

UM Train

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Getting Started Using Universal Mechanism: Train Dynamics

This manual leads you through the basic possibilities of **UM Train** module in simulation of longitudinal train dynamics. It assumes that you studied the [gs_UM.pdf](#)¹ chapter, which is devoted to general concepts of simulation using Universal Mechanism, and know how to fulfill simple operations in **UM Simulation** program: work with graphic windows, create new variables, set identifier values, etc, as well as have some experience in train dynamics.

¹ www.universalmechanism.com/download/90/eng/gs_um.pdf

1. Simulation of train braking mode

1.1. What we will learn

This lesson is devoted to the general overview of the **UM Train** possibilities and workflow. The creation of a new train model and simulation of its dynamics in braking mode will be shown, the following questions will be considered:

- description of the macro geometry of the track;
- measurement of the resistance force of rail vehicle;
- designation of braking parameters;
- demonstration of simulation results.

Here you will create the train model which consists of Russian two-section electric locomotive VL80s and 58 freight open wagons.

1.2. Creating new train object

At first open **UM Input** program. In **UM Input**, select the **Tools | Train wizard...** menu command to open the **Train wizard**, Figure 1.1.

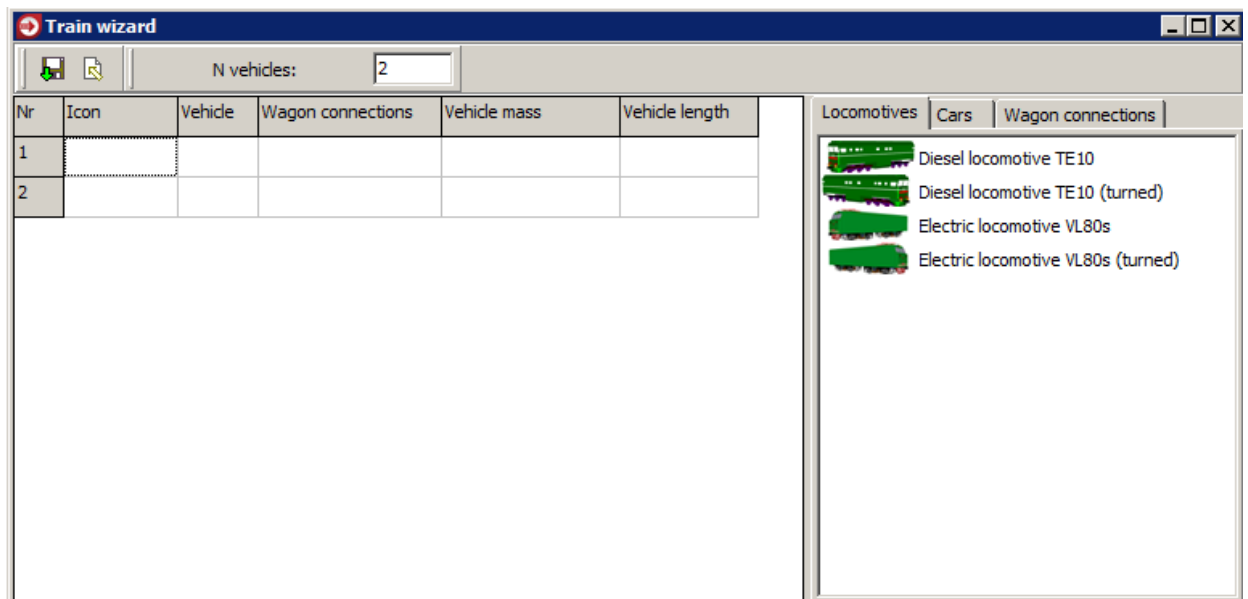


Figure 1.1. Train wizard

When creating a train model, the user points the number of vehicles in the model with the help of this wizard. Necessary models of locomotives, cars and wagon connections for the designed train model are selected from the respective tabs of the database on the right side of the **Train wizard**.

To set the number of vehicles in the train set **N vehicles** to **60**, see Figure 1.2. It leads to increasing the number of rows of vehicles to 60.

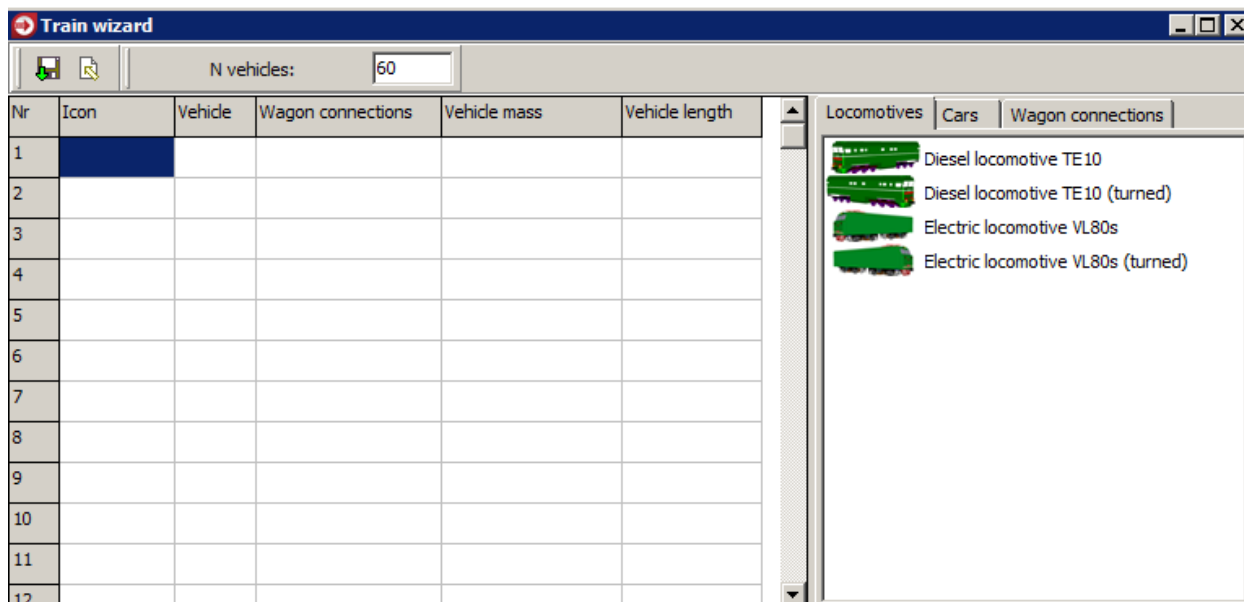


Figure 1.2. **Train wizard** with unassigned (empty) 60 vehicles

The next step is to assign vehicles to the train model. At first we set the two-section electric locomotive VL80s. To do it double click **Electric locomotive VL80s** element in the right part of the **Train wizard**, see Figure 1.3, it assigns the first section of the locomotive to the first vehicle of the train model. After double click **Electric locomotive VL80s (turned)** to assign the second (turned around) section to the second vehicle. Wagon connection types have not yet been determined. Vehicle mass and length have been defined automatically but user can change these values.

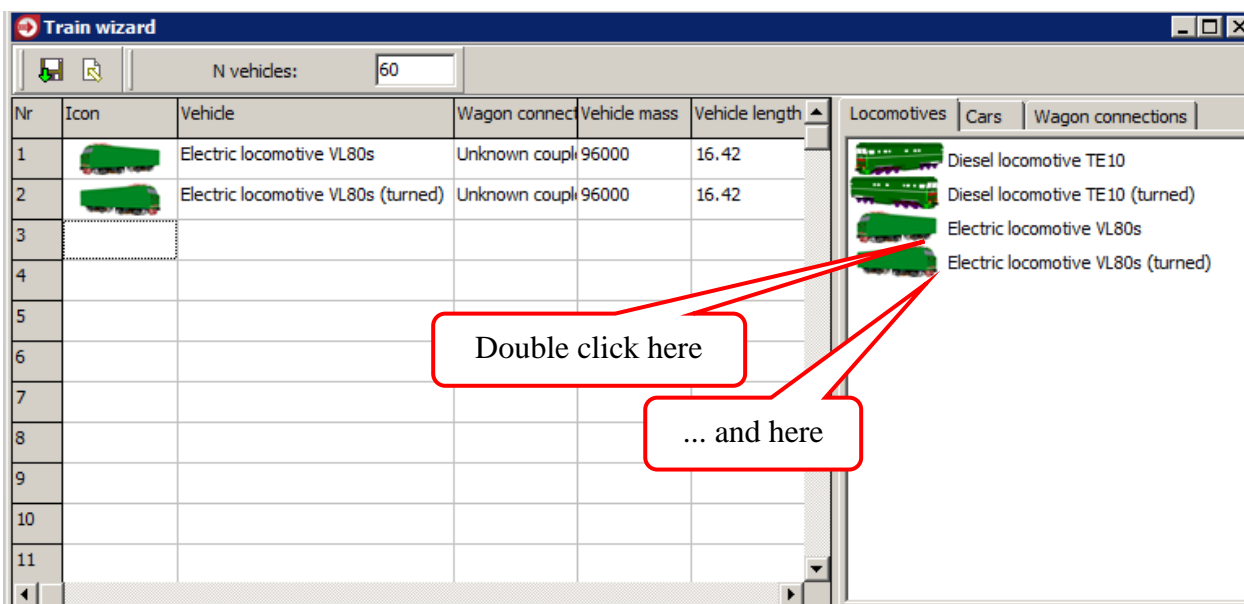


Figure 1.3. **Train wizard** with two section locomotive

To set freight open wagons to the rest of vehicles, select the **Cars** tab, click right mouse button on the **Open wagon** element to open the popup menu and choose the **Assign to selected...**

item from the menu, Figure 1.4. In the opened **Choice the element from list** form, only “empty” vehicles are checked by default. Click **OK** to assign open wagon to these vehicles.

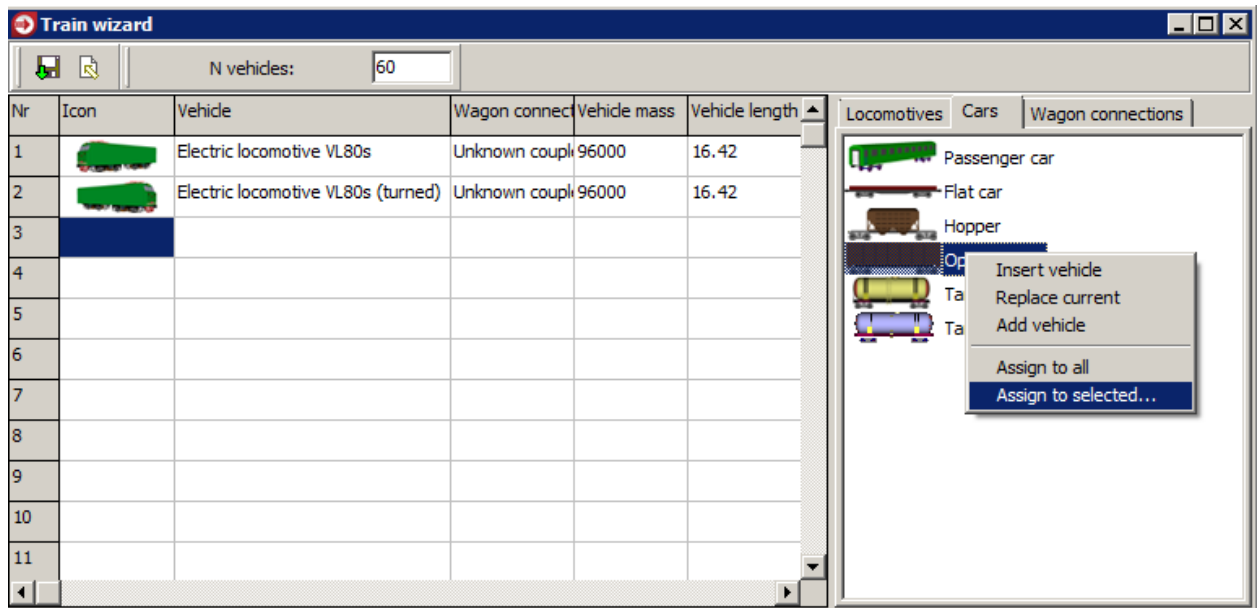


Figure 1.4. **Train wizard** – assigning open wagons

Now the **Train wizard** looks like in Figure 1.5.

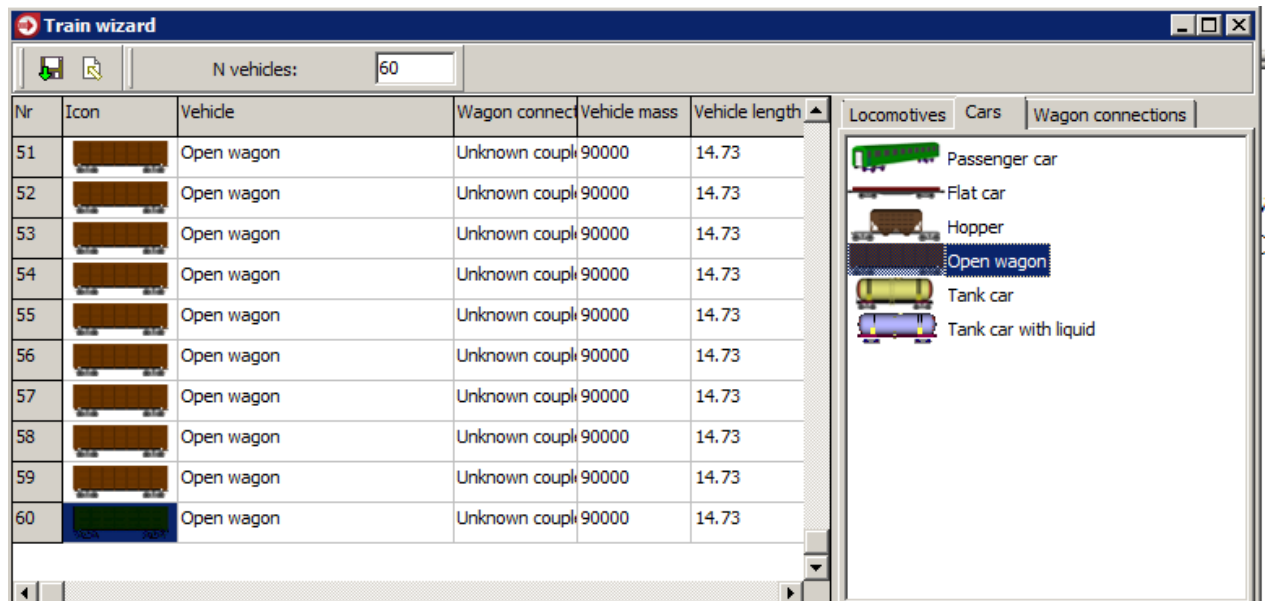


Figure 1.5. **Train wizard** with all assigned vehicles

The last step of model creating is assigning wagon connections to the vehicles. We will assign to all vehicles the wagon connections with Russian draft gear Sh-2-T. For this select the **Wagon connections** tab, select **Sh-2-T** and click the **Assign to all** context menu command, Figure 1.6.

