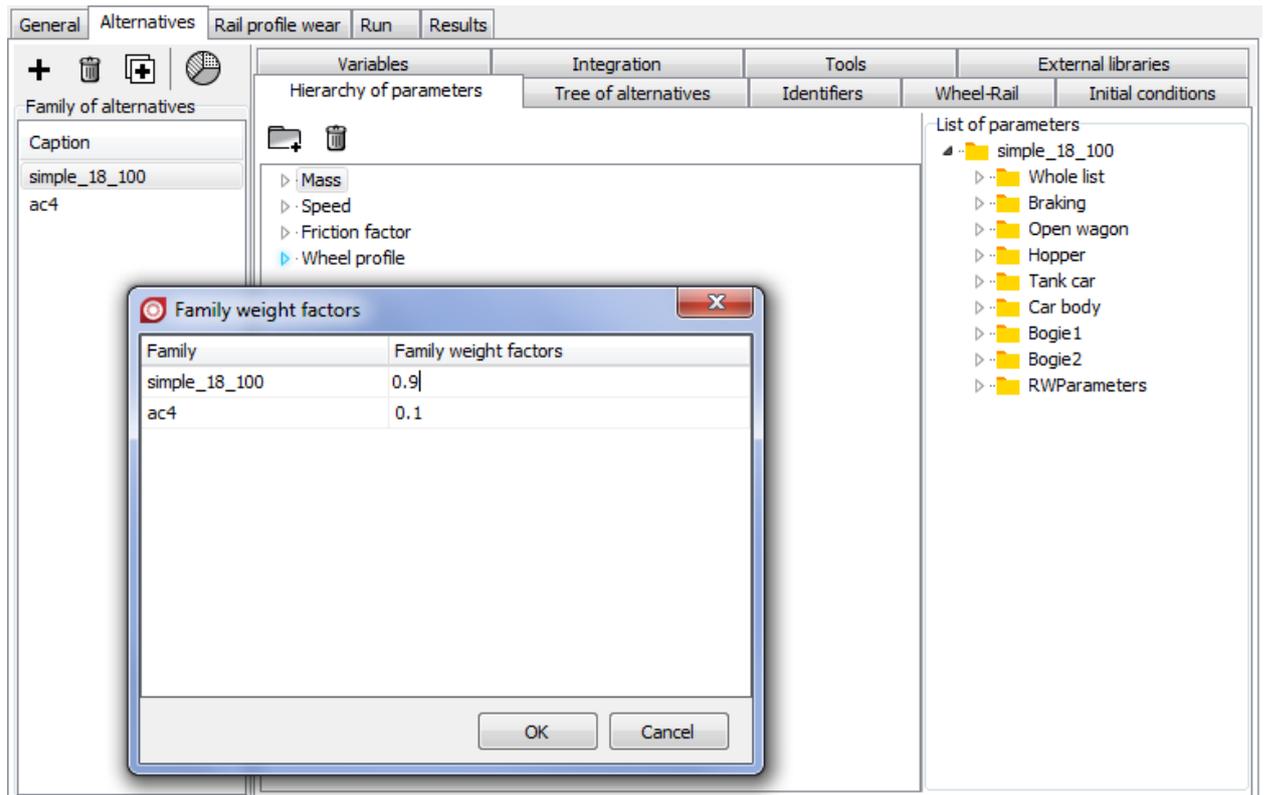


Figure 16.27. Assigning family weight factors

Create the hierarchy of parameters for the added vehicles. To do this, choose one of the vehicles in the **Family of alternatives** list and open the **Hierarchy of parameters** tab. Define groups of parameters that describe different conditions of the selected vehicle in operation, such as new or worn wheel profiles, speed, loaded or empty car, friction coefficients in the wheel-rail contact, etc. (Figure 16.28).

