

# UM Loco

## Contents

<b>GETTING STARTED USING UNIVERSAL MECHANISM: RAILWAY VEHICLE DYNAMICS.....</b>	<b>3</b>
<b>1. SIMULATION OF A SINGLE WHEELSET DYNAMICS.....</b>	<b>4</b>
<b>1.1. CREATING THE MODEL .....</b>	<b>4</b>
<b>1.2. SIMULATION OF THE WHEELSET DYNAMICS.....</b>	<b>6</b>
1.2.1. Preparing environment for the simulation of railway vehicle dynamics .....	6
1.2.2. Simulation of the motion.....	8
<b>2. CREATING THE MODEL OF RAILCAR .....</b>	<b>12</b>
<b>2.1. BASIC ELEMENTS OF MODEL.....</b>	<b>12</b>
<b>2.2. CREATING NEW OBJECT.....</b>	<b>14</b>
<b>2.3. CREATING WHEELSETS .....</b>	<b>14</b>
<b>2.4. CREATING GRAPHICAL OBJECTS .....</b>	<b>18</b>
2.4.1. Creating image of spring.....	19
2.4.2. Add images from files.....	20
2.4.3. Images of right axle boxes .....	20
<b>2.5. ADDING AXLE-BOXES TO THE MODEL.....</b>	<b>22</b>
<b>2.6. ADDING CAR BODY .....</b>	<b>25</b>
<b>2.7. ADDING FORCE ELEMENTS.....</b>	<b>26</b>
2.7.1. Springs .....	26
2.7.2. Inclined dampers .....	30
2.7.3. Traction rods .....	31
2.7.4. Lateral dampers.....	33
<b>3. SCANNING: IMPLEMENTATION TO RAILWAY VEHICLE DYNAMICS.....</b>	<b>34</b>
<b>3.1. CREATING SCANNING PROJECT .....</b>	<b>35</b>
3.1.1. Preface .....	35
3.1.2. Creating new scanning project.....	37
3.1.3. Loading a model .....	38
3.1.4. Hierarchy of parameters .....	39
3.1.5. Railway configuration.....	41
3.1.6. Integration parameters.....	43
3.1.7. Finish conditions .....	45
3.1.8. Variables to save .....	46
<b>3.2. RUNNING THE PROJECT.....</b>	<b>47</b>
<b>3.3. ANALYZING OBTAINED RESULTS .....</b>	<b>49</b>
3.3.1. Results of separate experiments .....	49
3.3.2. Summary graphs .....	52

## Getting Started Using Universal Mechanism: Railway Vehicle Dynamics

This manual leads you through the basic possibilities of Universal Mechanism software in simulation of railway vehicle dynamics. It assumes that you studied the [gs\\_um.pdf](#)<sup>1</sup> chapter, which is devoted to general concepts of simulation using Universal Mechanism, and know how to fulfill simple operations: create a new model, add graphical objects, bodies and joints, generate and compile equations of motion.

Firstly, example of the simulation of a single wheelset is discussed, and then creating a model of a two-axel rail car is shown. The last section is devoted to creating a scanning project for evaluation of the critical speed of the rail car.

---

<sup>1</sup> [www.universalmechanism.com/download/90/eng/gs\\_um.pdf](http://www.universalmechanism.com/download/90/eng/gs_um.pdf)

# 1. Simulation of a single wheelset dynamics

## 1.1. Creating the model

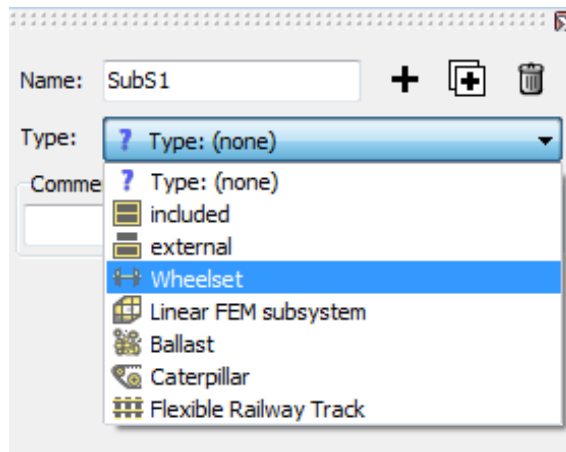
### Create new object to simulate

1. Select the **File | New object** menu command in the **UM Input** program.

### Adding new wheelset

Wheelset is the one of the standard UM subsystems. The following steps are necessary to create a new wheelset.

2. Select the **Subsystems** item in the *Tree of elements*.
3. Add a new subsystem by the **+** button in the *Inspector*.
4. Select the type of the subsystem – **Wheelset**.



**Note.** The **v0** parameter (speed of the vehicle) is added automatically to the identifier list after adding the wheelset subsystem type.

Now you can see the wheelset in the animation window, see Figure 1.1.

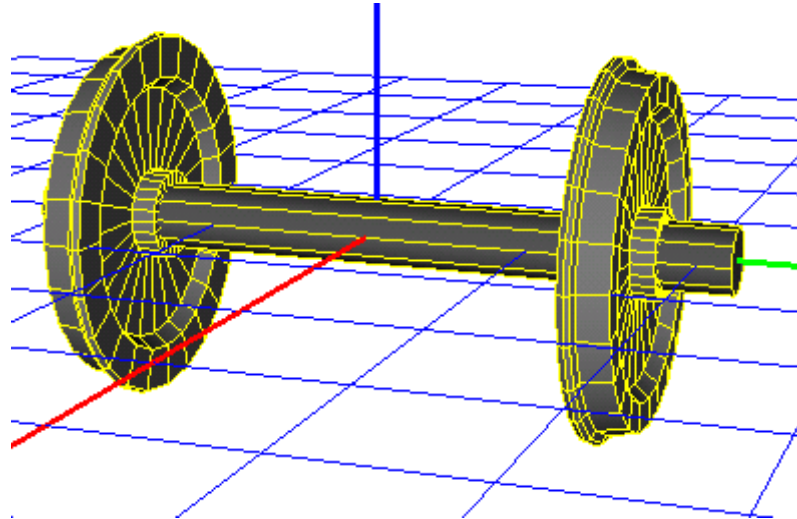


Figure 1.1. Animation of the wheelset

5. Rename the wheelset. Set the **Name** parameter to **Wheelset**.
6. Save the model with the name **WSet** by the **File | Save as...** menu command.

The model is ready to be loaded in the simulation program **UM Simulation**.

7. Run simulation program. From the menu **Object** select **Simulation...** or use the  button.

## 1.2. Simulation of the wheelset dynamics

### 1.2.1. Preparing environment for the simulation of railway vehicle dynamics

To perform the simulation of a rail vehicle, it is necessary to set the following data: wheel and rail profiles.

The following profiles are set by default:

- the new Russian locomotive wheel profiles, the *newlocow.wpf* file;
- the Russian R65 new rail profile, the *r65new.rpf* file.

#### Setting wheel and rail profiles

1. From menu **Analysis** select **Simulation** or use the **F9** key. **Object simulation inspector** appears.
2. Select the **Rail/Wheel** tab.
3. Point to the **Profiles** and then **Rails** tabs, see Figure 1.2.
4. For **Left rail** and **Right rail** load one the desired **\*.rpf** file.

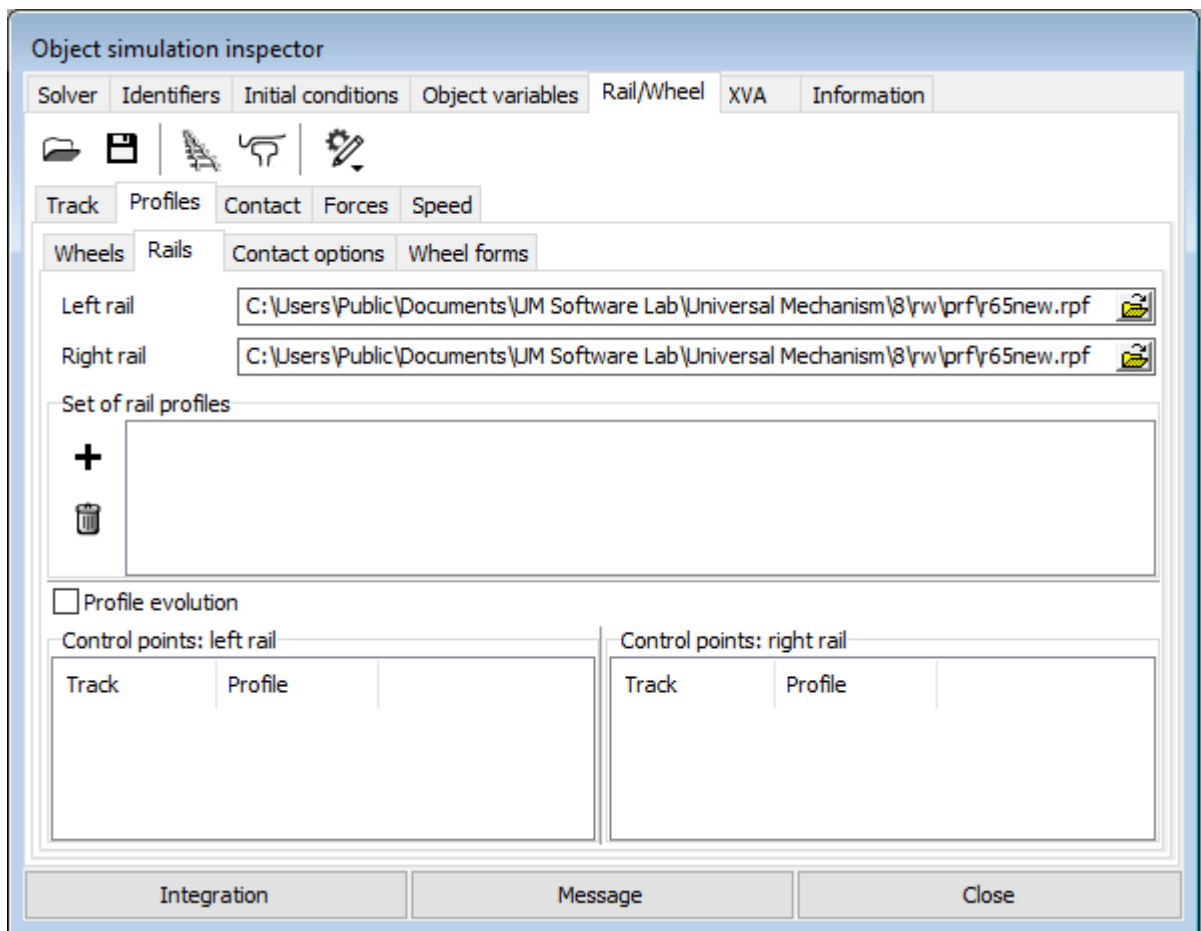


Figure 1.2. Rail and wheel profiles

5. Point to the **Wheels | Profiles** tab, see Figure 1.3.
6. Click the **+** button (add profile to list) and select the desired \*.wpf file, for example **newwagnw.wpf**.

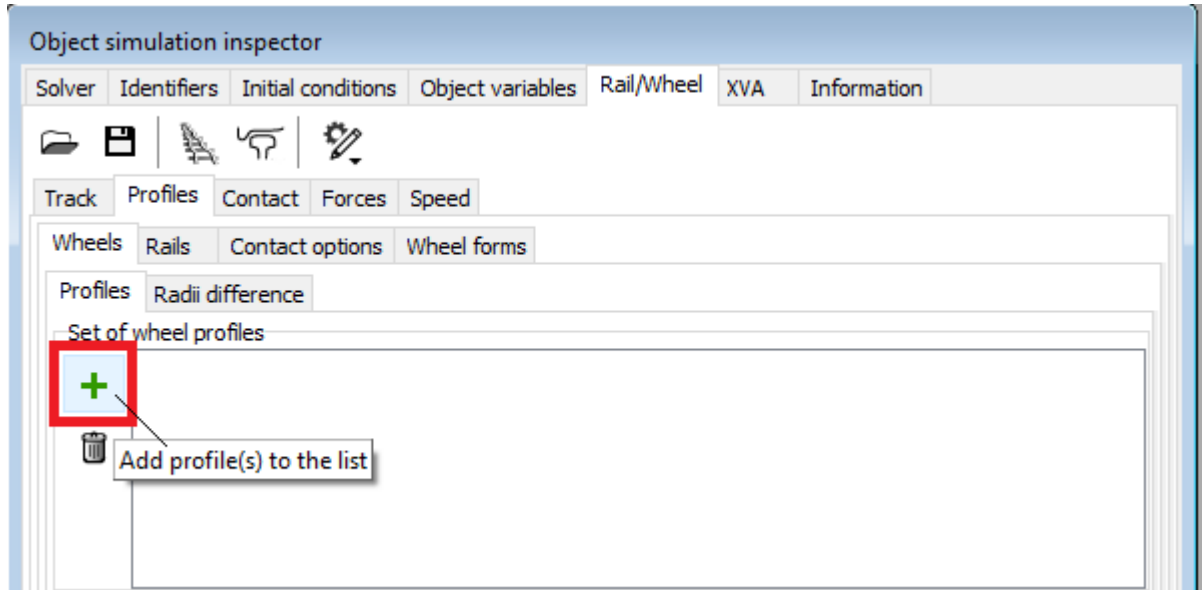



Figure 1.3. Rail and wheel profiles

7. Click the right mouse button on the just added profile and select **Assign to all**, see Figure 1.4.
8. Click the  button. Window with rail and wheel profiles appears.

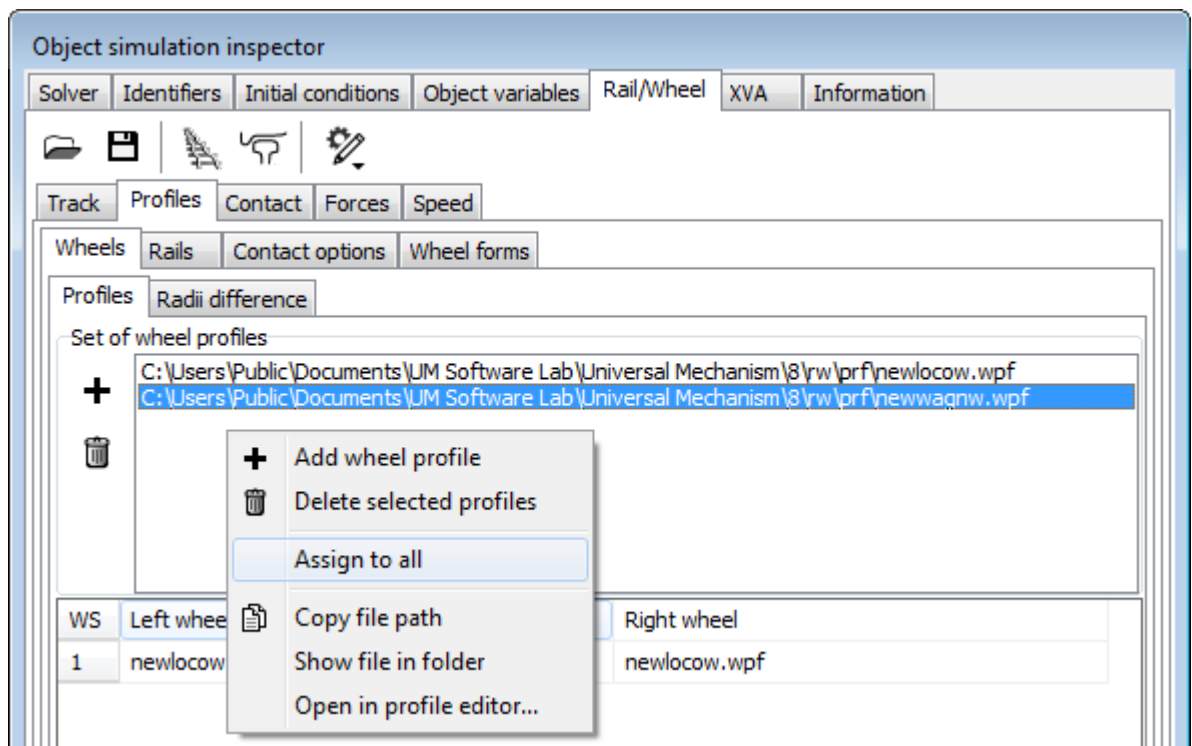


Figure 1.4. Rail and wheel profiles

## 1.2.2. Simulation of the motion

### Set ideal even way

1. Select **Object simulation inspector**, you can also use **F9**.
2. Point to **Rail/Wheel | Track | Irregularities** tab.
3. Set **Track type** to **Even**.
4. Point to **Macrogeometry** tab.
5. Set **Track type** to **Tangent**.

### Animation of rail/wheel contact

Open the window for animation rail/wheel contact forces and turn on animation of contact forces.

1. To open the window for rail/wheel animation use the **Tools | Animation of contact** menu command. The rail/wheel contact window appears.
2. Turn on the **Animation of forces** and **N1** check boxes, see Figure 1.5. In order to get quite large-scale vectors of forces we need to change scale of vectors.
3. Set **Scale** to 10 (kN/m).

**Note.** Forces are shown after the simulation of wheelset dynamics starts.

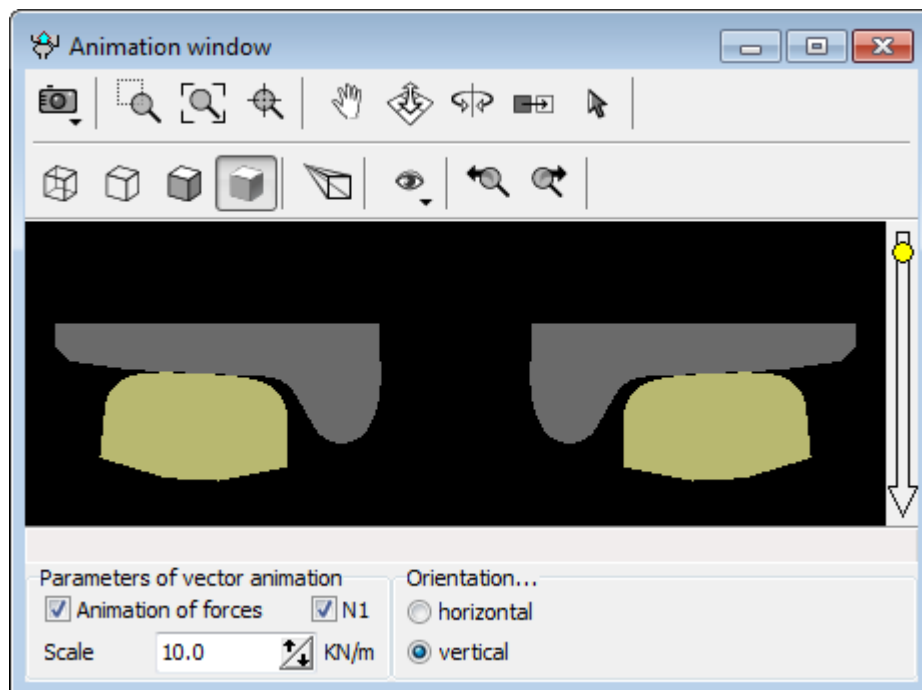


Figure 1.5. Animation of contact

### Stationary motion

Before simulation starts we need to set parameters of the numerical method.

1. Select **Object simulation inspector**, **F9**.
2. Point to the **Solver** tab.

3. Set **Solver** to **Park**.
4. Set **Error tolerance** to **4E-8**.
5. Click **Integration**.

If all coordinates are zero, a stationary regime of motion occurs: the wheelset does not move in the lateral direction and does not rotate about the vertical axis. The contact forces are constant.

6. After simulation finishes **Pause** window appears. Click **Interrupt**.

### Perturbed motion

Now we'll shift the wheelset from the steady state and analyze its dynamics.

1. Select **Object simulation inspector**.
2. Point to the **Initial conditions** | **Coordinates** tab, see Figure 1.6.
3. Set second (1.2) coordinate to 0.001 (m). Press **Enter**.