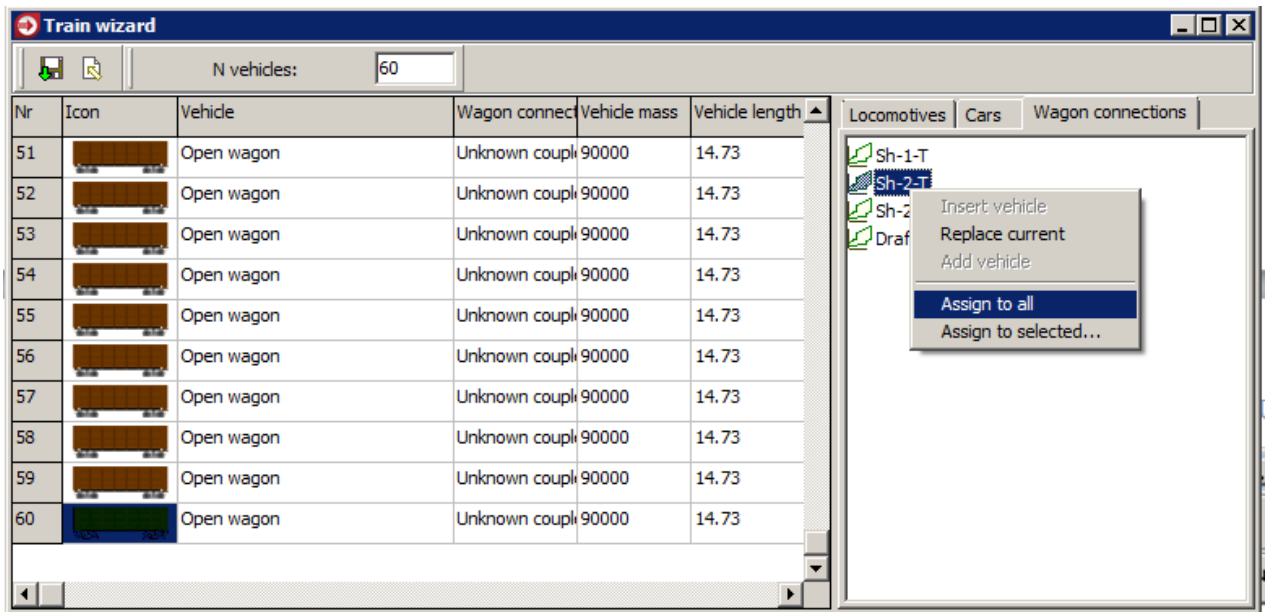



Figure 1.6. **Train wizard**: assigning the couplings

Now the train model is ready, see Figure 1.7. Save it by using  button. In the **Save as** dialog window input the path with object name, for example: **{UM Data}\My models\Trains\TestTrain**.

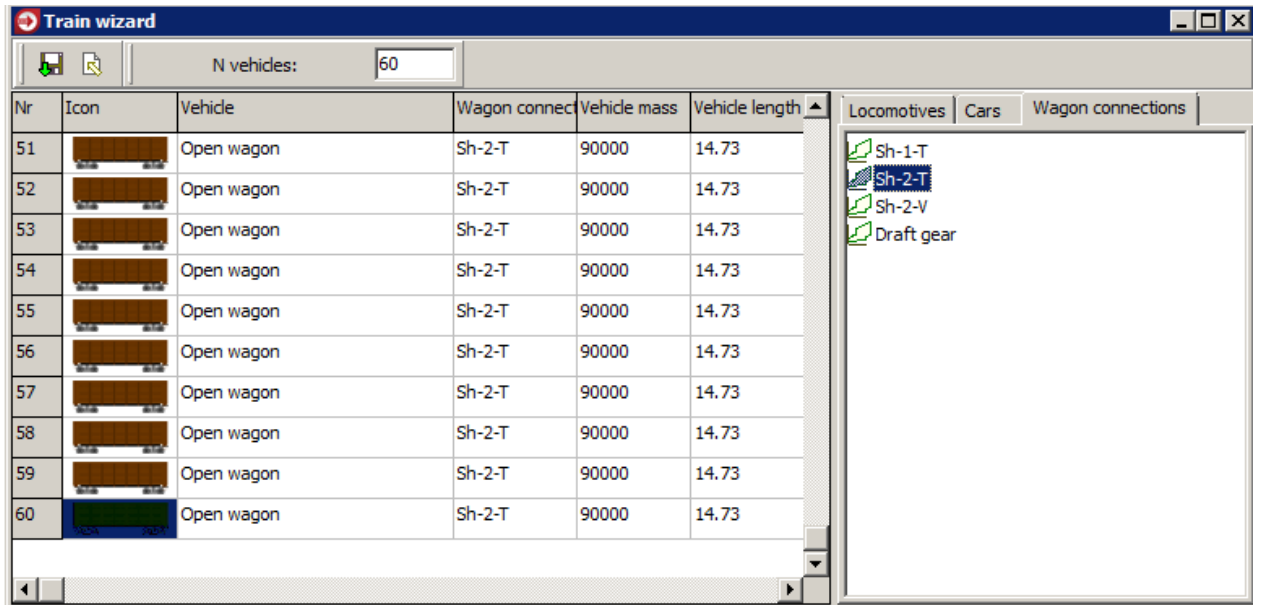


Figure 1.7. **Train wizard**: ready train model

1.3. Simulation of train dynamics

In this paragraph, it will be shown the process of the simulation of dynamics of the created train model during service braking in $R = 600$ m curve with downhill -7% , initial velocity is 30 m/s.

1.3.1. Setting train model parameters

At first run **UM Simulation** program and open the created train model.

Setting solver parameters

Now let us set the solver parameters to optimize the speed of train dynamics simulation. Using the menu item **Analysis | Simulation... (F9)** and open **Object simulation inspector** and on the **Solver** tab choose **Park** method. Also turn on the **Computation of Jacobian** switch and set the **Simulation time** () to 55 seconds, Figure 1.8.

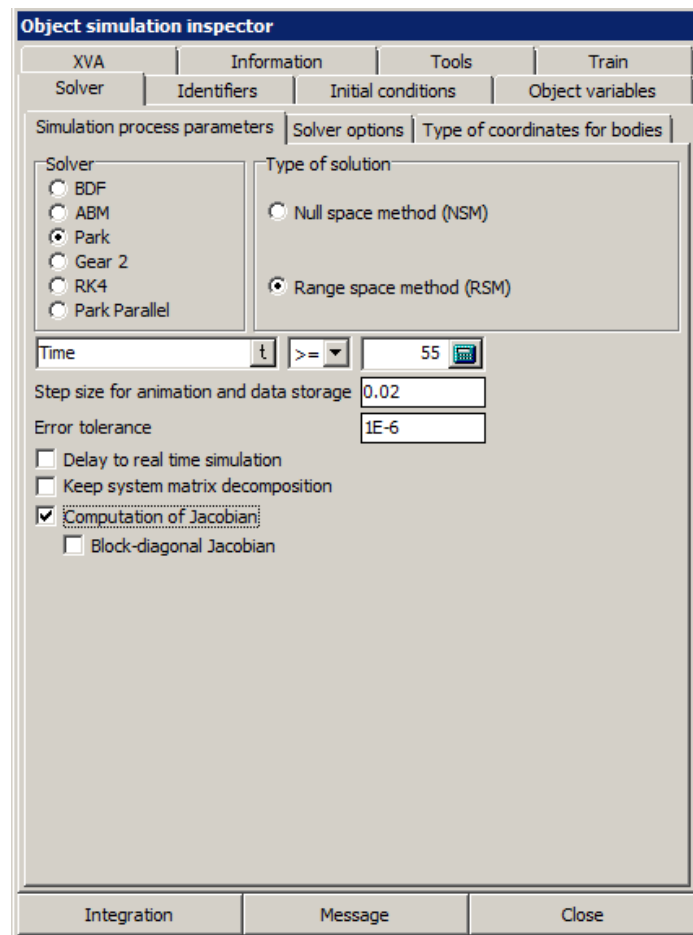



Figure 1.8. Object simulation inspector

Creating track macrogeometry

By default the train model runs on tangent track without grades. We will simulate the train dynamics in $R = 600$ m curve, downhill -7% .

To open the tool for creation of new track macrogeometry file, select the **Tools | Macrogeometry Editor | Railway or monorail track** menu item or click  button on the tool panel. It opens the **Macrogeometry** window, Figure 1.9.

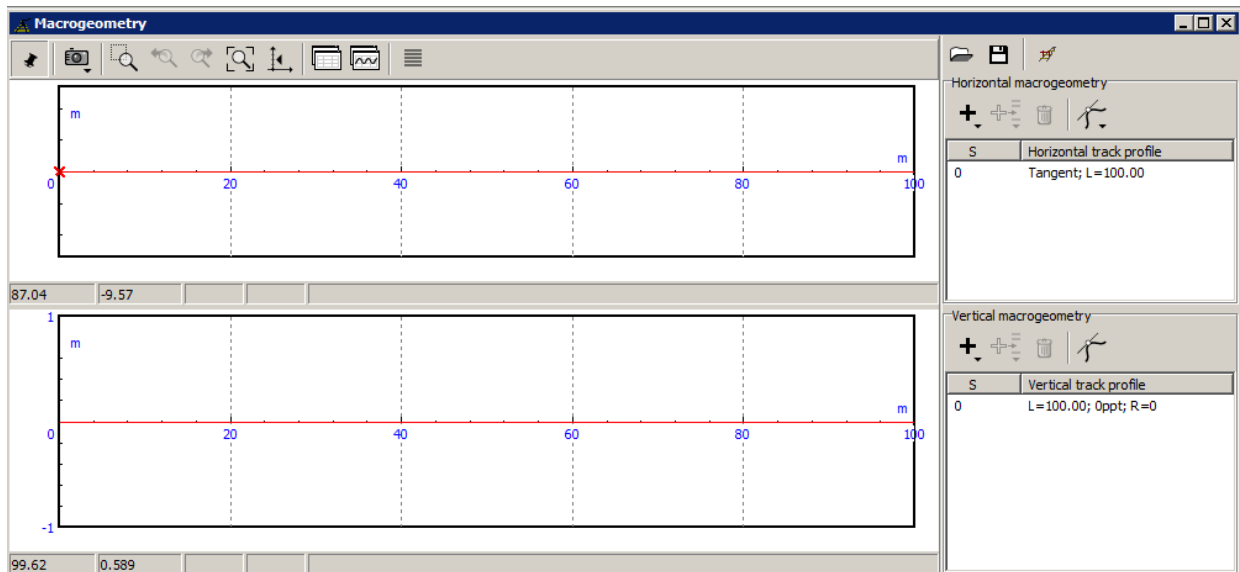



Figure 1.9. **Macrogeometry** tool

The upper part of the window is used for the description of the track geometry in the horizontal plane. We will leave the default tangent section and set its length to 100 m, Figure 1.9; the curve will be the second section of the track. To add a curve to the track click on the  button on **Horizontal macrogeometry** panel and select the **Add curve** item from the menu. By default the radius of an added curve is 300 m. So we should change the radius to 600 m. To edit the section parameters, double click on the corresponding line of the section list or select the line and press *Enter*. In this case it is necessary to choose the second line which contains parameters of the curve. Input **600** in the **R** edit box of the **Curve parameters** window, Figure 1.10 and click **Apply** button.

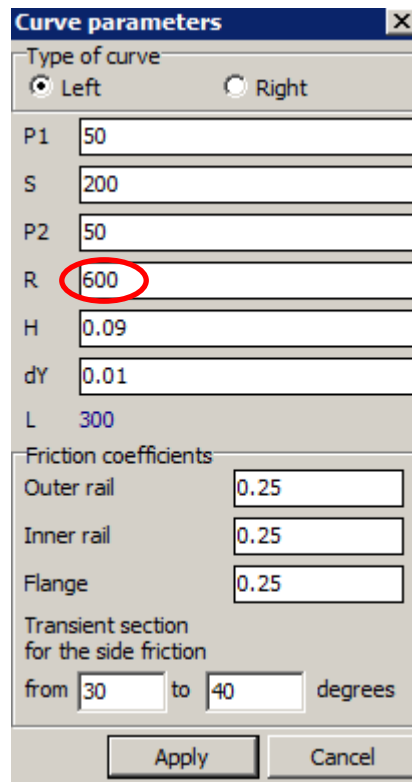


Figure 1.10. Curve parameters

The lower part of the **Macrogeometry** window contains the vertical profile of the track (**Vertical macrogeometry**), Figure 1.9. Since the whole track is a downhill, it is not necessary to add one more section to the vertical profile list. You can simply change the grade (slope) value of the first one. By using mouse double click or *Enter* button open the **Gradient** window, Figure 1.11, input **600** in the **Length, m** edit box and **-7** in the **Gradient, ppt** edit box, and then click **Apply**.

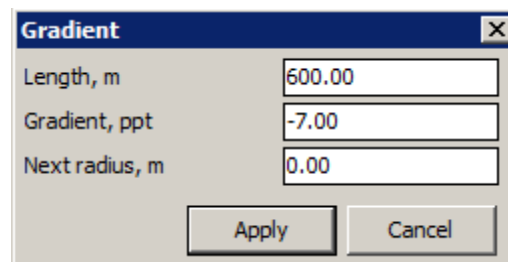


Figure 1.11. Slope parameters

Now the track macrogeometry looks like in Figure 1.12.

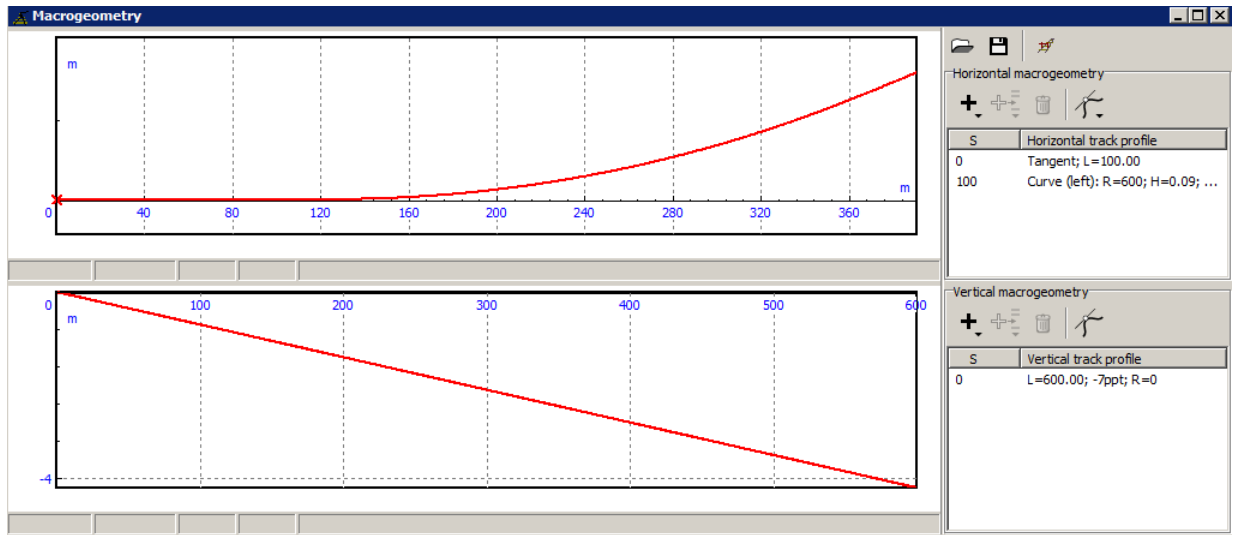



Figure 1.12. Macrogeometry

Save the created macrogeometry in file by using  button, for example with name {UM Data}\My models\Trains\TestTrain\r600.mcg, and close the **Macrogeometry** window.