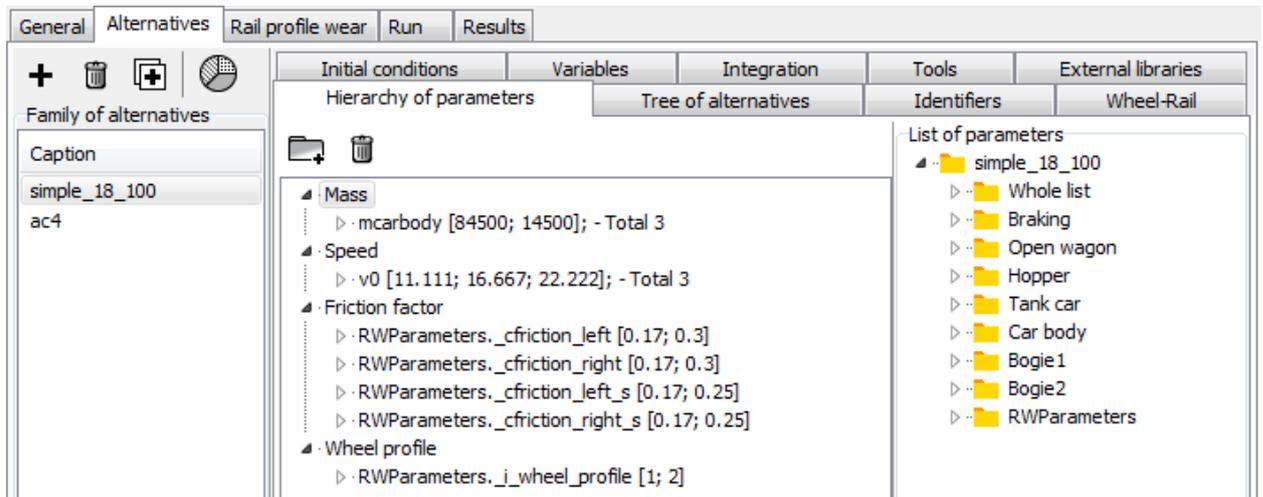


Figure 16.28. Example of hierarchy of parameters

For each parameter group a weight coefficient is assigned. A set of weight coefficients determines the histogram distribution of parameter values in the group.

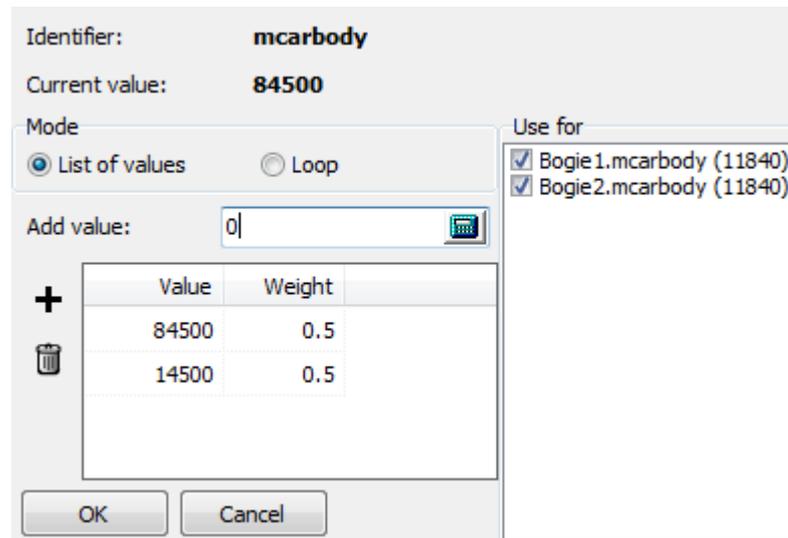


Figure 16.29. Assigning values and weights to a parameter

Open the **Rail profile wear** tab. On the **Track**, **R/W contact forces** and **Rails profiles** tabs are assigned track parameters (track gauge, track geometry, irregularities, etc.), wheel-rail contact parameters and rail profiles for ALL vehicles in the project. On the **Wear parameters** tab parameters for the wear simulation and the wear model are set, Figure 16.30.