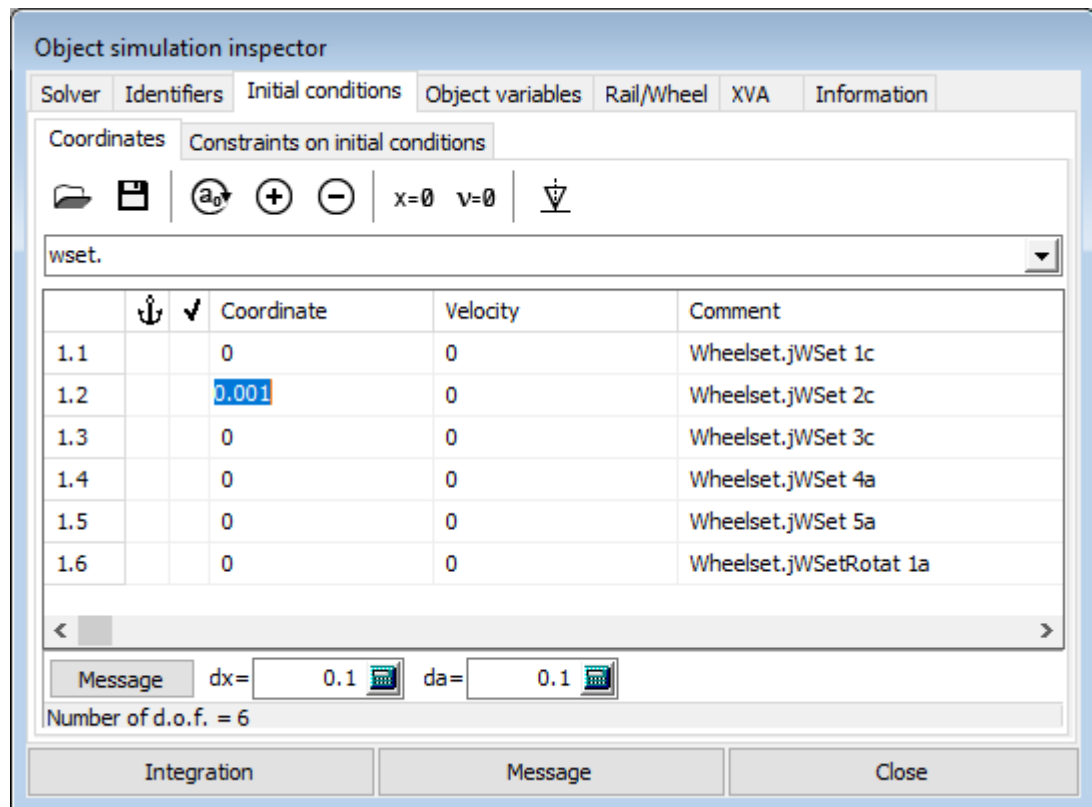



Figure 1.6. Initial conditions

4. Start simulation. Make sure that the wheelset is unstable – a small perturbation of initial position leads to self-excited vibrations.

Repeat the simulation to obtain plots for coordinate Y of the wheelset and for the angle of rotation about Z axis.

5. Open a new **graphical window** (from **Tools** menu).

6. Open **Wizard of variables** (from **Tools** menu).
7. In the **Wizard of variables** select the **Coordinates** tab.
8. Select **Wheelset | jWSet | 1.2** and **1.4**, see Figure 1.7.
9. Click the  to create the variable and set it to the container of variables.
10. Drag variables to the graphical windows.
11. Start simulation of motion.

Plots of the lateral position of the wheelset and its turning angle relative to the vertical axis are shown.

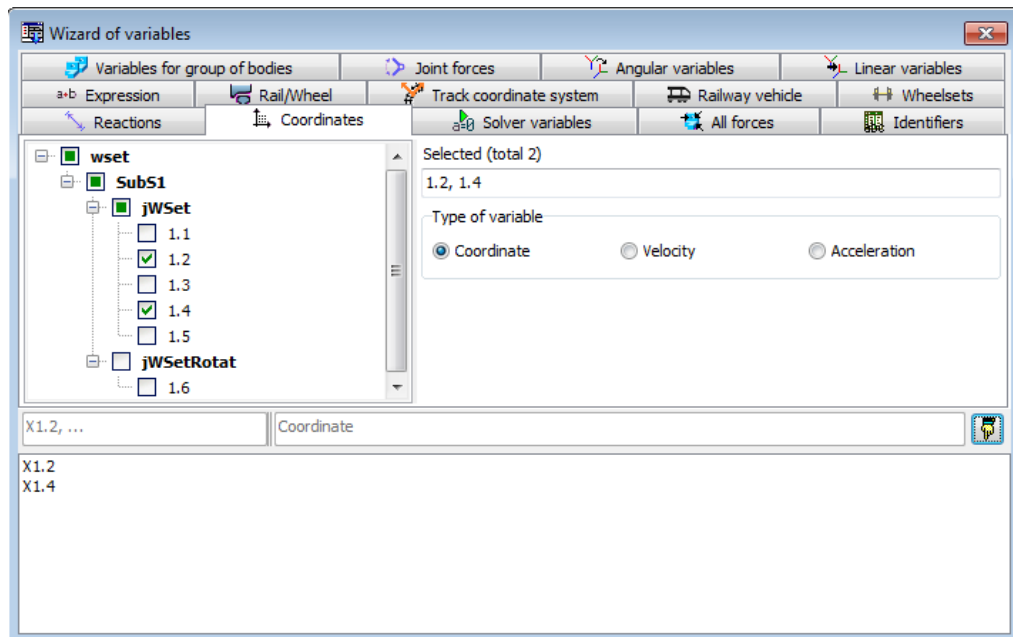


Figure 1.7. Wheelset coordinates

**Note.** If you have too many open windows use **List of windows**, menu command **Windows | List of windows**.

Set initial speed of the vehicle and simulation time.

1. Select **Object simulation inspector**, point to **Identifiers** tab.
2. Set **Expression** for the **v0** to **20** m/s.
3. Select the **Solver** tab, set **Simulation time** to **20** seconds.
4. Start simulation of motion. You see that the wheelset is unstable as well but the period of oscillation increases, see Figure 1.8.

**Note.** Lateral displacement and angle of attack (hunting) are quite small. Use **Full view** button to tune the window scales, see Figure 1.8.

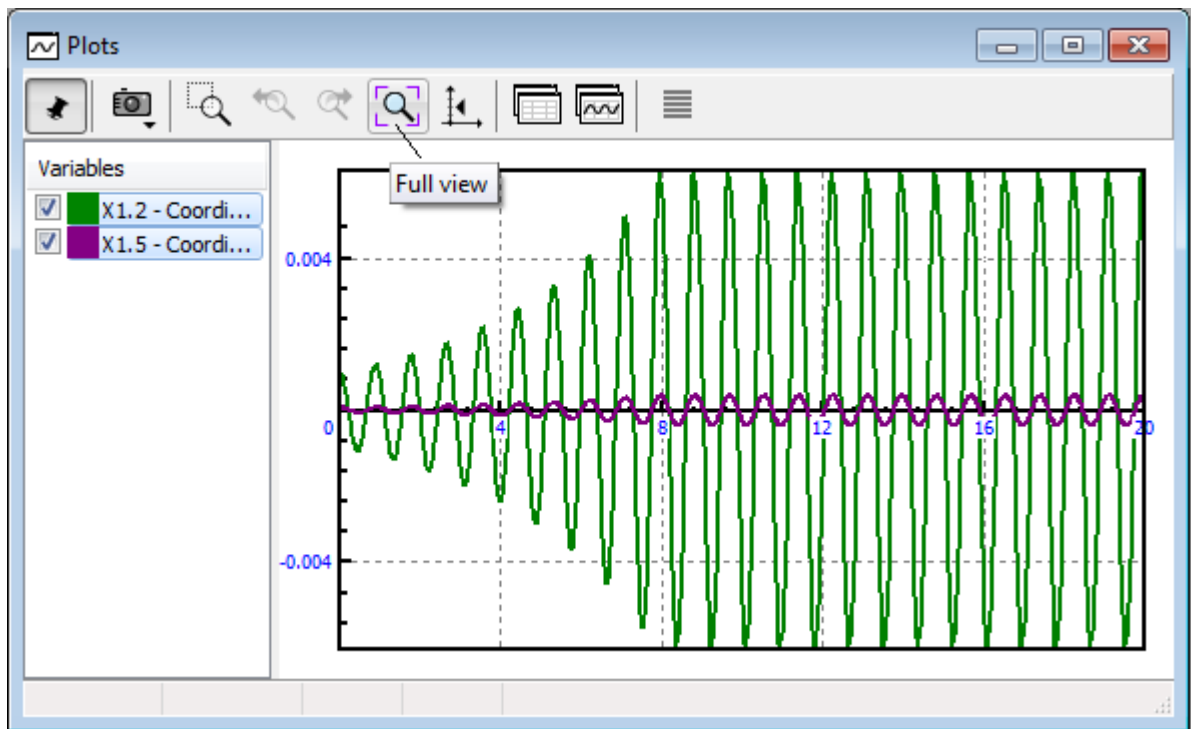


Figure 1.8. Wheelset coordinates

## 2. Creating the model of railcar

Here we consider the development of a simplified model of a railcar. The main simplification is absence of the traction engines. You can find this model in the [{UM Data}\SAMPLES\Rail Vehicles\AC4](#)<sup>1</sup> directory.

### 2.1. Basic elements of model

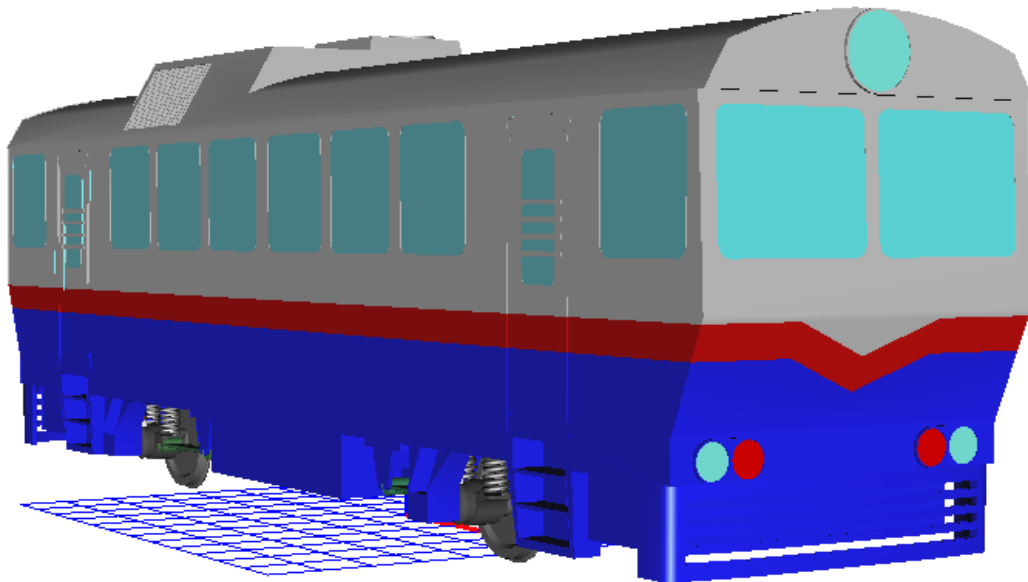


Figure 2.1. UM model of the ac4 railcar

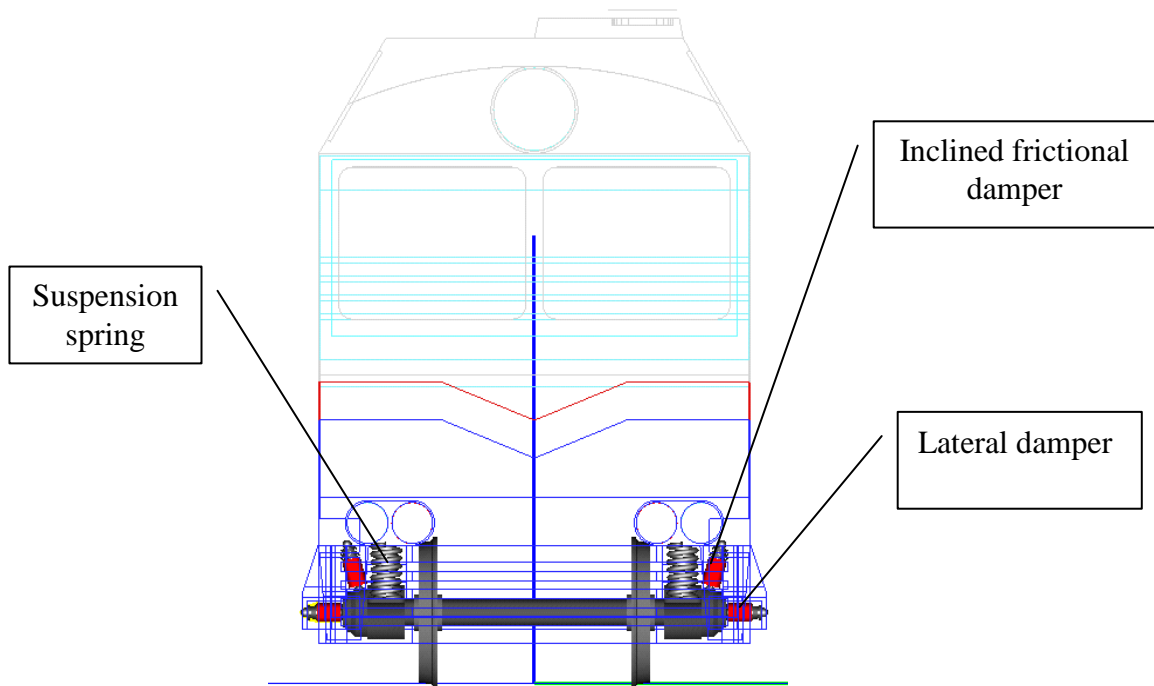


Figure 2.2. Basic elements of the model

<sup>1</sup> Model is also available at [www.universalmecanism.com/download/90/ac4.zip](http://www.universalmecanism.com/download/90/ac4.zip)

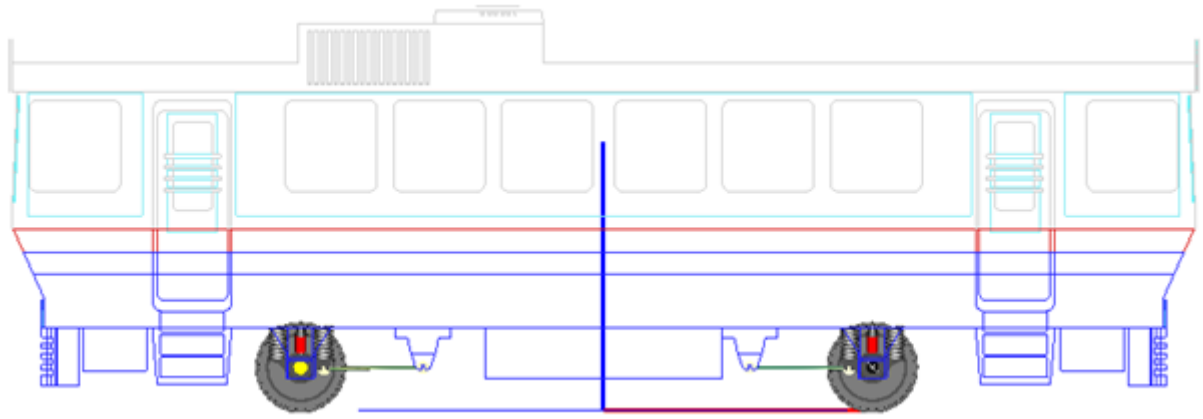


Figure 2.3. Basic element of the model

The model consists of the following elements.

1. Two standard UM subsystems – wheelsets.
2. Four graphic objects (car body, damper, spring, traction rod).
3. Five bodies – a car body and four axle-boxes.
4. One joint introducing car body coordinates, and for rotational joints for axle-box/wheelset pairs.
5. Twelve bipolar force elements (4 inclined and 4 lateral dampers, 4 traction rods).
6. Eight special force elements of the spring type as suspension springs.

## 2.2. Creating new object

1. Run **UM Input** program.
2. Create new object by clicking the  button or by the **File | New object** menu command.
3. Save the empty object by clicking the **File | Save as...** menu command.

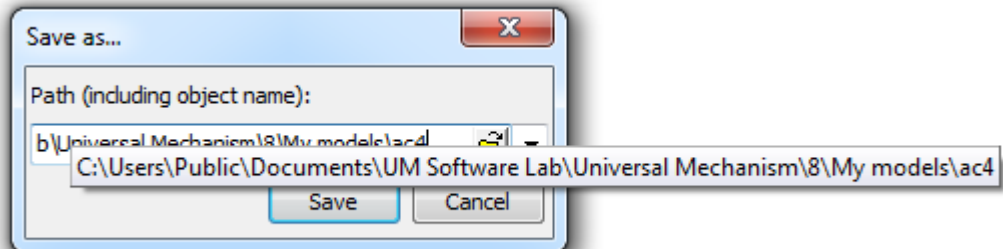





Figure 2.4. Save dialog

Select a desirable directory including the object name (ac4, Figure 2.4). Any letters in the path are allowed except the object name where Latin letters and digits can be used only. The terminal directory in the path (with the object name, ac4) will contain all information about the model as well as working files.

While describing the object elements, use the  /  button in the toolbar of the animation window to switch the object image modes: full object mode and separate element mode.

## 2.3. Creating wheelsets

General information about a wheelset as a standard subsystem can be found in [Chapter 8](#), Sect. *Wheelset and single wheel*.

1. Select Subsystems in the element tree (Figure 2.5, left) and add a subsystem by clicking the  button on the data inspector, rename it to **WheelSet1** and choose the type of the subsystem – **Wheelset** (Figure 2.5, right). Wheelset appears in the animation window and the data in inspector reflect its current geometrical and inertia parameters. Some of the wheelset parameters can be corrected right here, see Figure 2.6. If necessary, here you can change semi base and the running radius.
2. Set the wheelset position relative to the center of the vehicle. Select the **Position** tab and set **Position | x** to **Length1**. Press **Enter** and input **Length1 = 3.29** m. The identifier appears in the list of identifiers together with the standard identifier **v0** (initial vehicle speed). You can modify values of identifiers in the list any time you wish.
3. On the next step the user can decide where the origin of the reference frame (SC0) is located: either on the rail head level (recommended) or on the wheelset axle level (obsolescent). In this example we will go through the recommended way. Set **Position | z** to **rwheel**, press **Enter** and then input **rwheel = 0.525** m.

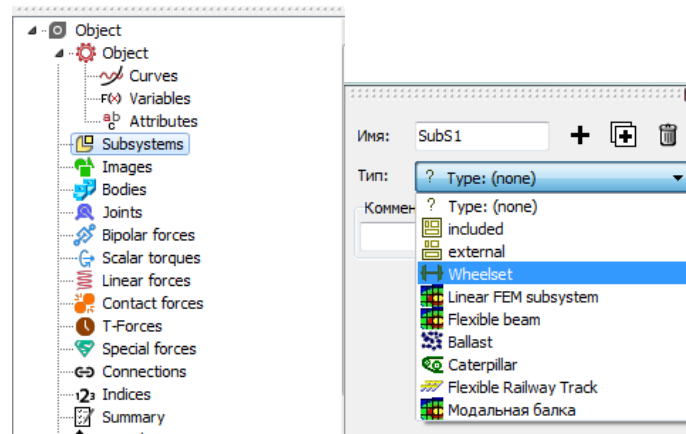


Figure 2.5. Adding a standard subsystem – “wheelset”

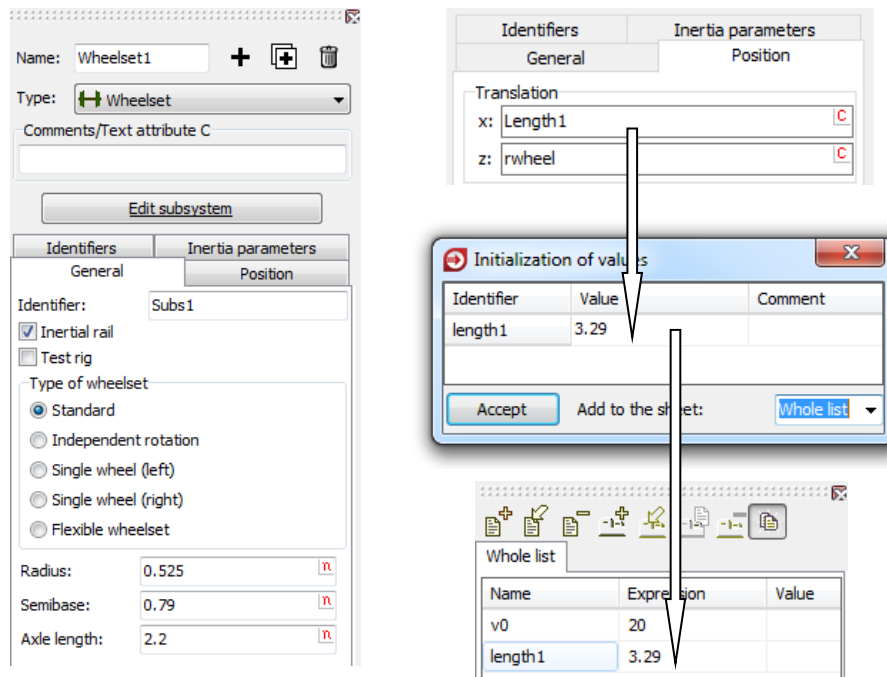


Figure 2.6. Wheelset parameters

**Inertia data of wheelset**

1. Select the **Identifiers** tab and modify inertia parameters as follows, see Figure 2.7.
2. Set wheelset mass **mwset = 3650 kg**.
3. Set moments of inertia relative to X and Z axes **ixwset = 1000 kg·m<sup>2</sup>**.
4. Set the moment of inertia relative to Y axis to **iywset = 500 kg·m<sup>2</sup>**.