On the **Train | Options | Track** tab of **Object simulation inspector**, load the created file, Figure 1.13.

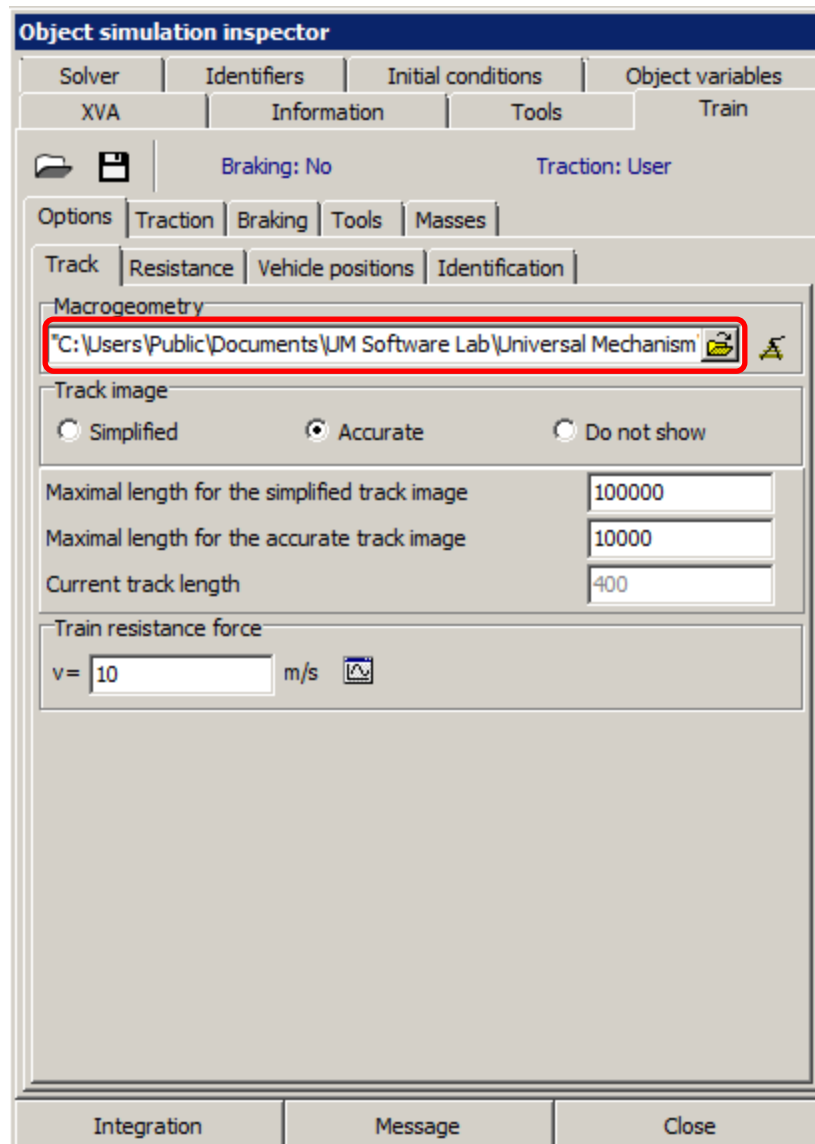




Figure 1.13. Track tab

Setting models of resistance forces

All train settings are situated on the **Train** tab of the **Object simulation inspector**. To set resistance force models to vehicles, select the **Train | Options | Resistance | Propulsion** tab, Figure 1.14. Two lists are placed on this tab. The upper list (the list of loaded resistance force models) contains resistance force models loaded for the current train model. To add or delete resistance force models, use buttons  or  respectively. The lower list (the list of assigned models) contains the list of vehicles and resistance force models assigned to them from the upper list.

To assign a resistance force model from the list of loaded models (from the upper list) use mouse button double-clicking on the cell of the **Resistance model** column (the lower list) for the respective vehicle. Every double-click selects models from the list of loaded resistance force models. The **Assign to all** item of the popup menu of the list of loaded resistance force models assigns the current model to all vehicles.

There are four standard models of train driving resistance forces for traveling on long-welded rails which always present in the list of loaded resistance force models and cannot be deleted from the list. Set the **Locomotive** model to VL80s and the **Loaded freight car, long-welded rails** model to all cars, Figure 1.14.

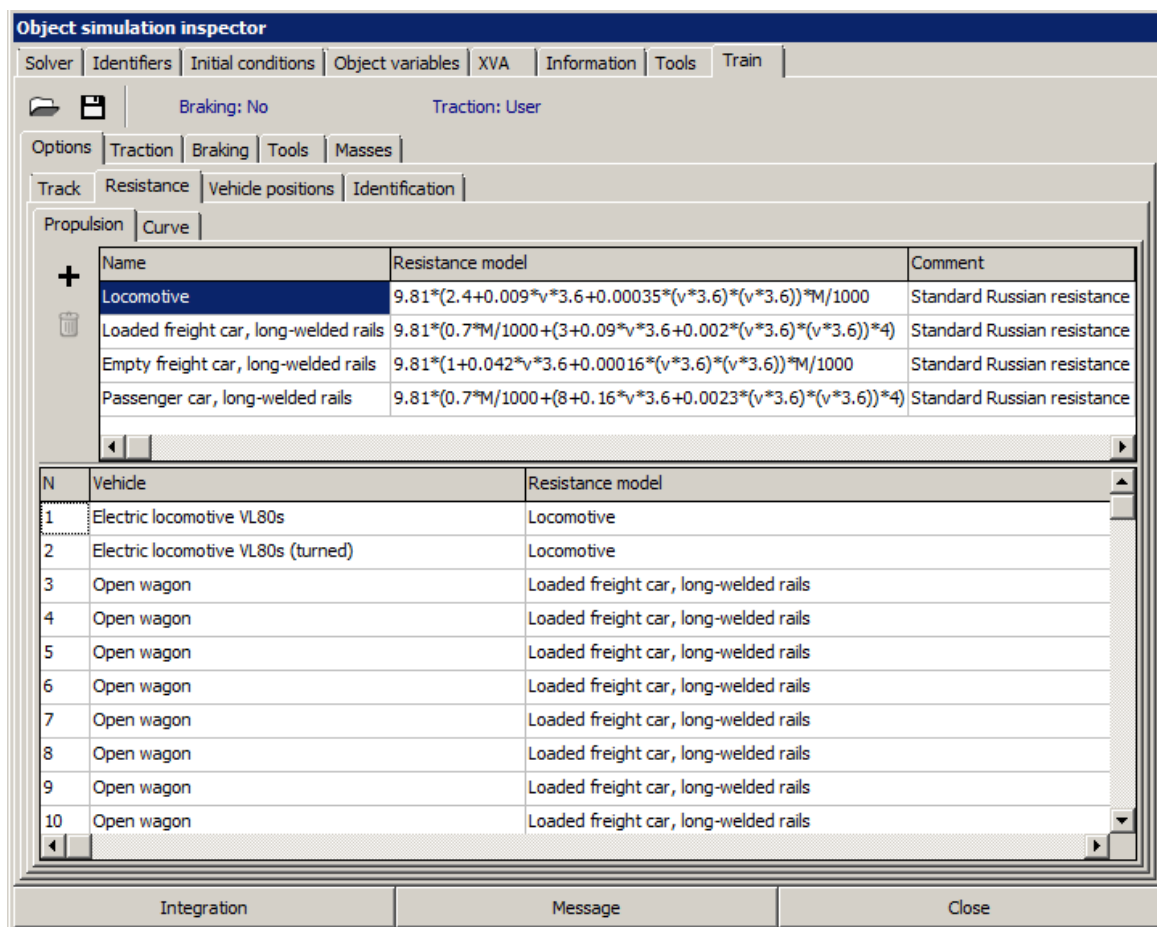


Figure 1.14. Resistance | Propulsion tab

Leave curve resistance force models on the **Train | Options | Resistance | Curve** tab without changes.

Setting braking system

Let us set the parameters of braking system. Train brake system is formed in the **Object simulation inspector** on the **Train | Braking | Brake equipment** tab.

When creating the train brake system, it is necessary to set the following parameters: friction coefficient between wheel and friction pad, type of braking modes (service, emergency, release mode), brake rigging models, speed of braking wave.

The brake force is defined as

$$F_B = f \cdot F_N,$$

where f is the friction coefficient at the contact between wheel and brake pad, F_N is the normal (loading) force at the contact between wheel and brake pad.

Loading force and friction coefficient are calculated separately for every vehicle taking into account the number of friction pairs “wheel – pad”. For that, models of friction coefficients and loading forces are created and assigned to train vehicles.

At first set the speed of service braking wave which is equal to 280 m/s. For this purpose, on the **Train | Braking | Brake equipment** tab in **Speed of braking wave, m/s** edit box input **280**, Figure 1.15.

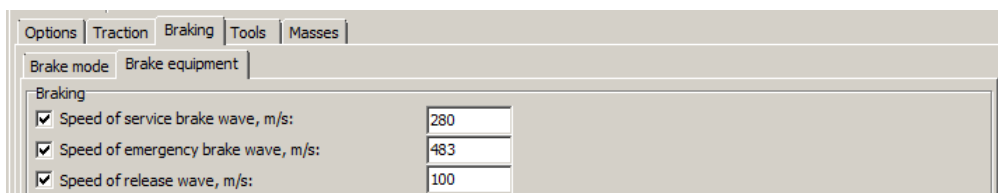



Figure 1.15. Setting braking wave speed

Now we should set models of loading forces to vehicles.

On the **Train | Braking | Brake equipment | Rigging** tab choose the brake rigging type. For that use  button and choose files *VL80, grey iron.pf* for locomotives and *Freight car, grey iron.pf* for wagons brake riggings. After that set this brake rigging models to all vehicles by using the **Assign to all** popup menu item for the **Freight car, iron shoes** element of the list (Figure 1.16).

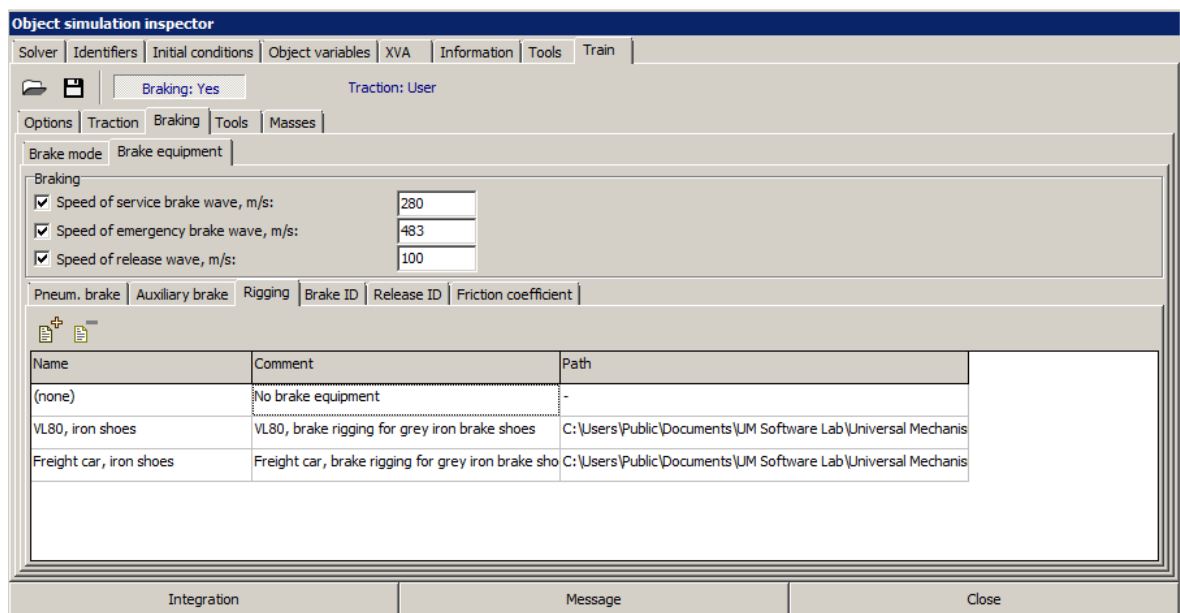


Figure 1.16. The brake rigging models

As a result on **Train | Braking | Brake equipment | Pneum. brake** on field **Rigging system** of each vehicles we can see **Freight car, iron shoes**. Set **VL80, iron shoes** for two locomotives by two double clicks of the left mouse button (Figure 1.17).

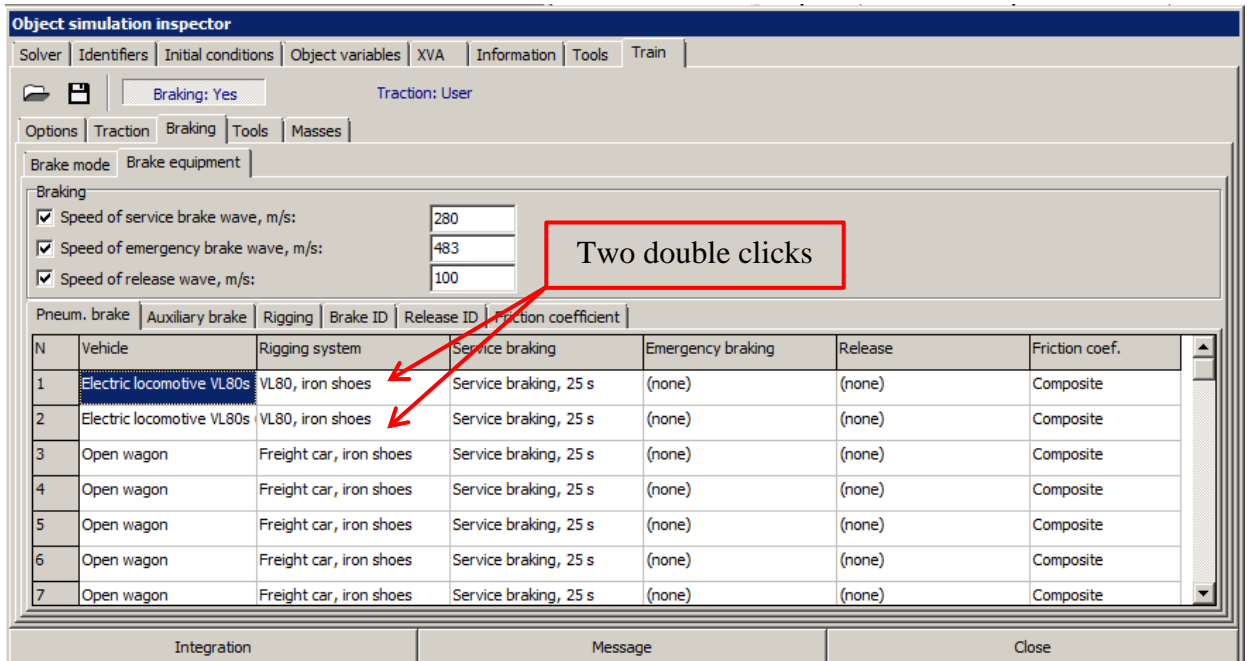


Figure 1.17. Setting rigging system models for locomotives

Set the service braking models. For that select **Braking | Brake equipment | Brake ID** and loading force model by using and choosing *service_braking_25s_example.id*. Click using the right mouse button on the *Service braking* field and change **Assign as service braking to all**, Figure 1.18.