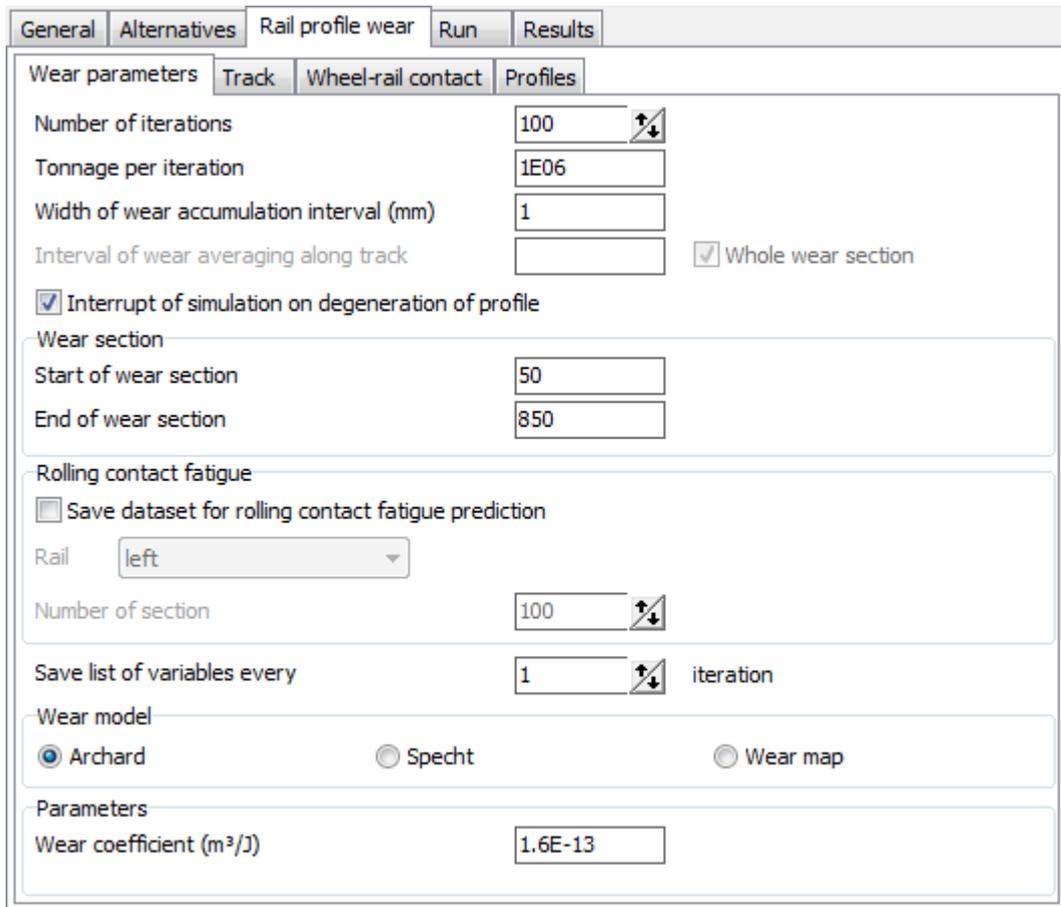


Figure 16.30. Parameters of rail profile wear simulation

Number of iterations (N_{it}) is the number of iterations of rail profile wear simulation. One iteration is a single calculation of the set of numerical experiments of all families of alternatives.

Tonnage per iteration (M_{it}) is the tonnage assigned to one wear iteration. The tonnage value is used to scale the wear depth at the end of each iteration. The purpose of scaling procedure is to amplify the small wear with a small total mass of the vehicles that passed on the track. In fact, the wear depth is multiplied by the scale factor c_{scale} :

$$c_{scale} = M_{it} / \sum_{i=1}^N M_{vi} \tag{16.18}$$

where M_v is the vehicle mass, N is the number of vehicles.

The total tonnage:

$$M_{tot} = N_{it} M_{it} \tag{16.19}$$

Width of wear accumulation interval (h) is the discretization step along the arc-coordinate of the rail surface into longitudinal stripes. It is used for creating a histogram of the wear distribution on the rail profile, Figure 16.3.

Interrupt of simulation on degeneration of profile option, see Sect. 16.1.1.3. "The wear simulation settings. The profile-updating procedure", p. 16-13. A typical reason for profile degeneration is large value of the **Tonnage** parameter.

Start of wear section (S_b) and **End of wear section** (S_e) determine the boundaries of the wear simulation region along the track. These parameters are used to exclude from the simulation "smoothing irregularities", the length of a straight section before and after the curve and so on. Finish conditions are formulated in the following way: "Interrupt a numerical experiment if vehicle reaches the end of the wear section".

In the **Wear model** group choose one of the available wear models.

Let us consider a method of updating profile. Let $w_{ij,l}$ and $w_{ij,r}$ be the volume wear for the left (l) and the right rails (r) calculated for j -th numerical experiment of the family i . Accumulated volume wear is calculated as follows:

$$w_{l,r} = \sum_{i=1}^N \alpha_i \sum_{j=1}^{M_i} \beta_{ij} w_{ij,l,r}, \quad (16.20)$$

where N is the number of vehicles, α_i is the vehicle weight coefficient, M_i is the number of numerical experiments for the i -th vehicle, β_{ij} is the weight coefficient of the numerical experiment.

The wear depth in the center of strip:

$$\delta_{l,r}(s_i) = \frac{\tilde{w}_{l,r}(s_i)}{(S_e - S_b)h}, \quad (16.21)$$

where s_i is an arc-coordinate of the center of the strip, $\tilde{w}_{l,r}$ is a smoothed volume wear, h is the strip width.

16.2.2. Creating a sample project of the evolution of rail profiles

16.2.2.1. Project description

As an example let us consider the creation of a project of the evolution of R65 rail profiles (GOST R 51685-2013) in a tangent track section.

Note Preliminary prepared project is available in the [{UM Data}\samples\tutorial\RailWear](#) folder.

The project will contain two families of alternatives.

The first family of alternatives is a freight car with three-piece bogie 18-100. The model of the car can be found in the following folder: [{UM Data}\samples\Rail_Vehicles\simple_18_100](#).

The following parameters will be varied.

1. Weight of the car: loaded is 84500 kg and empty is 14500 kg.
2. The movement of the car at speeds of 40, 60 and 80 km/h
3. Friction coefficient on the heads of the left and right rails is 0.17 and 0.3; friction coefficient on the side surface of the left and right rails is 0.17 and 0.25.
4. GOST 10791-2011 wheel profile: in new state and after a mileage of 100 thou. km, obtained by simulation of the wheel profile wear in UM software.

The second family of alternatives is the AC4 railcar. The model of the railcar is located in the following folder: [{UM data}\samples\Rail_Vehicles\AC4](#).

The following parameters will be varied.

1. The movement of the car at speeds of 40, 60 and 80 km/h.
2. Friction coefficient on the heads of the left and right rails is 0.17 and 0.3; friction coefficient on the side surface of the left and right rails is 0.17 and 0.25.
3. GOST 10791-2011 wheel profile and DMetI wheel.

