



User`s manual



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 in the geometry of railway profiles due to wear has a strong affects on the vehicle dynamic behavior. This in turn affects more performances, the main of which are running stability, derailment risks and ride comfort.

Two different approaches to simulation of the wheel and rail profiles wear is exist [1]: parallel treatment and sequential treatment. In the parallel approach, the mutual affect of wear processes and vehicle dynamics is taken into account, i.e. small changes in the profile geometry due to wear occur directly in the dynamic integration loop. In the sequential approach does not take into account the effect of the change of the profile geometry due to wear on the vehicle dynamics – the profile geometry updates after the dynamics simulation. To obtain measurable wear, sequential simulation must be performed quite a large number of times.

Algorithms of predicting of the evolution geometry of the wheel/rail profiles due to wear, implemented in Universal Mechanism software (UM), are based on the experimental relationship between the volume loses of material and a work of frictional forces in contact [2] [3] [4]. The following wear laws are available in UM: *Fleischer* [5], *Krause-Poll* [4] [6] and *Archard KTH* [2] [3].

- Fleischer model.

In the Fleisher wear law uses a linear relationship between a volume wear (volume of worn material) and the work of frictional forces:

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

where k_V is the wear coefficient, A is the work of frictional forces.

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

where P is the power of frictional forces.

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

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

- Krause-Poll model.

In the Krause-Poll wear law also linear relationship between the 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.

$$k_V(p) = \begin{cases} k_V, & p < p^* \\ \gamma k_V, & p \geq p^* \end{cases} \quad (16.4)$$

where $p^* = P/F$ is the critical power density of frictional forces, γ is the jump coefficient.

- Archard model

According to the Archard wear law, the volume wear is calculated as follows:

$$W_V = k \frac{Ns}{H}, \quad (16.5)$$

where N is the normal force in contact, s is the sliding distance, H is the hardness of the softest contacting surfaces. The coefficient k is determined by a wear chart (Figure 16.1) from experimental data collected.

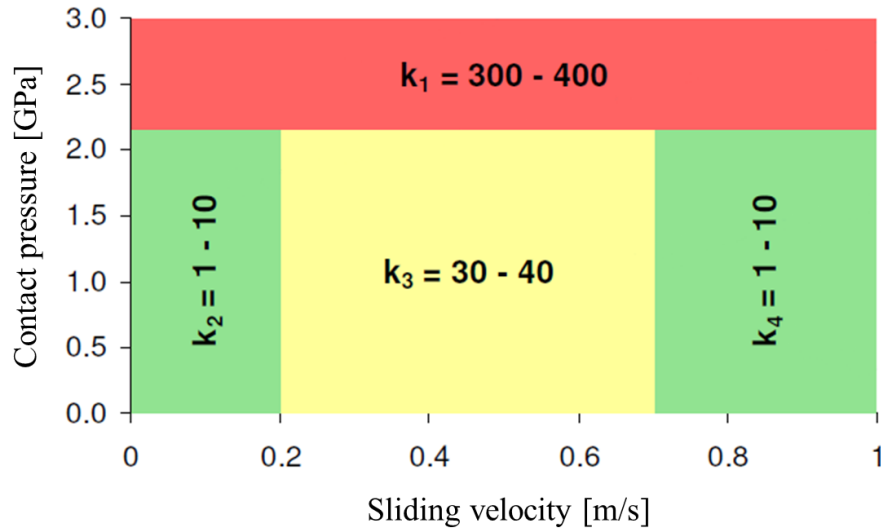


Figure 16.1. Wear coefficient chart for Archard model

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) or (16.5) as follows:

$$W_{V_{i,j}} = k_v \tau_{ij} \mathbf{w}_{ij} v \Delta F_j \Delta t, \tag{16.6}$$

where v is the wheelset velocity, \mathbf{w}_{ij} is the creepages in the center of the element, ΔF_j is the area of the element in the strip, Δt is the integration time step size;

$$W_{V_{i,j}} = k \left(v_{s_{ij}}, p_{n_{ij}} \right) \frac{p_{n_{ij}} \Delta F_j}{H} |\mathbf{w}_{ij}| \Delta x_j, \tag{16.7}$$

where $p_{n_{ij}}$ is the normal, $v_{s_{ij}}$ is the sliding velocity Δx_j is the element size along the x -axis.

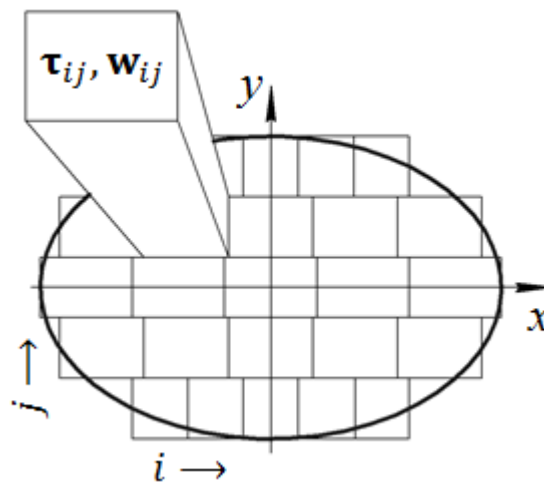


Figure 16.2. Discretization of the contact patch in the FASTSIM algorithm

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

The above relationships 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 bins (intervals) of equal width h . During simulation of rail vehicle dynamics, this discretization is used to determine of a histogram of the volume wear distribution along the profile, Figure 16.3. The resulting histogram is approximated by the B-Spline.

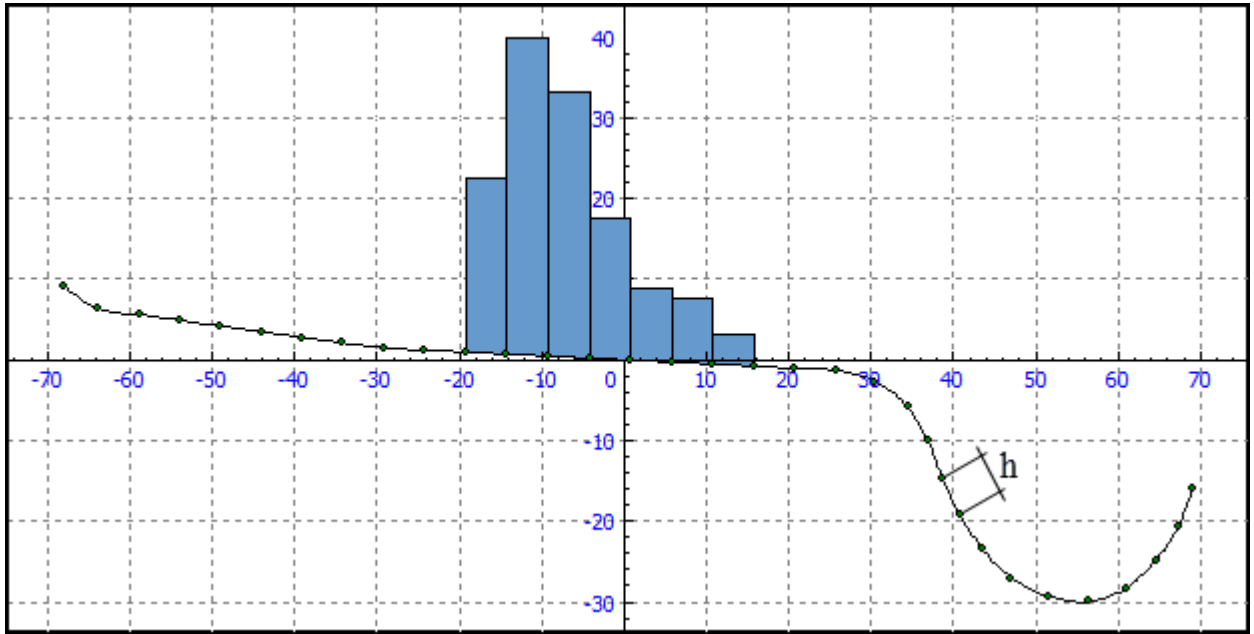


Figure 16.3. Histogram of the wear distribution along the wheel profile, h is the step of discretization the profile into segments

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

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

where $W_V(s)$ is the distributional volume wear along profile, R is the wheel radius, s is the arc-coordinate.

When calculating the wear depth, it is considered that the wheel in circumferential direction has uniform wear, i.e. retain an axisymmetric shape.

Wear depth for the rail profile:

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

where L is the length of the wear section of a track.

When calculating the rail profile wear, it is assumed that the rail has uniform wear in the longitudinal direction, i.e. the rail profile does not change along the track section.

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 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.

The wear value is numerically evaluated by the by *wear control parameters*. The wear control parameters of the wheel profile are shown in Figure 16.4 and Figure 16.5.

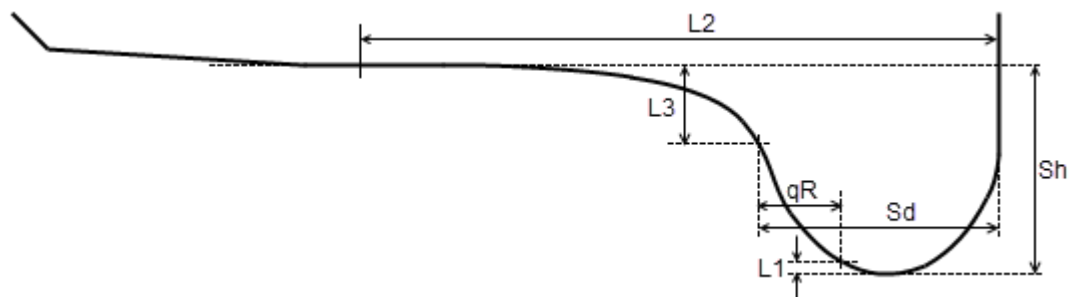


Figure 16.4. Wheel wear control parameters Sd , Sh and qR [7]

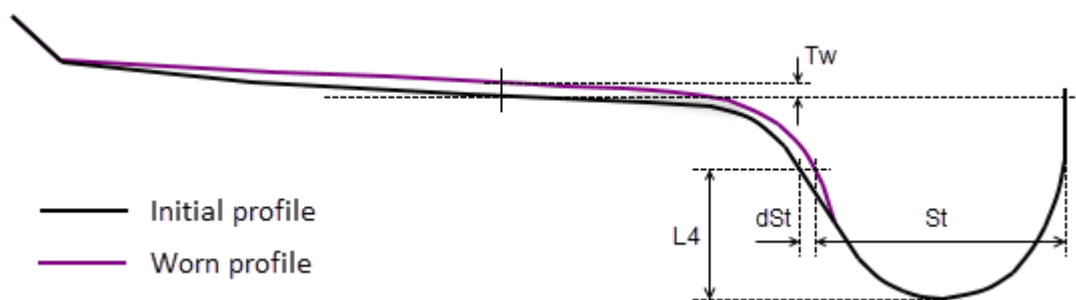


Figure 16.5. Wheel wear control parameters Tw , St and dSt [8]

Wear control parameters of the wheel profile are

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

Note Approaches of determining of wear control parameters Sd and St are different in the selected reference point. The value Sd is measured in some distance from the wheel tape-circle. Note that an origin of the wheel tape-circle is not constant during the wear simulation i.e. the reference point is changes. On the other hand, St

is measured from the flange vertex, where under normal operating conditions there should be not change shape.

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

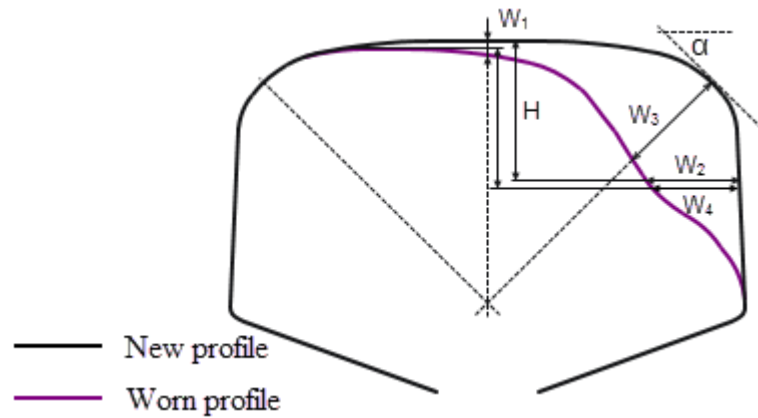


Figure 16.6. Wear control parameters of rail profile: W_1 is the vertical head wear W_2 is the lateral wear, W_3 is the gauge corner wear, W_4 is the lateral wear measured from worn running surface

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 of the railway profiles wear

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

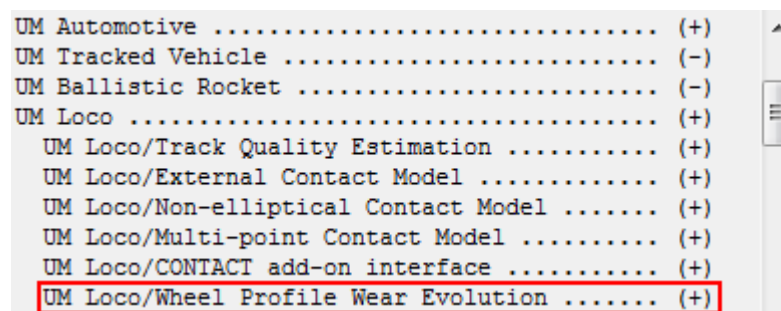


Figure 16.8. Current UM configuration in **About** window

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 RCF Wheel** 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 predicting of the wheel profiles wear when vehicle running along entire railroad requires an extremely large of simulation time. A possible solution is to wear simulation on a set of configurations (routes) of short length which takes into account the general statistical properties of the considered railway, Table 16.1. *This set of routes should be a representative set of working conditions in which the rail vehicle is operated.*

Note. On general-purposed railroads, the total length of left-hand and right-hand curves is approximately equal. Therefore, in statistical analysis of railway, are limited to the general weights of curves without dividing into left-hand and right-hand curves.