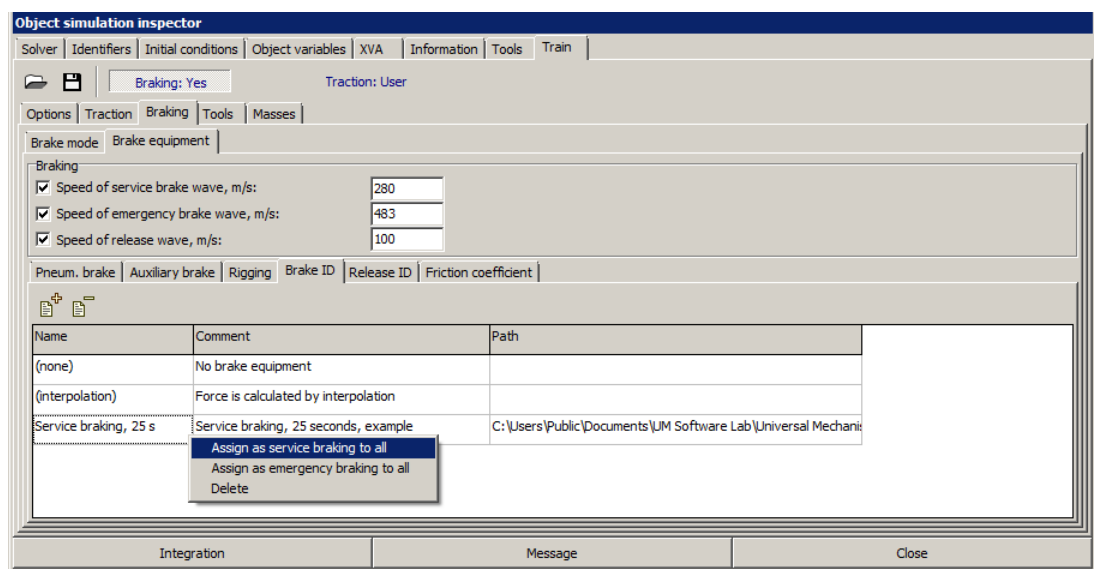



Figure 1.18. Brake ID tab

Set friction coefficient models to vehicles. On the **Train | Braking | Brake equipment | Friction coefficient** tab, add files *composite.cf* which contain friction coefficient models for

brake pads by using  button (Figure 1.19). Set **Composite** models to all freight cars and two sections of VL80s by using double click of right mouse button on the **Composite** ->**Assign to all**.

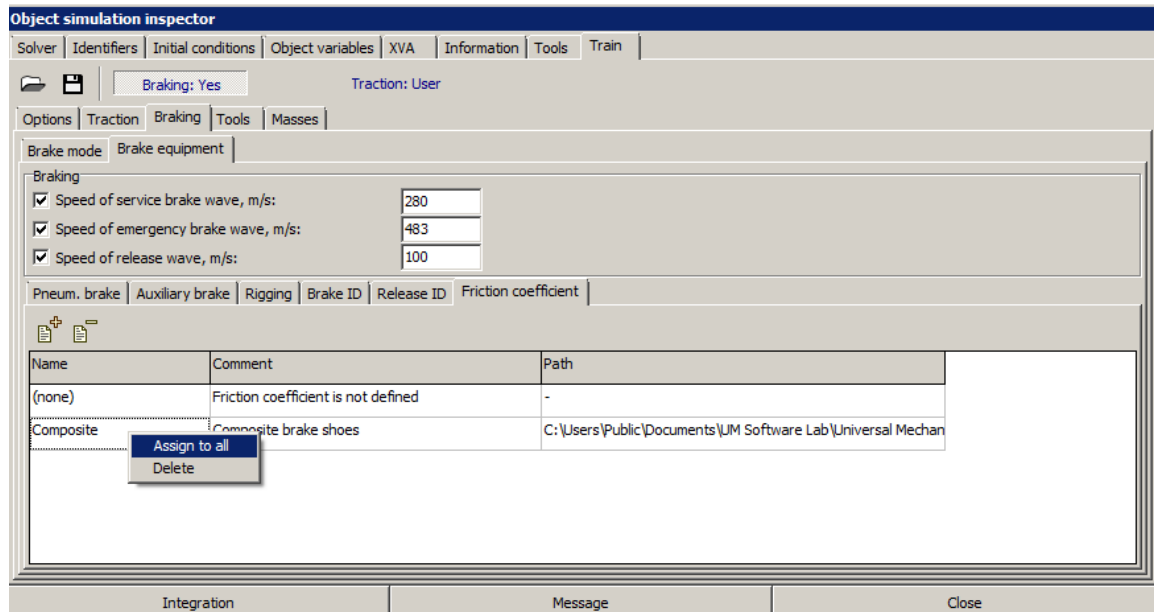



Figure 1.19. Friction coefficient tab

On the **Train | Braking | Braking mode** tab, select the **Braking** switch. Add a braking mode tab by using  button. This tab (Figure 1.20) contains the following data: **Time** – 0 s, **Types of brake** – Brake pipe, **Mode** – Service braking, **Vehicle** – 1. Electric locomotive VL80s. It means that at 0 second of simulation time the braking by using brake pipe from the first section of VL80s starts.

Comment: after adding braking mode the option Braking will be activated (Braking: Yes). Otherwise braking mode is not enabled (Braking: No).

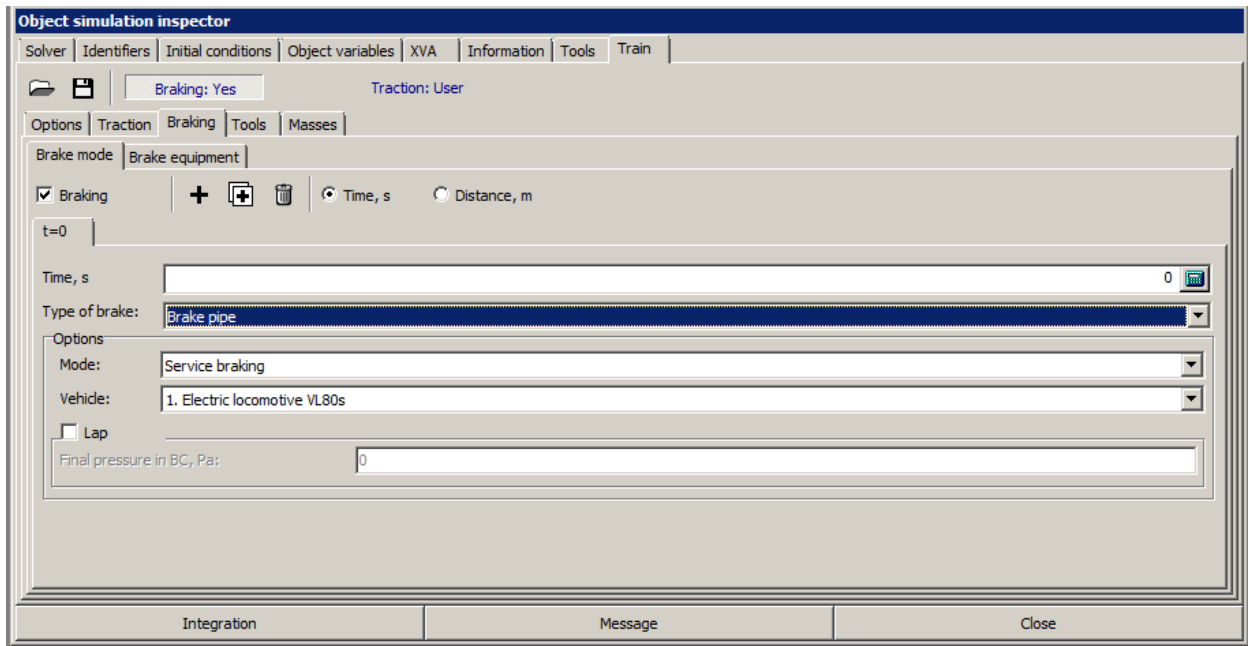


Figure 1.20. Braking mode tab

Set the **v0** identifier to 30 on the **Identifier** tab, Figure 1.21. It means that we set the initial velocity of the train to 30 m/s.

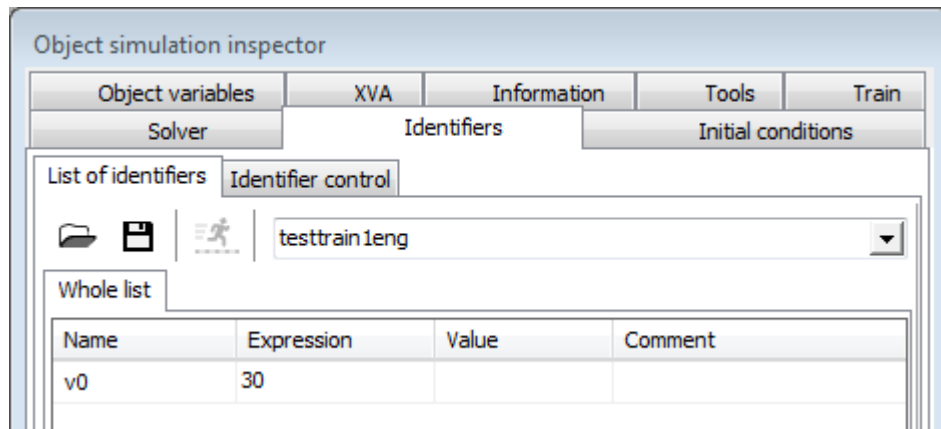


Figure 1.21. Identifier of initial velocity

Let us add variables which allow us analyzing the train dynamics. We need braking forces for all vehicles, forces in all wagon connections, the velocity of the first vehicle, and the vehicle distance. Add these variables by using **Wizard of variables** (menu item **Tools** | **Wizard of variables...** Ctrl+M): braking forces, forces in wagon connections, and the travelled distance on the **Train** tab. In Figure 1.22, the example of the formation of braking forces for all vehicles is presented. Add them separately: braking forces to one graphic window, forces in wagon connections to the second one, and the vehicle distance to the third one.

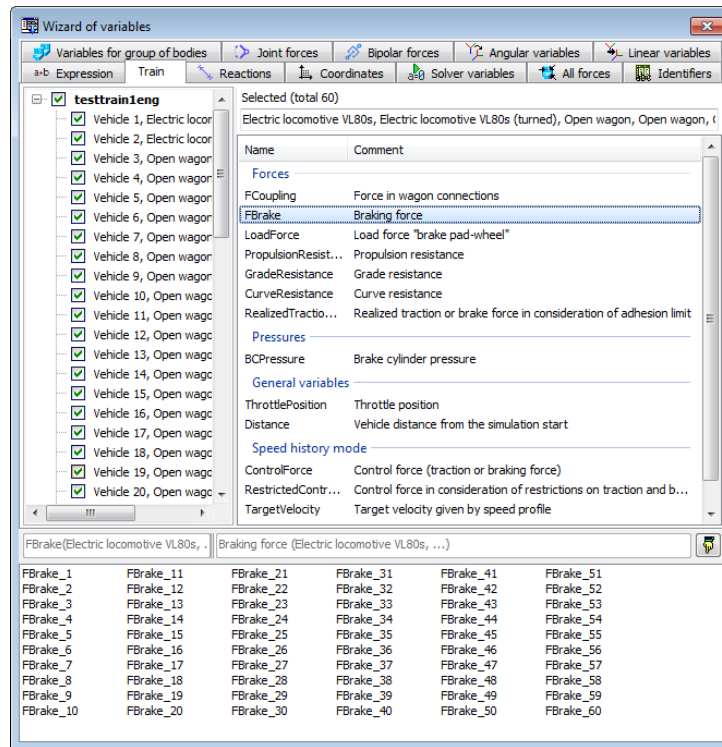


Figure 1.22. Train tab of Wizard of variables

The velocity of the first vehicle is formed on the **Linear var.** tab. You need to choose the **Vehicle** body of the first subsystem **Electric locomotive VL80s**, **Type – Velocity**, **Component – X**, Figure 1.23. Open new graphic window and add new variable there.

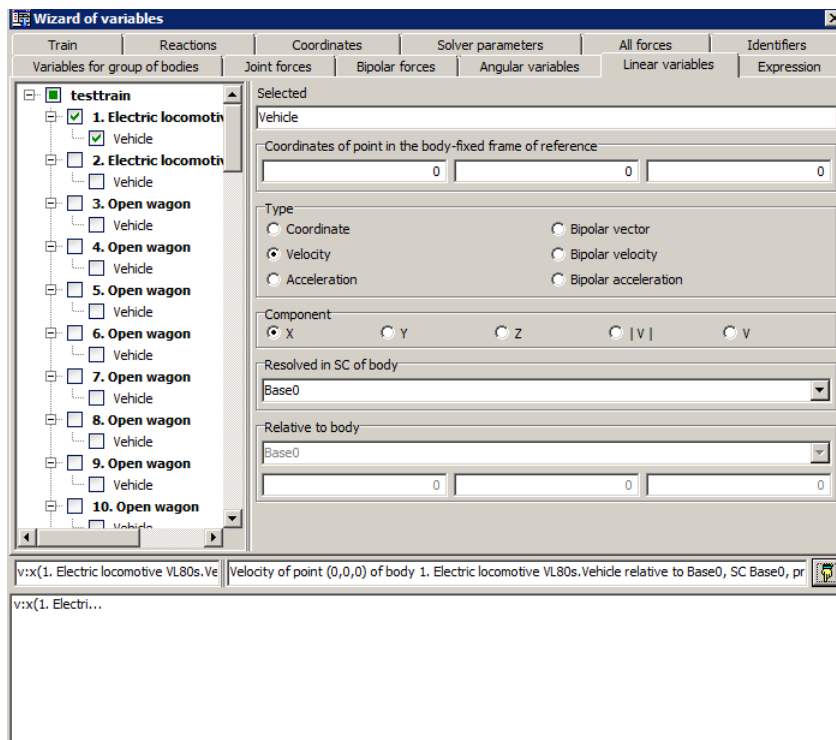


Figure 1.23. Linear var. tab of Master of variables

1.3.2. Simulation of train dynamics

Now everything is ready for the simulation of dynamics of braking mode. The desktop should look like in Figure 1.24.