The track irregularities correspond to the track of a bad quality according to the UIC standard.

16.2.2.2. Project creation

1. Run **UM Simulation** program. On the main menu toolbar, in the **Speed unit** group, set **m/s**. Create a new rail profile wear prediction project.

2. Let us create the first configuration.

1. Open the **Alternatives**. Click the **+** button and select the [{UM Data}\samples\Rail_Vehicles\simple_18_100](#) model. The selected model will be shown in the list of the **Family of alternatives**.

2. Open the **Wheel-Rail | Profiles | Wheels | Profiles** tab. Clear the **Set of wheel profiles** by deleting the default profiles with the button . Use the button **+** to add to the **Set of wheel profiles** from the [{UM Data}\rw\prf](#) directory *newwagnw.wpf* and *wornwagnw100000km.wpf* profiles. Assign the newly added *newwagnw.wpf* profile to all wheels.

3. Open the **Wheel-Rail | Speed** tab and select the mode of the longitudinal motion **v = const**. In **Speed control parameters** group in the **Body** list select *simple_18_100.Car body*.

4. Open the **Integration | Simulation process parameters** tab. Set the following values for the simulation parameters:

- **Error tolerance** = 1E-7;
- **Computation of Jacobian** = yes;
- **Jacobian for wheel/rail forces** = yes.

5. Open the **Hierarchy of parameters** tab. Use the button  to add a new group of parameters and name it **Mass**. In the list of model parameters, select the *simple_18_100 | Whole list | mcarbody* parameter. In the **Changing parameter values** window that appears, enter the values **84500** and **14500** (kg) and the weight coefficients 0.5 for these values, as it is shown in Figure 16.31. Click **OK** to close the window.

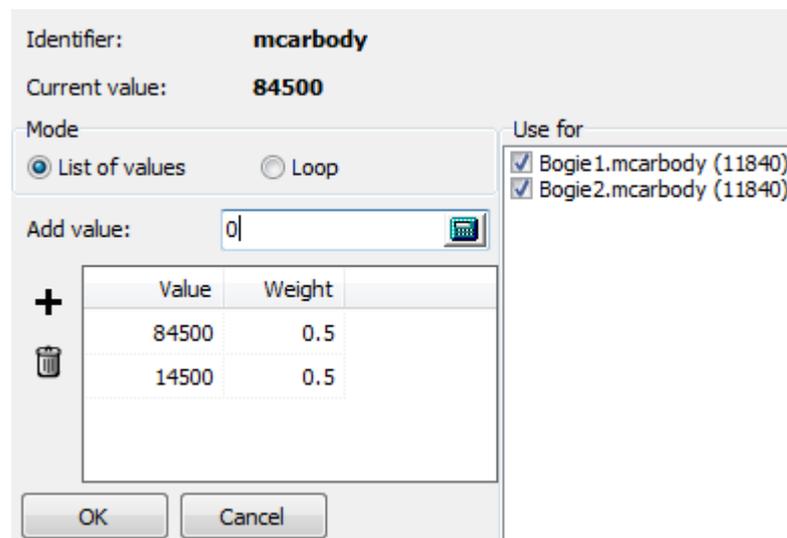


Figure 16.31. Assigning values and weights to the *mcarbody* parameter

6. Add a new group of parameters and name it **Speed**. In the list of model parameters, select the *simple_18_100 | Whole list | v0*. In the **Changing parameter values** window, enter the values **11.111**, **16.667**, and **22.222** (m/s) and the weight coefficients **0.3**, **0.5**, and **0.2**, respectively.

7. Add a new group of parameters and name it **Friction factor**. In the list of model parameters, select *simple_18_100 | RWParameters | Rail/Wheel contact friction coeff. | _cfriiction_left*. In the **Changing parameter values** window, enter the values **0.17** and **0.3** and the weight coefficients **0.5** for these values. Then in the list of model parameters select *simple_18_100 | RWParameters | Rail/Wheel contact friction coeff. | _cfriiction_right*. In the **Change parameter values** window enter the values **0.17** and **0.3** and the weight coefficients **0.5** for these values.

8. In the list of model parameters, select *simple_18_100 | RWParameters | Rail/Wheel contact friction coeff. | _cfriiction_left_s*. In the **Changing parameter values** window, enter the values **0.17** and **0.25** and the weight coefficients **0.5** for these values. Then, in the list of model parameters, click *simple_18_100 | RWParameters | Rail/Wheel contact friction coeff. | _cfriiction_right_s*. In the **Changing parameter values** window, enter the values **0.17** and **0.25** and the weight coefficients **0.5** for these values.

9. Add a new parameter group and name it the **Wheel profile**. In the list of model parameters, select *simple_18_100 / RWParameters / Profiles / _i_wheel_profile*. In the **Changing parameter values** window, enter values **1** (*newwagnw* profile) and **2** (*wornwagnw100000km* profile) and weight coefficients **0.2** and **0.8**, respectively. Finally the completed hierarchy of parameters for the *simple_18_100* alternative family will look as it is shown in Figure 16.32.