Table 16.1

Example of statistical analysis of railroad

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 section	-	-	0.54

In **Wheel Profile Wear Evolution** tool the parallel approach with discrete updates of wheel profiles is implemented. In the parallel approach different scenarios running of the rail vehicle are simulated in parallel. These scenarios are named "configurations". Configurations differ in track geometry, rail profiles, vehicle mass and so on. Wheel profiles are the same for all configurations at any arbitrary time, Figure 16.9. The running distance of the vehicle into a sequence of many small intervals is divided. The number of intervals is the same for all configurations. These intervals are named "wear steps". In each wear step the material losses are calculated according to the uses wear model and accumulated. Within each wear step the wheel profiles are not changed. At output of each wear step the material losses is summed up for the respective wheels by taking into account the scaling factor, statistical weights of configurations and the wear averaging, if any. The profile geometry is updated according to the weighted sum of material losses.

Parallel calculation of configurations on multithreading CPUs is implemented to speed up the simulation process, see Sect. 16.1.4. "Parallel computations on multithreading CPUs", p. 16-27.

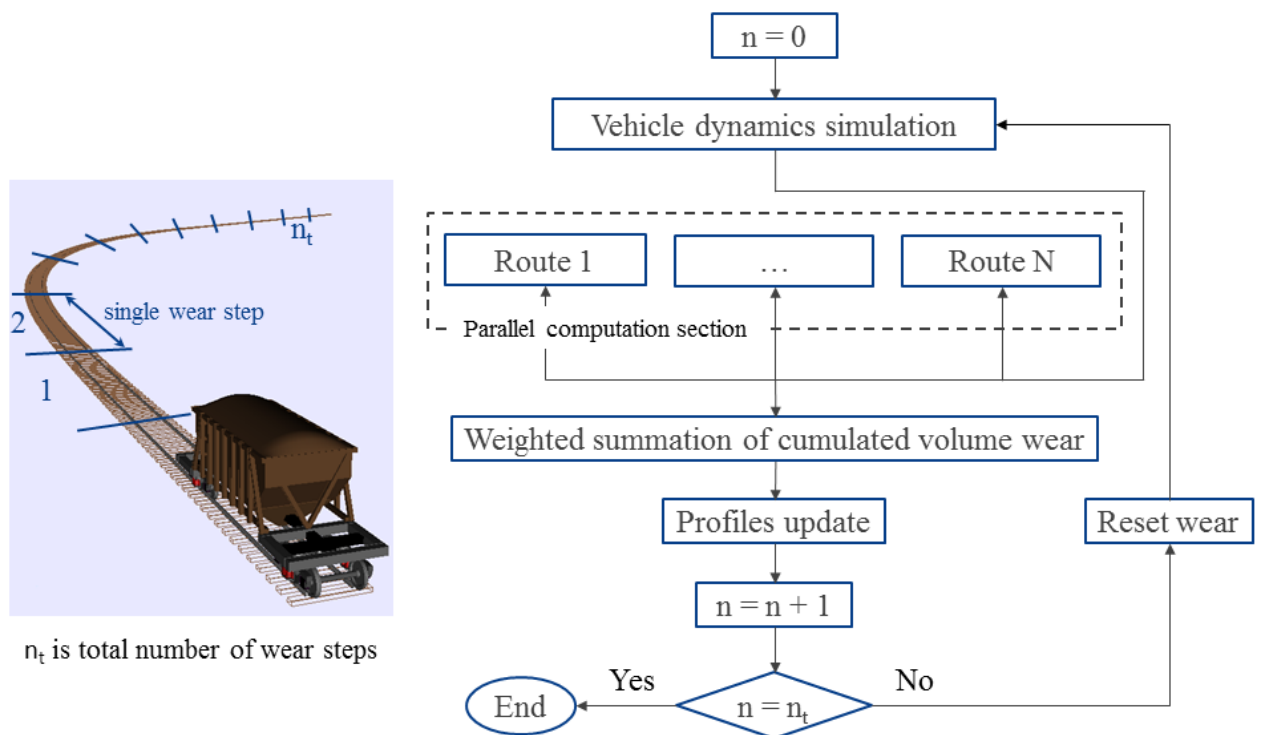




Figure 16.9. Flow chart of parallel ("online") wear simulation of wheel profiles

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 **Rail vehicle | Wheel profiles wear** tab, 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.

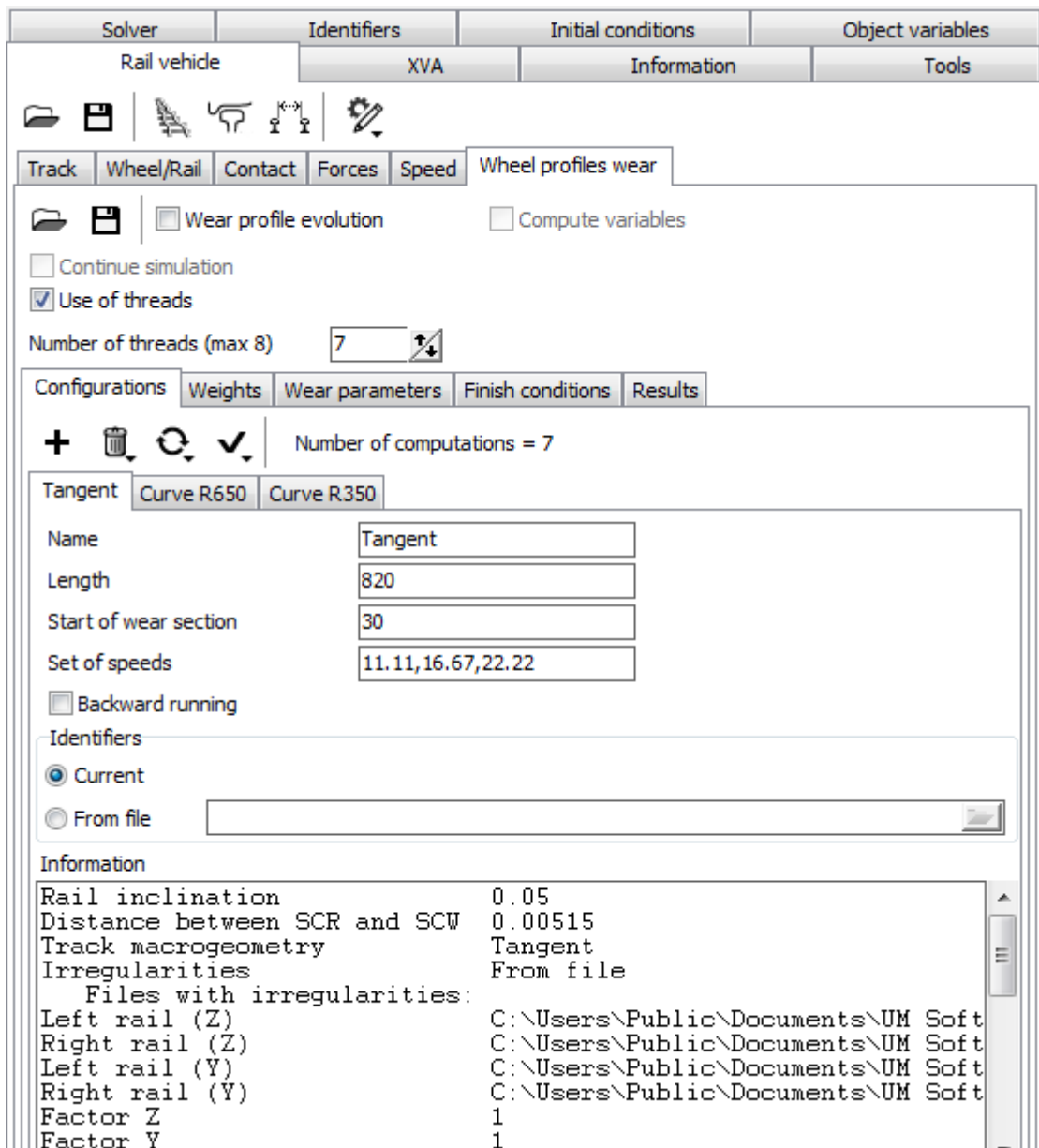






Figure 16.10. Wheel profiles wear tab

16.1.1.1. Creating set of configurations

To edit the configurations 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. The term "*current railway parameters*" should be understood the parameters set in the tabs **Track**, **Wheel/Rail**, **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 factors of configurations and speeds

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

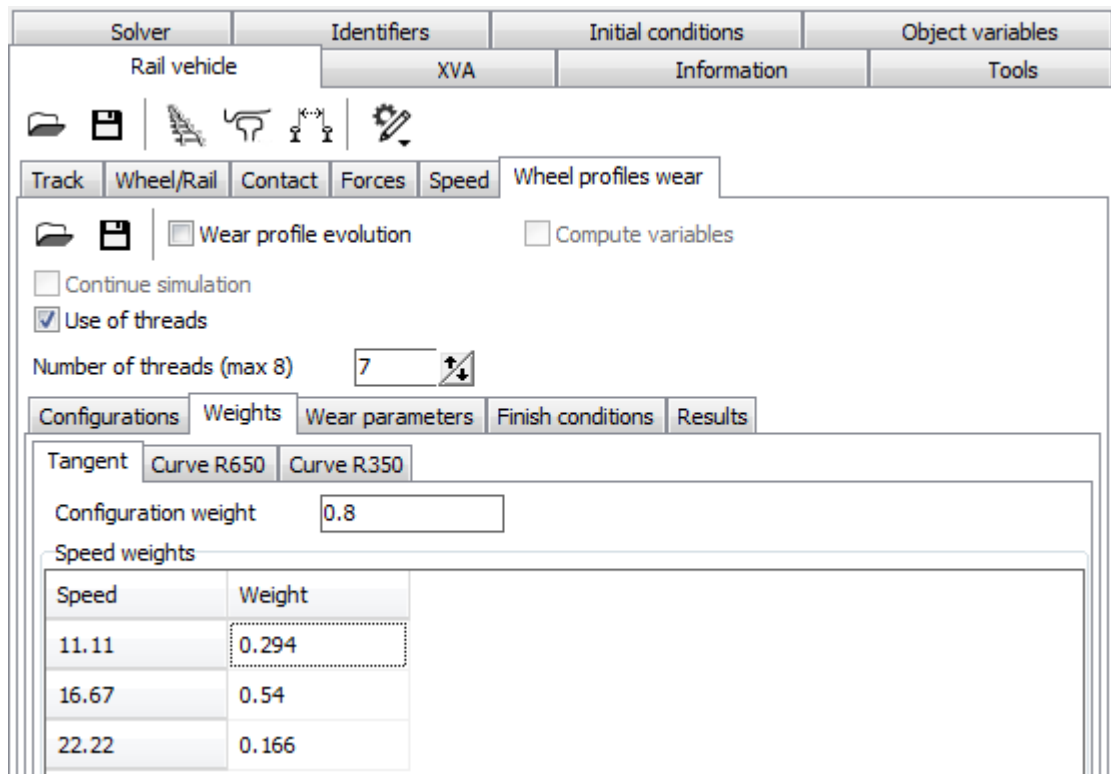


Figure 16.11. **Weights** tab

Configuration weight (α_i) represents the frequency with which each parameter that separates the configuration, for example, the radius of the curved track, appears on the considered railroad, Table 16.1. **Speeds weight** (β_{ij}) determine a distribution of speeds of the vehicle for this route.

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

The wear simulation parameters and the wear model are set on the **Wear parameters** tab, Figure 16.12. On the tab has the following parameters and options: **Number of iterations**, **Number of wear steps**, **Mileage**, **Width of wear accumulation bin**, **Average wheelsets wear**, **Average wheels wear of same wheelset** and **Interrupt simulation on degeneration of profile**.