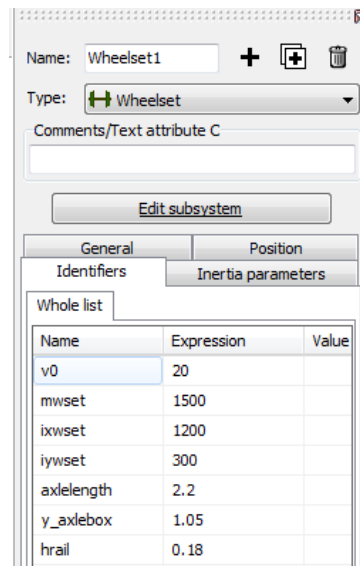

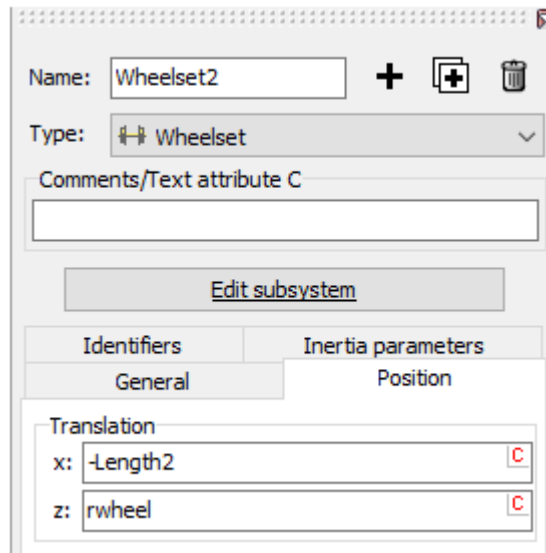


Figure 2.7. Inertia parameters of wheelset base and gyrostat

### Creating the second wheelset

1. To create the trailing wheelset, copy the leading wheelset by clicking the  button. Change the **Name** to **WheelSet2** and identifier of the new wheelset to **WS2**. Set the wheelset location on the **Position** tab as **-Length2**, where **Length2** = 3.71 m. Use the expression **-Length2** (minus **Length2**) to set the negative coordinate.



2. Description of the wheelsets is complete. Save the object using the **File | Save** menu command.

## 2.4. Creating graphical objects

It is important to remember that one graphic object (GO) can be assigned to any number of elements having the same image. For instance, a GO ‘spring’ is assigned to four suspension springs as their image. The same statement is valid for dampers and traction rods.

At present, CAD programs are often used for creating images of bodies. UM allows import of graphic objects from many of the CAD programs as well as from STEP and IGES formats. By development of the current model, we will use several preliminary created GO imported from a CAD program (car body, axle-boxes, traction rods).

Use the **Images** item of the list of elements to get GO in the inspector, Figure 2.8. So far the list is empty.

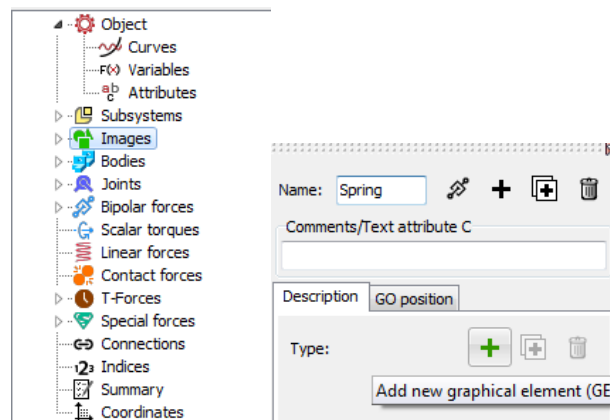


Figure 2.8. List of images. Buttons and their functions

### 2.4.1. Creating image of spring

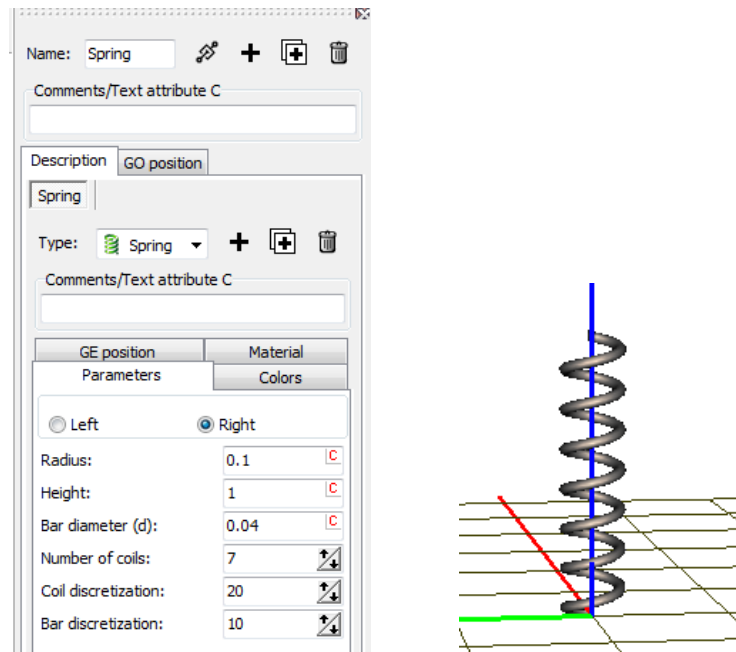



Figure 2.9. Image of spring

1. Add new GO to the list by the upper **+** button, and change its name to **Spring**.
2. Select the **Spring** type from the drop-down list. Set spring radius **0.1** m and number of coils 7, Figure 2.9.

**Note.** Note that images of force elements in the simplest case have 1 m length along the Z-axis. Program manages its length and orientation automatically.

## 2.4.2. Add images from files

The button  on the tool panel as well as the **Edit | Read from file...** menu command allow the user to add preliminary created elements from files, in particular, GO (file extension \*.img). All the GO, which we will add to the railcar model, are located in the directory {UM Data}\rw\Images.

Read sequentially the following files:

- AC4\_CarBody;
- AC4\_TractionRod\_F (the front rod);
- AC4\_TractionRod\_R (the rear rod);
- AC4\_AxleBox LF (the left axle-box of the leading wheelset);
- AC4\_AxleBox LR (the left axle-box of the trailing wheelset);
- Damper.

All of these images except the damper are imported from one of the CAD software, Figure 2.10.

Note that the car body image consists of several graphic objects. Images of axle-boxes and rods are similar but differ in some details.

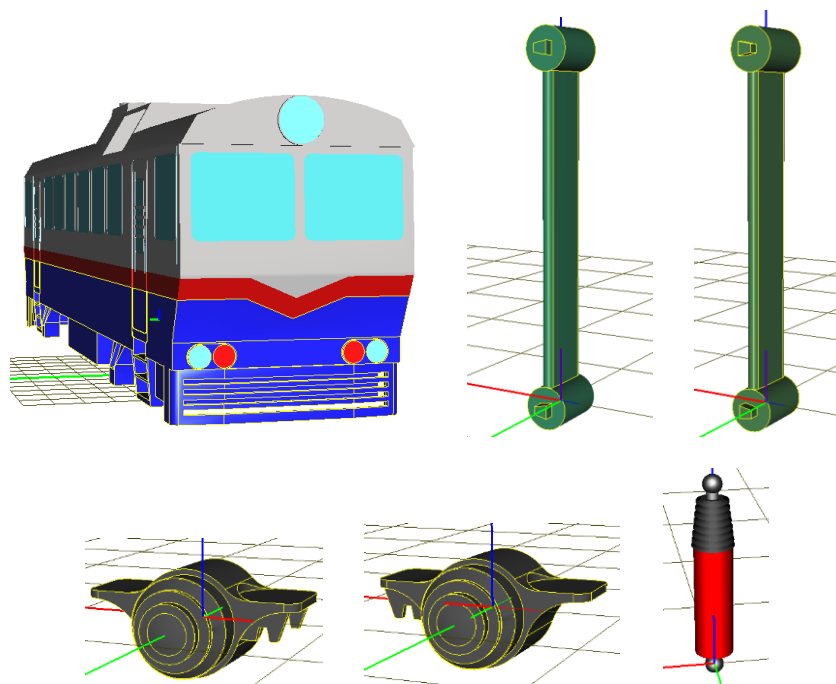




Figure 2.10. Images from files

## 2.4.3. Images of right axle boxes

Images of the *left* axle-boxes were read from files. GO for the *right* axle-boxes are created from the left ones by the rotation on 180 degrees about the vertical axis.

- Create a new GO by the  button. Rename it as **Axle-box RF** – (R)ight, (F)ront.
- Add a graphic element (GE) by the lower button .

- Assign the **GO** type to the new GE, i.e. a reference to one of the existing GO. Select the **Axle-box LR GO** from the drop-down list, Figure 2.11, Left.
- In the **GE position** tab, rotate the image on **180** degrees about the Z-axis, Figure 2.11, right.

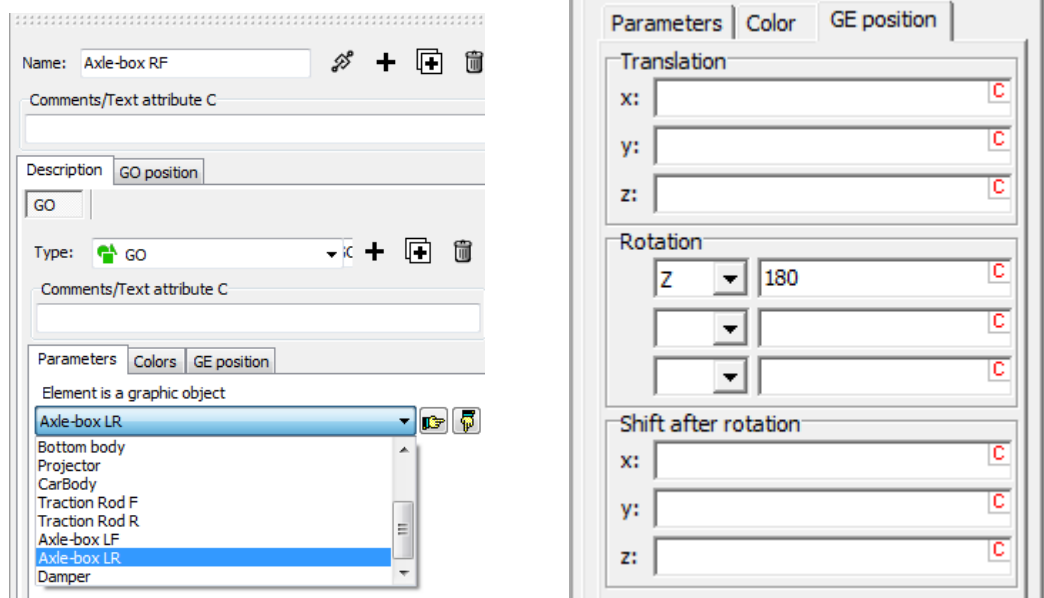


Figure 2.11. Creating image for the right front axle-box by rotation of the left rear axle-box

In the same way, a GO for the right rear axle-box with the name **Axle-box RR** can be created by the rotation of image of the left front axle box.

## 2.5. Adding axle-boxes to the model

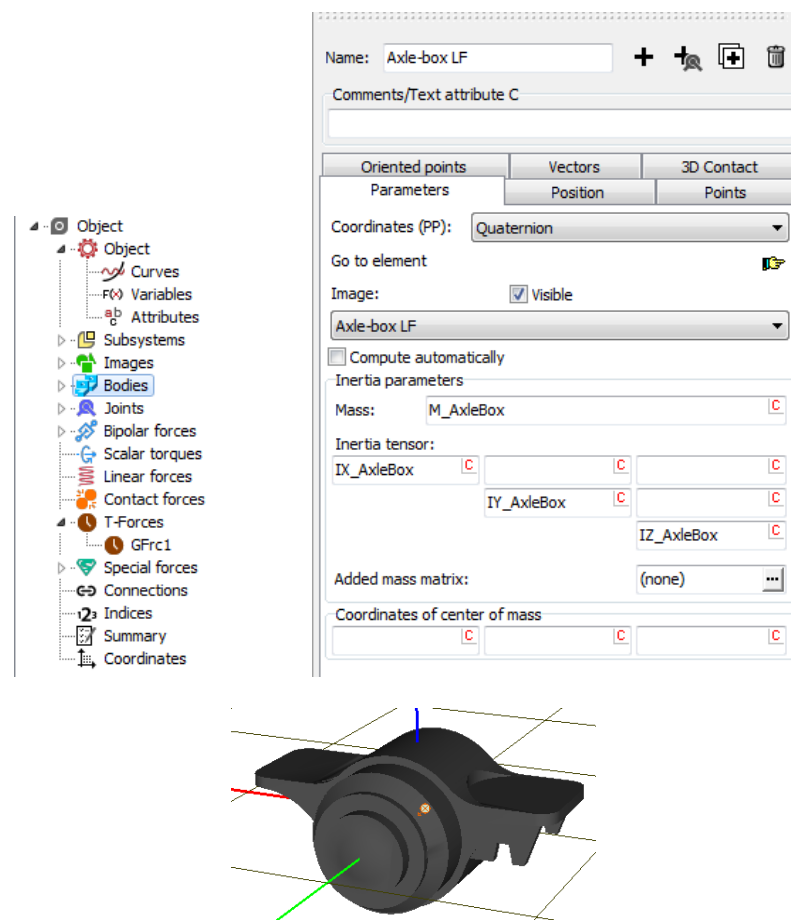


Figure 2.12. Adding a body: the left front axle-box

Adding each of the axle-boxes is made in two steps. Firstly, a body is created and then a rotational joint introducing a rotational degree of freedom of the axle-box relatively to the wheelset base.

- Open the empty list of bodies, Figure 2.12, left.
- Add a body by the **+** button.
- Rename it as **Axle-box LF** – (L)eft(F)ront.
- Assign the GO of the same name from the drop-down list.
- Set the moment of inertia relative to the lateral Y-axis by the identifier **IY\_AxleBox** =  $3 \text{ kg} \cdot \text{m}^2$ .

**Note** Please note that the most effective **Park Parallel** solver requires that mass and diagonal components of inertia tensor should be implemented. Otherwise **Park Parallel** will not be applicable. So you may specify Y-axis moment of inertia only, as it is described above and use any solver besides **Park Parallel** or specify all required fields (mass and all axis moments of inertia), Figure 2.12, and make **Park Parallel** also available.

- Set the moments of inertia relative to the longitudinal X-axis and relative to the vertical Z-axis by the identifier **IX\_AxleBox** = 3 kg·m<sup>2</sup>, **IZ\_AxleBox** = 3 kg·m<sup>2</sup>.

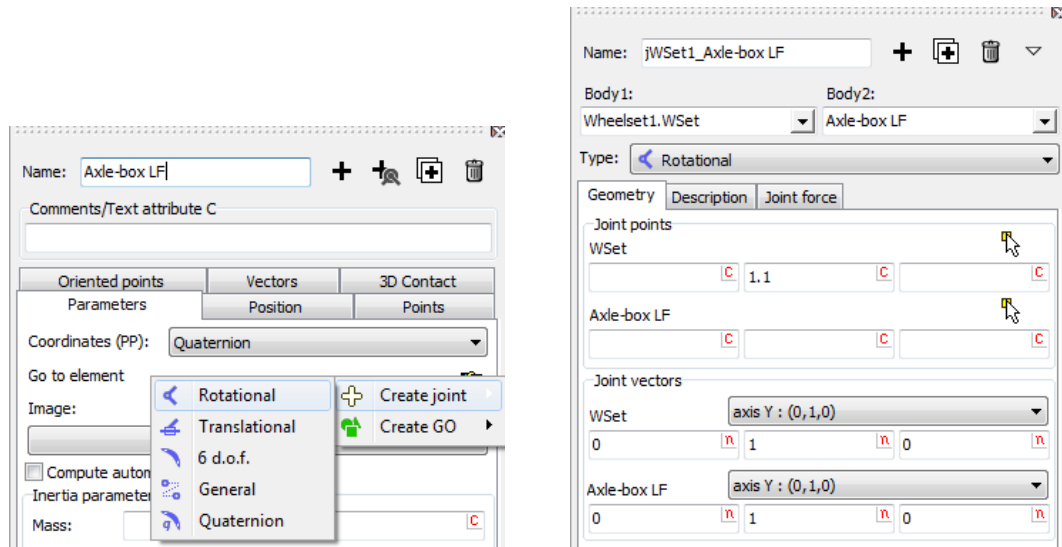


Figure 2.13. Creating a rotational joint for the axle-box

Create a rotational joint for the axle-box.

- Click on the button and select the **Create joint | Rotational** menu command, Figure 2.13, left. A joint is added automatically.
- Set the first body **WheelSet1.WSet** from the drop-down list (the base body of the leading wheelset), Figure 2.13, right.
- Set lateral position of the left axle-box on the wheelset axle **1.1** m in the **Joint points** group.
- Set directions of rotation axis (0, 1, 0) for each of the bodies in the kinematic pair.

Note that no image is assigned to the base body of the wheelset. To see the result of the joint creation use the / button to set the full object mode in the animation window, Figure 2.14.



Figure 2.14. Toolbox button to switch between whole object and the current element

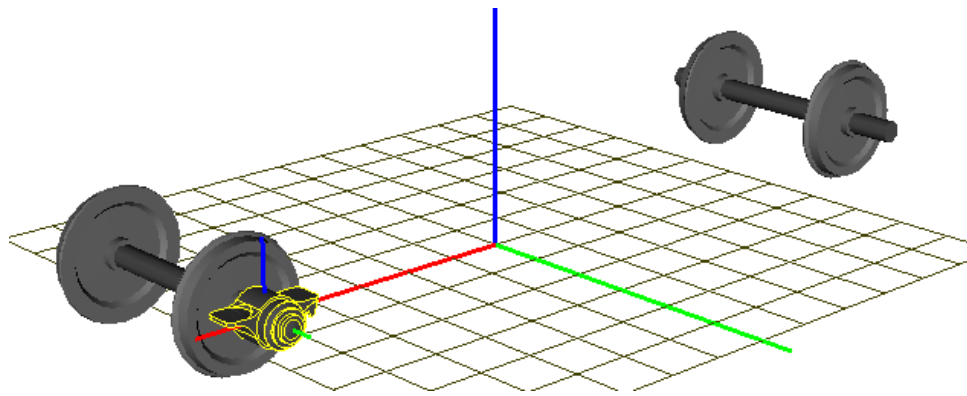


Figure 2.15. Model with added axle-box

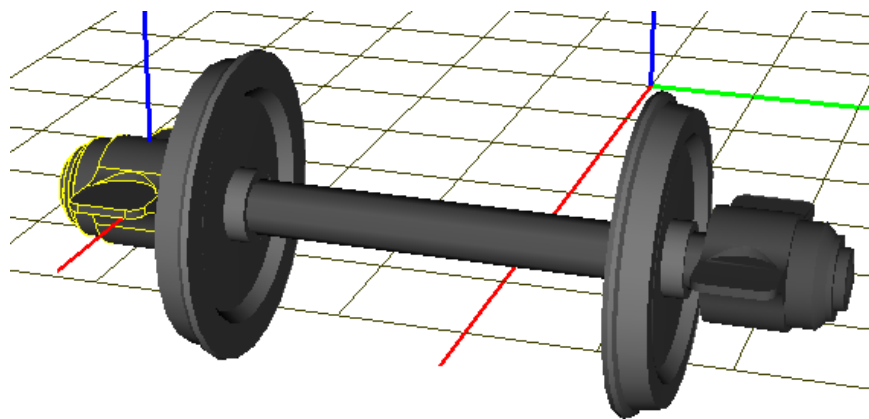



Figure 2.16. Leading wheelset with axle-boxes

To add the second axle-box, we recommend to use the copy operation for the body and joint specifying the first axle-box.