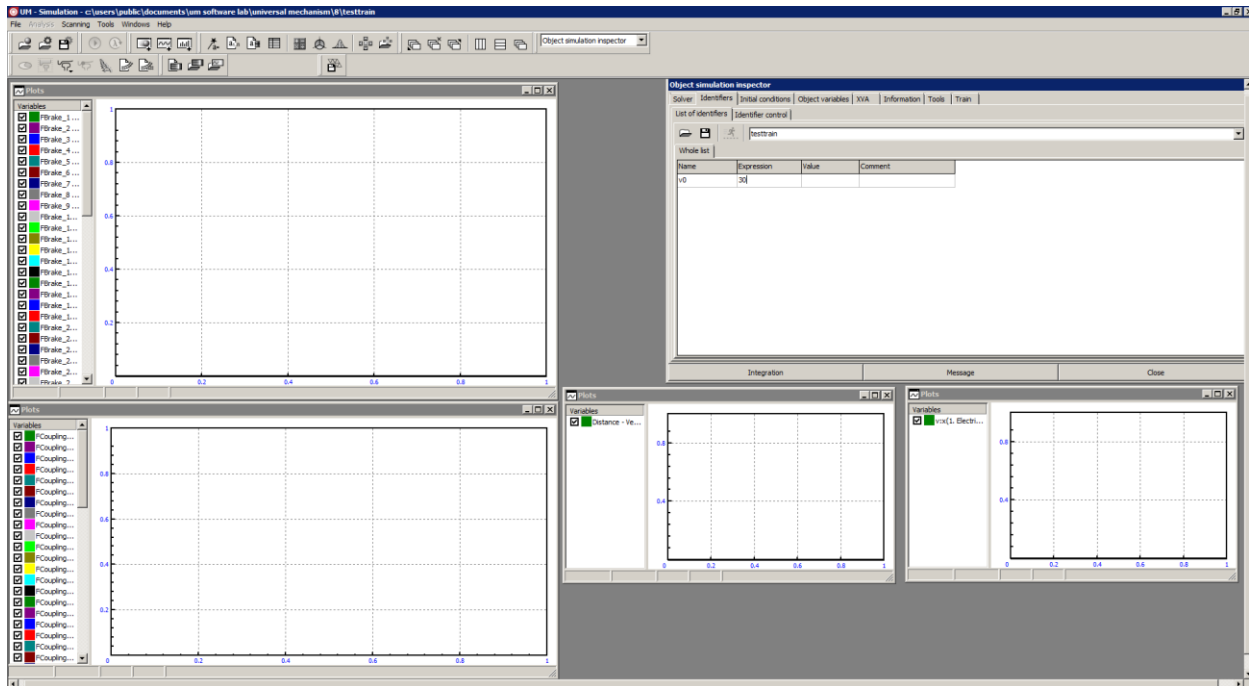


Figure 1.24. Desktop of ready train model

Run simulation by using $F9$ or the **Integration** button of the **Object simulation inspector**. The braking time will be about 55 s, the travelled distance is about 910 m.

After first starting simulation process the message window (Figure 1.25) is appearing. Every wagon has only one connection with the next wagon obviously last wagon has not such connection. So this wagon coupling force is not considered. Press **Continue** for beginning simulation process. In order to liquidate this message activate options *Do not show this window anymore*.

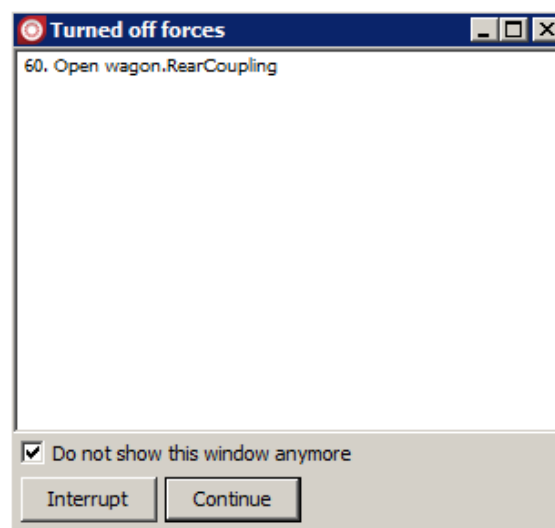


Figure 1.25. Message window

The plots of braking forces are presented in Figure 1.26. Here you can see two different kinds of the forces: two first plots correspond to two sections of VL80s and the rest ones to the forces for cars.

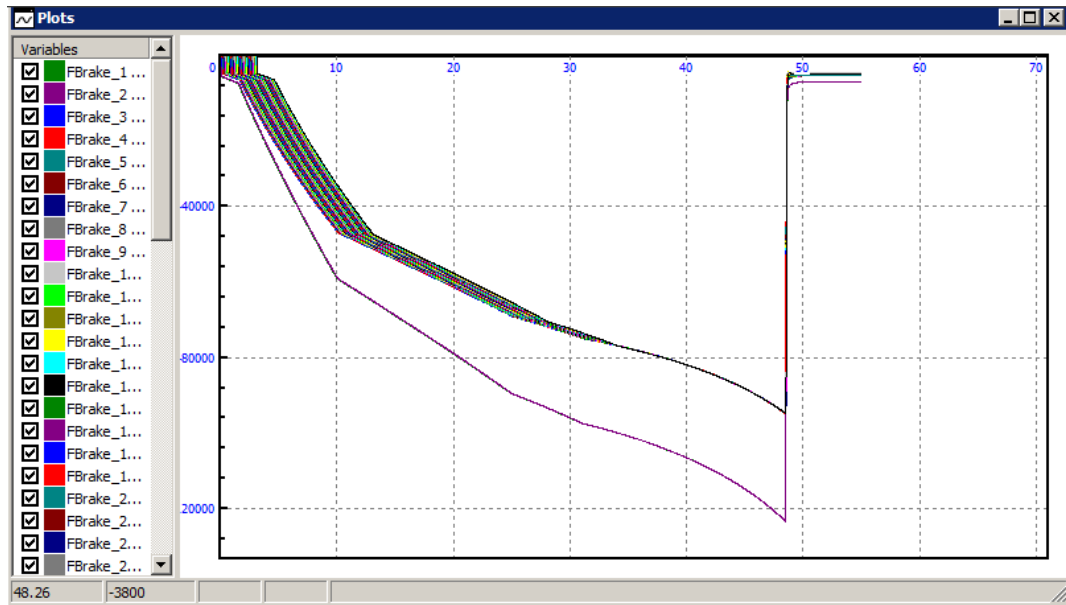


Figure 1.26. Braking forces

The forces in wagon connections are shown in Figure 1.27. The maximal force is about 365 kN on the 43rd vehicle.

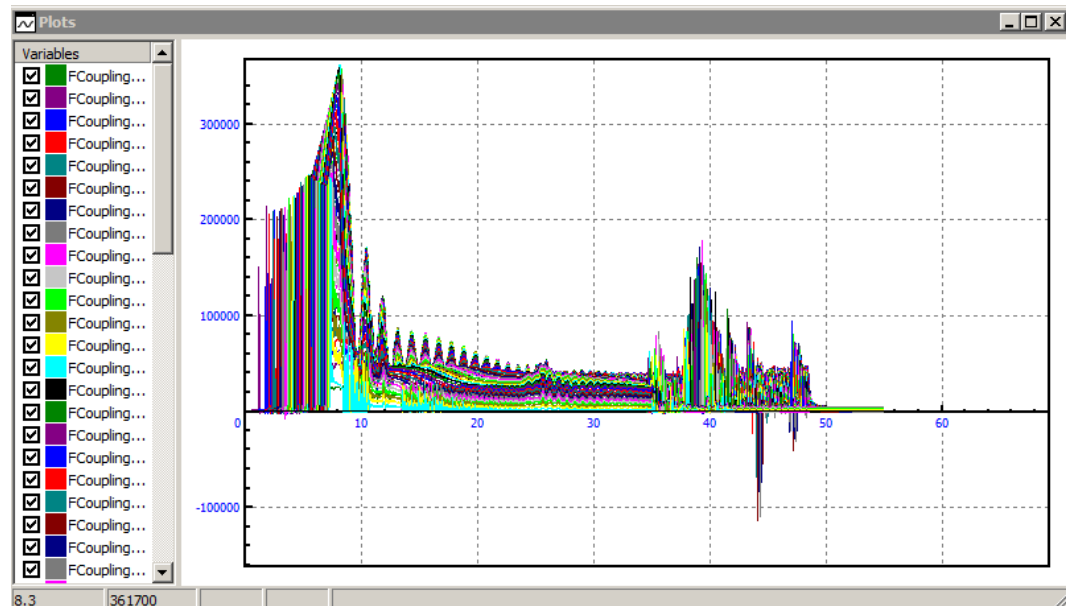


Figure 1.27. Forces in wagon connections

The graph of changing the velocity of the first vehicle is shown in Figure 1.28.

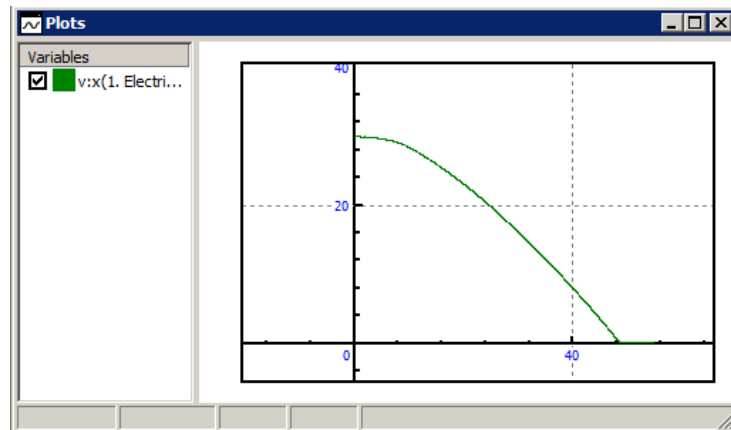



Figure 1.28. Velocity of the first vehicle.

Often it is more informative to represent the forces in wagon connections in a histogram form. To do it, open a histogram window by using the **Tools | Histogram** menu item or  button on the tool panel and drag there the necessary variables – in this case forces in wagon connections from the corresponding graphic window, Figure 1.29.

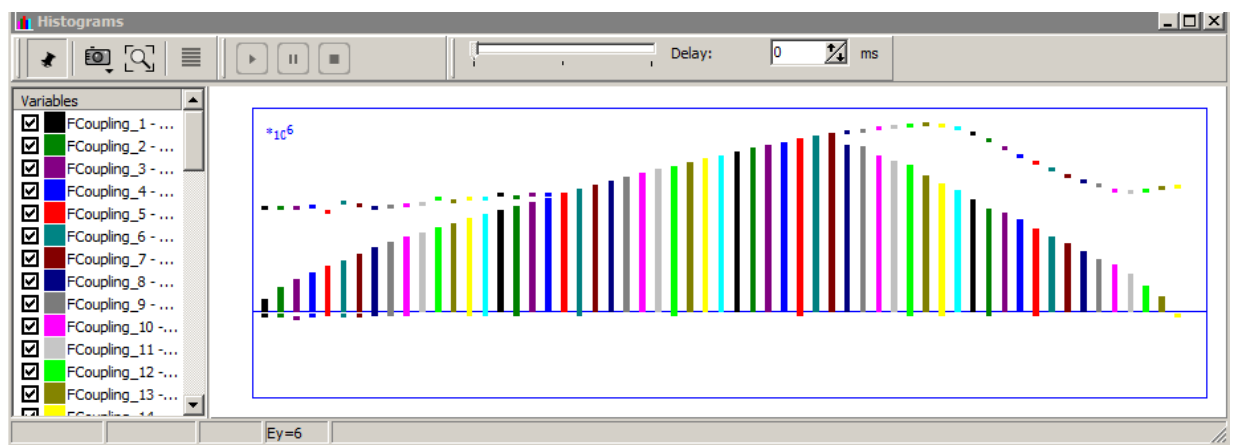



Figure 1.29. Forces in wagon connections in histogram window

By using the buttons on the tool panel of histogram window *draw, pause, stop*  you can control the animation of forces while the simulation is in the pause mode of integration.

2. International benchmarking of longitudinal train dynamics simulators

2.1. What we will learn

In 2016 UM software took part in the international benchmarking of longitudinal train dynamics simulators organized by the Centre for Railway Engineering, Central Queensland University, Rockhampton, Australia. This benchmarking is described in details in [1], [2] and [3]. Nine programs from Australia, China, Italy, the Netherlands and France were compared.

The objectives of the LTD benchmark include: (1) to enable developers to gain better understanding of their own simulators by software-to-software comparisons; (2) reveal the differences between different simulators so as to open the issues that need further studies; (3) provide an assessment approach for existing and newly developed simulators.

Totally four train configurations with two types of 6-axle locomotives with axle load of 22,33 and 32,5 tonnes two types of freight cars with axle load of 32 and 40 tonnes were considered.

Source data included the follows: locomotive and wagon specification, train configuration, dynamic characteristics of the friction-rubber draft gear, track geometry, initial speed, traction and braking characteristics. The following data were provided as outputs to compare: the position and the velocity of the leading locomotive in time-domain, the coupler forces in time-domain at specified positions, the draft gear deflection in time-domain at specified positions, maximum compressive and tensile force of each coupler.

UM showed a very good agreement with other software and proved again that it is a reliable tool for simulation of longitudinal train dynamics.

This part of the lesson will cover an example of modeling the longitudinal dynamics of a train in the first configuration, including 2 leading locomotives and 50 freight cars.

The finished model can be found in the folder:

[{UM Data}/SAMPLES/Trains/LTDB-Train Configuration 1](#)

2.2. Creating train model

Open **UM Input** program. In **program menu** choose **Tools | Train wizard...**, **Train wizard** window appears, see Figure 2.1.

To include 52 vehicles in the train model type **52** in **N vehicles** field, Figure 2.2.

The next step is to choose the types of vehicles. You need to place two locomotives in the head of the train. To do this, choose **LTDB-Loco Type 1** on the right side of **Train wizard** using double-click, then double-click again on **LTDB-Loco Type 1**. It will be the second vehicle. The type of wagon connection is undefined. Mass and length of vehicles are set automatically when adding the vehicle. However it can be changed by the user.


To add freight wagons into the train choose the **Cars** tab and right-click on **LTDB-Wagon Type 1**. In the appeared menu choose **Assign to selected**, Figure 2.3.

In the appeared window **Select element from list** only uncertain earlier cars are available for assigning **LTDB-Wagon Type 1**. Click **OK** to assign for "empty" cars type **LTDB-Wagon Type 1**.

Now every vehicle in the train is specified.

The final stage of model creation is the assignment of the types of inter-car connections. Define for all inter-car connections the **LTDB Draft Gear 10 mm slacks**. For this select in the context menu the command **Assign to all**, Figure 2.4.

Dynamic characteristics of the friction-rubber draft gear are described as shown in Figure 2.5.

The train model is ready, see Figure 2.6. Save it by clicking  and specifying the name and path to the object in the dialog box, for example: **{UM Data}\My model\Trains\LTDBTrain**.