Number of iterations (N_{it}) is the number of rerun of the wear simulation. Wear iterations are series of calculations of the same structure that differ only in the initial wheel profiles. One iteration is a single calculation of 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 get measurable wear with a short running distance. At output of the wear step the volume wear 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 loses due to wear depends almost linearly on the running distance, which is true within one wear step.

$$\text{Total mileage } km_{tot} = N_{it} N_{ws} km_{step}.$$

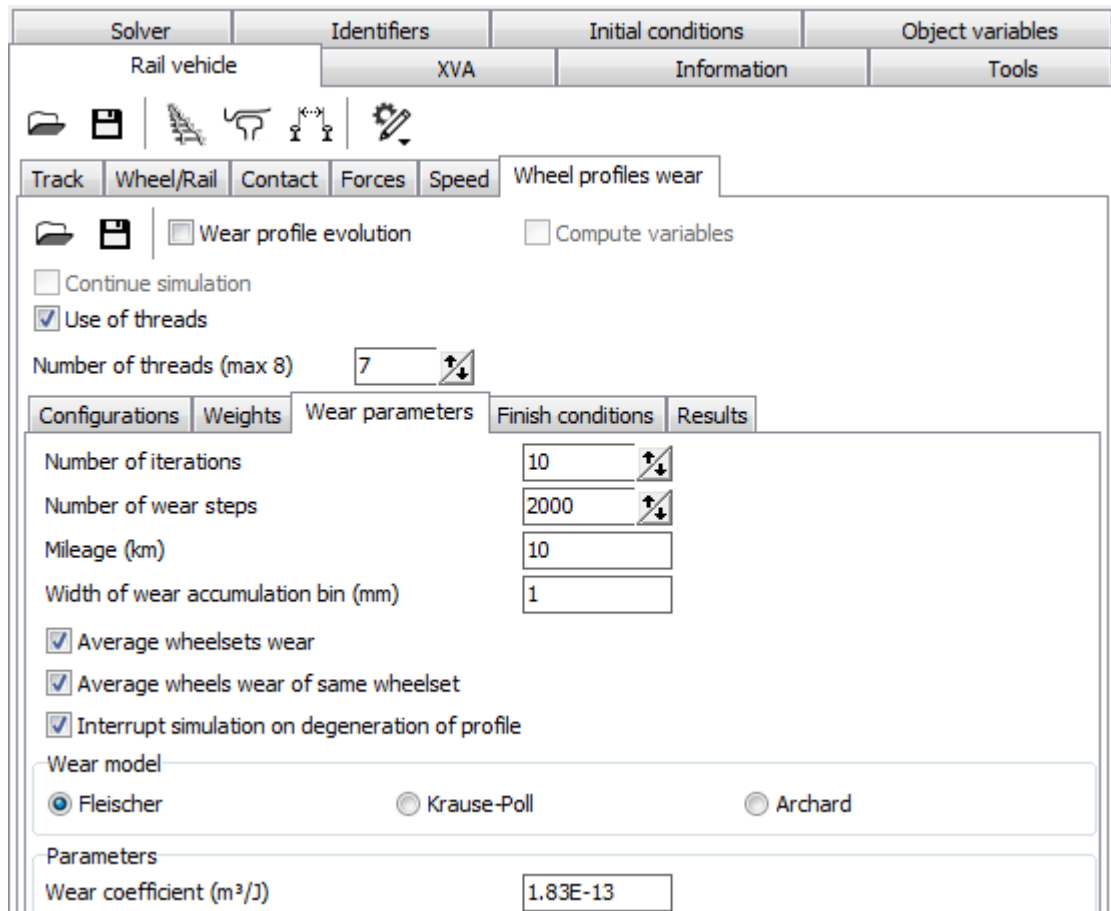


Figure 16.12. **Wear parameters** tab

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

The option **Average wheelsets wear** should be used if the rail vehicle is running along the route in forward and backward directions without a turn of 180. In this case, the wear of the wheel profiles having a skew-symmetric arrangement relative to the center of the vehicle is averaged, i.e. the left wheel of the leading wheelset and the right wheel of the trailing wheelset wear out equally, etc.

The option **Average wheels wear of same wheelset** should be used if statistical weight of left-hand and right-hand curves of similar radius on the route is approximately equal. In this case, the profiles of the wheels of same wheelset wear out equally. When using this option, only configurations with right-hand curves should be included in the configuration set.

Options **Average wheelsets wear** and **Average wheels wear of same wheelset** allow reducing the number of configurations and simplifying the calculation. Comparison of the results of the wear simulation of the wheel profile on the full and simplified sets of configurations is shown in Figure 16.13. The "*simplified set*" is the set of configurations with only right-hand curves and forward routes.

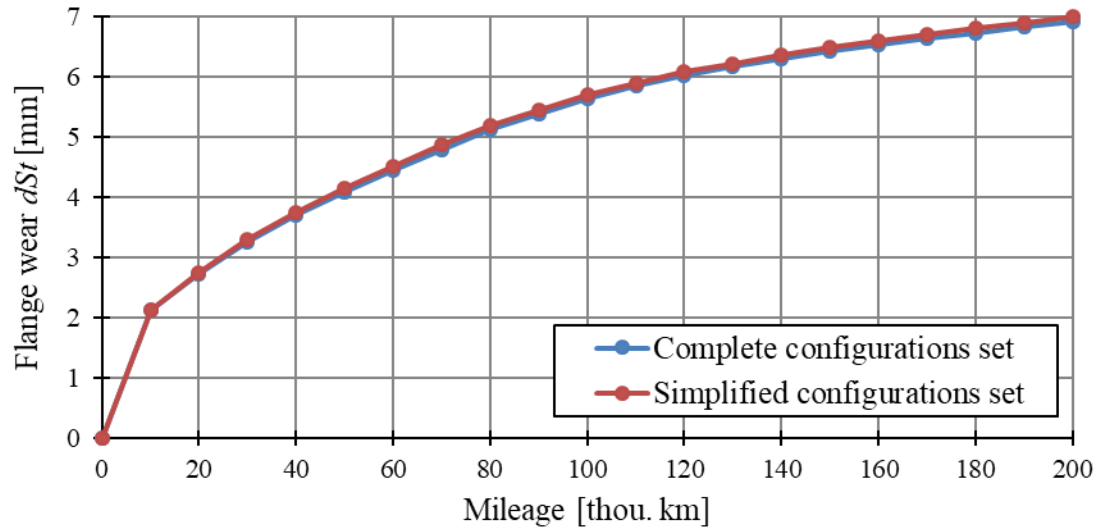


Figure 16.13. Comparison of simulation results of full and simplified sets of configurations

The **Interrupt simulation on degeneration of profile** option is used for processing a scenario of the profile degeneration. Degeneration is breaking of a strict monotonically of the x-coordinate of the profile, Figure 16.14. If the option is on, the calculation will be interrupted with the output of the corresponding warning. 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.

In the **Wear model** radio group, select one of the available models and set its parameters.

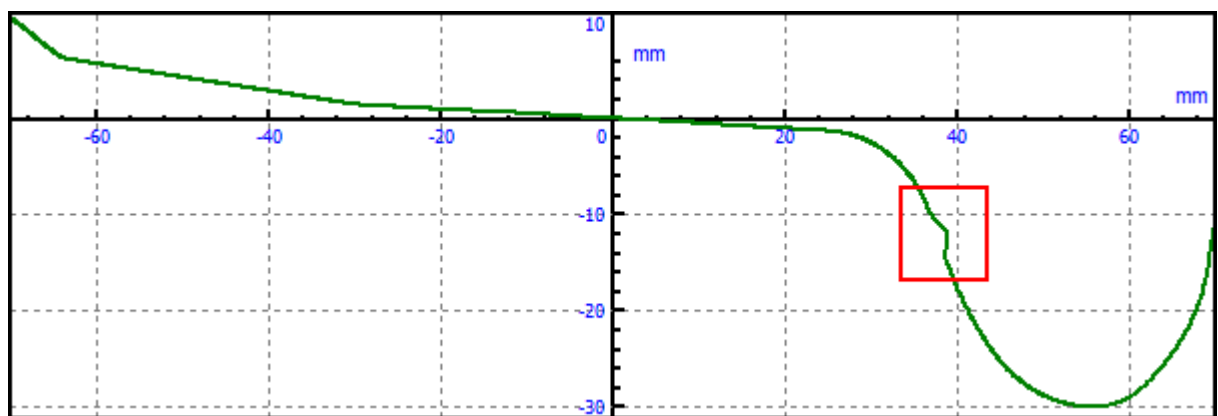


Figure 16.14. Degeneration of profile ()

Let us consider an algorithm of updating the wheel profile. Let $W_{V_{ijk,l}}$ and $W_{V_{ijk,r}}$ be volume wear for left and right wheels of the wheelset with the index k cumulated for the route i at j -th running route speed.

1. If option **Average wheels wear of same wheelset** is used, then wear of the wheels of same wheelset is averaging:

$$W_{V_{ijk,l}} = W_{V_{ijk,r}} = \frac{1}{2} (W_{V_{ijk,l}} + W_{V_{ijk,r}}). \quad (16.12)$$

2. If option **Average wheelsets wear** is used, then wear of wheel profiles having the skew-symmetric arrangement relative to the center of the vehicle is averaging:

$$W_{V_{ijk,l}} = W_{V_{(n_{ws}-k+1),r}} = \frac{1}{2} (W_{V_{ijk,l}} + W_{V_{(n_{ws}-k+1),r}}), \quad l \neq r, \quad (16.13)$$

where n_{ws} is the number of wheelsets.

3. Calculation of the total accumulated of the volume wear:

$$W_{V_{k,m}} = \sum_{i=1}^{n_r} \alpha_i \sum_{j=1}^{n_{v_i}} \beta_{ij} W_{V_{ijk,m}}, \quad m = l, r. \quad (16.14)$$

The distribution of accumulated volume wear along the profile is approximated (smoothed) by the B-spline.

4. Calculation of the wear depth in the center of each circumferential strip:

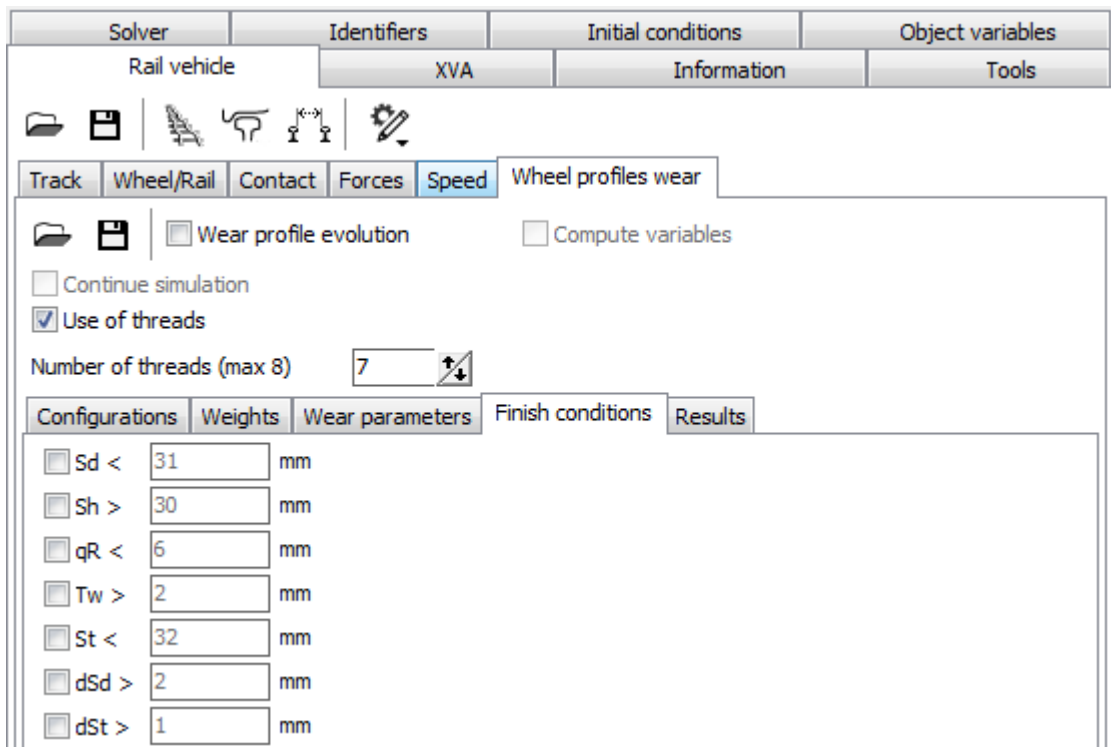
$$\delta_{k,m}(s_i) = \frac{\tilde{W}_{V_{k,m}}(s_i)}{2\pi R_{k,m}(s_i)h}, \quad m = l, r, \quad (16.15)$$

where s_i is the arc-coordinate of the center of the strip, $\tilde{W}_{V_{k,m}}$ is the smoothed distribution of the volume wear along the profile, $R_{k,m}$ is the wheel radius, h is the strip width. New coordinates of the profile points are calculated according to the equation (16.10).

16.1.1.4. Finish conditions

Finish conditions are set on the **Finish conditions** tab, Figure 16.15. In **Wheel Profile Wear Evolution** tool the wear control parameters of the wheel are used as stopping criteria (Figure 16.4 and Figure 16.5).

A wear simulation will be interrupted when one of the finish conditions is satisfied (the logical operator OR). If finish conditions are not selected, the simulation will be completed when the specified number of wear iterations is done.

Figure 16.15. **Finish conditions** tab

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 16.16. 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.