- Open the list of bodies and copy the axle-box by the  button. Rename the new body as **Axle-box RF** – (R)ight(F)ront. Assign the GO of the same name.
- Open the list of joints and copy the rotational joint of the first axle-box. Assign **Axle-box RF** as the second body. Change sign by the lateral coordinate **-1.1**. The result is shown in Figure 2.16.

Create the third and the fourth axle-boxes for the trailing wheelset in the same manner.

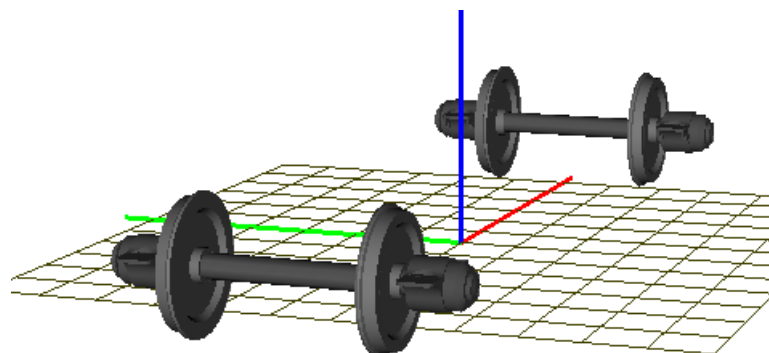


Figure 2.17. Wheelset with axle-boxes

## 2.6. Adding car body

Now we will add the car body and its inertial parameters to the object. Note that creation of the body image (the **Car body** GO) in the previous section does not mean that you have added the car body itself. You have added a picture to the list of pictures, nothing more. The car body appears in the model if you add the corresponding element to the list of bodies and set its coordinates.

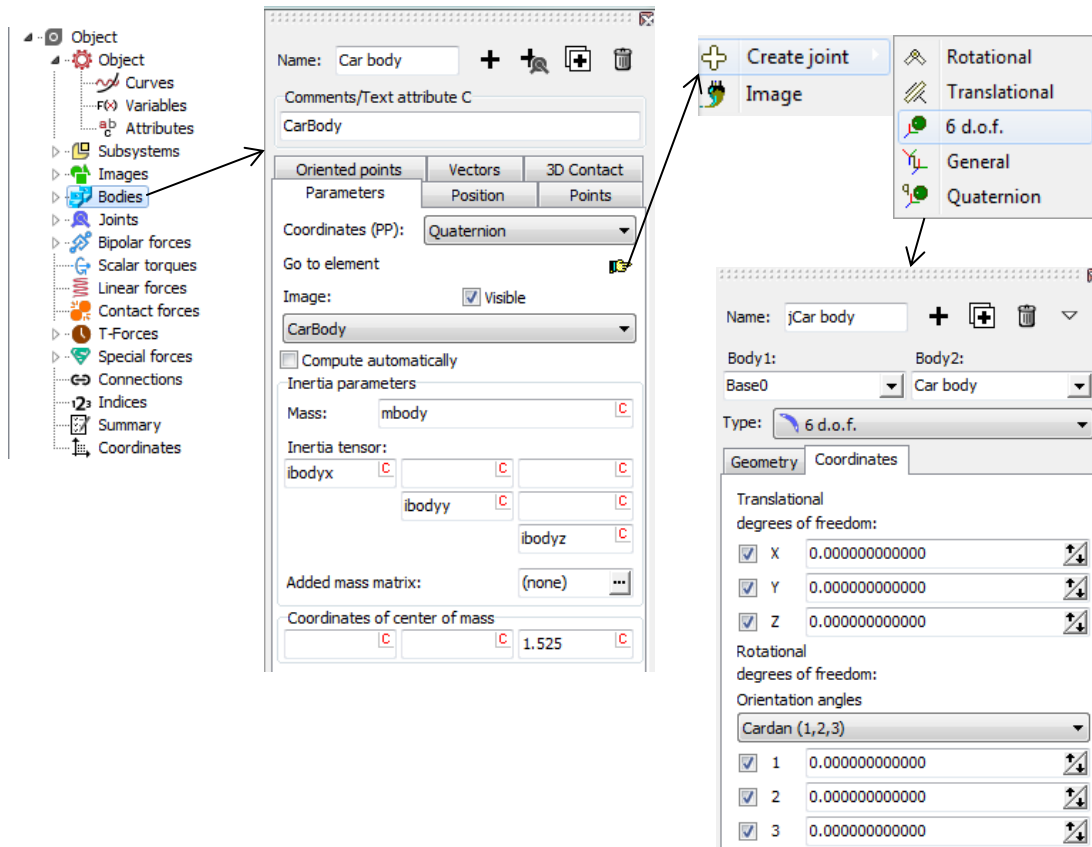


Figure 2.18. Adding car body and its joint

1. Select the **Bodies** item in the tree of elements and add a new body by clicking the **+** button. Rename it as **Car body**.
2. Fill out the inspector window like Figure 2.18: choose the corresponding image from the list, set inertia parameters as identifiers:


$$\mathbf{mbody} = 38300 \text{ kg,}$$

$$\mathbf{ibodyx} = 140000 \text{ kg}\cdot\text{m}^2,$$

$$\mathbf{ibodyy} = 626000 \text{ kg}\cdot\text{m}^2,$$

$$\mathbf{ibodyz} = 599000 \text{ kg}\cdot\text{m}^2,$$

$$\mathbf{zbody} = 1.525 \text{ m.}$$

3. **Adjust a joint** by clicking the  button and select its type **6 degrees of freedom**. The corresponding joint (jCar body) will be added to the list of joints. The joint assigns 6 coordinates to the body: three Cartesian coordinates in SC0 and three angles of orientation in the sequence 1, 2, 3 (sequence of rotations about X, then Y and finally Z axes).

## 2.7. Adding force elements

### 2.7.1. Springs

The simplest way to create a spring consists in using a special force element Spring ([Chapter 2](#), Sect. *Special forces / Spring*, [Chapter 3](#), Sect. *Input of force elements / Special forces / Spring*).

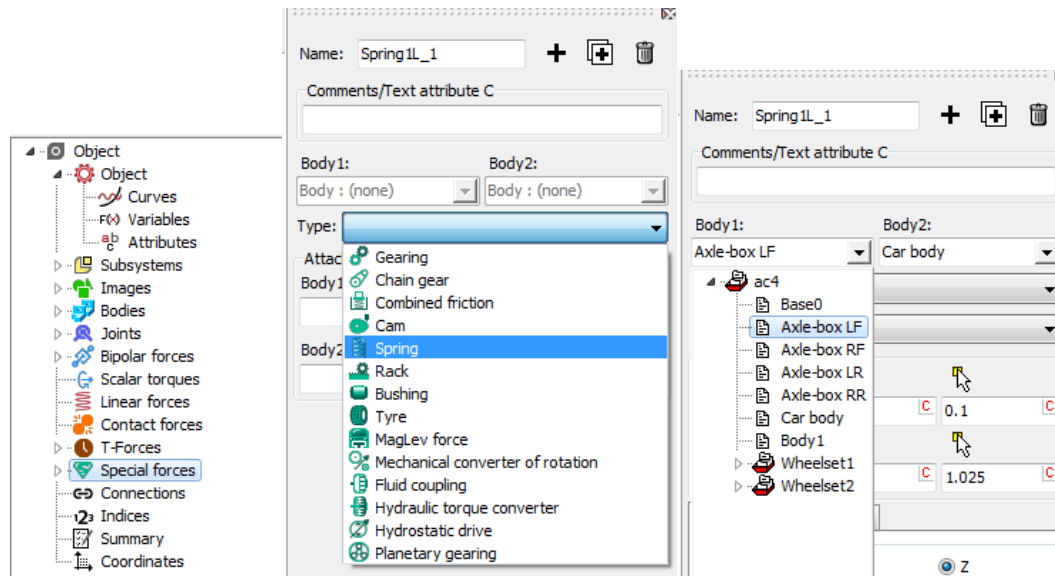



Figure 2.19. Creating spring

1. Select the **Special forces** tab (Figure 2.19, left) and add the first element corresponding to the front spring of the front right axle-box by clicking the  button. Rename it as “**Spring1L\_1**”. Set its type **Spring** (Figure 2.19, center).
2. Set bodies connected by the spring: **Axle-box LF** and **Car body** (Figure 2.19, right). Assign the **GO Spring**.
3. Set coordinates of attachment point to the axle-box (**0.28, 0, 0.1**) and height of the spring under the static load **0.4** m (the **Length** parameter). Check the automatic calculation of the second attachment point (the **Autocomputing for 2nd body** check box), Figure 2.20, left. As a result, the spring takes its final position in the animation window. Now click the **Compute for the second body** button, the coordinates of attachment point for the second body are visualized (**3.57, 1.1, 1.025**).

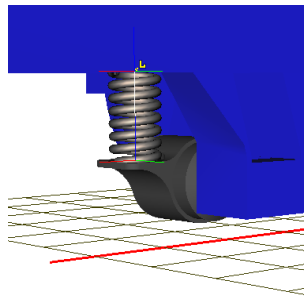
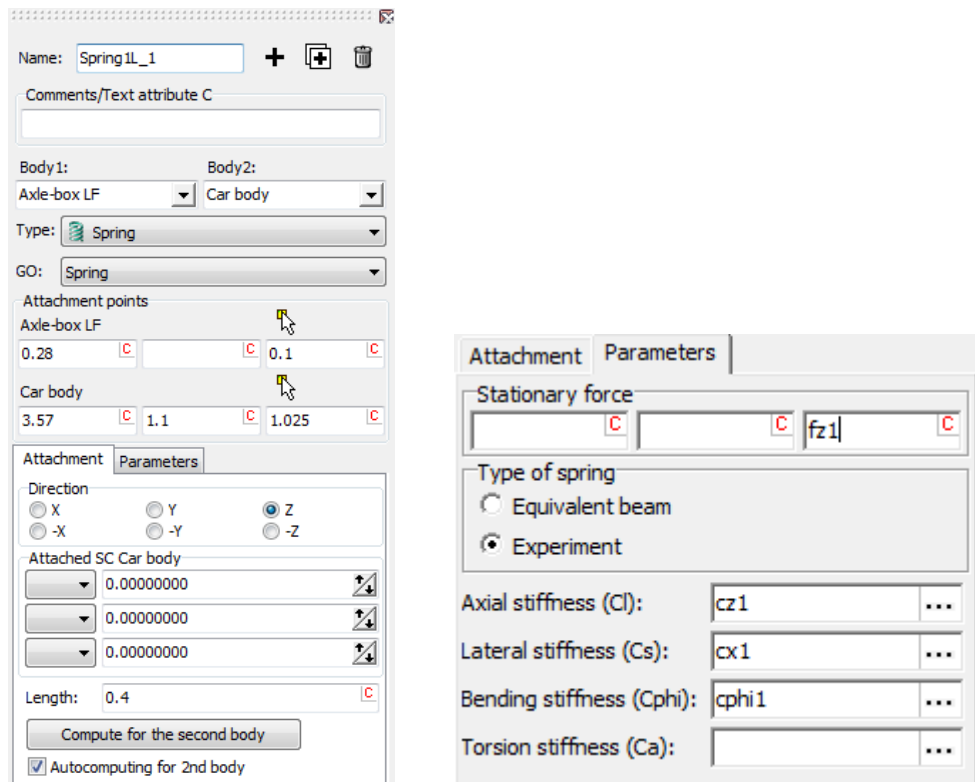


Figure 2.20. Parameters of spring

4. Select the spring type **Experiment** and set shear (lateral) **Cs**, longitudinal (vertical) **Cl** and bending **Cphi** stiffness with identifiers **cx1** = 370000 N/m, **cz1** = 377000 N/m, **cphi1** = 5500 N·m/rad.
5. Set the static load for the spring. Set Z component of the **Stationary force** to **fz1**. Initialize **fz1** first by zero value.

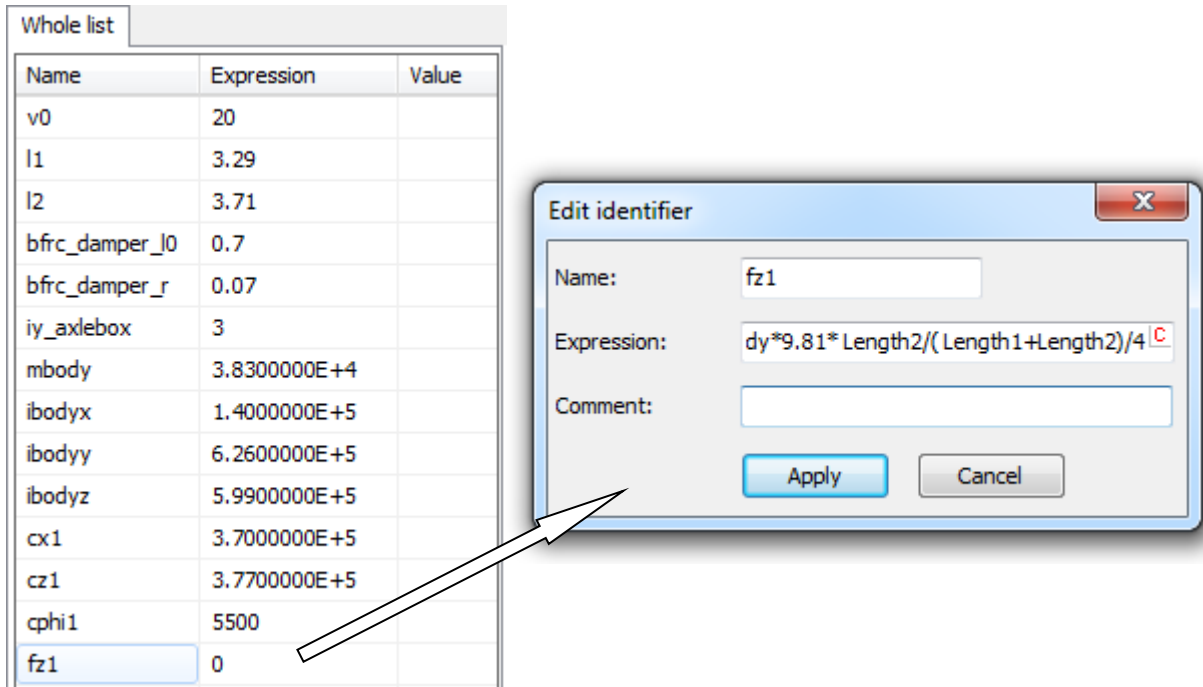



Figure 2.21. Static spring force as an expression

It is quite clear that the static load for the front springs is a function of the car body mass as well as longitudinal positions of wheels, which are set with the help of identifiers **mbody**, **Length1**, **Length2**. Now it is possible to express the static load value in terms of these identifiers

$$fz1 = mbody * 9.81 * Length2 / (Length1 + Length2) / 4.$$

6. To insert this expression instead of the value of the identifier, double click by the left mouse button on the corresponding (**fz1**) row of the identifier list and write down the expression in the appeared window (Figure 2.21).
7. Copy the first spring by the  button. Rename it as '**Spring1L\_2**' (rear spring).
8. Change the sign for the X-coordinate of the spring attachment to the axle-box, **-0.28** instead of **0.28**.
9. Copy the first and the second springs. Rename them as **Spring1R\_1**, **Spring1R\_2** (front and rear springs of the right front axle-box). Set the first body **Axle-box RF**.
10. Now create the front spring for the left axle-box of the trailing wheelset. Copy the first spring, rename it as **Spring2L\_1**, change the first body to **Axle-box LR**. Set the following stiffness constants  
 $cx2 = 330000, cz2 = 370000, cphi2 = 5250.$
11. Set the stationary force as the **fz2** identifies. Initialize it to zero and then double click on the **fz2** identifier in the **List of identifier** and set  
 $fz2 = mbody * 9.81 * Length1 / (Length1 + Length2) / 4.$
12. Copy the last spring three times, create the remaining springs (**Spring2L\_2**, **Spring2R\_1**, **Spring2R\_2**) and modify them like the corresponding springs of the leading wheelset, Figure 2.22.

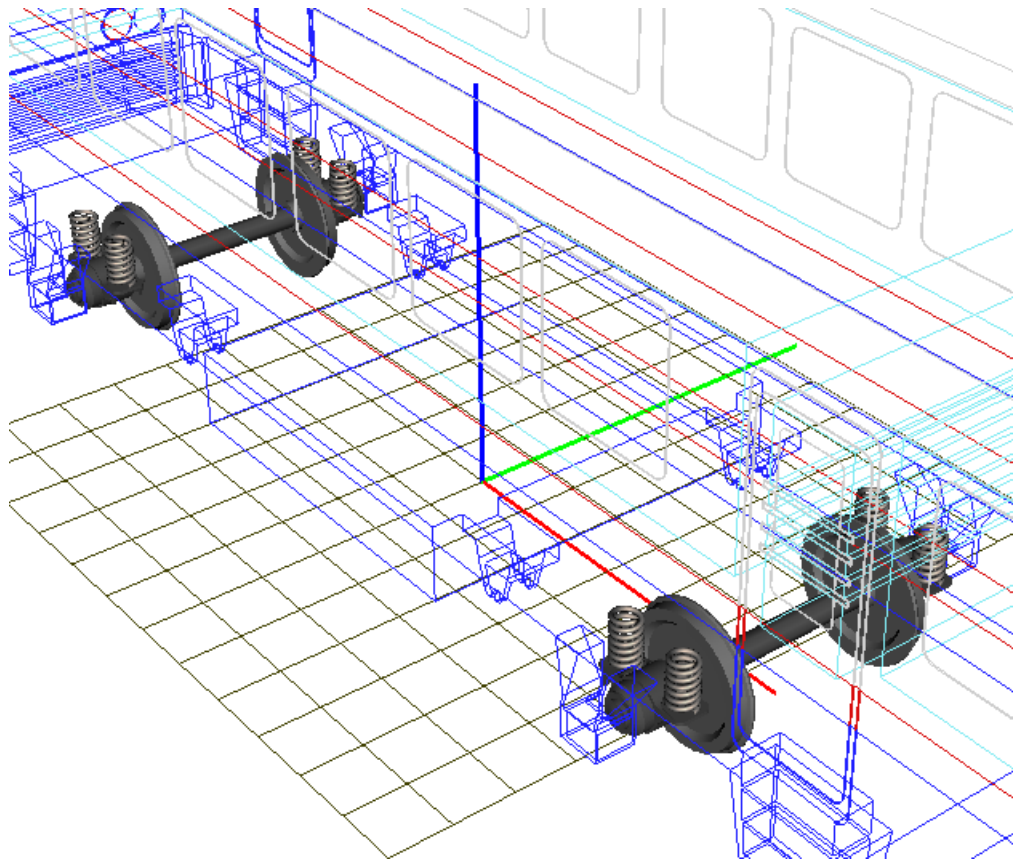


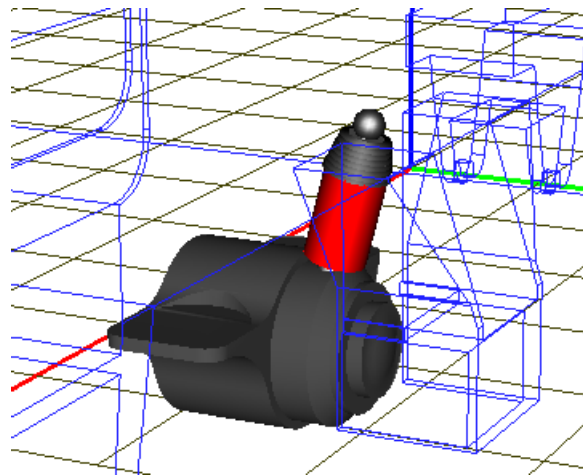
Figure 2.22. Suspension springs

## 2.7.2. Inclined dampers

Bipolar force elements should be used to add inclined frictional dampers to the model, [Chapter 2](#), Sect. *Bipolar forces*, [Chapter 3](#), Sect. *Input of force elements/Input of bipolar force elements*.