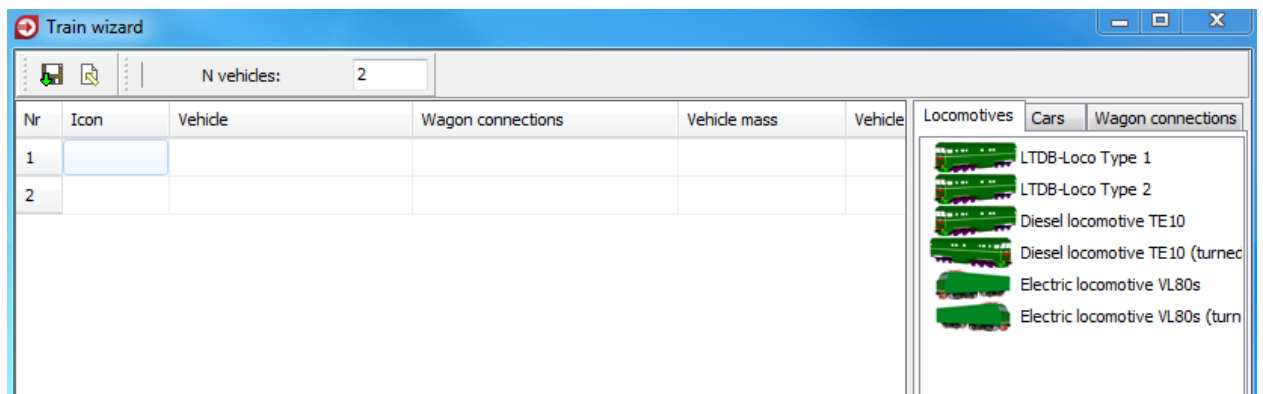


Figure 2.1. Train wizard

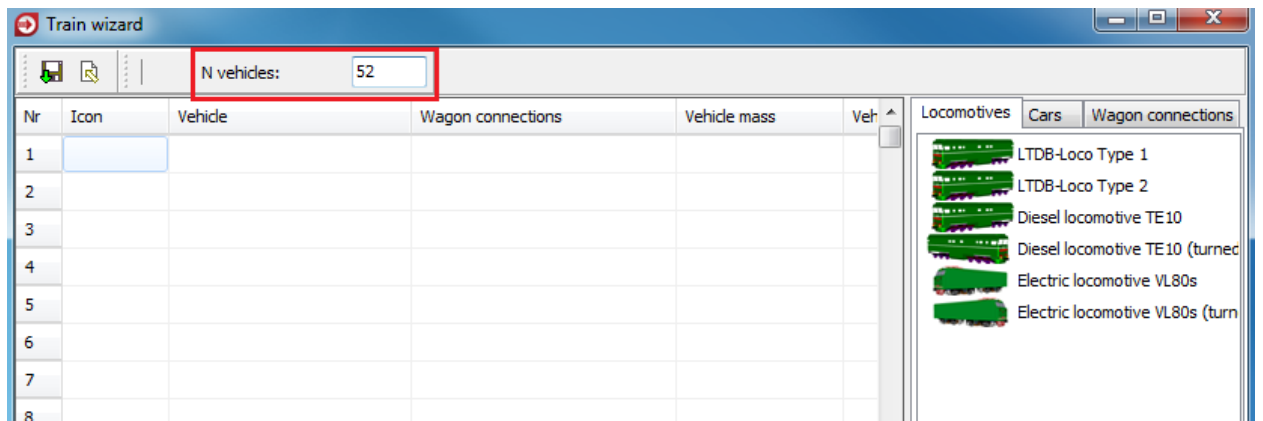


Figure 2.2. N vehicles tab

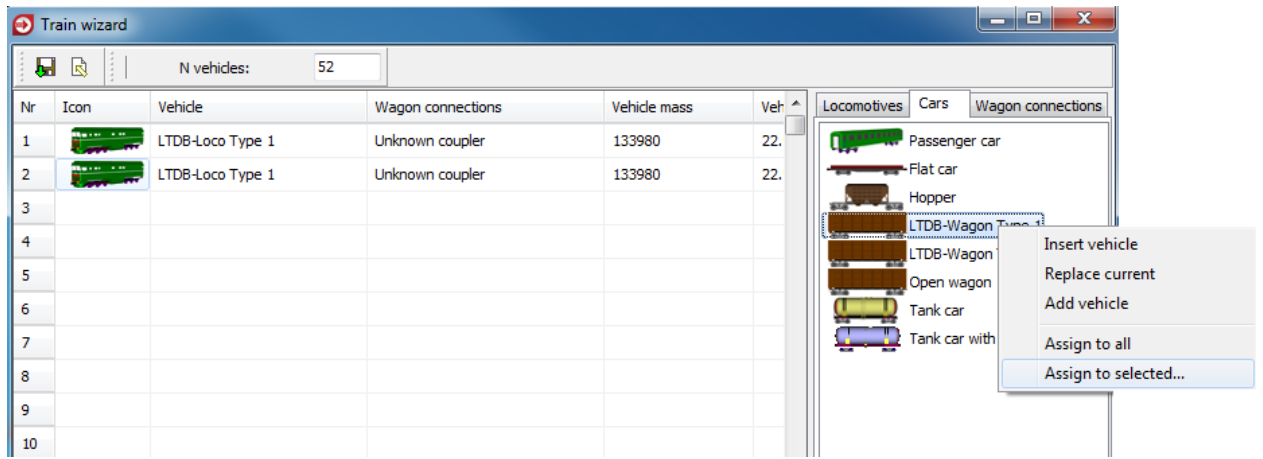


Figure 2.3. Assigning car types

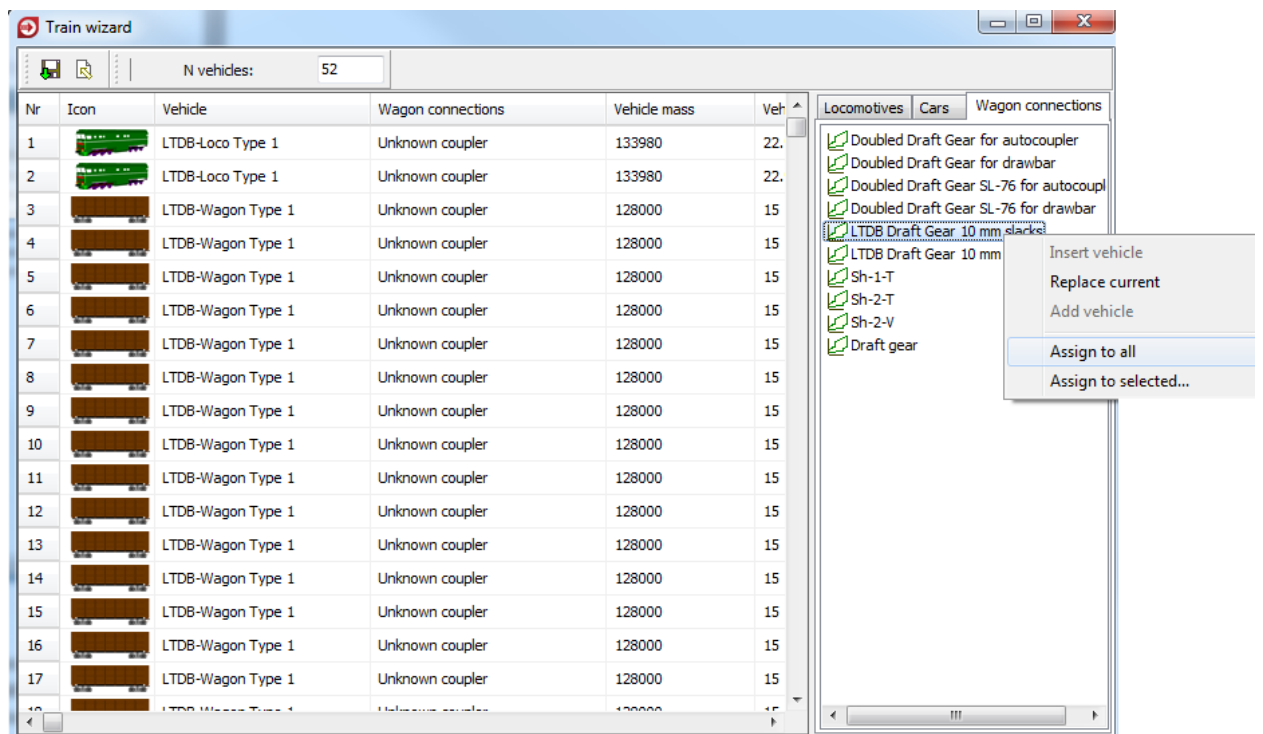


Figure 2.4. Assigning inter-car connections

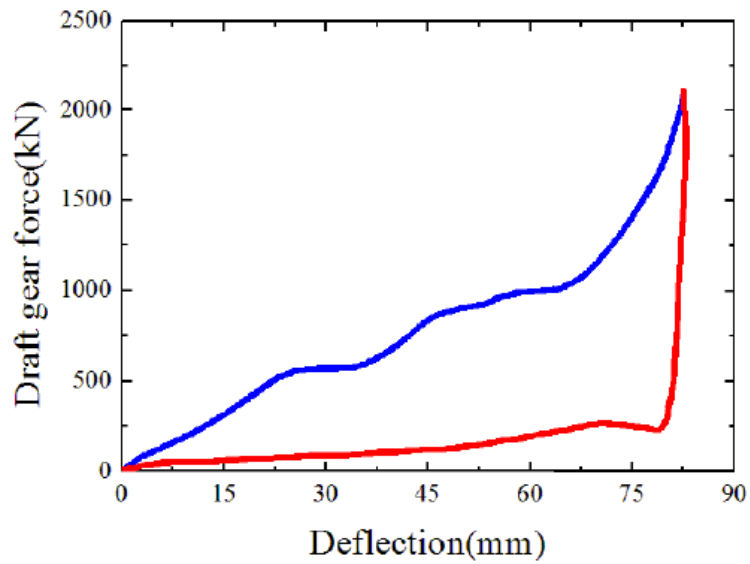


Figure 2.5. Characteristics of draft gear

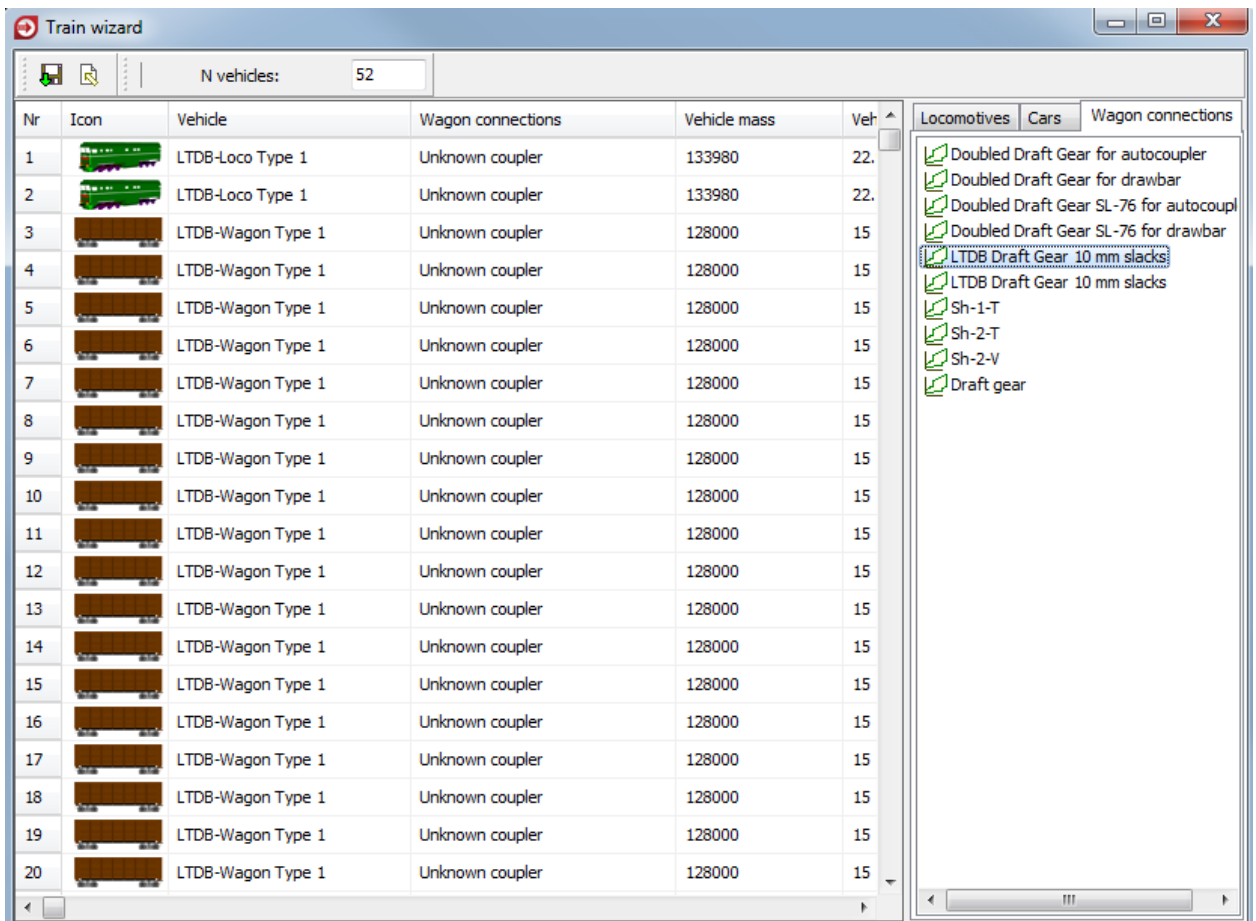


Figure 2.6. Ready train model

2.3. Assigning model parameters

Run **UM Simulation** program and open the train model which was created on the previous step.

Integration parameters settings

Set the parameters of the integration process. Open **Object simulation inspector**, on the **Simulation process parameters** tab, set the **Park** method. Choose **Range space method (RSM)** as a **Type of solution**. Enable the options **Computation of Jacobian** and **Block-diagonal Jacobian**, set **Distance** > 50 000, Figure 2.7.

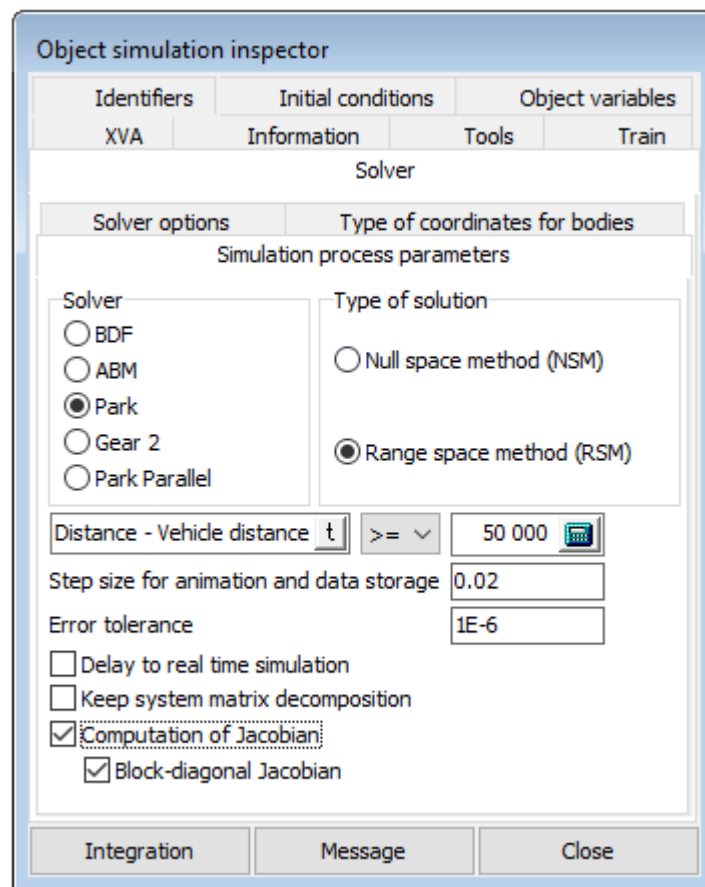


Figure 2.7. Object simulation inspector

Assigning braking mode

Dynamic brake characteristics of the locomotives are shown in Figure 2.8. Time history of driving control including traction and braking notch positions vs. time was provided as source data. All we have to do is load the preliminary prepared file.