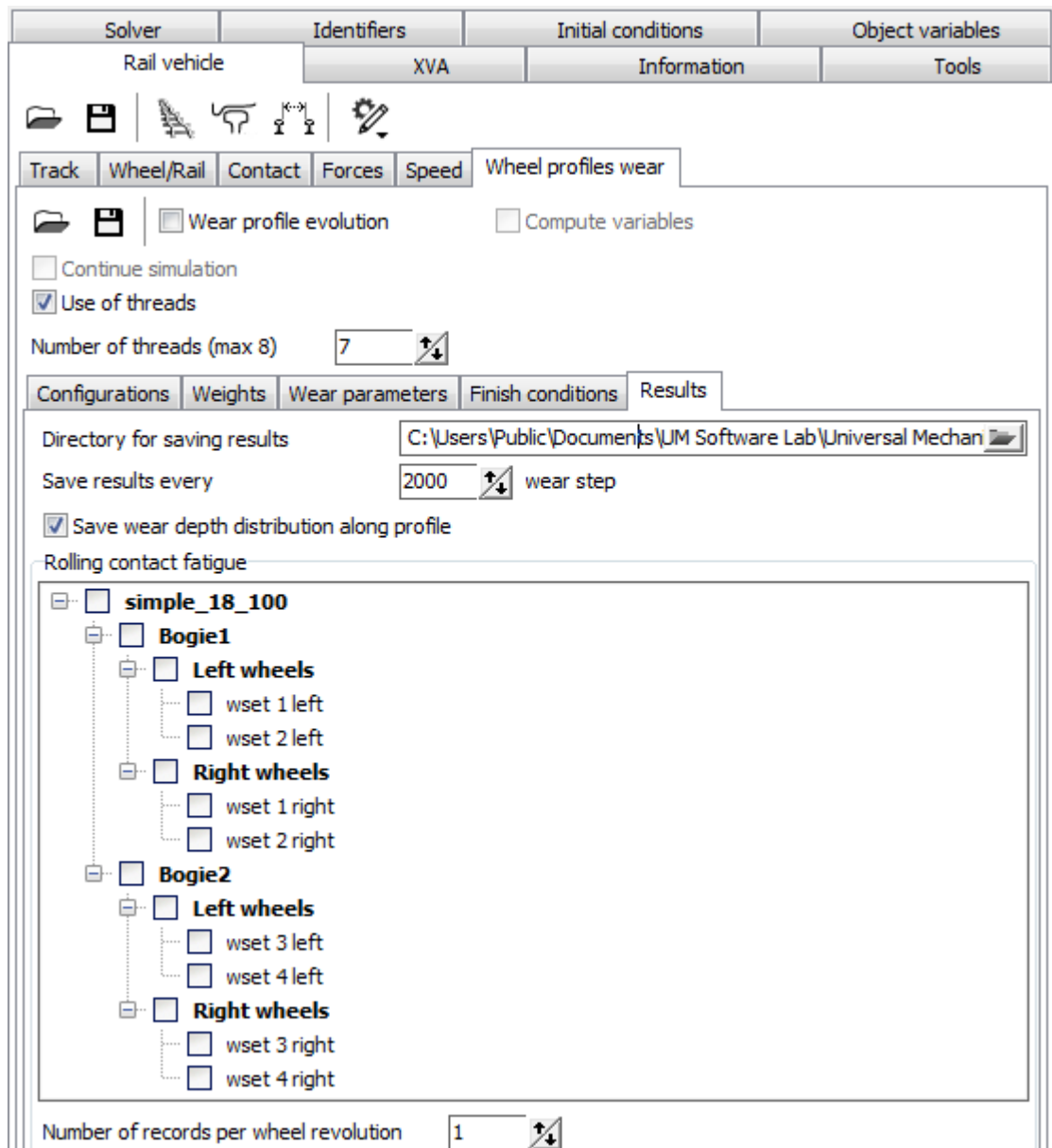


Figure 16.16. Results tab

16.1.1.6. Wear simulation process

Run the simulation by clicking the **Integrate** button in the **Object simulation inspector** window. After clicking, the **Monitor of wear of railway wheel profiles** window appears (Figure 16.17), 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 (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*).

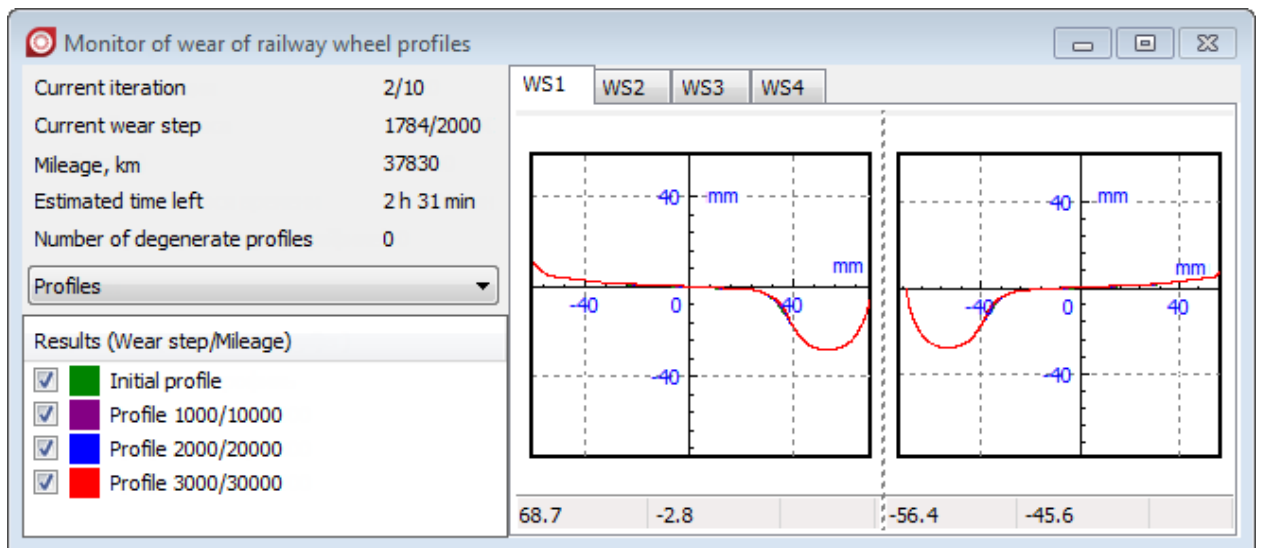



Figure 16.17. Monitor of wear of railway wheel profiles window

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 running 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 16.18. 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 16.19.

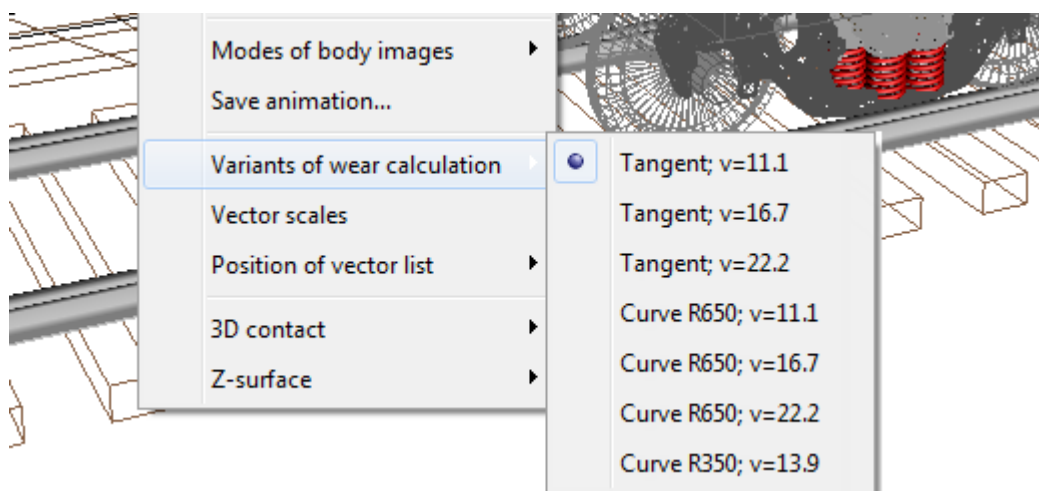


Figure 16.18. Choosing variant of wear calculation in the **Animation window**

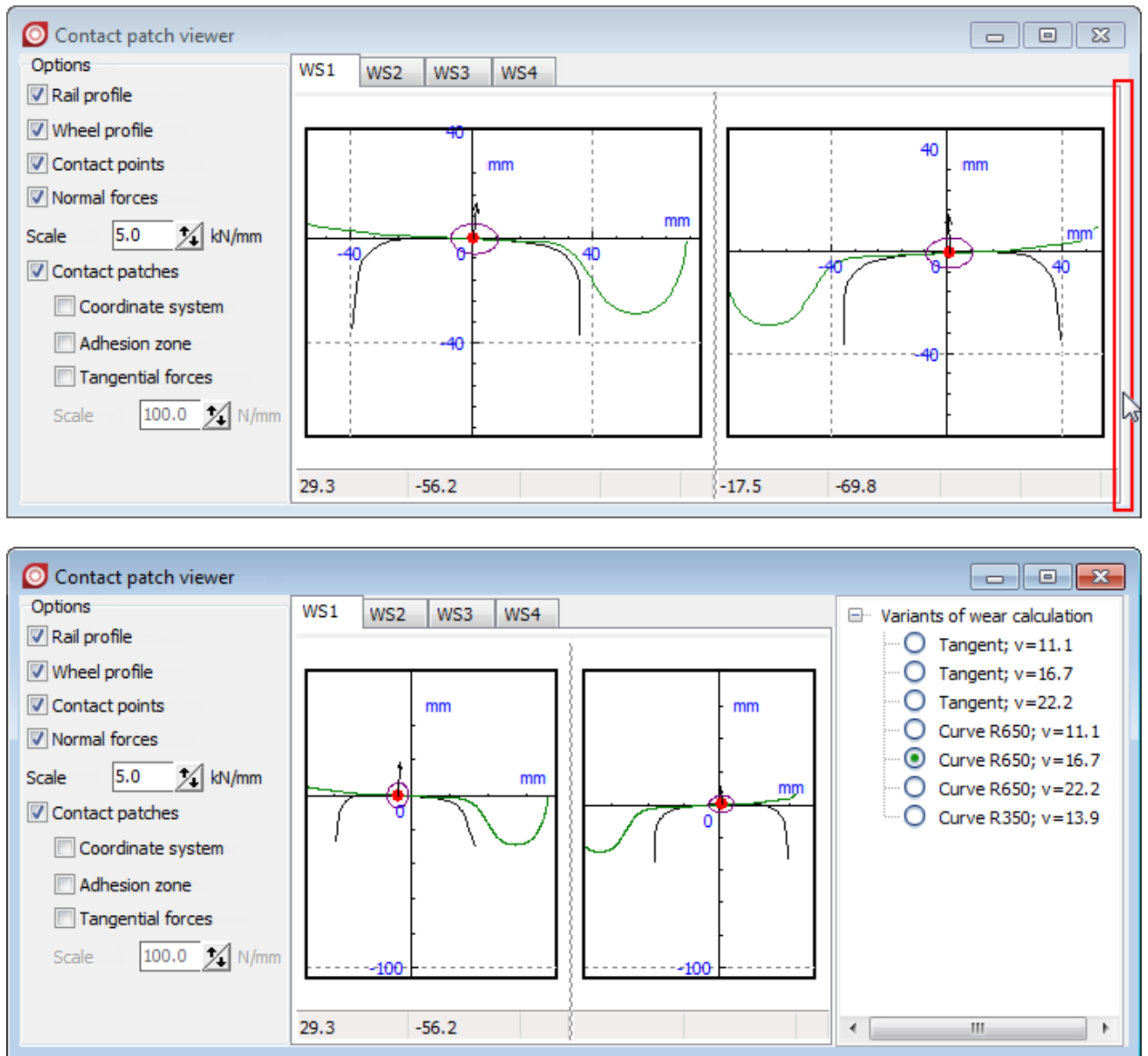


Figure 16.19. Choosing variant of wear calculation in the **Contact patch viewer** window

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

16.1.2.1. Project description

As an example, consider the wear of wheel profiles of a freight car with three-piece bogie 18-100. The freight car is used on the railroad, the statistical analysis of which is shown in Table 16.2. The freight car model is in the [{UM Data}\samples\Rail Vehicles\simple 18 100](#) folder.

Table 16.2

Parameters of a representative route for the wear predicting

Weighted average radius, m	Weighted average length, m	Weigh	Speeds, km/h
350	410	0.05	50
650	410	0.15	40, 60, 80
Tangent	-	0.80	40, 60, 80

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 factors


The wear project will contain 3 configurations.

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

The rails in the tangent track and the inner rail in the curves have a new profile R65, the outer rail in the curves is a worn profile R65.

1. Run **UM Simulation**. Open the freight car model from the [{UM Data}\samples\Rail Vehicles\simple 18 100](#) folder. Open **Object simulation inspector** and select **Rail vehicle** tab.

2. Creating the first configuration:

1. Open the **Track | Parameters** tab and set the **Track type** to *Moving rigid body*.
2. Open the **Track | Macrogeometry** tab and set the **Track type** to *Tangent*.
3. Open the **Track | Irregularities** tab, set the **Track type** to *Uneven*, set the **Type of irregularities** to *From file*. Use the **Load** button  to assign the group of irregularities *ERRI_Hi_3000m.tig* from the [{UM Data}\rw](#) folder.

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

5. Open the **Wheel/Rail | Rails | Profiles** tab and set the following values for rail geometry parameters:

- **Inclination (rad)** = 0.05;
- **SCR-SCW distance (mm)** = 4.845.

Note The **SCR-SCW** parameter value of 4.845 mm corresponds to the value of the track gauge of 1520 mm at the gauge measurement position of 13 mm.

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*.

6. 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.