1. Select the **Bipolar forces** in the tree of elements and add the first bipolar force. Rename it to **Damper1L**.
2. Set all parameters like it's shown in the figure below.

Name: Damper1L		+		+		-	
Comments/Text attribute C							
Body1:				Body2:			
Axle-box LF				Car body			
GO: Damper							
<input type="checkbox"/> Autodetection							
Attachment points							
Axle-box LF							
	C	0.2	C	0.17	C		
Car body							
l1	C	1.39	C	1.025	C		
Length 0.342053							
Frictional							
Friction force (F):		1.1e4		C			
Ratio (f0/f):		1.2		C			
Stiffness coef. (c):		5.0e7		C			
Damping coef. (d):		1.0e4		C			



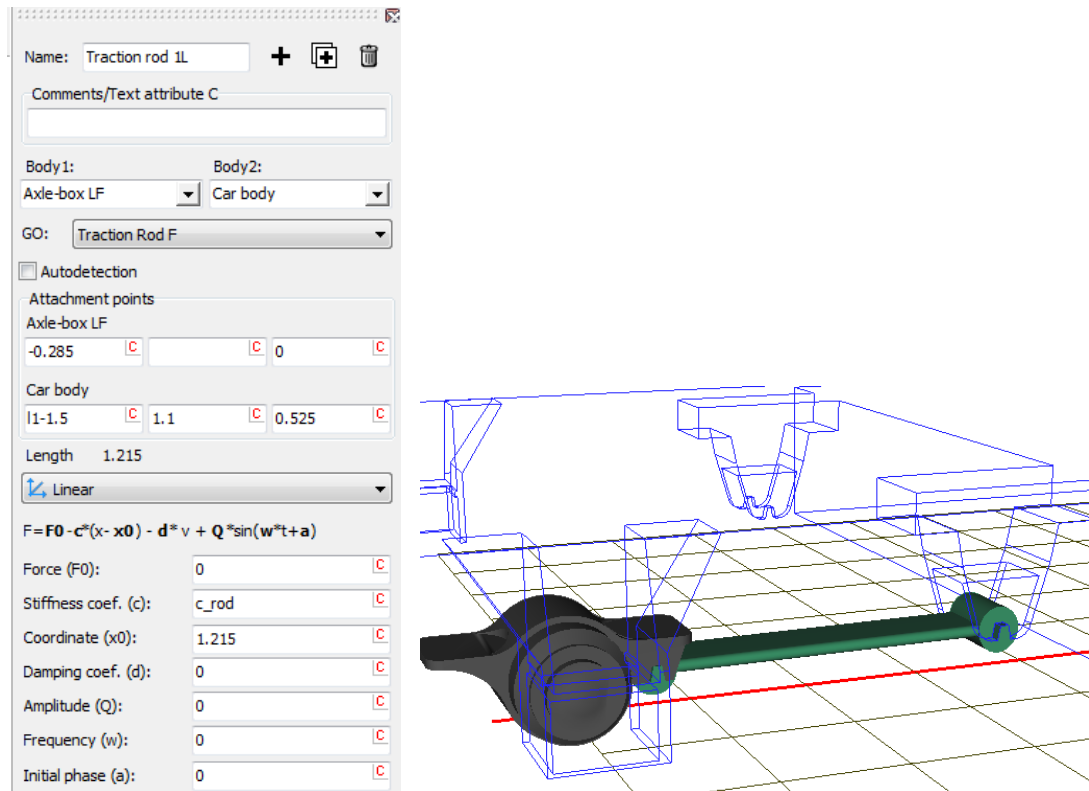
Other tree dampers are added by copying, renaming and correcting attachment point coordinates as well as the first body for the rear dampers.

3. The second damper (**Damper1R**), the first body **Axle-box RF**, attachment points **(0, -0.2, 0.17)** and **(Length1, -1.39, 1.025)**.
4. The third damper (**Damper2L**), the first body **Axle-box LR**, attachment points **(0, 0.2, 0.17)** and **(-Length2, 1.39, 1.025)**.
5. The last damper (**Damper2R**), the first body **Axle-box RR**, attachment points **(0, -0.2, 0.17)** and **(-Length2, -1.39, 1.025)**.

### 2.7.3. Traction rods

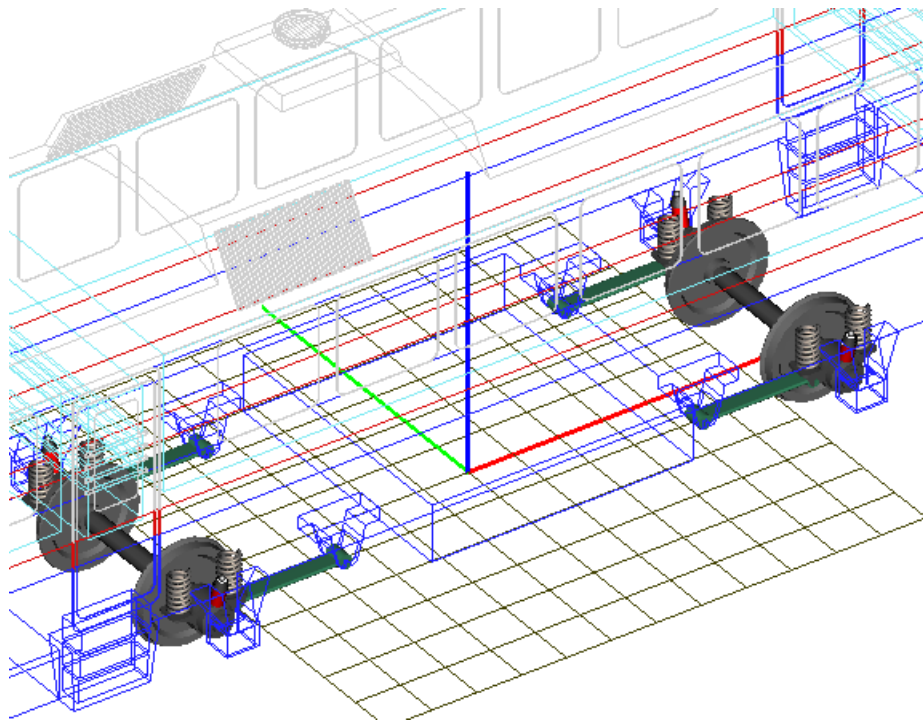
Traction rods producing a force along the rod exclusively are modeled by bipolar force elements. Let the element length in the unloaded state be 1.5 m.

1. Add the next bipolar element; rename it to **Traction rod 1L** (front left rod). Set the element type **Linear**.
2. Follow the figure to describe the element ( $c_{rod} = 2.5E7$  N/m).



Other three rods are added by copying, renaming and correcting attachment point coordinates as well as the first body for the rear rods.

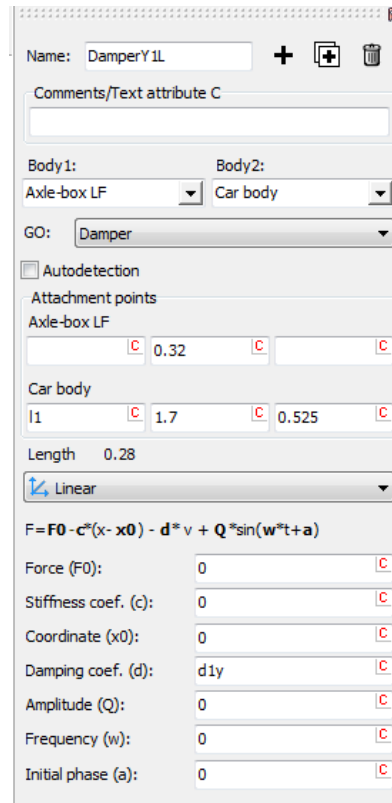
3. The second rod (**Traction rod 1R**), the first body **Axle-box RF**, attachment points **(-0.285, 0, 0)** and **(Length1-1.5, -1.1, 0.525)**.
4. The third rod (**Traction rod 2L**), the first body **Axle-box LR**, attachment points **(0.285, 0, 0)** and **(-Length2+1.5, 1.1, 0.525)**.
5. The last rod (**Traction rod 2R**), the first body **Axle-box RR**, attachment points **(0.285, 0, 0)** and **(-Length2+1.5, -1.1, 0.525)**.



### 2.7.4. Lateral dampers

Description of the lateral dampers is quite analogous to the description of the frictional dampers and the lateral traction rods.

1. Add the next bipolar force element, rename it to **DamperY1L**.
2. Use the figure below to describe the element ( $d_{1y} = 16400 \text{ N}\cdot\text{s/m}$ ).



3. The second lateral damper (**DamperY1R**), the first body **Axle-box RF**, attachment points **(0, -0.32, 0)** and **(Length1, -1.7, 0.525)**.
4. The third lateral damper (**DamperY2L**), the first body **Axle-box LR**, attachment points **(0, 0.32, 0)** and **(-Length2, 1.7, 0.525)**.
5. The last lateral damper (**DamperY2R**), the first body **Axle-box RR**, attachment points **(0, -0.32, 0)** and **(-Length2, -1.7, 0.525)**.

The model of the railcar is ready.

### 3. Scanning: implementation to railway vehicle dynamics

Here we discuss how to create and fulfill scanning project and then to analyze the obtained results. As an example, scanning project for railcar AC4 ([{UM Data}\SAMPLES\Rai\\_Vehicles\ac4](#)) is used.

Creating the AC4 model is considered in details in the previous section, see. Sect 2.

Scanning tool is a component of the **UM Experiments** module. To check if your UM installation has **UM Experiments** module please select the **Help | About...** menu command. The **About** dialog appears. There you can find the list of the installed UM modules.

Before starting scanning project please make sure that a model of the railcar AC4 is on your computer. You can find it in the [{UM Data}\SAMPLES\Rail\\_Vehicles\ac4](#) directory, download it from the Internet ([www.universalmechanism.com/download/90/ac4.zip](http://www.universalmechanism.com/download/90/ac4.zip)) or create the model like it's shown in the previous section.

Completely described scanning project, which is considered in this section, is available here: [www.universalmechanism.com/download/90/scan1.zip](http://www.universalmechanism.com/download/90/scan1.zip).

## 3.1. Creating scanning project

Here a scanning project for railcar AC4 is considered. The aim of this scanning project is to determine the critical speed of the railcar.

### 3.1.1. Preface

There are lots of criteria that engineers take into account during carrying out researches and optimization of parameters for railway vehicles. Stability of the railway vehicle is the one of the most important criteria of dynamical properties of the vehicle. Nowadays the most common estimation of the stability of the railway vehicle is its critical speed.

Here the approach, which helps us to estimate the critical speed of the vehicle numerically with the help of series of computer experiments, is shown. We will run the railcar with the various velocities on the even track with the single lateral irregularity at the beginning of the track. Amplitude of the irregularity is 20 mm and its length is 10 m. Then we will analyze lateral oscillations of the vehicle and will see if the single irregularity leads to stable or instable motion.

One of the informative characteristics is the lateral position of a wheelset relative to track axis or rather power of the lateral oscillation of the wheelset that can be estimated as standard deviation of the process.

Plots of lateral position of the first wheelset of the rail car are shown for  $v_0 = 30$  m/s (see Figure 3.1, in black) and 90 m/s (in green). It is obvious that the railcar is stable for  $v_0 = 30$  m/s and instable for 90 m/s. Standard deviation of the lateral oscillations of the first wheelset depending on vehicle speed is shown in the Figure 3.2. One can see stable, transition and instable zones there.

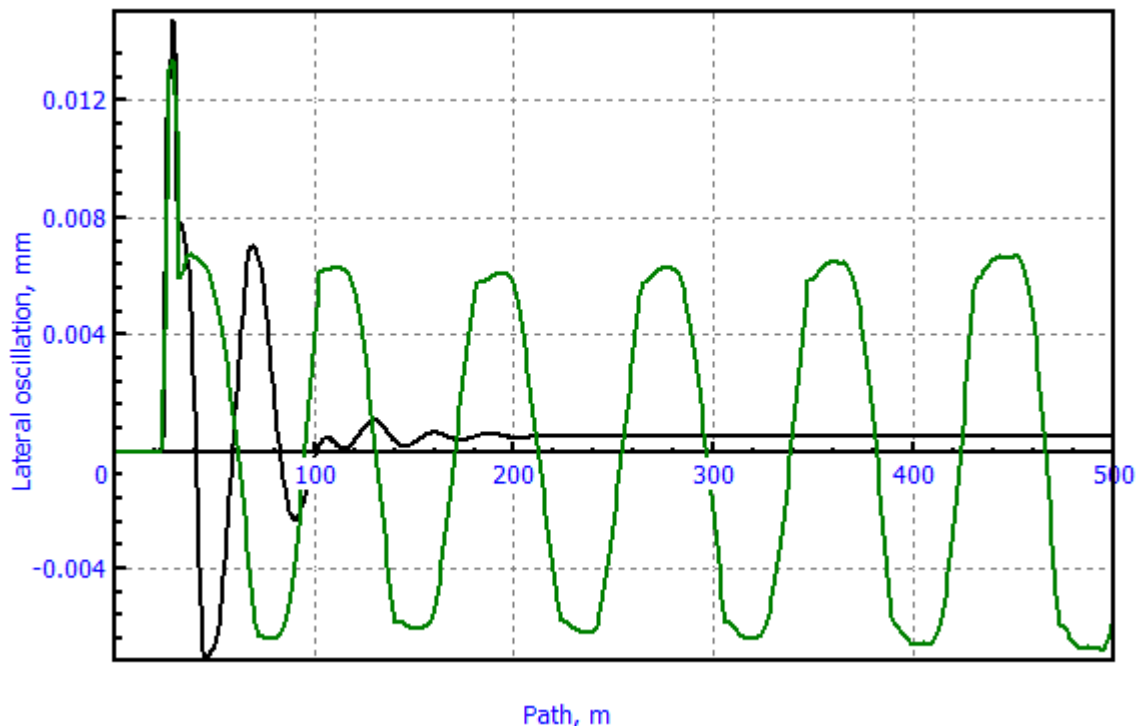


Figure 3.1. Lateral oscillation of a wheelset

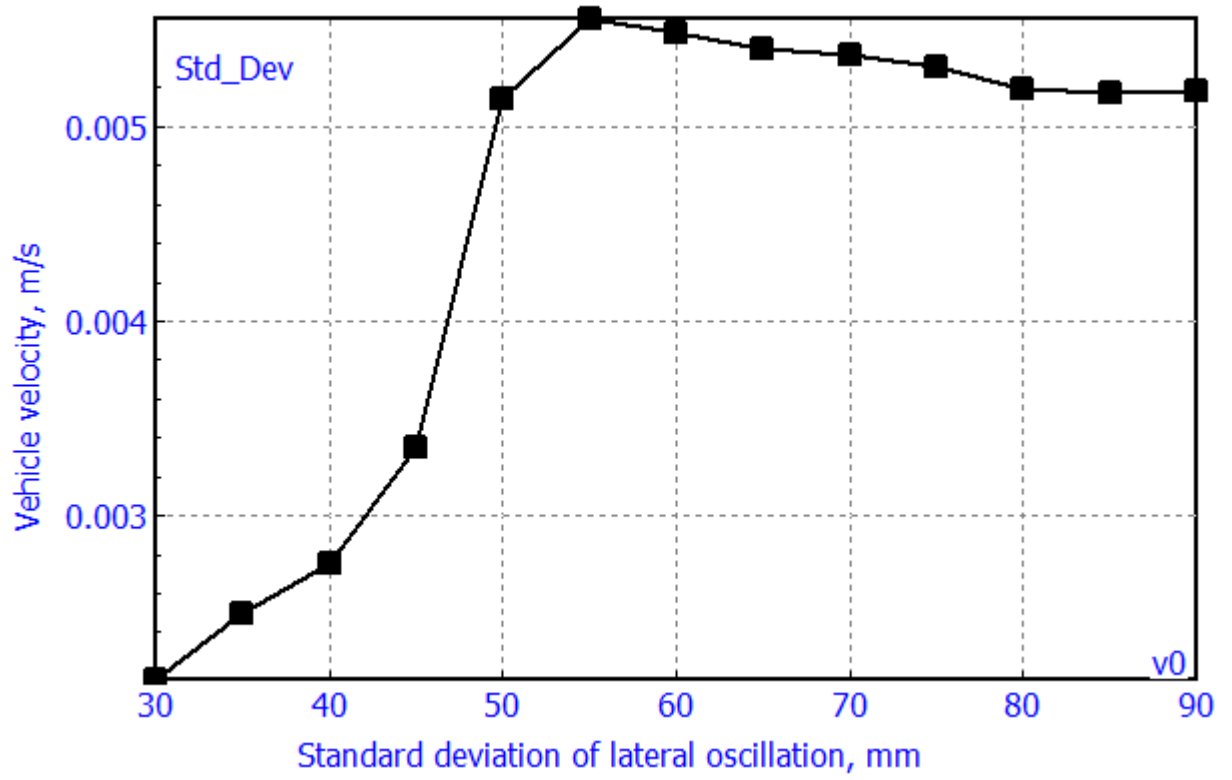


Figure 3.2. Standard deviation of lateral oscillations in dependence of vehicle speed

### 3.1.2. Creating new scanning project

1. From the **Scanning** menu point to **New project**.
2. Input the full path to the scanning directory including name of the project, Figure 3.3.