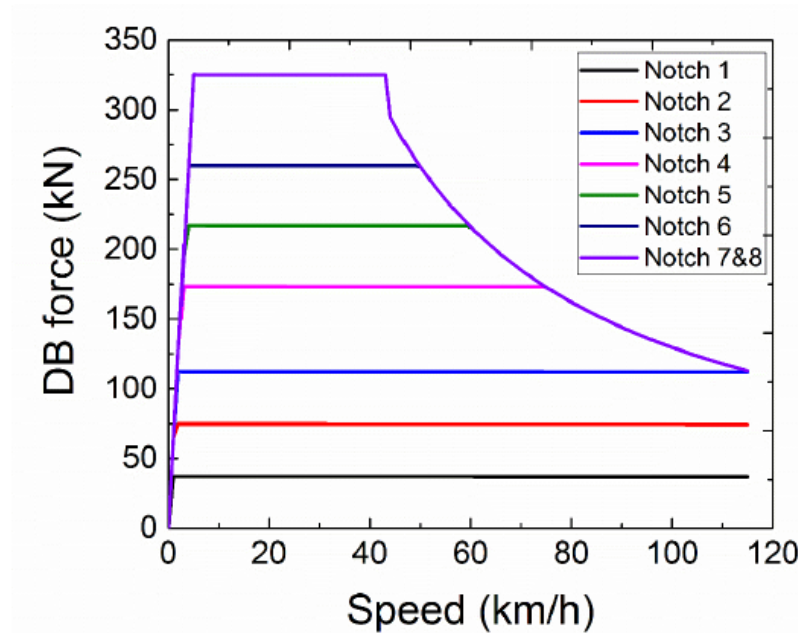


Figure 2.8. Dynamic brake characteristics

To do this go to tab **Identifiers | Identifier control**. Create identifiers. Click on **+** it will bring up a new dialog box. Then click on the button, highlighted in Figure 2.9. In the appeared list open **LTD-Loco Type 1**, and select **dynamic_brake_position**.

Assign value to identifiers with the same name - **All**.

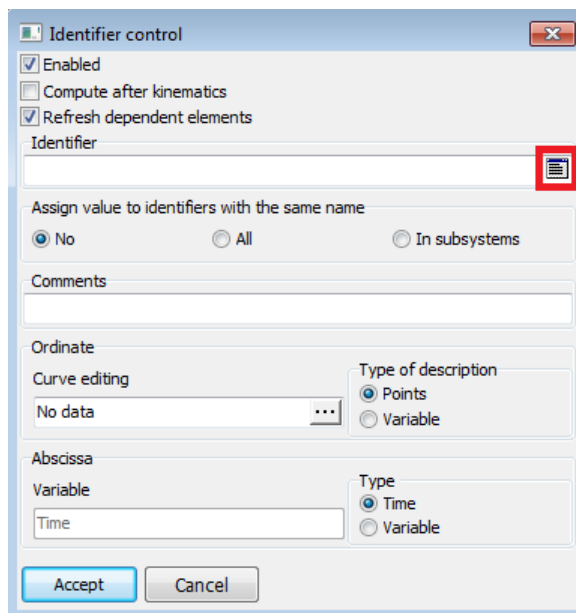


Figure 2.9. Identifier control

Click **...** in the **Curve editing** field to set the curve. A new window **Curve editor** appears. Load data from **{UM Data}\Samples\Trains\LTD-Train Configuration 1\Dynamic brake position.crv** file, Figure 2.10.

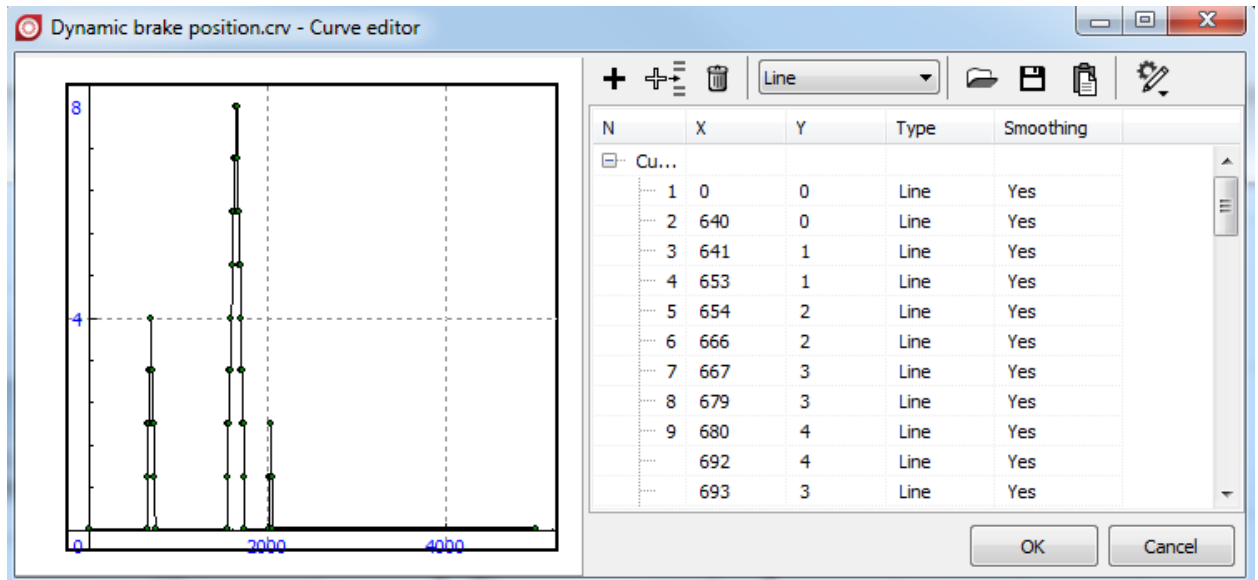


Figure 2.10. **Curve editor**. Dynamic brake position

Click **OK** and **Accept**.

Traction mode setting

Tractive effort vs. speed is shown below in Figure 2.11. As it was mentioned above time history of driving control including traction and braking notch positions vs. time was provided as source data. All we have to do is load the preliminary prepared file.

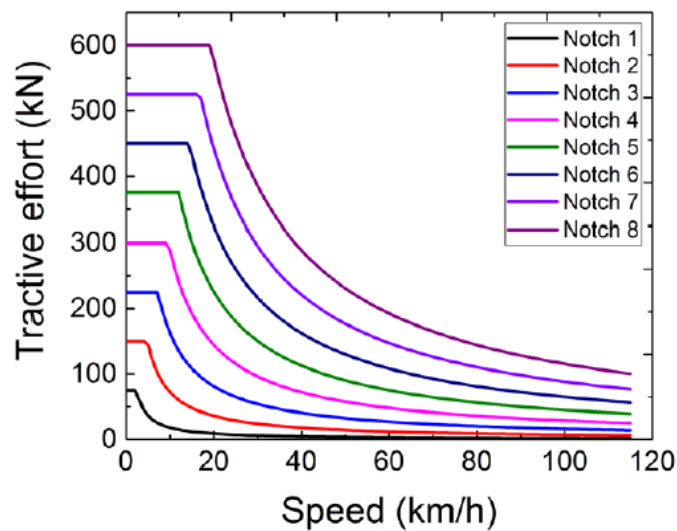


Figure 2.11. Drag characteristics

Let us create one more identifier but this time we should choose the **Throttle_position** one, Figure 2.12.

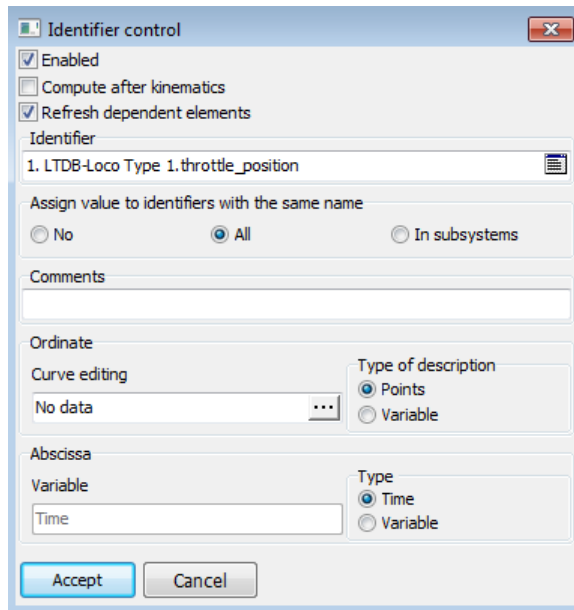


Figure 2.12. Identifier Control. Throttle position

Open curve editor and load file {UM Data}\Samples\Trains\LTDB-Train Configuration 1\Throttle position.crv.

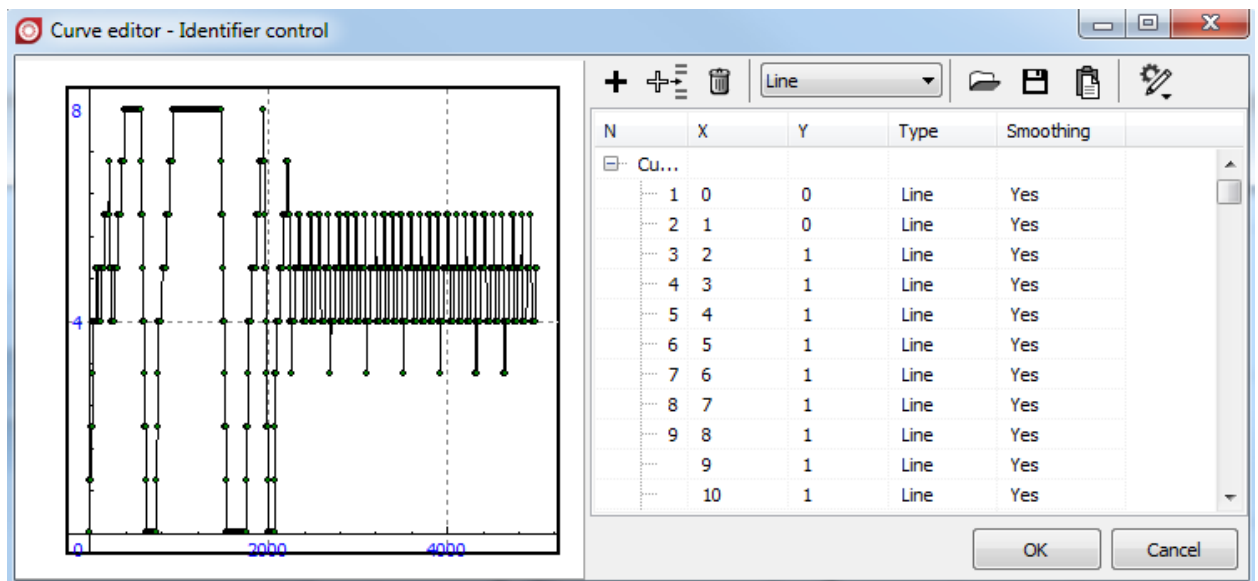


Figure 2.13. Curve Editor. Identifier control

Click **OK** and **Accept**.

Assigning track macrogeometry

Track elevation and curvature vs. location are shown in Figure 2.14 and Figure 2.15 correspondingly. This data was converted into UM-compatible format with the help of some transformation. Track macrogeometry in UM format is shown in Figure 2.16.

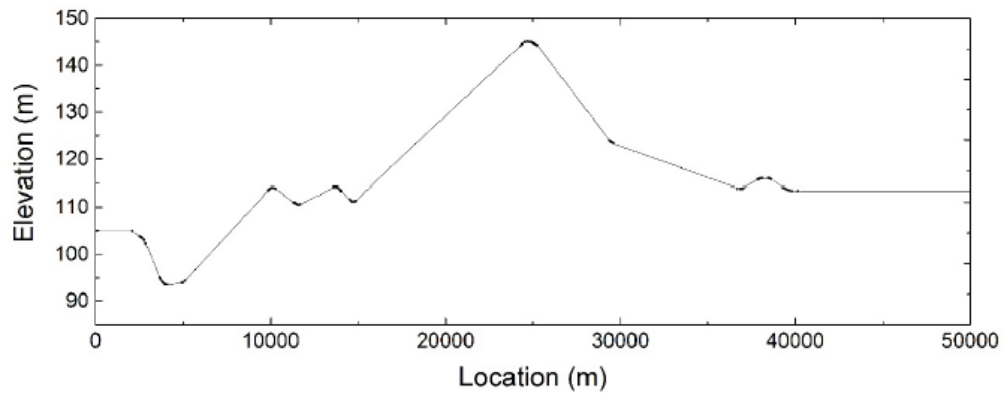


Figure 2.14. Elevation vs. location

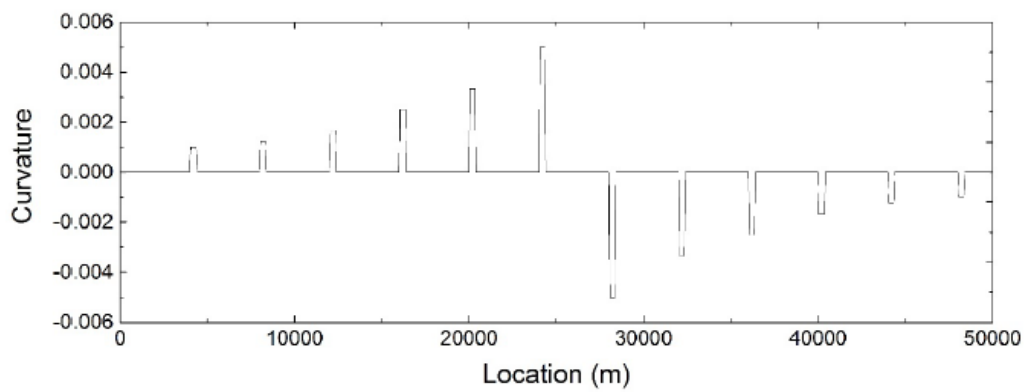


Figure 2.15. Track curvature

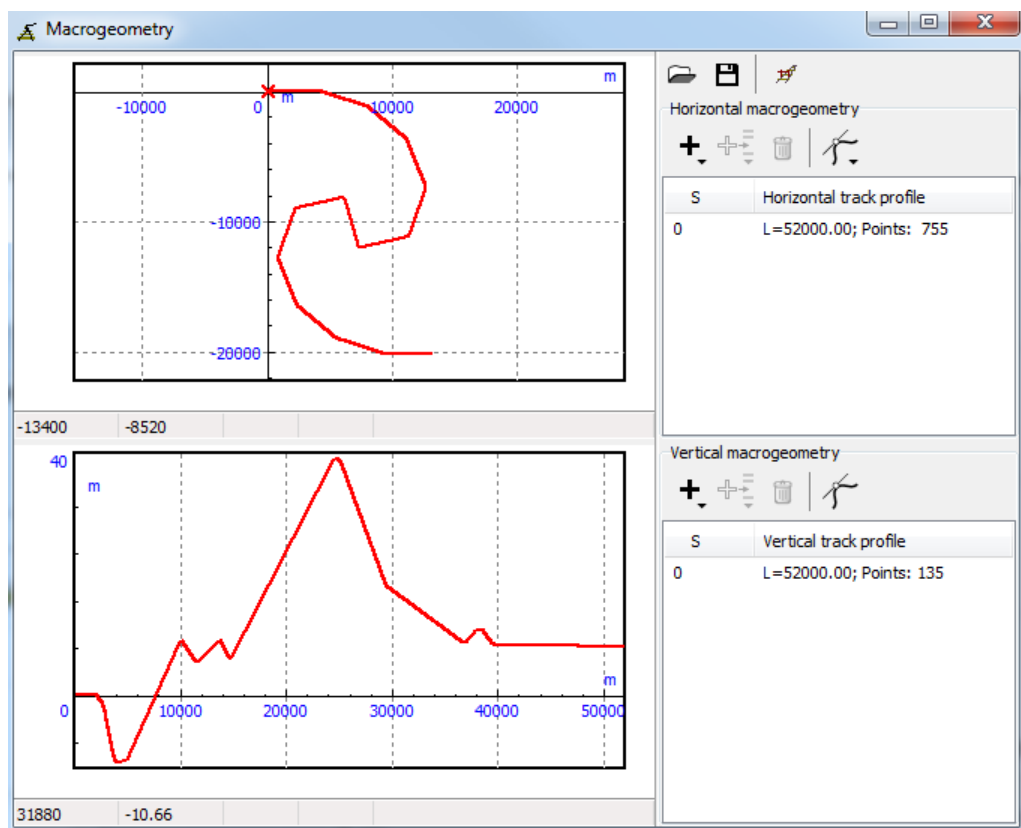


Figure 2.16. Macrogeometry

Select the **Train | Options | Track** tab and specify macrogeometry from {UM Data}\rw\MacroGeometry\LTDB-MacroGeometry.mcg file, Figure 2.17.