7. Open the **Wheel profiles wear** tab and add the configuration to the set of configurations (Sect. 16.1.1.1. *Creating set of configuration*, p. 16-11). Set the following values for the parameters of added configuration (Figure 16.20):

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

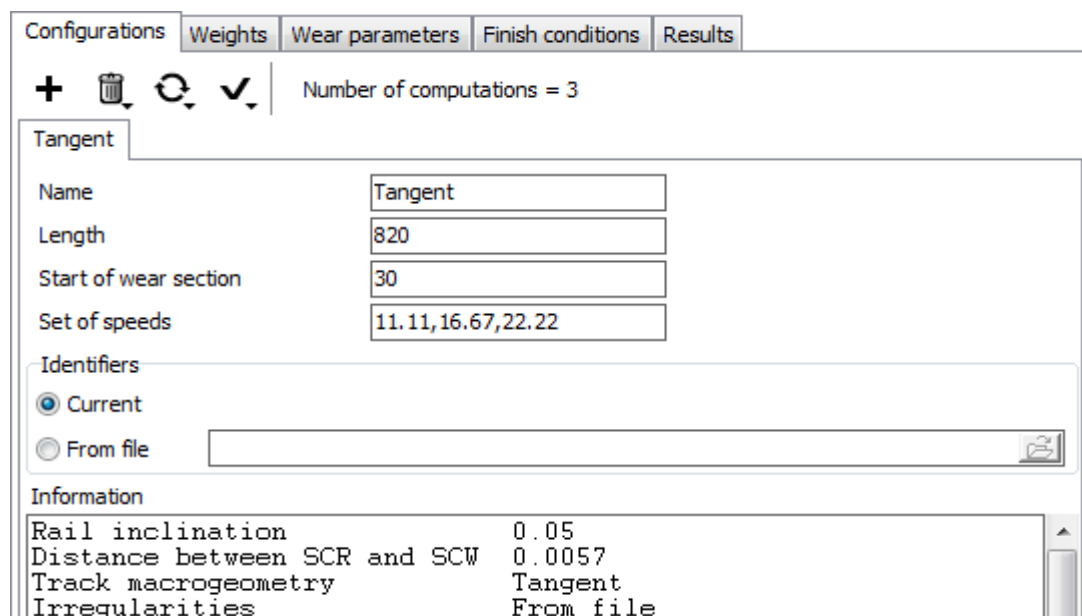


Figure 16.20. Configuration *Tangent*

8. Open the **Weights** tab. Set the **Configuration weight** to 0.8 and the **Speed weights** to 0.294, 0.54 and 0.166 respectively, Figure 16.21.

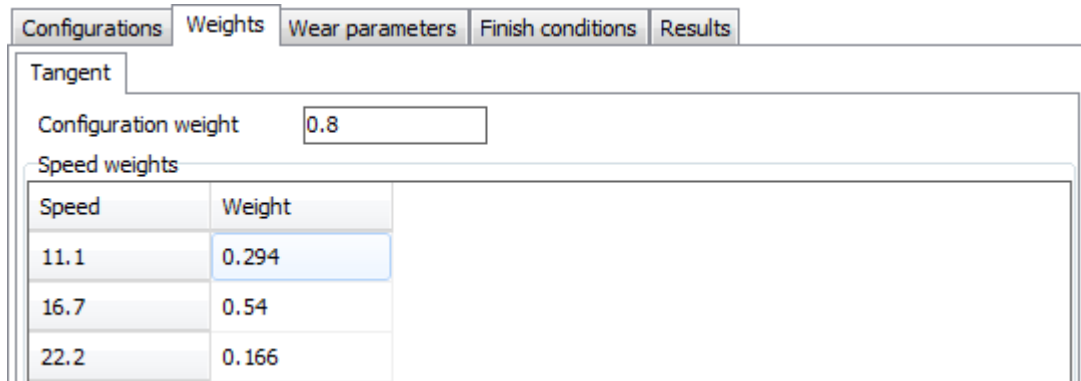


Figure 16.21. Configuration weight and speed weights

3. Let us create the second configuration:

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

- **L1** = 10;
- **P11** = 50;
- **S1** = 300;
- **R1** = 650;
- **H1** = 0.1;
- **P12** = 50;
- **dY1** = 0;
- **Smoothing** = 8.

2. Open the **Wheel/Rail | Rails | Profiles** 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 the configuration to the set of configurations. 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 m/s);
- **Identifiers** = *Current*.

4. Open the **Weights** tab. Set the **Configuration weight** to 0.15 and the **Speed weights** to 0.294, 0.54 and 0.166 respectively.

4. Let us create the third configuration:

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

- **L1** = 10;
- **P11** = 50;
- **S1** = 300;
- **R1** = 350;

- **H1** = 0.1;
- **P12** = 50;
- **dY1** = 0.01;
- **Smoothing** = 8.

Leave unchanged all other parameters.

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

- **Name** = *Curve R350*;
- **Length** = 410;
- **Start of wear section** = 60;
- **Set of speeds** = 50 (13.89 m/s);
- **Identifiers** = *Current*.

3. Open the **Weights** tab. Set the **Configuration weight** to 0.05 and the **Speed weights** to 1.

16.1.2.3. Wear parameters setting

Open the **Wear parameters** tab and set the following values for the wear parameters (Figure 16.22):

- **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 bin (mm)** = 1;
- **Average wheelsets wear** = on;
- **Average wheels wear of same wheelset** = on;
- **Interrupt simulation on degeneration of profile** = on;
- **Wear coefficient (m^3/J)** = $1.83 \cdot 10^{-13}$;
- **Jump coefficient** = 1.

Configurations	Weights	Wear parameters	Finish conditions	Results
		Number of iterations	20	↑↓
		Number of wear steps	2000	↑↓
		Mileage (km)	5	
		Width of wear accumulation bin (mm)	1	
		<input checked="" type="checkbox"/> Average wheelsets wear		
		<input checked="" type="checkbox"/> Average wheels wear of same wheelset		
		<input checked="" type="checkbox"/> Interrupt simulation on degeneration of profile		
		Krause-Poll wear law coefficients		
		Wear coefficient (m^3/J)	1.8E-13	
		Critical power density (W/mm^2)	4	
		Jump coefficient	1	

Figure 16.22. Wear parameters

16.1.2.4. Finish conditions setting

Select the **Finish conditions** tab and uncheck 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 done.

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 16.23):

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

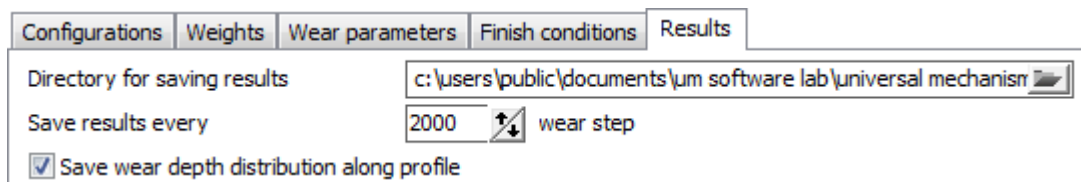


Figure 16.23. Saving results

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 16.24. To load calculation results, click the **Browse...** button and specify a folder with results or select a corresponding path from a reopen list.

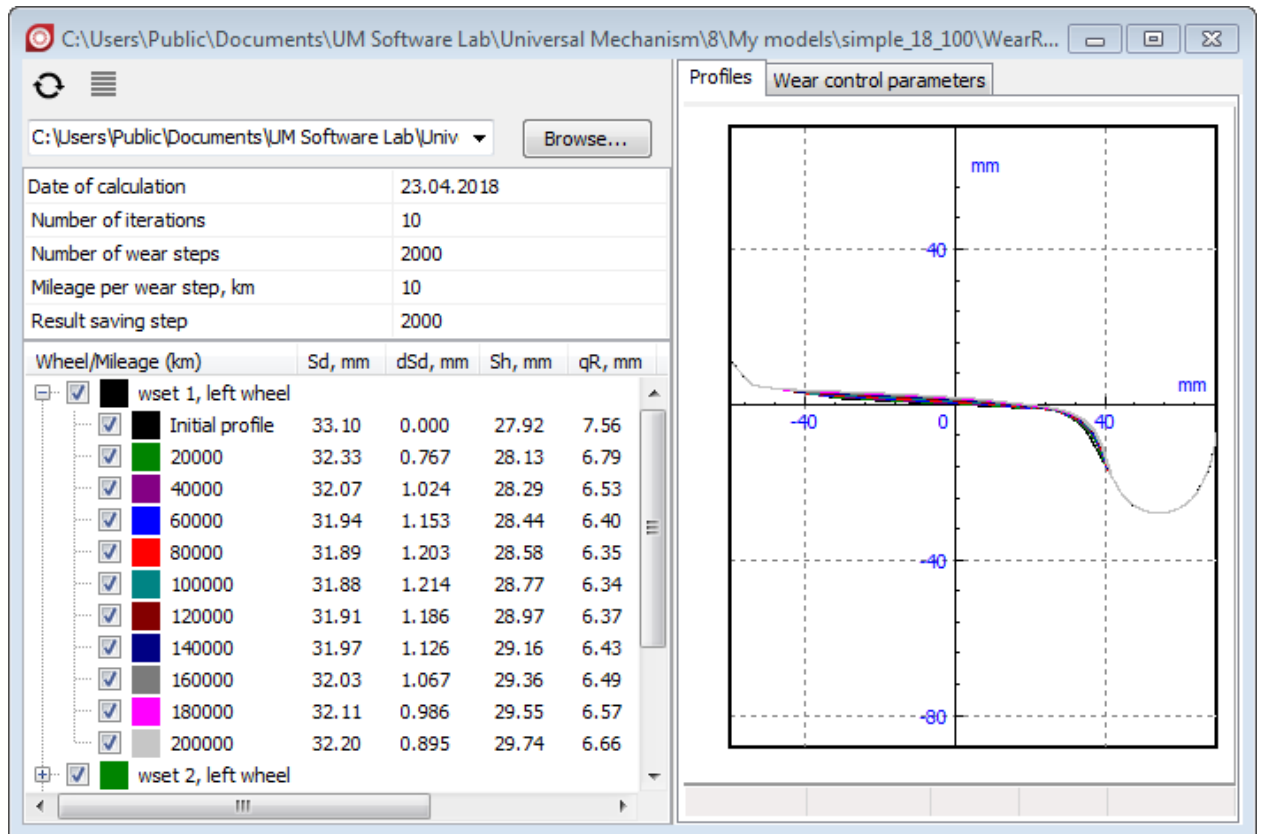



Figure 16.24. Analysis of wear of railway wheel profiles tool

In the results tree for each mileage value in the columns numerical values of control parameters of the wheel profile wear are shown (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. The profiles calculated for the respective mileage are shown on the **Profiles** tab, Figure 16.25. The graphs of wear control parameters vs mileage are shown on the **Wear control parameters** tab, Figure 16.26. Use the **Settings** button  to show/hide graphs and corresponding columns of the result tree.

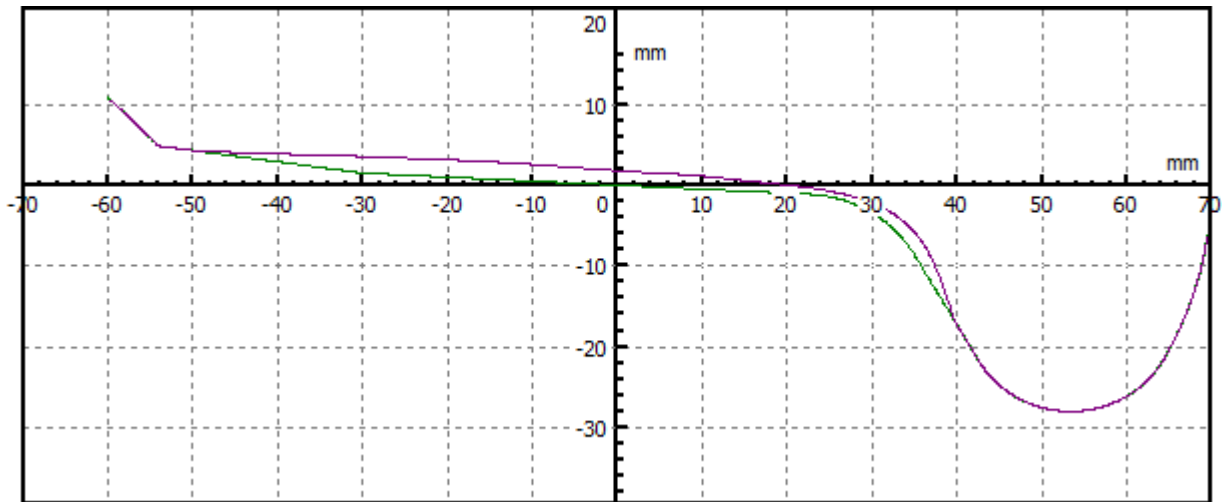


Figure 16.25. Profile of left wheel of the 1st wheelset in new state and after the mileage of 200 thou. km