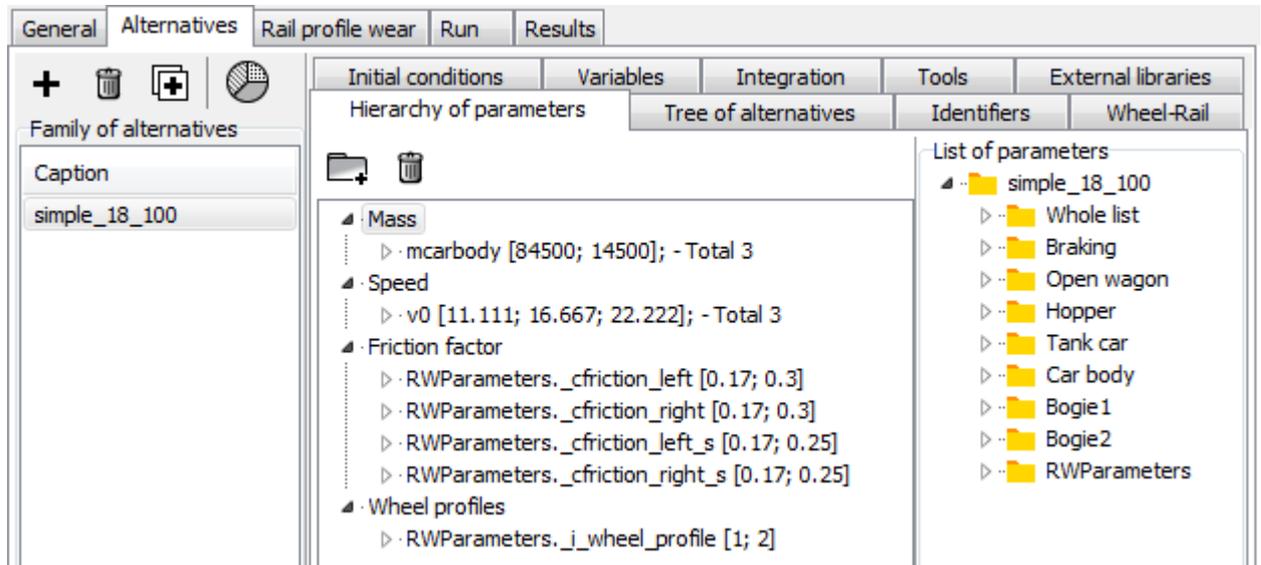


Figure 16.32. Hierarchy of parameters of family of alternatives *simple_18_100*

3. Let us create the second configuration.

1. Open the **Alternatives** tab Click the **+** button and select the [{UM data}\samples\Rail_Vehicles\AC4](#) model.

2. Open the **Wheel-Rail | Profiles | Wheels | Profiles** tab, Clear the **Set of wheel profiles**. Add to the **Set of wheel profiles** *newlocow.wpf* and *dmeti30.wpf* profiles. Assign a *newlocow.wpf* profile to all wheels.

3. Open the **Wheel-Rail | Speed** tab and select the mode of the longitudinal motion **v = const**. In **Speed control parameters** group in the **Body** list select, select *ac4.Car body*.

4. Open the **Integration | Simulation process parameters** tab. Set the following values for the simulation parameters:

- **Error tolerance** = 1E-7;
- **Computation of Jacobian** = yes;
- **Jacobian for wheel/rail forces** = yes.

5. Open the **Hierarchy of parameters** tab. Add a new group of parameters and name it **Speed**. In the list of model parameters, select the *ac4 / Whole list / v0* parameter. In the **Changing parameter values** window that appears, enter the values **11.111**, **16.667**, and **22.222** (m/s) and weight coefficients **0.6**, **0.3**, and **0.1**, respectively, for these values. Close the parameter value settings window and return to the scan project.

6. Add a new group of parameters and name it the **Friction factor**. In the list of model parameters, select the *ac4 / RWParameters / Rail/Wheel contact friction coeff. / _cfraction_left* parameter. In the **Changing parameter values** window, enter the values **0.17** and **0.3** and the weight coefficients **0.5** for these values. Then, in the list of model parameters, select the

ac4 | *RWParameters* | *Rail/Wheel contact friction coeff.* | *_cfraction_right* parameter. In the **Changing parameter values** window, enter the values **0.17** and **0.3** and the weight coefficients **0.5** for these values.

7. In the list of model parameters, select the *ac4* | *RWParameters* | *Rail/Wheel contact friction coeff.* | *_cfraction_left_s* parameter. In the **Changing parameter values** window, enter the values **0.17** and **0.25** and the weight coefficients **0.5** for these values. Then, in the list of model parameters, select *ac4* | *RWParameters* | *Rail/Wheel contact friction coeff.* | *_cfraction_right_s*. In the **Changing parameter values** window, enter the values **0.17** and **0.25** and the weight coefficients **0.5** for these values.