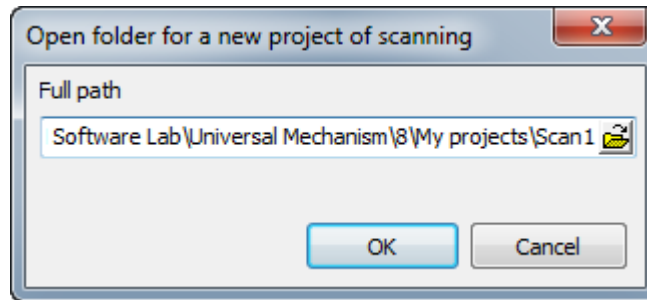


Figure 3.3. Folder for a new scanning project

3. Press the **OK** button and confirm creation of the new directory. The window of the new project appears, Figure 3.4.

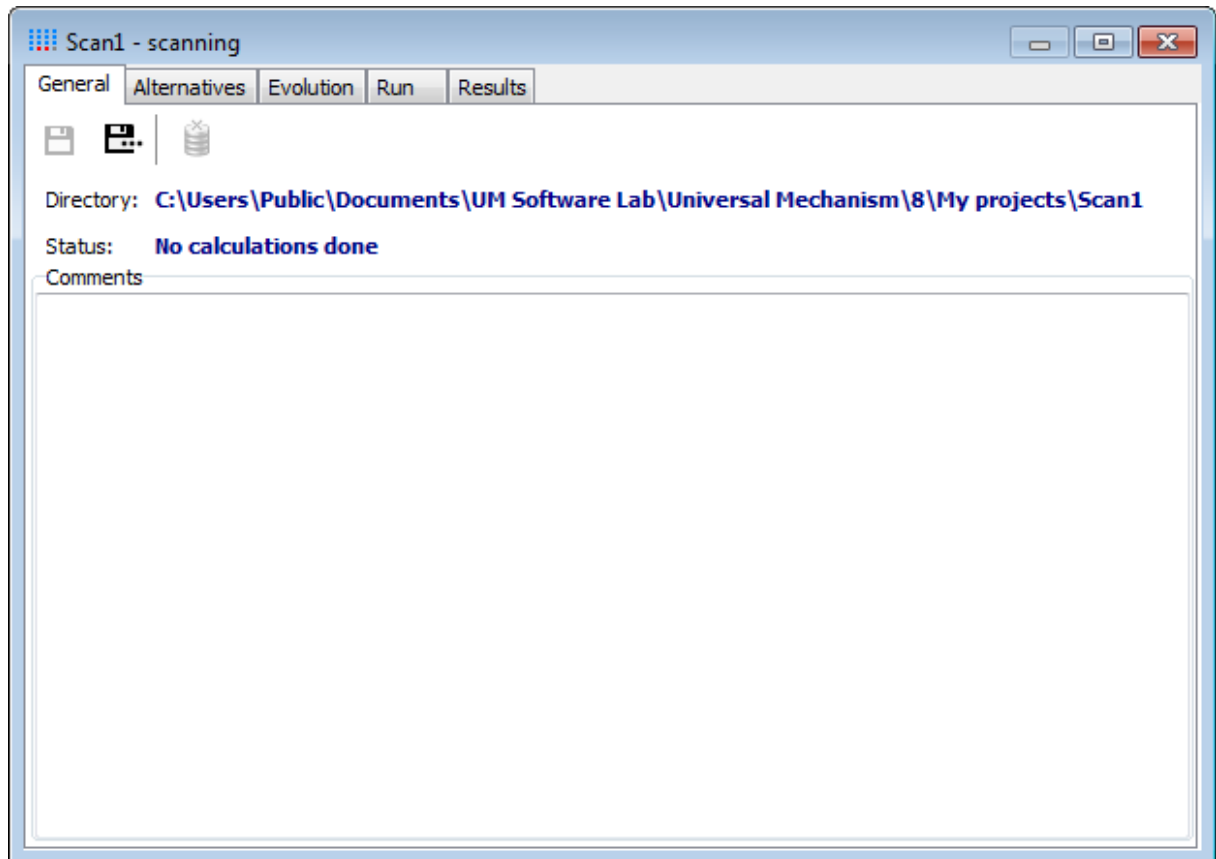


Figure 3.4. New scanning project

### 3.1.3. Loading a model

1. Select the Alternatives tab.
2. Click the **+** button (add family of alternatives).
3. In the open dialog choose the AC4 railcar model.

The model is loaded and added to the list of **Family of alternatives**, Figure 3.5.

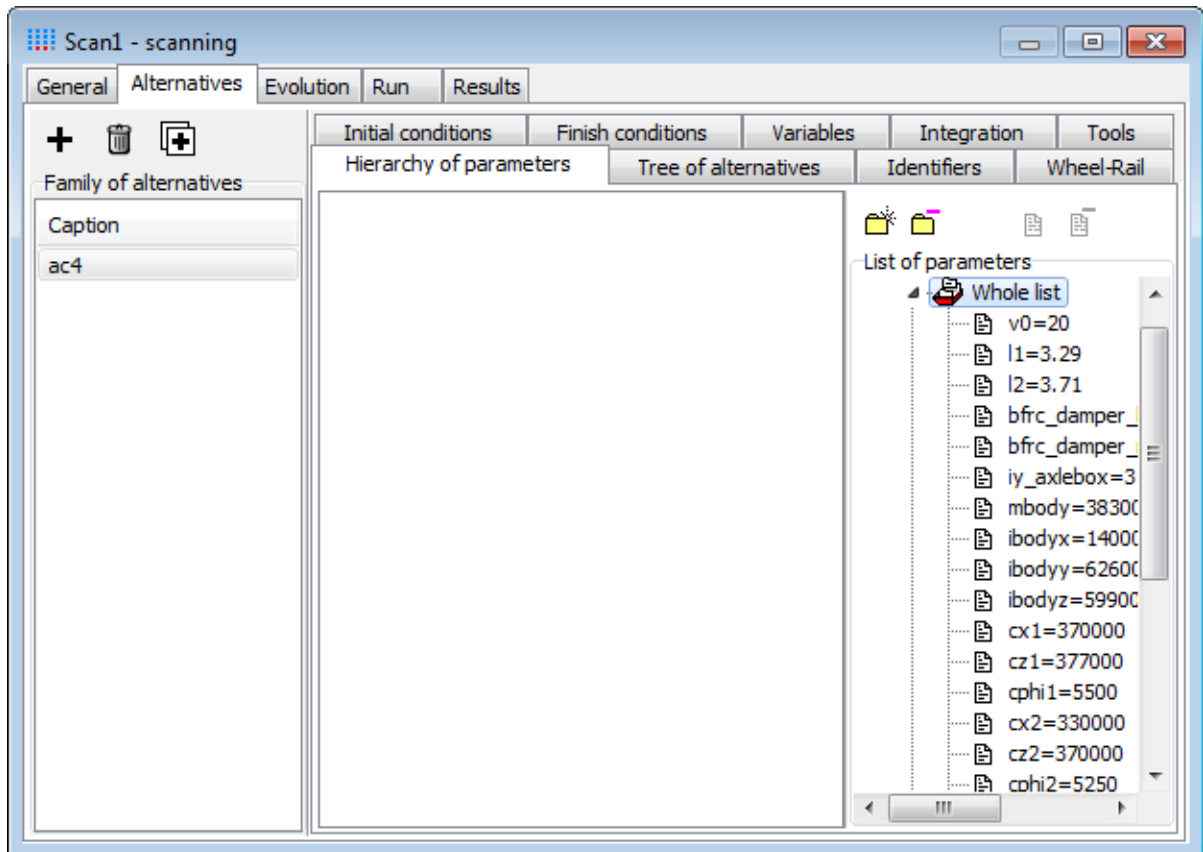


Figure 3.5. Scanning project: adding new model

### 3.1.4. Hierarchy of parameters

In this project we will scan dynamical properties of the railcar for only one parameter – speed of the vehicle.

1. Make sure that in the program the speed unit is set as m/s. To do this, select **Tools | Options...** menu, in the window that appears, choose the **General** tab and in the **Speed unit** field set the **m/s**.
2. In the **List of parameters** click **Whole list | v0**.
3. In the new window **Properties of identifier** input values from 30 up to 90 m/s with the step is 5 m/s, Figure 3.6. Click **OK**.
4. Rename group of parameters **Group1** to **v0** (using popup menu).

New group of the parameters **v0** appears on the **Hierarchy of parameters** tab. Thus, 13 numerical experiments will be done, Figure 3.7. Now we come to common settings for all of these experiments.

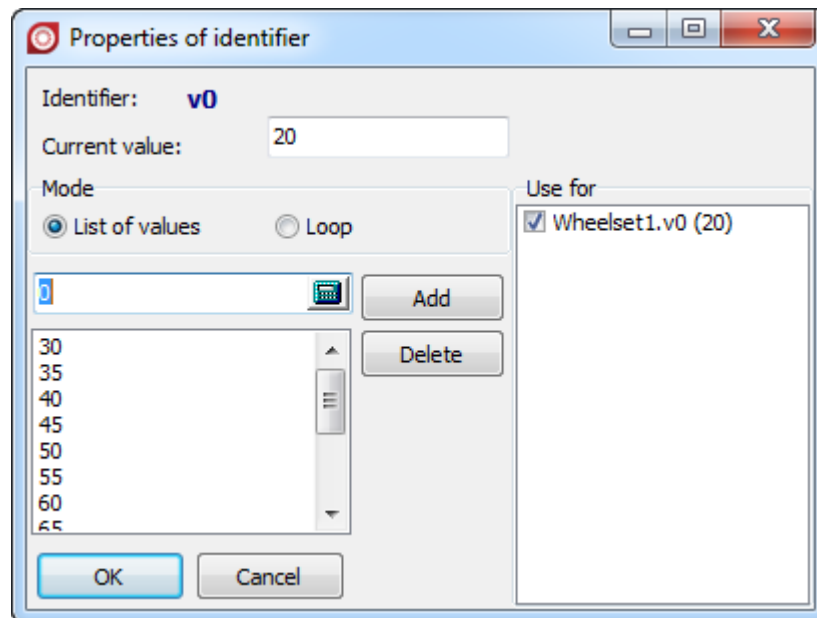


Figure 3.6. Values of parameters

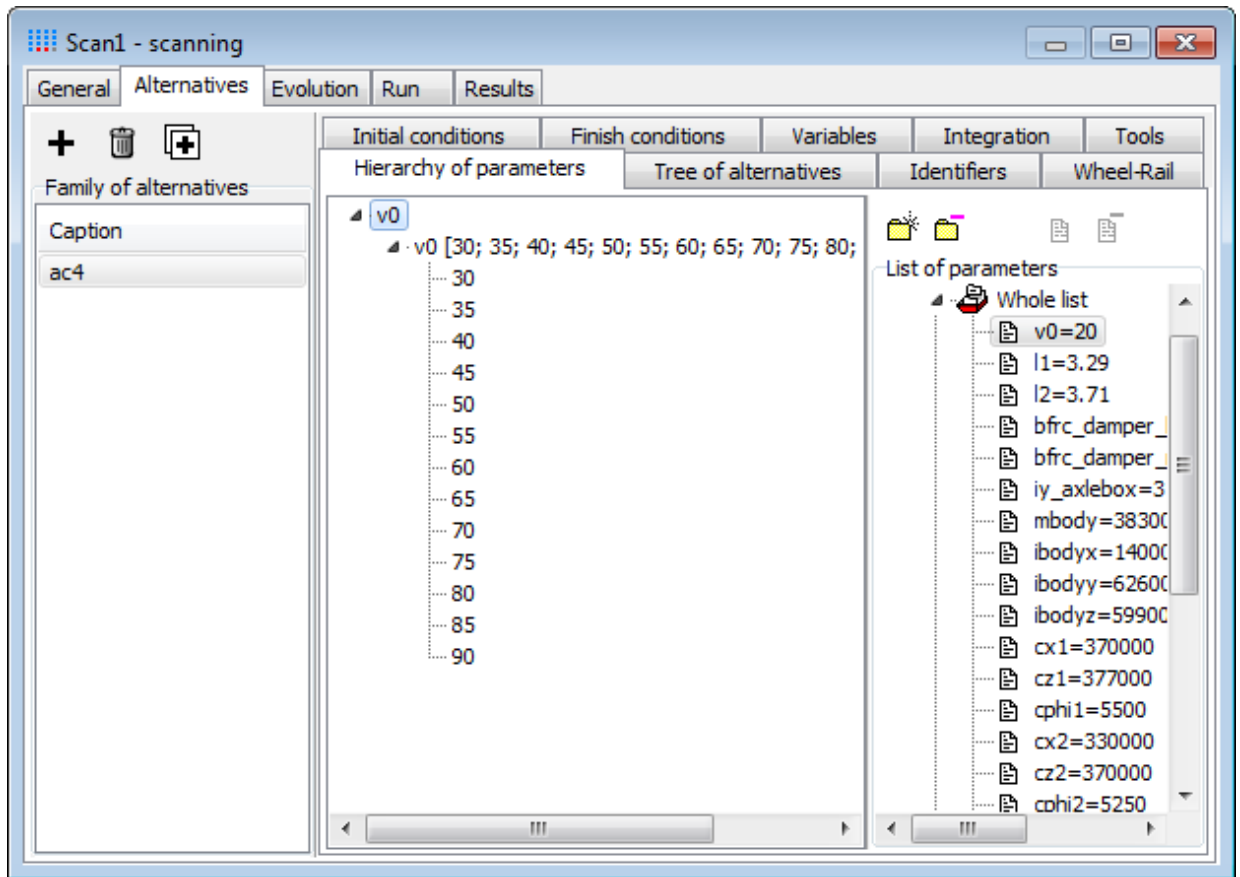


Figure 3.7. Scanning project: hierarchy of parameters

### 3.1.5. Railway configuration

1. Firstly, let's define track irregularities. Select the **Alternatives | Wheel-Rail | Track | Irregularities** tab.
2. Set **Track type** to **Uneven**.
3. Set **Type of irregularities** to **From file**.
4. Open file **NoIrregularities.way** for vertical irregularities and **g10\_20.way** (see Figure 3.8) in lateral direction, see Figure 3.9.
5. Select the **Alternatives | Wheel-Rail | Track | Macrogeometry** tab. In the **Track type** group choose **Tangent**.
6. Load rail profiles from the **r65new.rpf** file, and set **newlocow.wpf** profile for all wheels, see Figure 3.10 and Figure 3.11.
7. Select the **Alternatives | Wheel-Rail | Track | Model and parameters** tab. Set **Track model** to **Massless rail**.
8. Select the **Alternatives | Wheel-Rail | Contact | Contact forces** tab. Set **Model of creep forces** to **FASTSIM**.

Every numerical experiment will be done with such railway configuration.