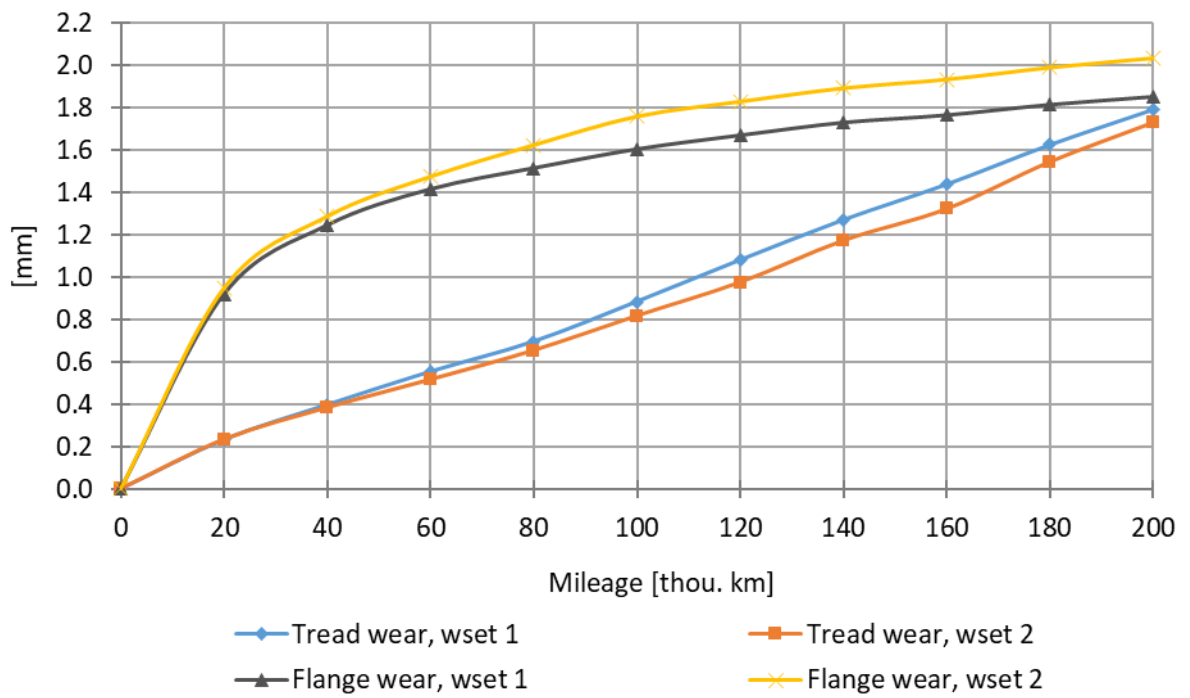


Figure 16.26. Tread and flange wear dSt of left wheels of the 1st and the 2nd wheelsets

16.1.4. Parallel computations on multithreading CPUs

Let us consider the efficiency of parallel computation on the example of the class 2ES10S electric freight locomotive and configurations set are listed in Table 16.3. The loco model includes 37 bodies with 110 degrees of freedom, Figure 16.27.

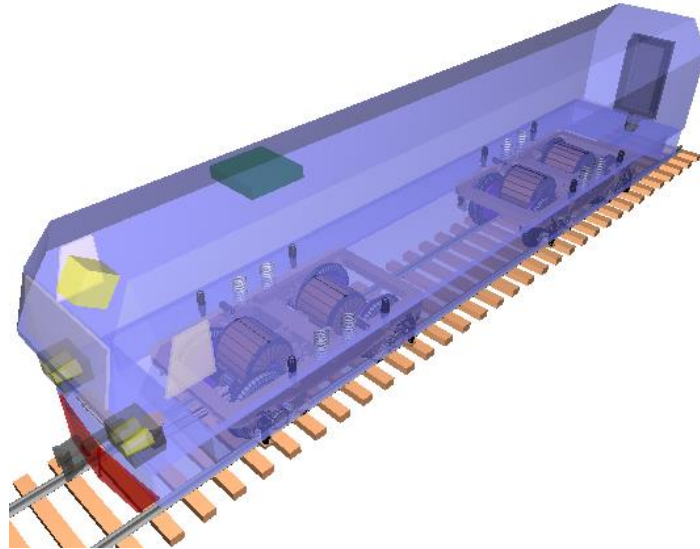


Figure 16.27. Model of the ES10S electric locomotive

Table 16.3

Set of configurations

Curve radius, m	Speeds, km/h	Traction
323	25.2, 50.4, 64.8	0/0.6
581	25.2, 50.4, 64.8	0/0.6
1497	25.2, 50.4, 64.8	0/0.6
Tangent	25.2, 50.4, 64.8	0/0.6
Total number of runs		24

The speed-up effect of the simulation of the wheel profile wear versus the number of parallel threads is shown in Figure 16.28. These results are obtained on a computer with Intel Core i7-12700KF CPU.

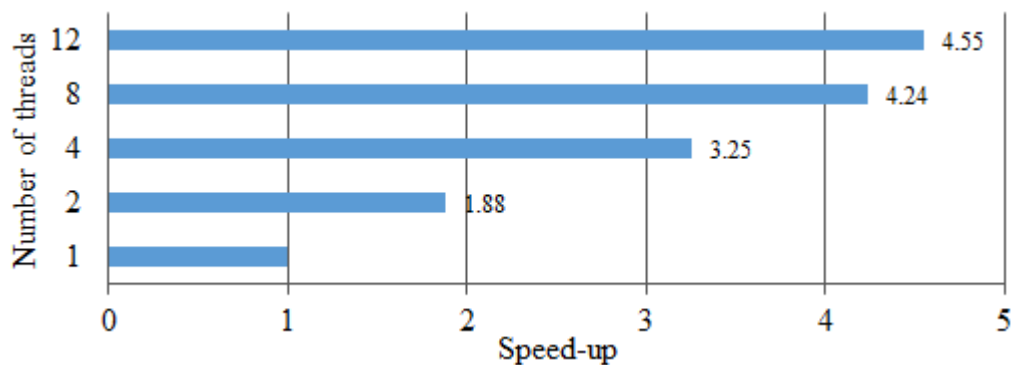


Figure 16.28. Speed-up of simulation of wheel profile wear vs. number of parallel threads

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

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 16.29.

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.

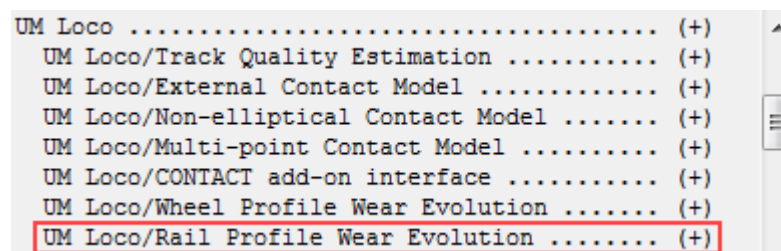


Figure 16.29. Current UM configuration in **About** window


The **Rail Profile Wear Evolution** tool is an add-on for the **UM Experiments** module, which has been extended by the term "*evolution*". The evolution is a series of multivariate calculations of the same structure that differ from each other only in rail profiles. Single computation of the multivariate calculation is named "*wear iteration*". Rail profiles do not change within iteration. Profiles are updated after of the iteration, taking into account the weight factors of numerical experiments (runs of vehicles) 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;
- saving list of variables for each wear iteration;
- creating source data sets for the simulation of accumulation of rolling contact fatigue damages in rails in **UM RCF Rail** module ([Chapter 25](#)).

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. Simulation of rail profiles wear

Run **UM Simulation** program. To create a new project of rail profiles wear prediction, select the **Scan | New project – rail profile wear...** main menu command. A standard scanning project window appears in which the **Rail profiles wear** tab is added. Open the **Alternatives** tab and add to the project the models of rail vehicles that are used on a consideration track section. Use the **Weight factors**  button to set the weight factors to the vehicles, Figure 16.30. The weight factor of the vehicle is the specific weight (percentage) of the vehicle type (freight car, locomotive etc.), operated on the considered track section.

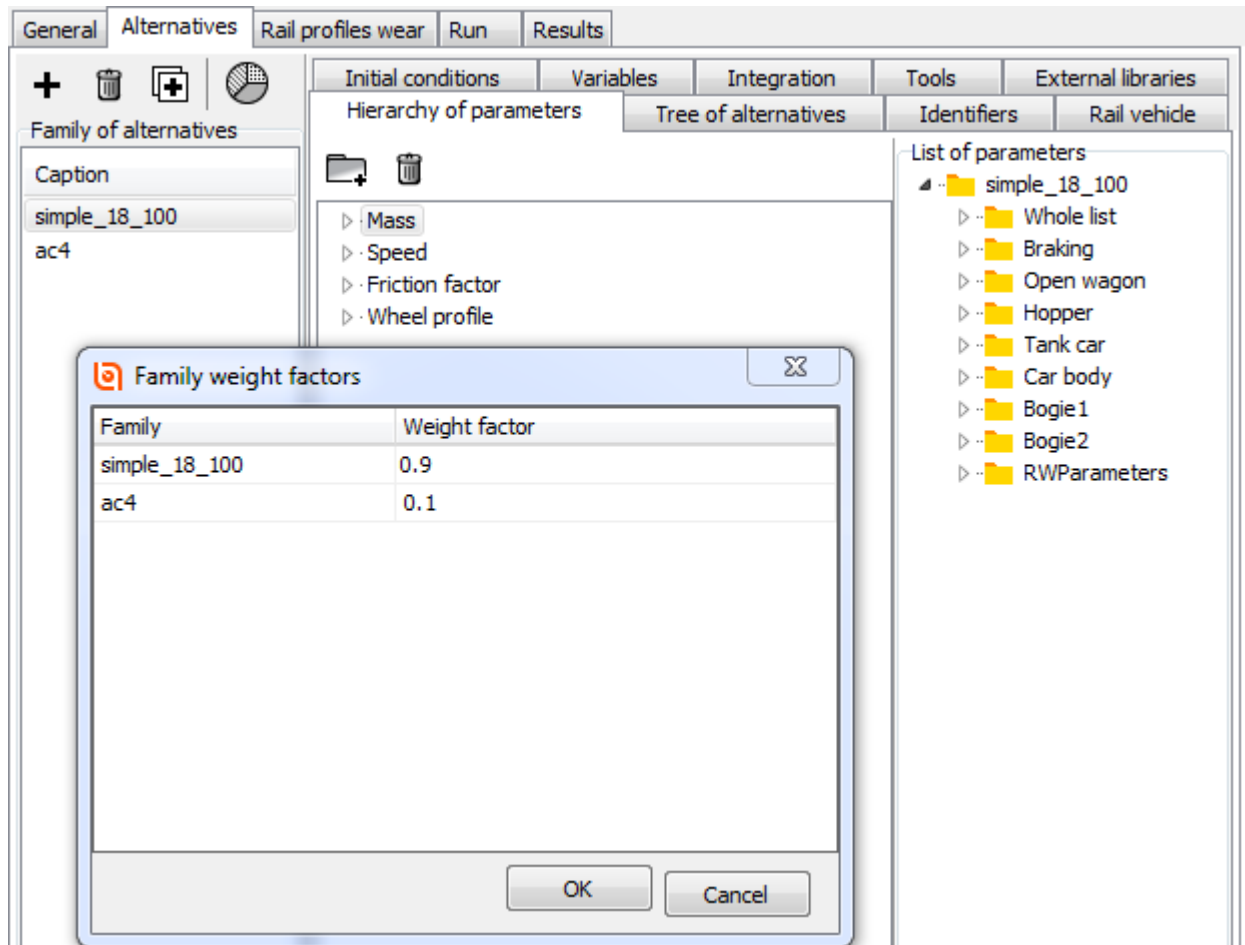


Figure 16.30. Assigning family weight factors

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 16.31.

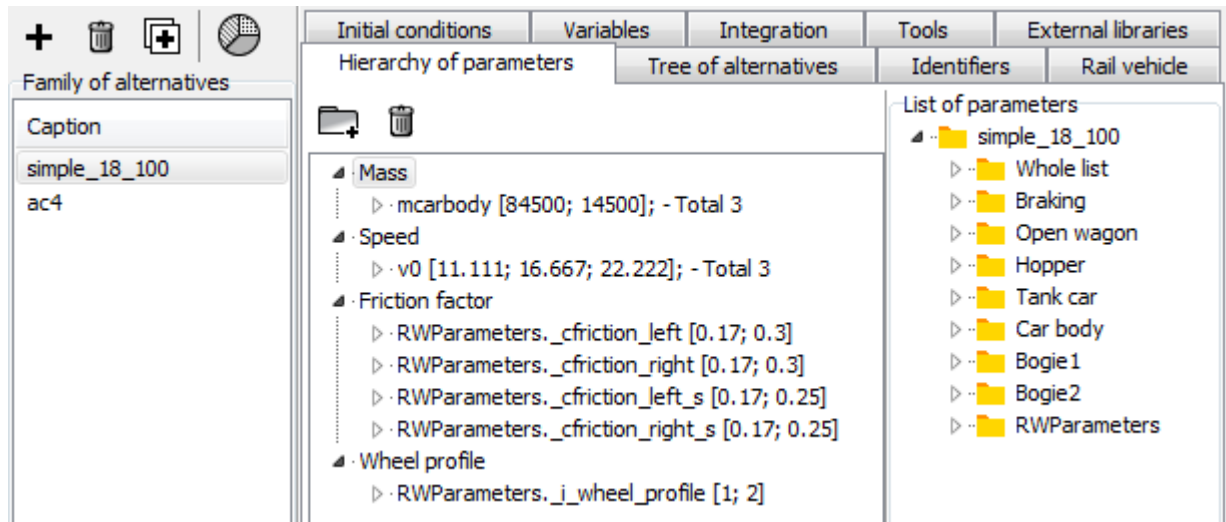


Figure 16.31. Example of hierarchy of parameters

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

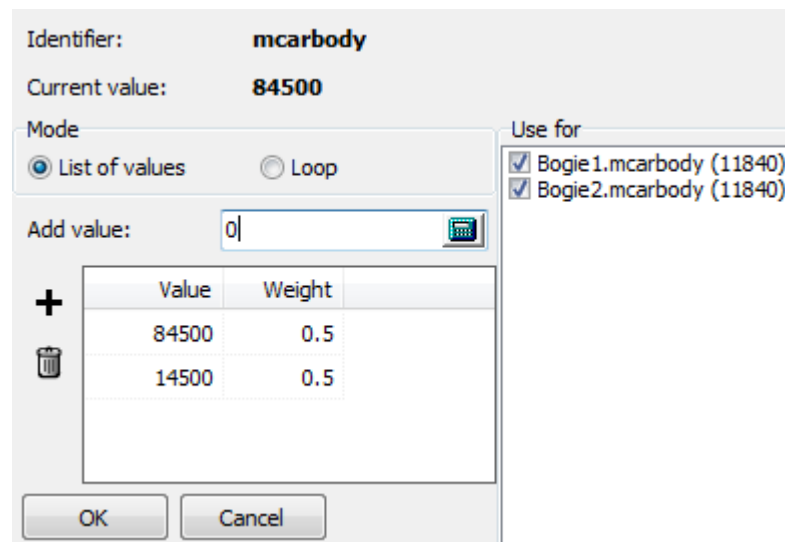


Figure 16.32. Assigning values and weights to a parameter

Open the **Rail profiles wear** tab. On the **Track**, **Wheel-rail contact** and **Profiles** tabs are set track parameters (track gauge, track geometry, irregularities, etc.), wheel-rail contact parameters and are assigned rail profiles for ALL vehicles in the project. On the **Wear parameters** tab parameters for the wear simulation are set, Figure 16.33.