8. Add a new parameter group and name it the **Wheel profile**. In the list of model parameters, select the *ac4* | *RWParameters* | *Profiles* | *_i_wheel_profile* parameter. In the **Changing parameter values** window, enter values **1** (*newlocow* profile) and **2** (*dmeti30* profile) and weights **0.5** for these values. After the actions are completed, the hierarchy of parameters for the *ac4* alternative family will look as shown in Figure 16.33.

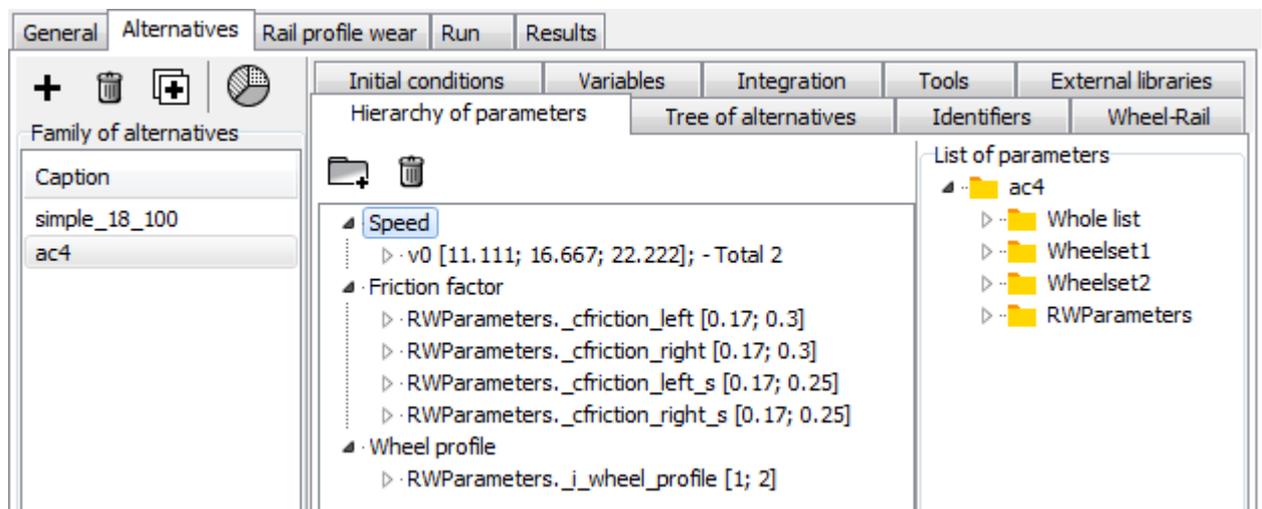


Figure 16.33. Hierarchy of parameters for the *ac4* alternative family

4. Open the **Alternatives** tab. Use the  button to open the window for setting weight coefficients of alternatives. For the *simple_18_100* model, set the weight coefficient **0.9**, and for the *AC4* model, set the weight coefficient **0.1**.

5. Open the **Rail profile wear** | **Wear parameters** tab and set the following values for the wear parameters:

- **Number of iterations** = 100;
- **Tonnage per iteration** = 10^6 ;

that is, the accumulated tonnage will be 100 million tons;

- **Width of wear accumulation interval (mm)** = 1;
- **Interrupt of simulation in degeneration of profile** = yes;
- **Start of wear section** = 50;
- **End of wear section** = 850;
- **List of variables saving step** = 1 iteration;
- **Wear model** = Archard;

- **Wear coefficient** (m^3/J) = $1.6 \cdot 10^{-13}$.

6. Open the **Rail profile wear | Track | Model and parameters** tab and set the following values for the parameters:

- **Rail inclination (rad)** = 0.05;
- **SCR-SCW distance (mm)** = 5.15;
- **Track model** = *Inertial rail*.

7. Open the **Rail profile wear | Track | Macrogeometry** tab and specify the **Track type** = **Tangent**.

8. Open the **Rail profile wear | Track | Irregularities** tab. Set **Track type** to **Uneven**, set **Type of irregularities** to **From file**. Using button  **Load group of irregularities from file** assign to the rails a group of irregularities *uic_bad_1000m.tig* from the [{UM Data}\rw](#) directory.

9. Open the **Rail profile wear | Rail profiles** tab and assign the *r65new.rpf* profile to both rails from the [{UM Data}\rw\prf](#) directory.

2. Open the **Rail profile wear | R/W contact forces** tab. Select the W. Kik and J. Piotrowski contact model and set the following values for contact parameters:

- **Young's modulus** = $2.1 \cdot 10^{11}$;
- **Poisson's ratio** = 0.27;
- **Width of strip (mm)** = 10;
- **Minimum number of strips** = 20;
- **Number of elements** = 20;
- **Interpenetration factor** = 0.55;
- **Damping ratio** = 0.01.
- **Use tables of contact points** = yes.

The project is ready. Open the **Run** tab. Use the protocol to make sure that the scan project is without errors. Set the required number of processes based on the parameters of your computer. Run the simulation by clicking the **Run** button.