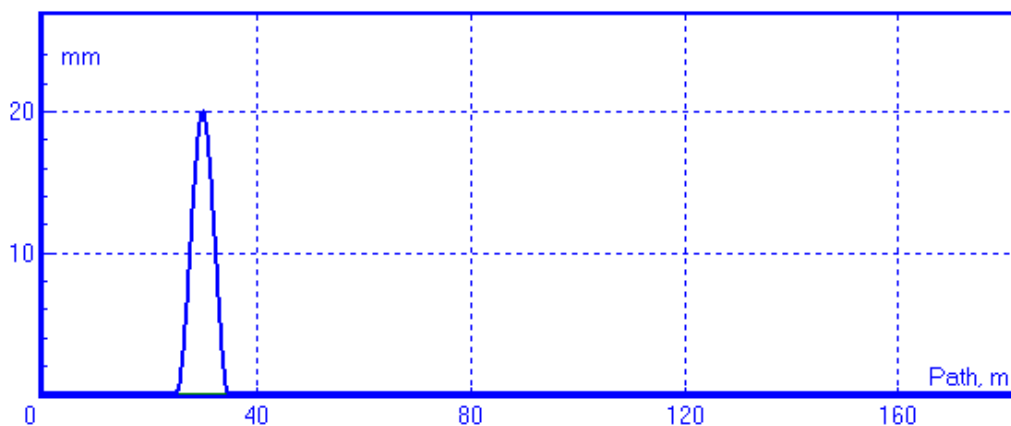


Figure 3.8. Single lateral irregularity. File **g10\_20.way**

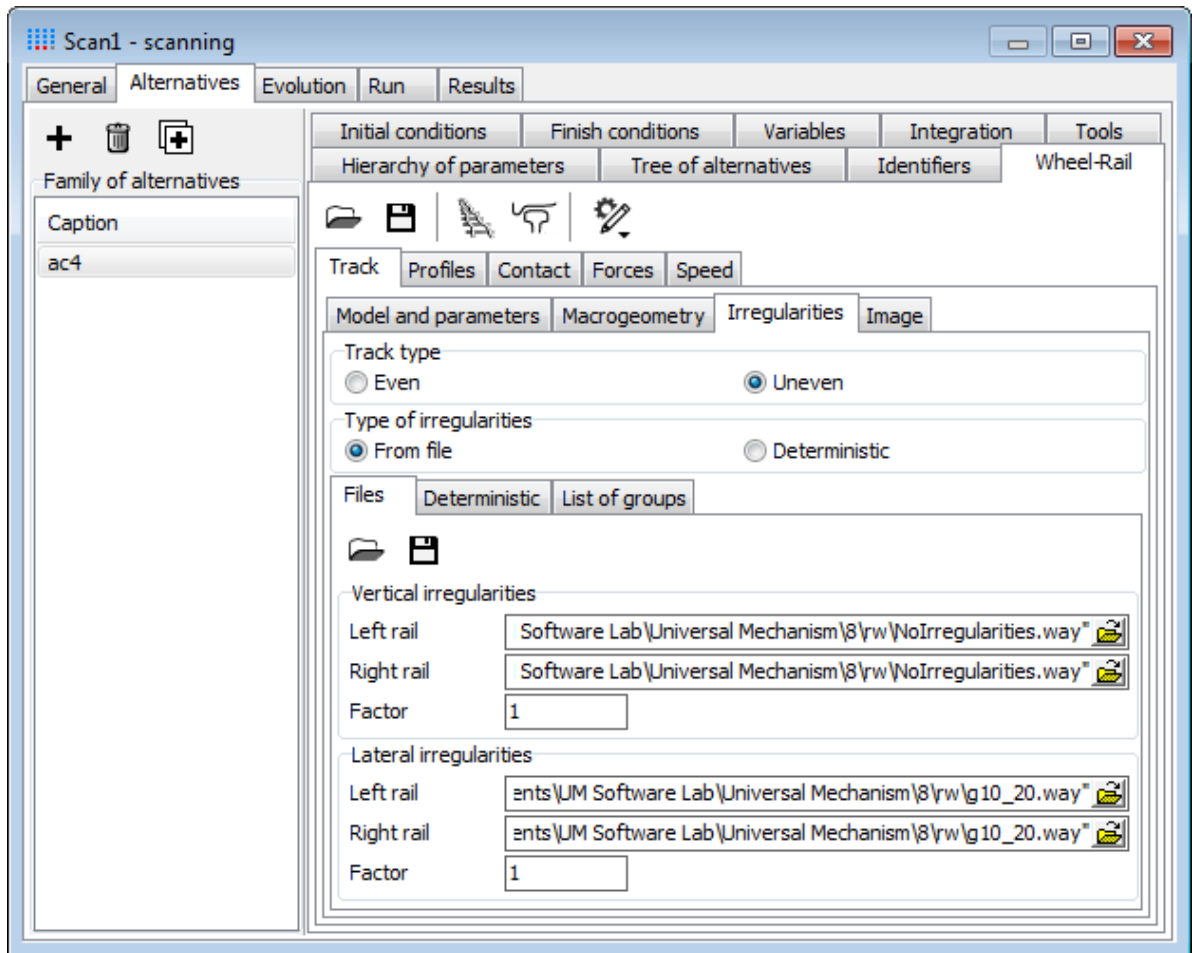


Figure 3.9. Railway track irregularities

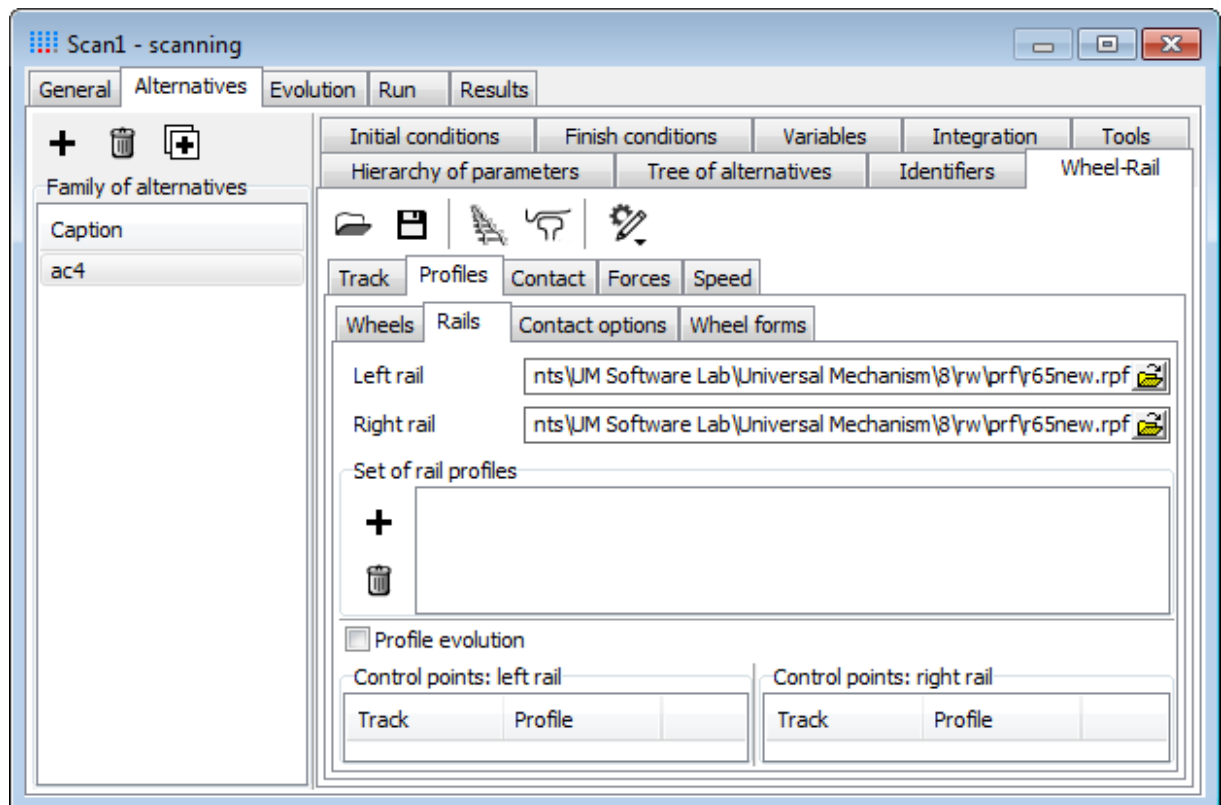


Figure 3.10. Rail profiles

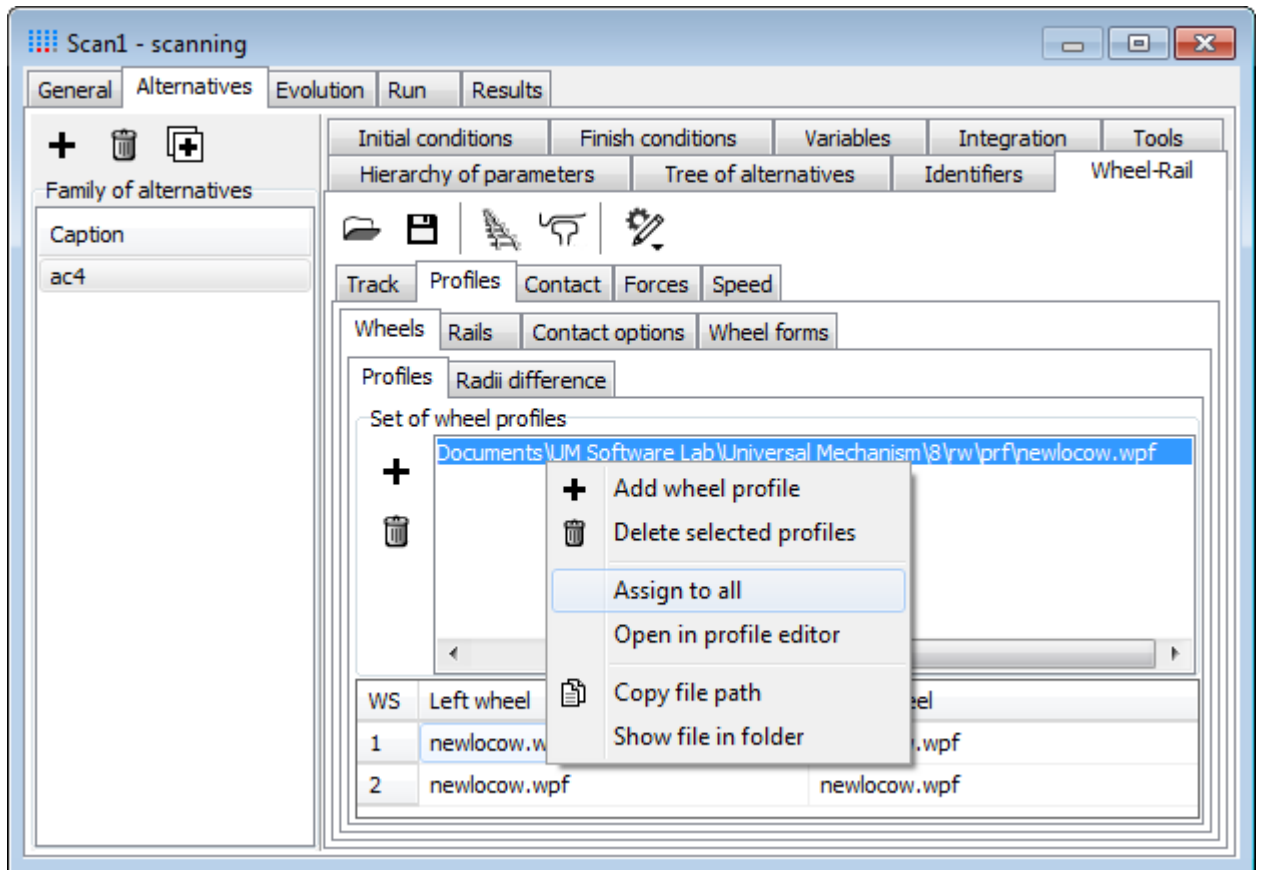


Figure 3.11. Wheel profiles

### 3.1.6. Integration parameters

1. Select the **Alternatives | Integration | Simulation process parameters** tab.
2. In the **Solver** group select **Park method**.
3. Set **Error tolerance** to **1E-6**.
4. Turn on check boxes **Computation of Jacobian** and **Jacobian for wheel/rail forces**.

Finally **Simulation process parameters** should look like in Figure 3.12.

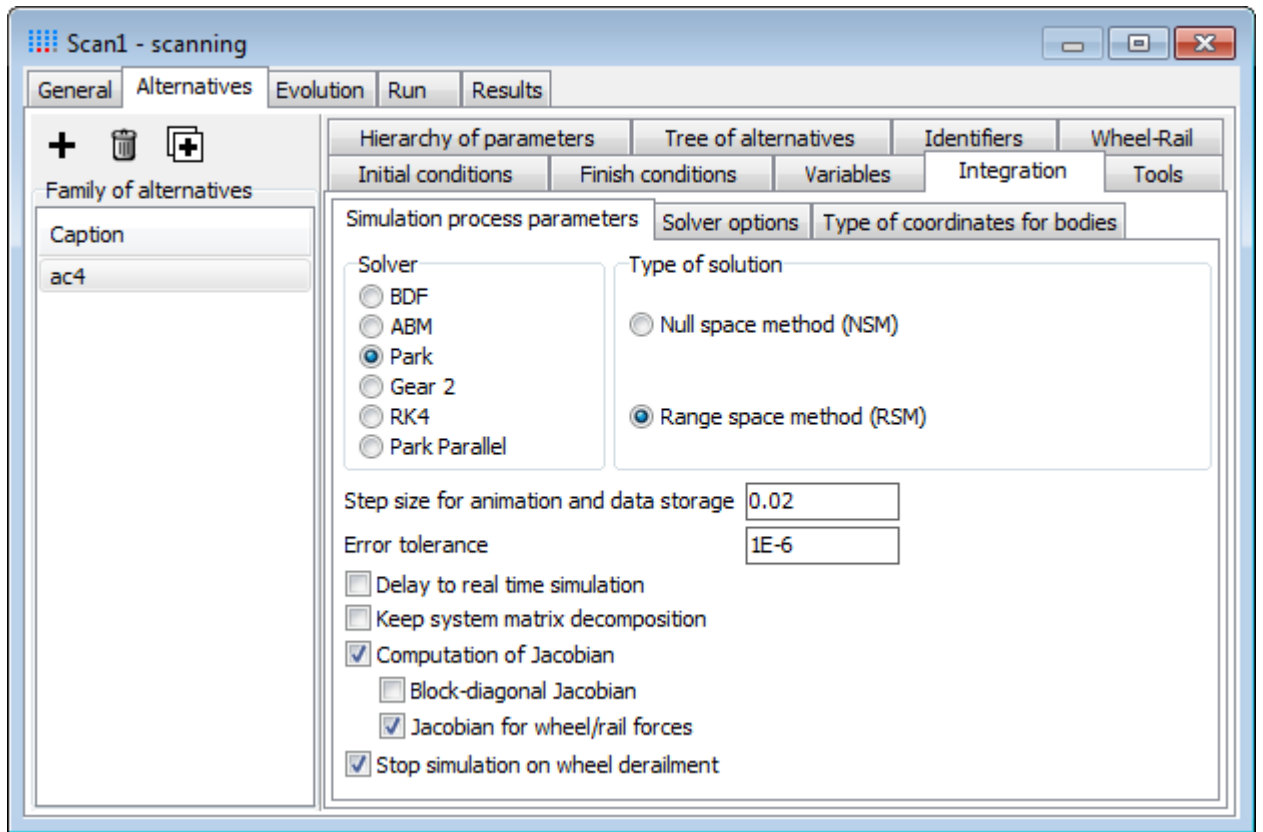


Figure 3.12. Simulation process parameters

### 3.1.7. Finish conditions

Here you can describe finish conditions for each numerical experiment in the current family (see Figure 3.13). Finish conditions are formulated in the following way: “Interrupt a numerical experiment if at least one of the conditions is satisfied”. Using scanning project you can set finish condition as

*Variable [Condition] Numerical value.*

You can use any variable from the **Wizard of variables** as stop criterion. By default, for the railway vehicle the following finish condition is formulated:

*Distance – Vehicle distance from the simulation start  $\geq 600$  m.*

It means every numerical experiment finishes when vehicle goes 600 m.

1. Select the **Alternatives | Finish conditions** tab.
2. Decrease vehicle distance down to **500** m, see Figure 3.13.

**Note.** If you need to use any other variable as finish criterion you should create that variable using **Wizard of variables** and drag it to the field with a variable on the **Finish conditions** tab.

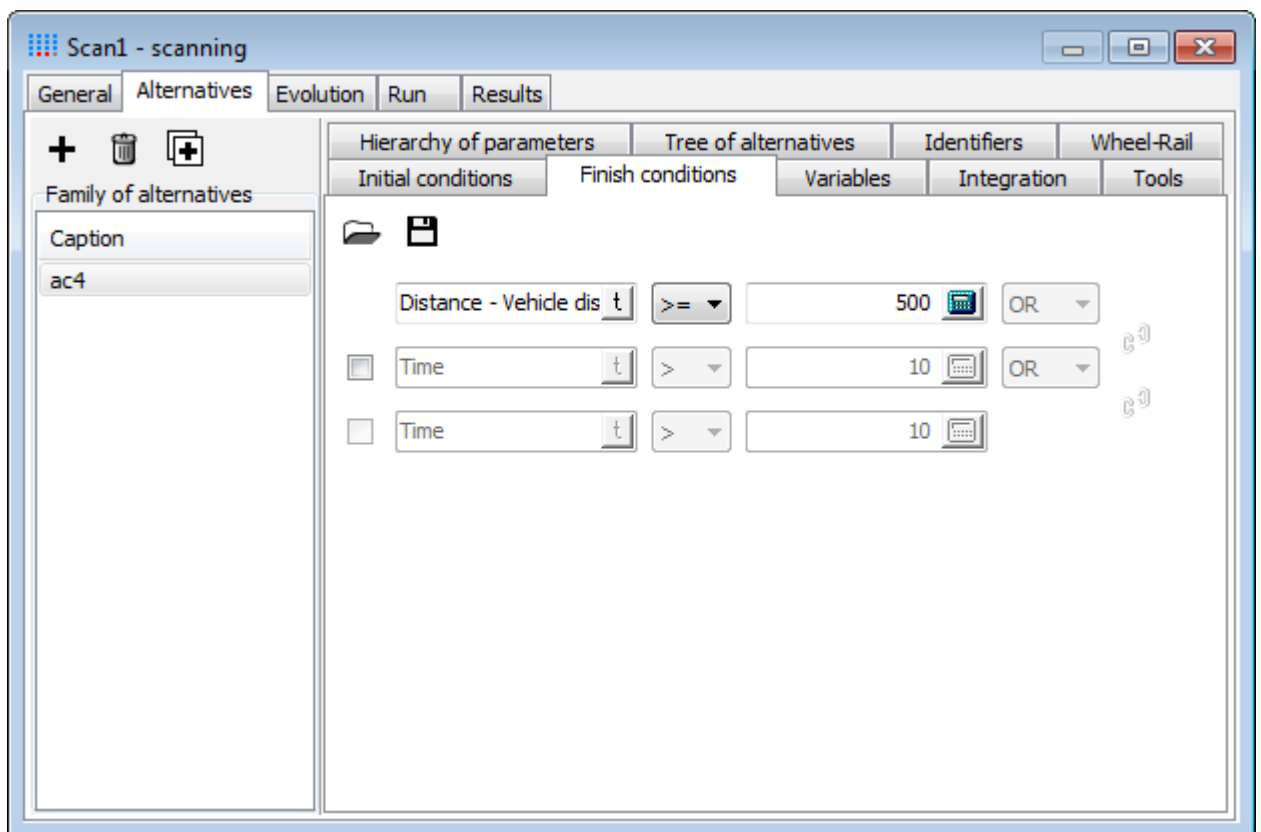




Figure 3.13. Finish conditions

### 3.1.8. Variables to save

1. Select the **Alternatives | Variables** tab.

Here you should form a *list of variables* (see [Chapter 4](#), Sect. *List of variables*), which will be stored for every numerical experiment. Variables from this list will be available as results of the scanning project.

2. Rename the **No name** tab to **Stability**, use  button.
3. Open **Wizard of variables**.
4. Point to the **Liner variables** tab. Select the **WheelSet1.Wset** body in the left part, set **Component** to **Y** (lateral direction). Create (button ) this variable and drag it into the **Stability** tab.
5. Point to the **Wizard of variables | Railway vehicle** tab. Select **Distance** variable from the list of characteristics. Create this variable and drag it into the **Stability** tab.

After all the **Variables** tab has to look like in the Figure 3.14.

6. Close **Wizard of variables**.

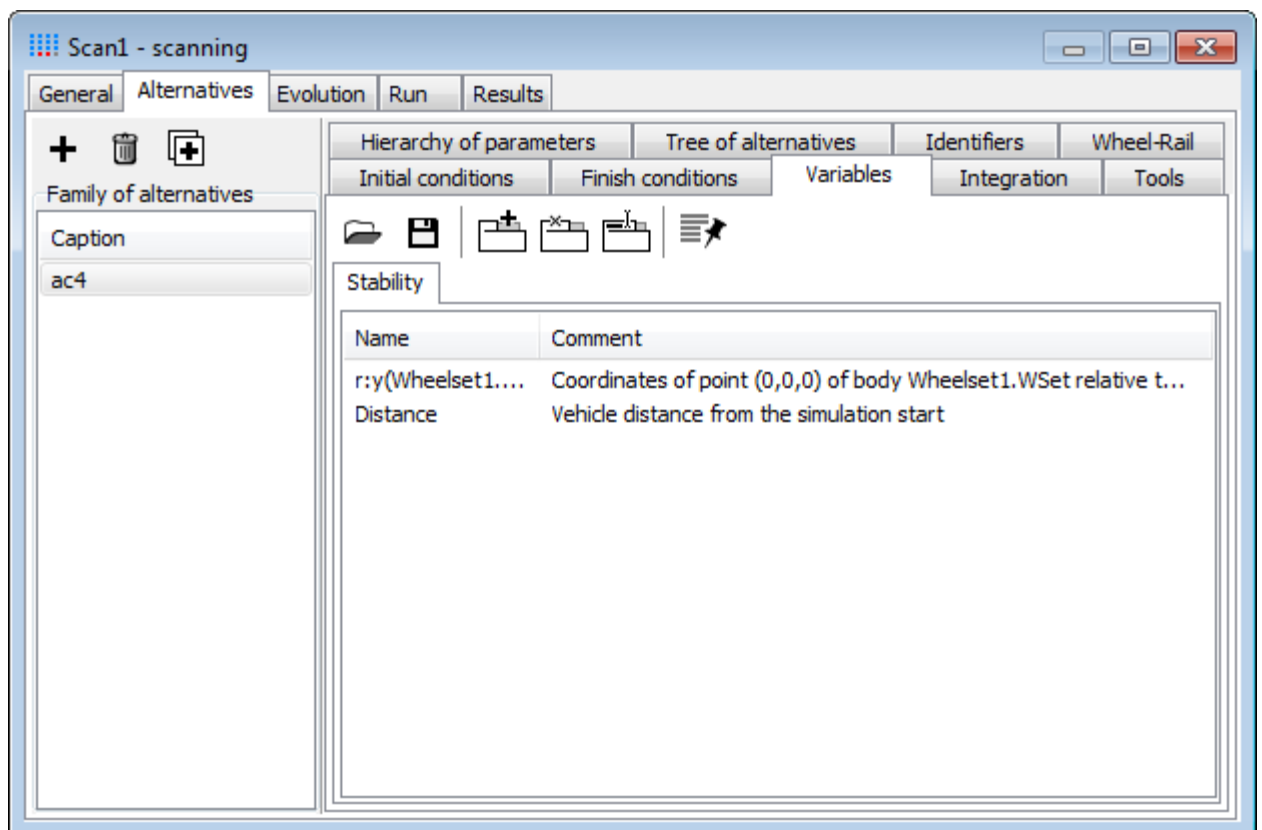


Figure 3.14. Scanning project: auto save variables

Now your scanning project is ready to run.

## 3.2. Running the project

1. Select the **Run** tab.
2. If you did not make any mistake during description the project you can see “**Error not found**” message in the **Event log**.
3. Click the **Run** button.

Fulfillment of the scanning project starts. **Event log** outputs time of the start and finish of every numerical experiment. The railcar model is rather simple one. That’s why every experiment takes you about 2-10 seconds in dependence of the speed of your computer.