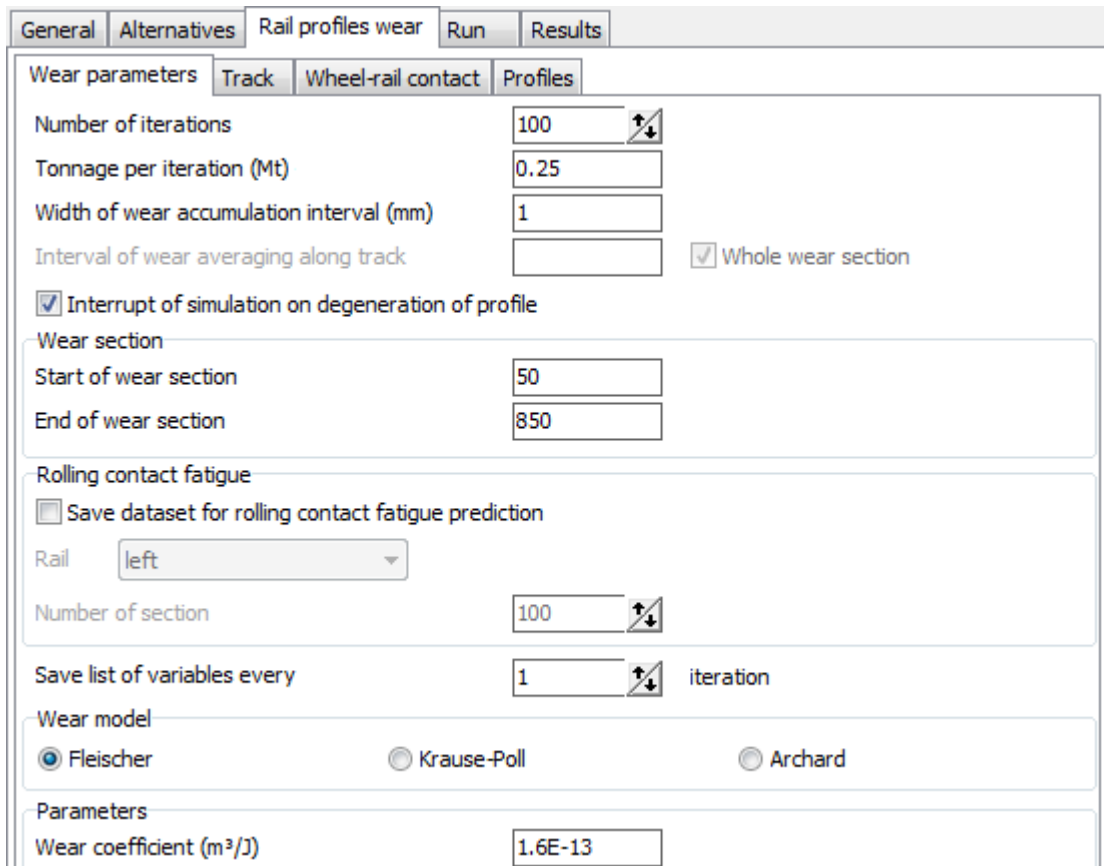


Figure 16.33. Parameters of rail profile wear simulation

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

Tonnage per iteration (M_{it} , millions of tons, Mt) 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 get measurable wear with a small total mass of the running vehicles on the consideration track section. After each wear iteration, the accumulated volume wear is multiplied by a scale factor:

$$c_{scale} = M_{it} / \sum_{i=1}^N M_{v_i} \tag{16.16}$$

where M_v is the vehicle mass, N is the number of vehicles. The total tonnage $M_{tot} = N_{it}M_{it}$.

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 the 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 parameters. The profile-updating procedure", p. 16-12. 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, select one of the available models and set its parameters.

Let us consider an algorithm of updating the rail profile. Let $W_{V_{ij,l}}$ and $W_{V_{ij,r}}$ be the volume wear for the left (l) and the right rails (r) calculated for j -th numerical experiment of the family i .

1. Calculation of the total accumulated of the volume wear:

$$W_{V_m} = \sum_{i=1}^{n_v} \alpha_i \sum_{j=1}^{n_{r_i}} \beta_{ij} W_{V_{ij,m}}, \quad m = l, r, \quad (16.17)$$

where n_v is the number of vehicles (alternatives), α_i is the vehicle weight factor, n_{r_i} is the number runs of the i -th vehicle (numerical experiments), β_{ij} is the weight factor of the vehicle run.

2. The distribution of accumulated volume wear is approximated (smoothed) by the B-spline and calculated of the wear depth in the center of each longitudinal strip:

$$\delta_{l,r}(s_i) = \frac{\tilde{W}_{l,r}(s_i)}{(S_e - S_b)h}, \quad (16.18)$$

where s_i is the arc-coordinate of the center of the strip, $\tilde{W}_{l,r}$ is the smoothed distribution of the volume wear along the profile, h is the strip width. New coordinates of the profile points are calculated according to the equation (16.10).

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 wear of rail profiles R65 in a curved track section with radius $R = 578$ m. Percentages of freight cars and locomotives:

- loaded freight cars 47%;
- empty freight cars 47%;
- locomotives 6%.

Average running speed is 60 km/h. Locomotives use flange lubrication.

Note Preliminary prepared project is available in the [{UM Data}\samples\tutorial\R65RailWear](#) folder.

The project will contain three families of alternatives.

The first family of alternatives is a loaded freight car with three-piece bogie 18-100. The model of the freight car can be found in the following folder: [{UM Data}\samples\Rail Vehicles\simple 18 100](#). The second family of alternatives is the empty freight car. The third family of alternatives is a locomotive with two COCO bogies. The model of the locomotive is located in the following folder: [{UM data}\samples\Rail Vehicles\Co. Co.](#)

The following parameters will be varied.

1. Friction coefficient on the side surface of the high (outside) rail is 0.17 and 0.3.
2. Wheel profile of the freight car: 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.
3. Wheel profile of the locomotive: GOST 11018-2011 and DMetI profiles.

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

The structure of multivariate calculation is shown in Figure 16.34.

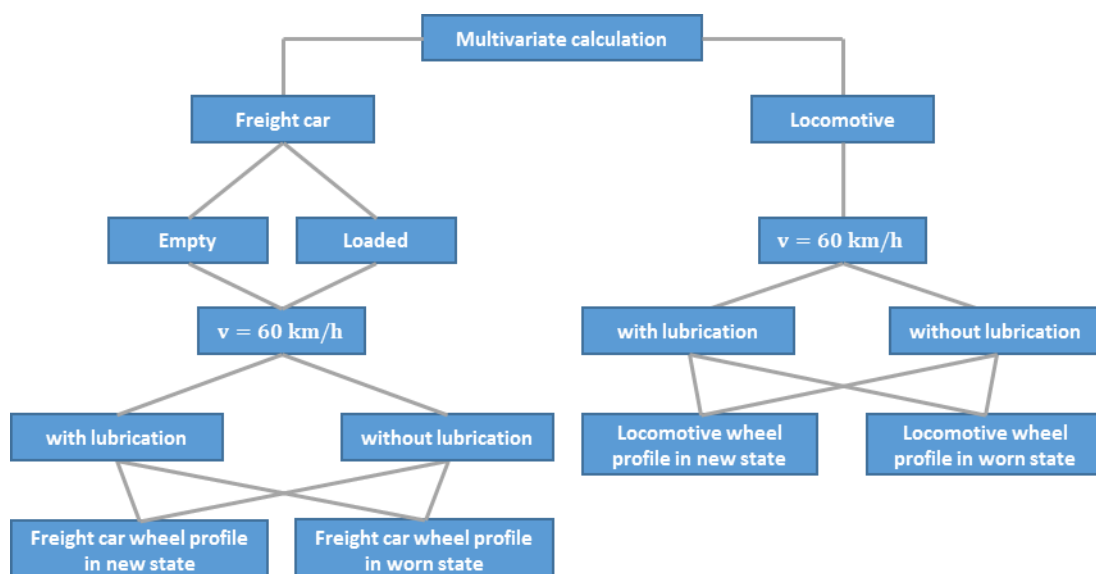


Figure 16.34. Structure of multivariate calculation

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** tab. Click the **Add** button **+** and select the freight car model from the [{UM Data}\samples\Rail Vehicles\simple_18_100](#) directory. The selected model will be shown in the list of the **Family of alternatives**. Rename the family to *simple_18_100_loaded* (use the F2 key).

2. Open the **Identifiers** tab and load the *Loaded car.par* file of parameters then corresponds to the loaded state of the freight car.

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

4. Open the **Rail vehicle | Speed** tab and select the mode of the longitudinal motion $v = const$. In the **Speed control parameters** group in the **Body** list select *Car body*.

5. Open the **Rail vehicle | Contact | Friction** tab and activate the **Lubrication of rail side face** key.

6. 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.

7. Open the **Hierarchy of parameters** tab. Use the **Add group** button to add a new group of parameters and name it *Speed*. Select the *simple_18_100 | Whole list | v0* parameter from the list of model parameters In the **Changing parameter values** form add the parameter value of *16.67* (m/s) and set it the weight factor *1*, Figure 16.35. Click **OK** to close the window.

Identifier: **v0**
 Current value: **20**
 Mode
 List of values Loop
 Add value:

Value	Weight
16.67	1

 Use for
 Bogie1.v0 (20)
 Bogie2.v0 (20)
 OK Cancel

Figure 16.35. Assigning values and weights to the parameter

8. Add the new group of parameters and name it *Friction factor*. Select the *simple_18_100 / RWParameters / Rail/Wheel contact friction coeff. / _cfriiction_left* parameter. Add two values of parameter 0.3 and 0.3, set the weight factors 0.5 for both values. Then select the *simple_18_100 / RWParameters / Rail/Wheel contact friction coeff. / _cfriiction_right* parameter. Add two values of parameter 0.3 and 0.3, set the weight factors 0.5 for both values.

9. Select the *simple_18_100 / RWParameters / Rail/Wheel contact friction coeff. / _cfriiction_left_s* parameter. Add two values of parameter 0.17 and 0.3, set the weight factors 0.5 for both values. Then select the *simple_18_100 / RWParameters / Rail/Wheel contact friction coeff. / _cfriiction_right_s* parameter. Add two values of parameter 0.3 and 0.3, set the weight factors 0.5 for both values.

10. Add the new parameter group and name it the *Wheel profile*. Select the *simple_18_100 / RWParameters / Profiles / _i_wheel_profile* parameter. Add two values of parameter 1 (*newwagnw* profile) and 2 (*wornwagnw100000km* profile), set the weight factors 0.2 and 0.8, respectively. Finally the completed hierarchy of parameters for the *simple_18_100_loaded* family of alternatives will look as it is shown in Figure 16.36.

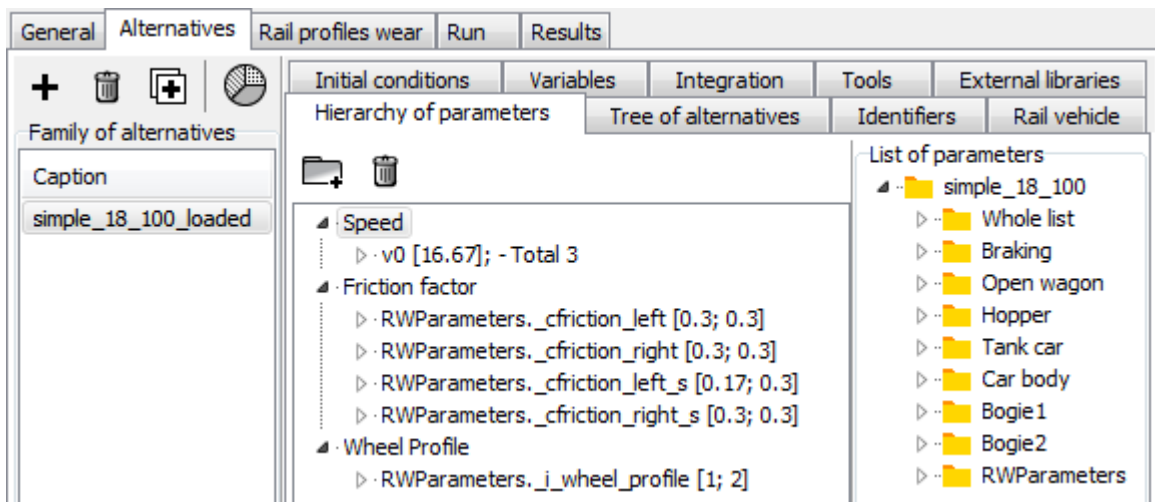



Figure 16.36. Hierarchy of parameters of family of alternatives *simple_18_100_loaded*

3. Let us create the second configuration.

1. Open the **Alternatives** tab. Click the **Duplicate** button  and duplicate the *simple_18_100_loaded* family.

2. Rename the family to *simple_18_100_empty*.

3. Open the **Identifiers** tab and load the *Empty car.par* file of parameters then corresponds to the empty state of the freight car.