16.2.3. Analysis of the results

The calculation results are processed using the specialized tool **Analysis of wear of railway rail profiles** (**Main menu | Tools | Analysis of wear of railway profiles | Rail profiles...**), Figure 16.34. To load calculation results click the **Browse...** button and specify the folder with results or choose the corresponding path from the reopen list. In addition, the calculation results can be analyzed directly in the scanning project. To do this, after completing the project, open the **Results | Analysis of rail profile wear** tab.

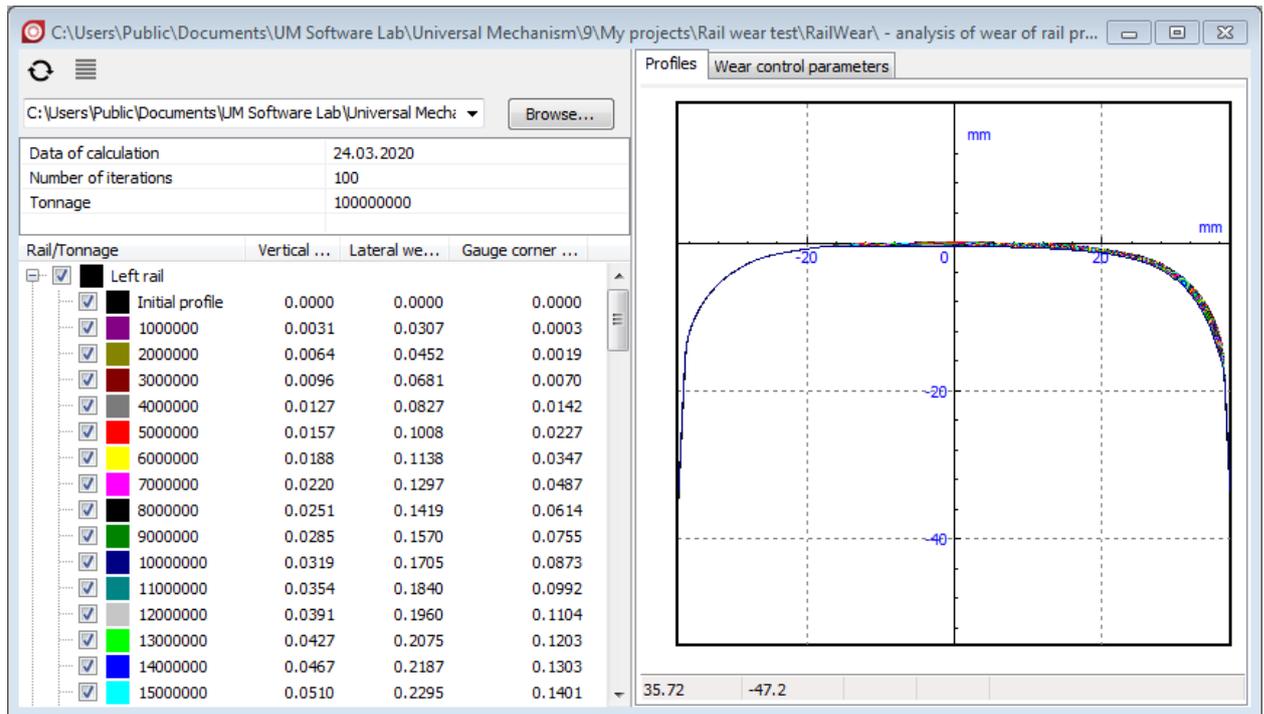


Figure 16.34. Analysis of rail profile wear tool.

Use right mouse button click on the result tree to open the context menu. Context menu commands provide additional features for processing results: open a profile in the profile editor and copy wear control parameters to the clipboard. On the **Profiles** tab there are profiles obtained at the corresponding tonnage, Figure 16.35. On the **Wear control parameters** tab graphs of dependence of wear control parameters vs tonnage are available, Figure 16.36. Use  button to set parameters for evaluating the profile wear: H , α , and reference profiles, Figure 16.37.