4. When project is done the message “**Calculation of the project of scanning is over**”.

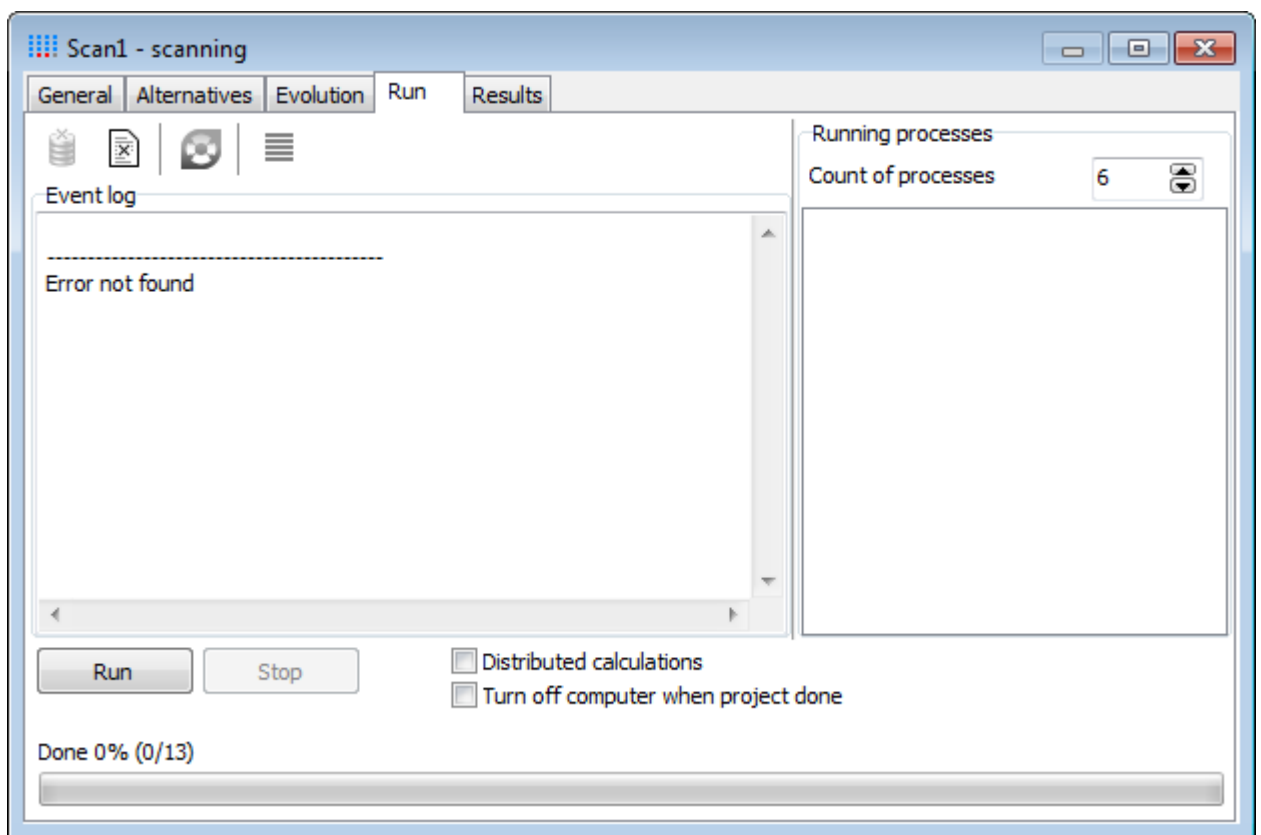


Figure 3.15. Scanning project: running

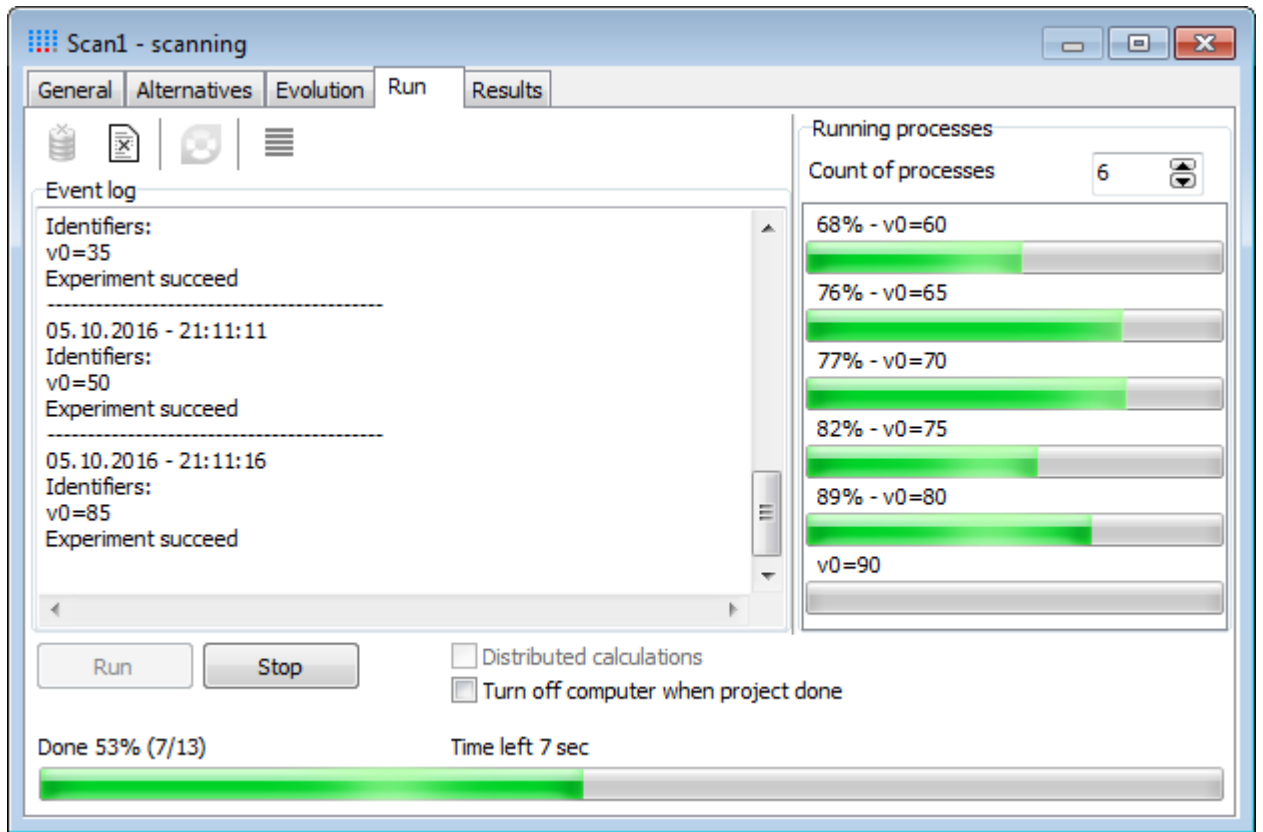


Figure 3.16. Scanning project: running

### 3.3. Analyzing obtained results

#### 3.3.1. Results of separate experiments

Now we come to the analyzing of the railcar dynamics. Our analysis is based on the results of the scanning project we have just finished.

1. Select the **Results | Families | AC4** tab, see Figure 3.17.

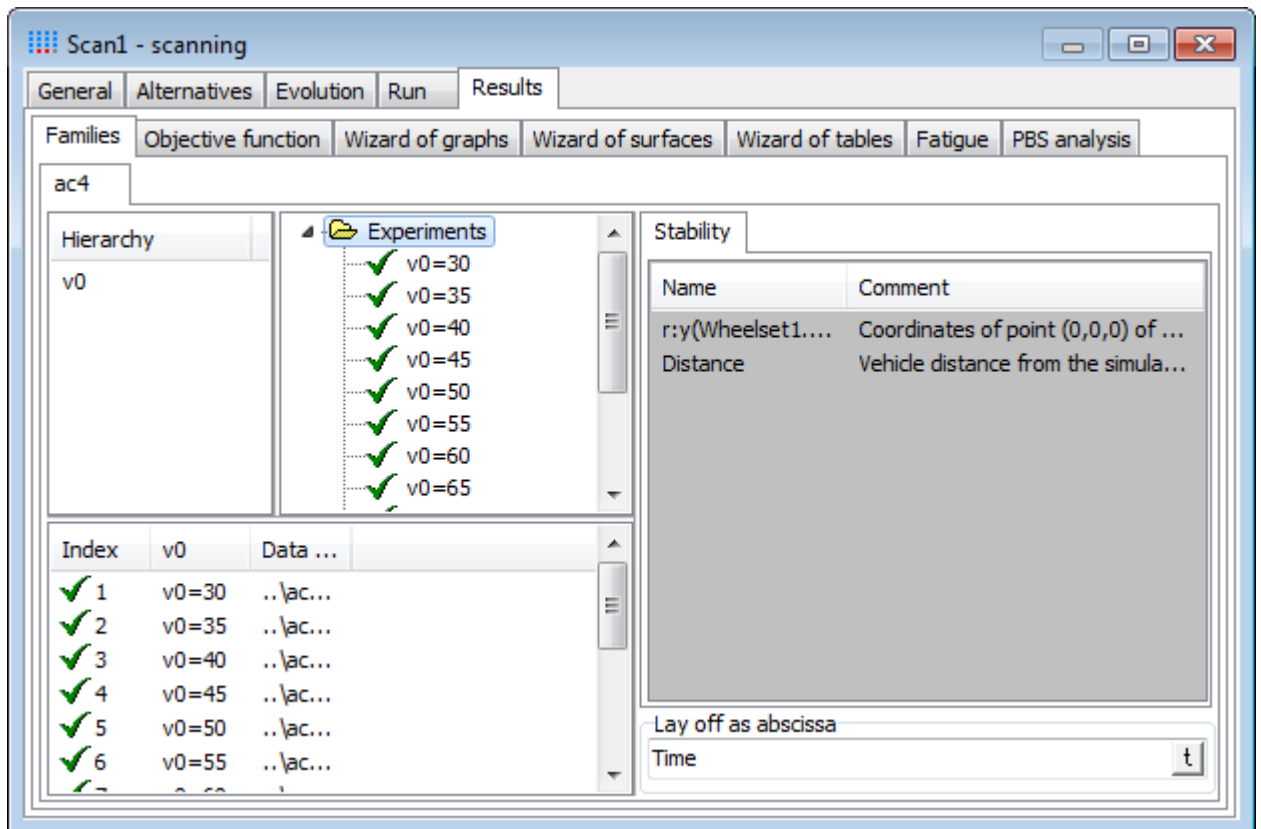


Figure 3.17. Scanning project: results

Let's have a look at the results of several single experiments. We will compare results for lateral oscillation of the first wheelset at 30 and 90 m/s.

It is more convenient to lay **Distance** off as abscissa because the vehicle runs the same way 500 m with different velocities for different time.

2. Select the **Distance** variable in the list of variables and drag it to the **Lay off as abscissa** box, see Figure 3.18.

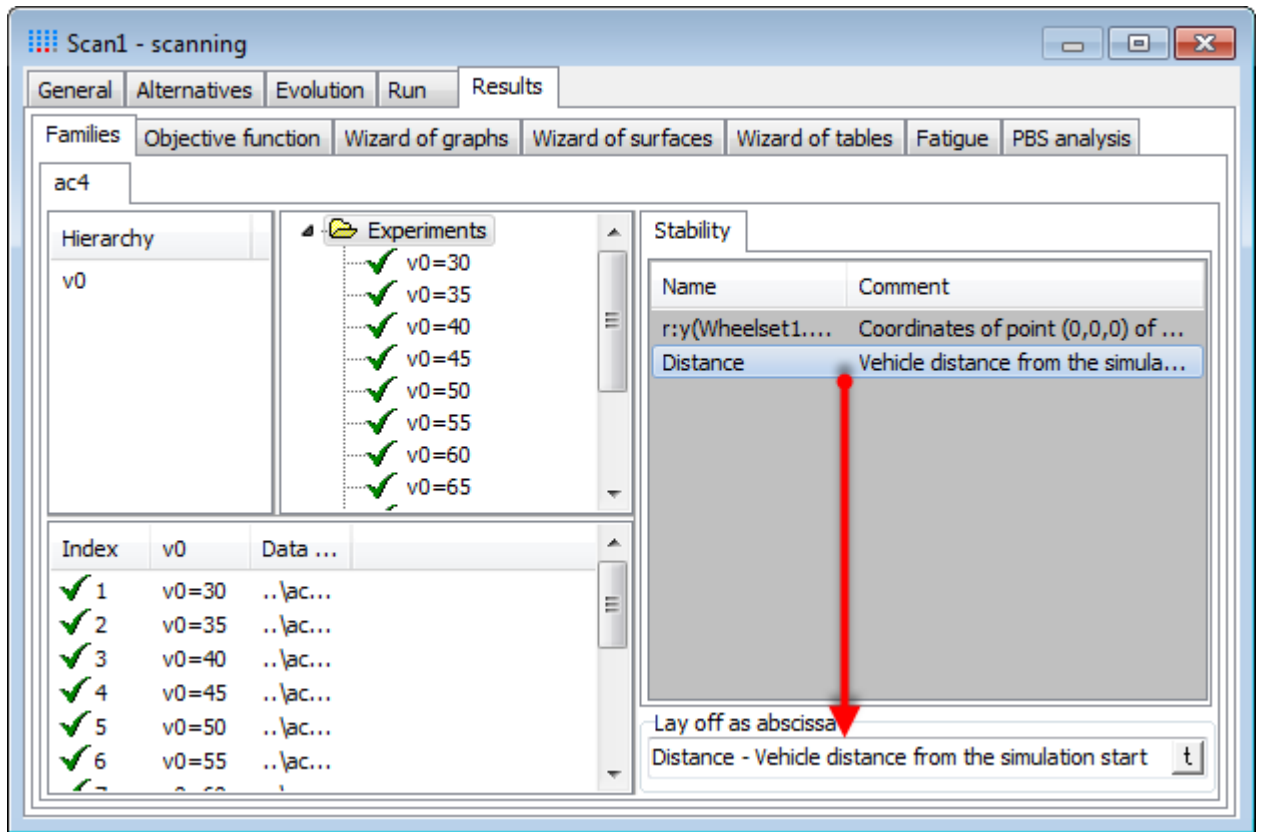


Figure 3.18. Lay **Distance** off as abscissa

3. Open new **Graphical window**.
4. Select scanning project window again, and select the experiment “ $v_0 = 30$ ” on the **ac4** tab.
5. Select the **r:y(Wheelset1.Wset)** variable in the list of variables and drag it to the graphical window.
6. Select another experiment – “ $v_0 = 90$ ” and drag the same **r:y(Wheelset1.Wset)** variable to the graphical window, see Figure 3.19.

It is quite clear, Figure 3.19, those lateral oscillations that rose by singular lateral irregularity diminish in the long run at 30 m/s, but at 90 m/s reach maximum amplitude. In other words the railcar is stable at 30 m/s and instable at 90 m/s.

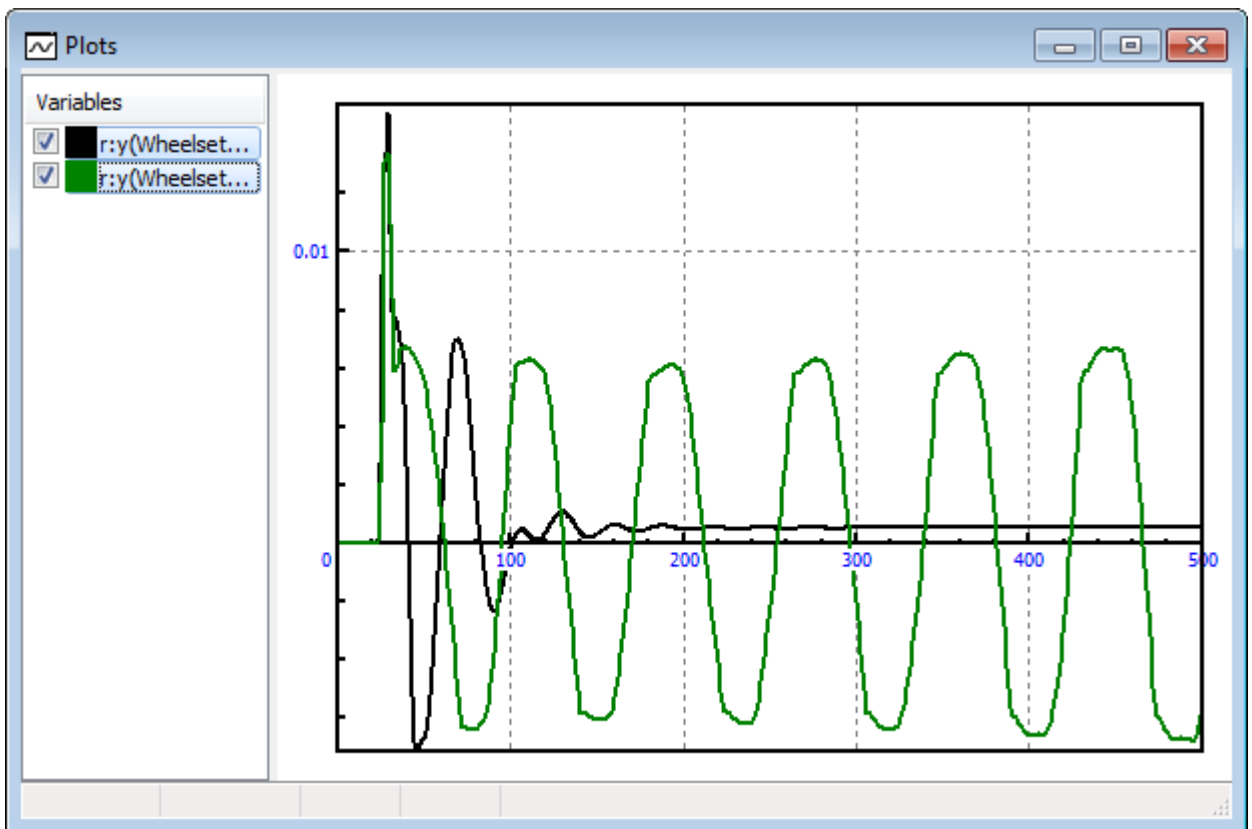



Figure 3.19. Lateral oscillations of the first wheelset in black – 30 m/s, in green – 90 m/s.

### 3.3.2. Summary graphs

There are several tools for overall analysis in scanning project: summary graphs, tables and surfaces. Here let's plot the dependence of the standard deviation of the lateral oscillations of the first wheelset on speed of the vehicle. Such graph is shown in the Figure 3.20.

1. Select the **Results | Wizard of graphs** tab.
2. Select the **r:y(Wheelset1.Wset)** variable in the list of variables
3. Set **Functional** to **Std\_Dev** (Standard deviation).
4. Set **Parameter** to **v0**.
5. Click  in the top of the window to create summary graph.

This summary graph clearly shows us that critical speed of the vehicle is in the 45...50 m/s interval.

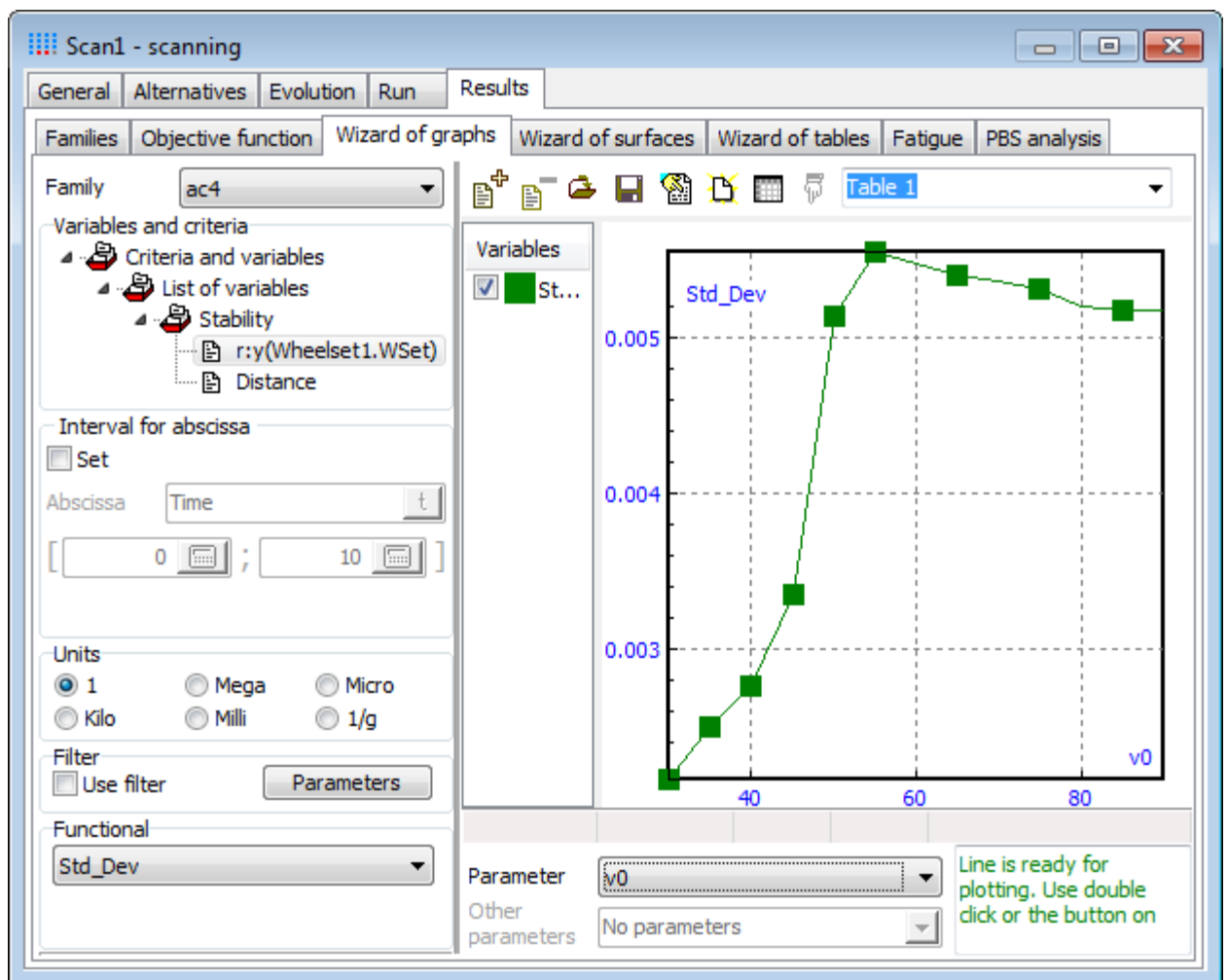


Figure 3.20. Wizard of summary graphs