4. Let us create the third configuration.

1. Open the **Alternatives** tab Add the locomotive model from the [{UM data}\samples\Rail_Vehicles\Co_Co](#) directory.

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 the *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 *Body*.

4. Open the **Rail vehicle | Contact | Friction** tab and activate the **Lubrication of rail side face** key.

5. 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.

6. Open the **Hierarchy of parameters** tab. Add the new group of parameters and name it *Speed*. Select the *co_co | Whole list | v0* parameter. Add the parameter value of 16.67 (m/s) and set it the weight factor 1. Close the parameter values settings form and return to the scan project.

7. Add the new group of parameters and name it the *Friction factor*. Select the *co_co | RWParameters | Rail/Wheel contact friction coeff. | _cfraction_left* parameter. Add two values of parameter 0.3 and 0.3, set the weight factors 0.5 for both values. Then select the *co_co | RWParameters | Rail/Wheel contact friction coeff. | _cfraction_right* parameter. Add two values of parameter 0.3 and 0.3, set the weight factors 0.5 for both values.

8. Select the *co_co | RWParameters | Rail/Wheel contact friction coeff. | _cfraction_left_s* parameter. Add two values of parameter 0.17 and 0.3, set the weight factors 0.5 for both values. Then select the *co_co | RWParameters | Rail/Wheel contact friction coeff. | _cfraction_right_s* parameter. Add two values of parameter 0.3 and 0.3, set the weight factors 0.5 for both values.

9. Add the new parameter group and name it the *Wheel profile*. Select the *co_co | RWParameters | Profiles | _i_wheel_profile* parameter. Add two values of parameter 1 (*newlocow* profile) and 2 (*dmeti30* profile), set the weight factors 0.5 for both values.

4. Open the **Alternatives** tab. Click the **Weight factors** button  and set weight factors for *simple_18_100_loaded*, *simple_18_100_empty* and *Co_Co* families 0.47, 0.47 and 0.06, respectively.

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

- **L1** = 30;
- **P11** = 40;
- **S1** = 300;
- **R1** = 578;
- **H1** = 0.067;
- **P12** = 40;
- **dY1** = 0;
- **Smoothing** = 8.

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


- **Number of iterations** = 400;
- **Tonnage per iteration (Mt)** = 0.25;

i.e. 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** = 70;

- **End of wear section** = 380;
- **List of variables saving step** = 1 iteration;
- **Wear coefficient** (m^3/J) = $1.6 \cdot 10^{-13}$.
- **Jump coefficient** = 1.

7. Open the **Rail profiles wear | Track | Parameters** tab and check that the *Moving rigid body* track type is selected.

8. Open the **Rail profiles wear | Track | Irregularities** tab. Set the **Track type** to *Uneven*, set the **Type of irregularities** to *From file*. Use the **Load** button  to assign the group of irregularities *ERRI_Hi_3000m.tig* from the [{UM Data}\rw](#) directory.

9. Open the **Rail profiles wear | Profiles** tab and set the following values for rail geometry parameters:

- **Inclination (rad)** = 0.05;
- **SCR-SCW distance (mm)** = 4.845.

Note The **SCR-SCW** parameter value of 4.845 mm corresponds to the value of the track gauge of 1520 mm at the gauge measurement position of 13 mm.

Assign to both rails the *r65new.rpf* profile from the [{UM Data}\rw\prf](#) folder..

10. Open the **Rail profiles wear | Wheel-rail contact** 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)** = 1000;
- **Minimum number of strips** = 20;
- **Number of elements** = 20;
- **Interpenetration factor** = 0.55;
- **Damping ratio** = 0.01.
- **Use contact points lookup table** = 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 16.37. 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 wear of railway rail profiles** tab.

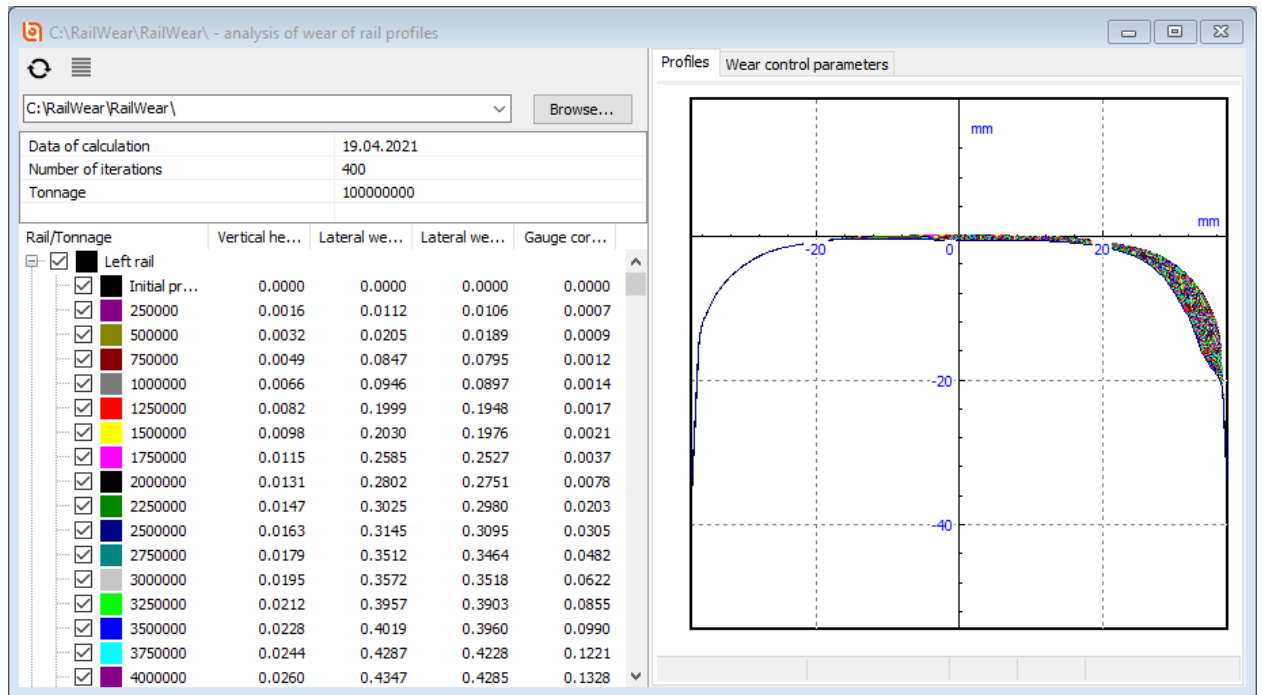



Figure 16.37. Analysis of rail profiles wear tool.

Use right mouse button click on the results 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. The profiles calculated for the respective tonnage are shown on the **Profiles** tab, Figure 16.38. The graphs of wear control parameters vs tonnage are shown on the **Wear control parameters** tab, Figure 16.39. Use the **Settings** button  to set parameters for evaluating the rail profile wear: H , α , and reference profiles, Figure 16.40.

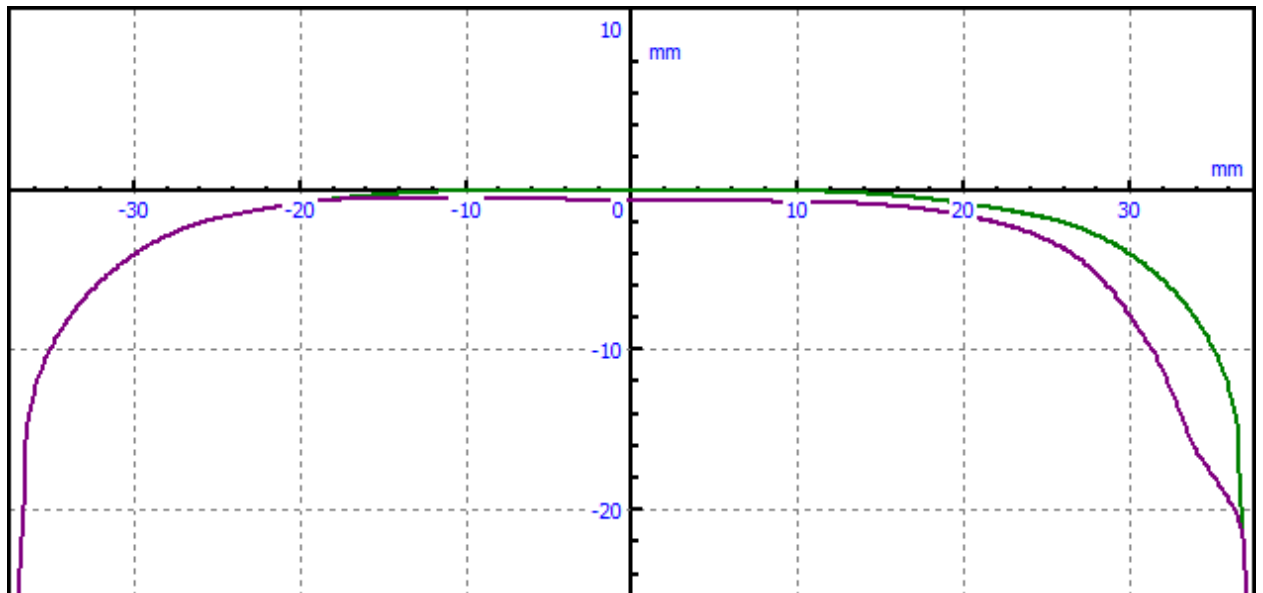


Figure 16.38. The high (outside) rail profile in new state and after a tonnage of 100 Mt

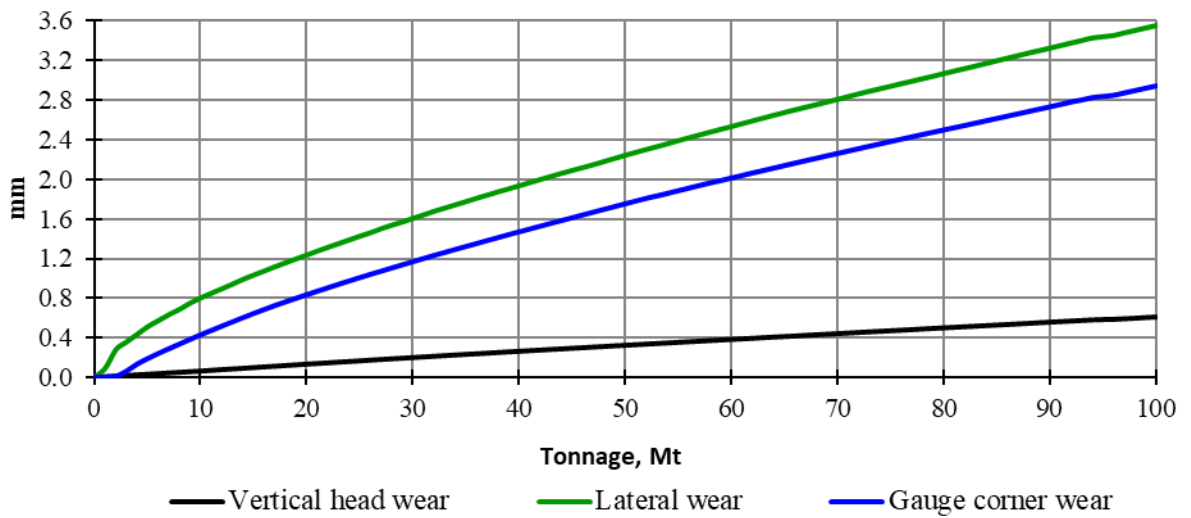


Figure 16.39. Evolution of the wear control parameters for the high (outside) rail

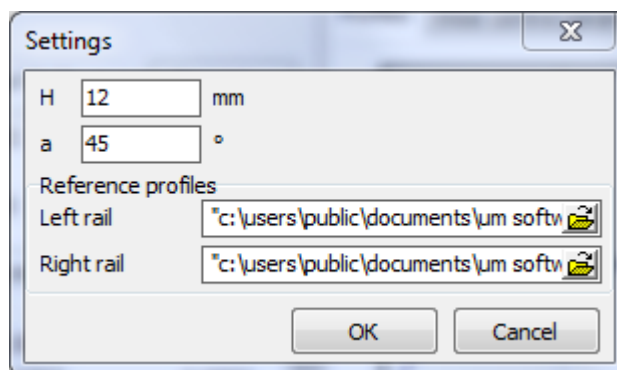


Figure 16.40. Parameters setting for computation the wear of rail profiles

16.3. References

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