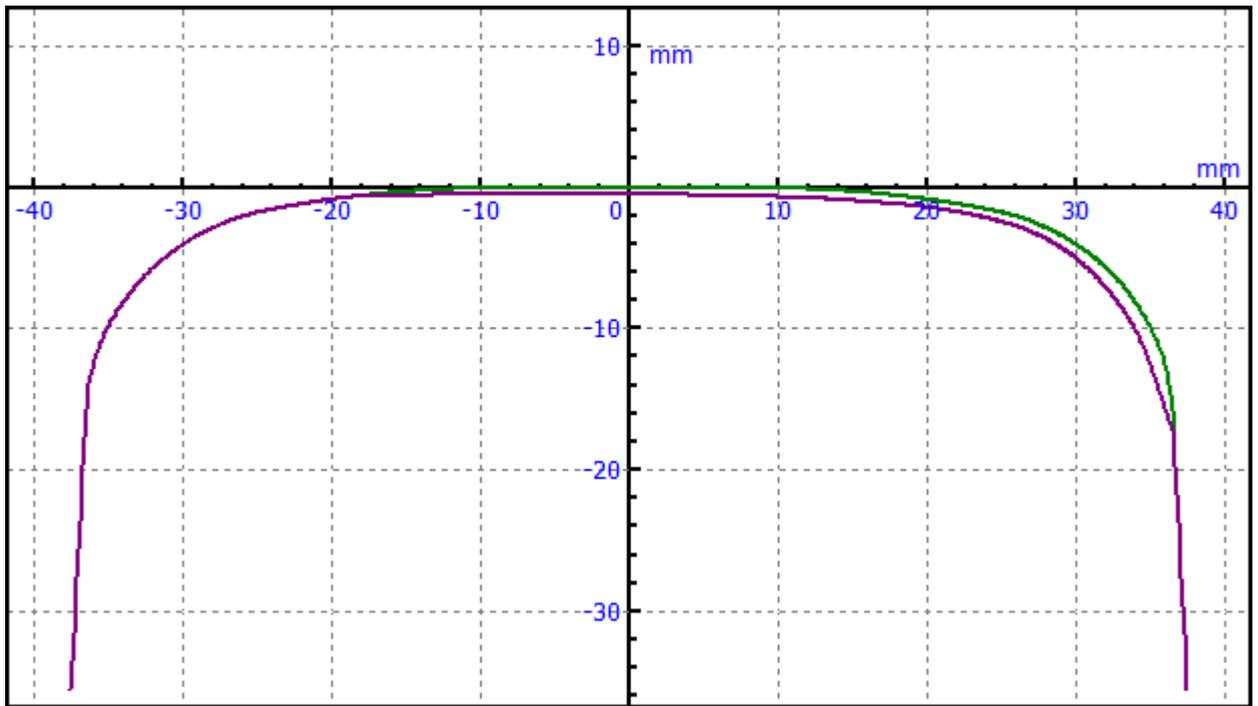


Figure 16.35. Left rail profile in in new state and after a tonnage of 100 Mt

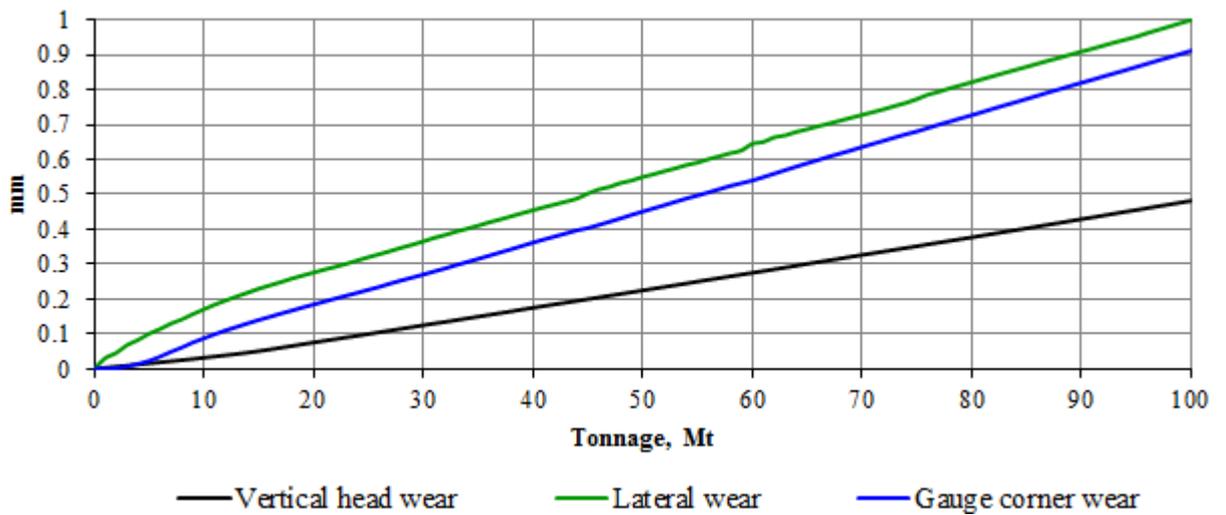


Figure 16.36. Wear control parameters for the left rail profile

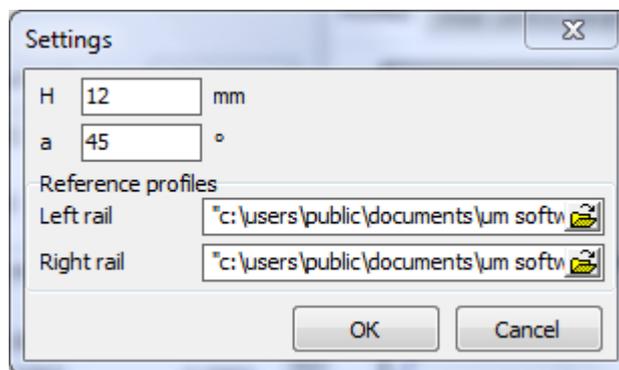


Figure 16.37. Parameters setting for evaluating rail profile wear

16.3. References

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