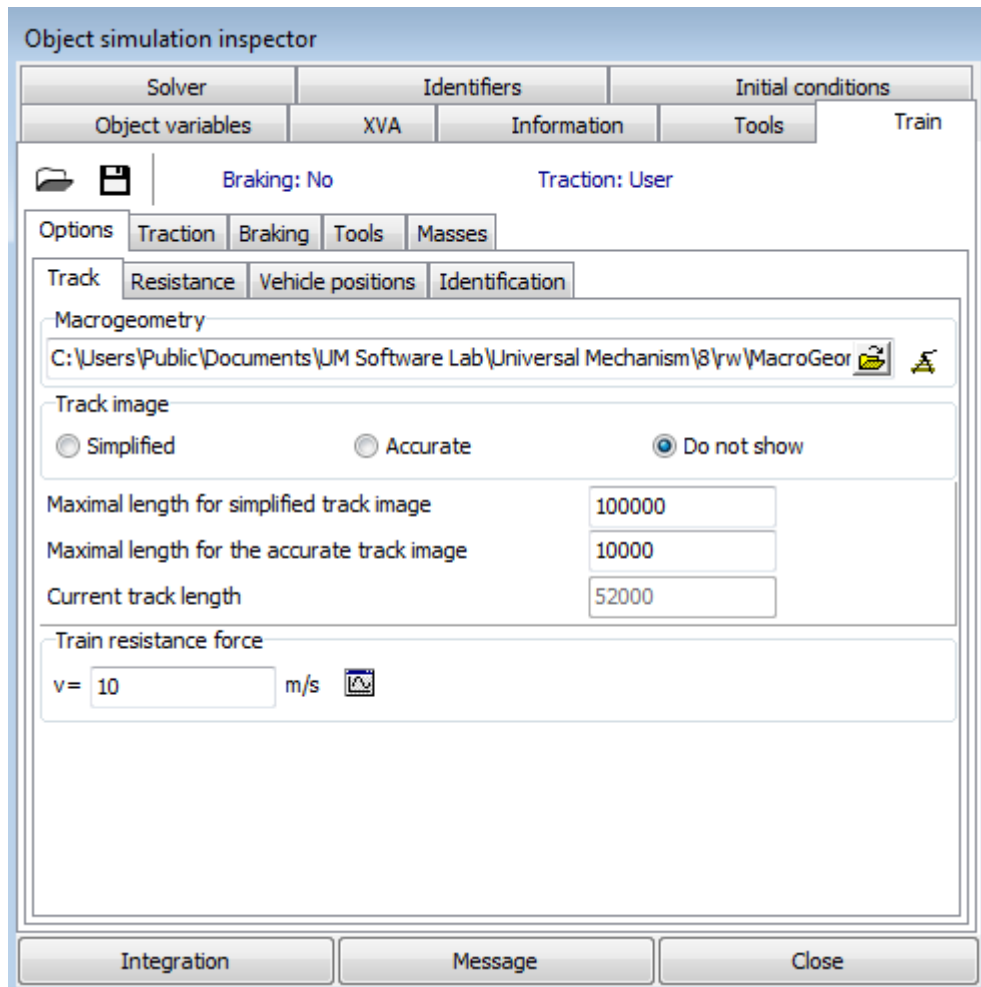


Figure 2.17. Assigning macrogeometry

Resistance forces

Propulsion resistance is given as follows:

$$F_{rr} = m_w \left(2.943 + \frac{89.2}{m_a} + 0.0306v + \frac{0.122v^2}{m_w} \right),$$

where m_w is wagon mass, t; $m_a = 32$ is axle load, t; v is wagon speed.

Additional resistance in curve is specified as follows:

$$F_{cr} = m_w \frac{6116}{R},$$

where R is a curve radius.

Click **Resistance | Propulsion** tab. Click **+** and load resistance force models. We need the follows: **LTDB-Leading Locomotive.rf**, **LTDB-All Other Locomotives.rf** and **LTDB-All Wagons.rf**. Then assign to all **LTDB-All Wagons**, right click on it, Figure 2.18. To assign to the first two locomotives other resistance models you need to click twice in the field **Resistance model**, Figure 2.19. Let us assign **LTDB-Leading Locomotive** to the first locomotive and **LTDB-All Other Locomotives** to the second locomotive.

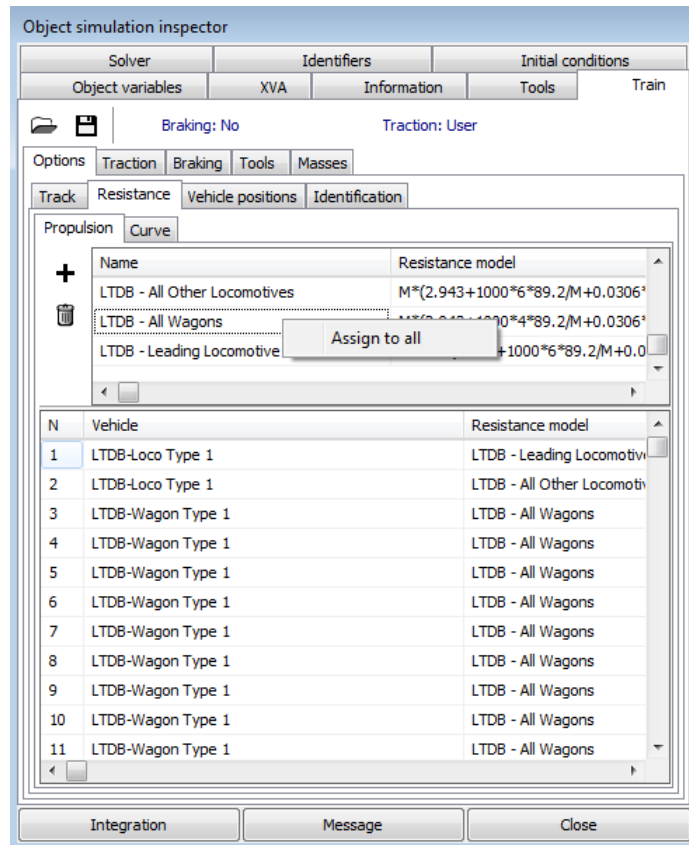


Figure 2.18. LTDB-All Wagons. Assign to all

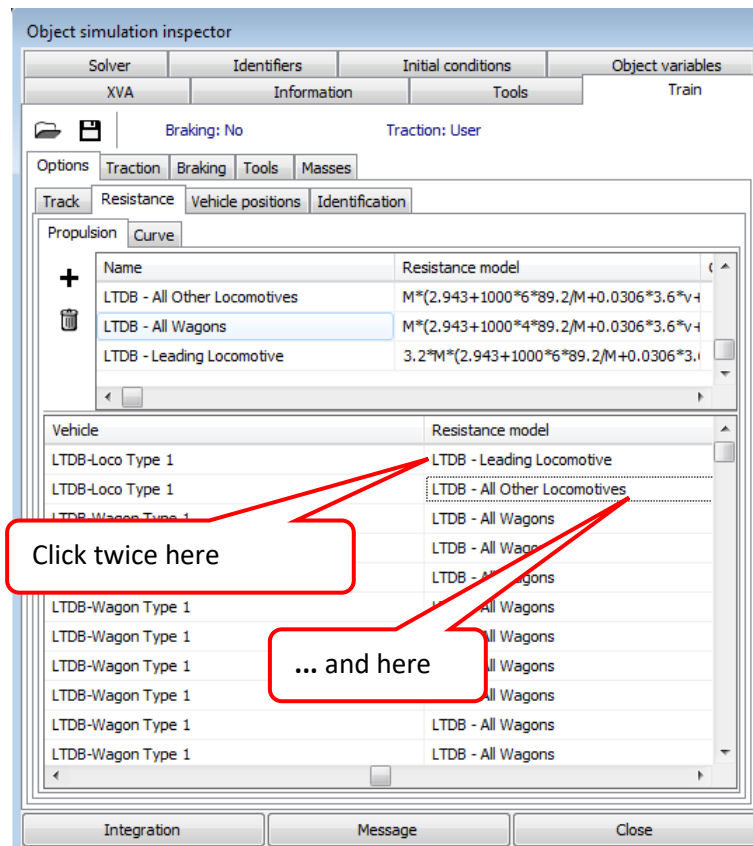


Figure 2.19. Resistance models for two first locomotives

Then select the **Curve** tab. Force model is $a/(R - b)$. Coefficients are a=6116, b=0, Figure 2.20.

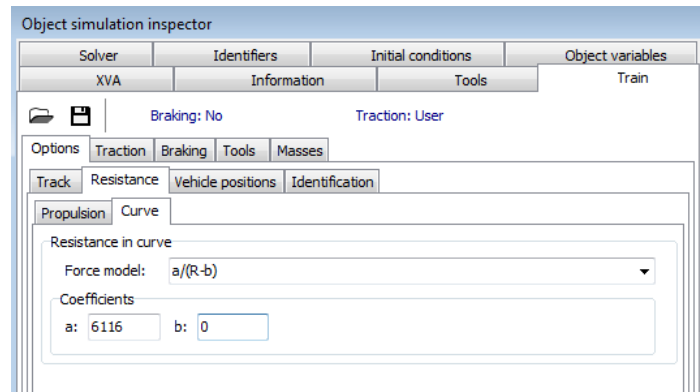


Figure 2.20. Assigning curve resistance

Assigning vehicle position

Select the **Vehicle position** tab and type **3011.475** in the **Position of the first car** field, Figure 2.21.

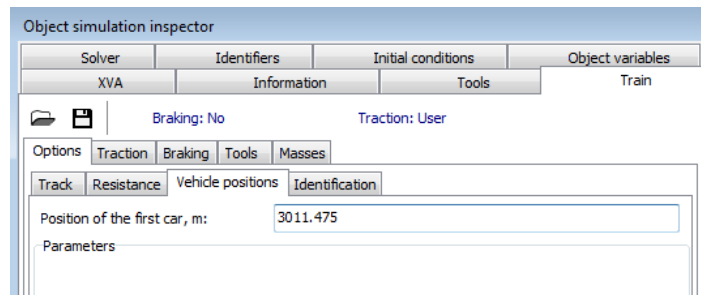


Figure 2.21. Position of the first car

Creating list of variables

Create **List of variables** (main menu **Tools** | **List of variables**). New list of variables appears, Figure 2.22.

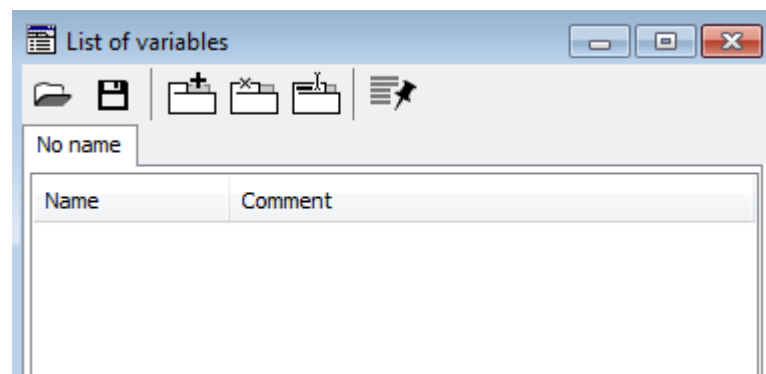



Figure 2.22. List of variables

Change the name of the tab using  button, Figure 2.23. Click **OK**.

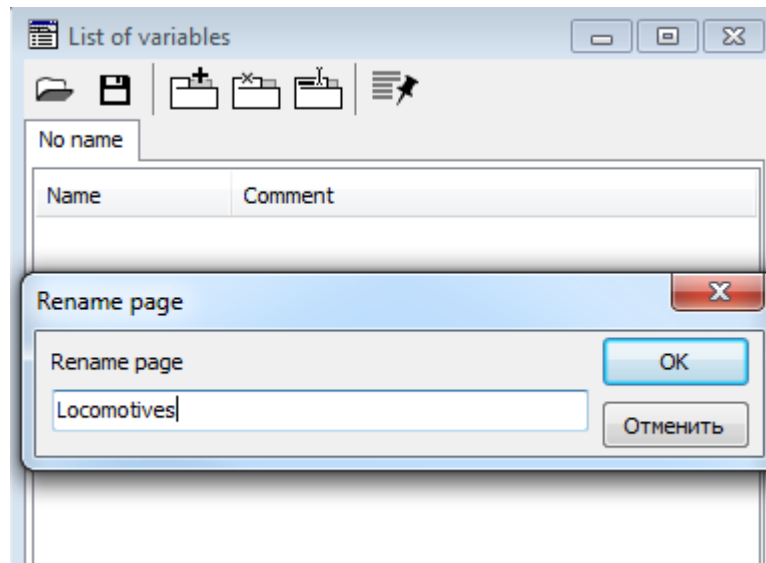


Figure 2.23. Locomotives tab

Now open **Wizard of variables** and create the coordinate, velocity, and acceleration one by one on the **Linear variables** tab, Figure 2.24. Select **Vehicle** bodies from subsystems **LTD black Type 1** and **LTD black Type 2** and set **Component** to **X**. Move them to the **List of variables**, Figure 2.25.

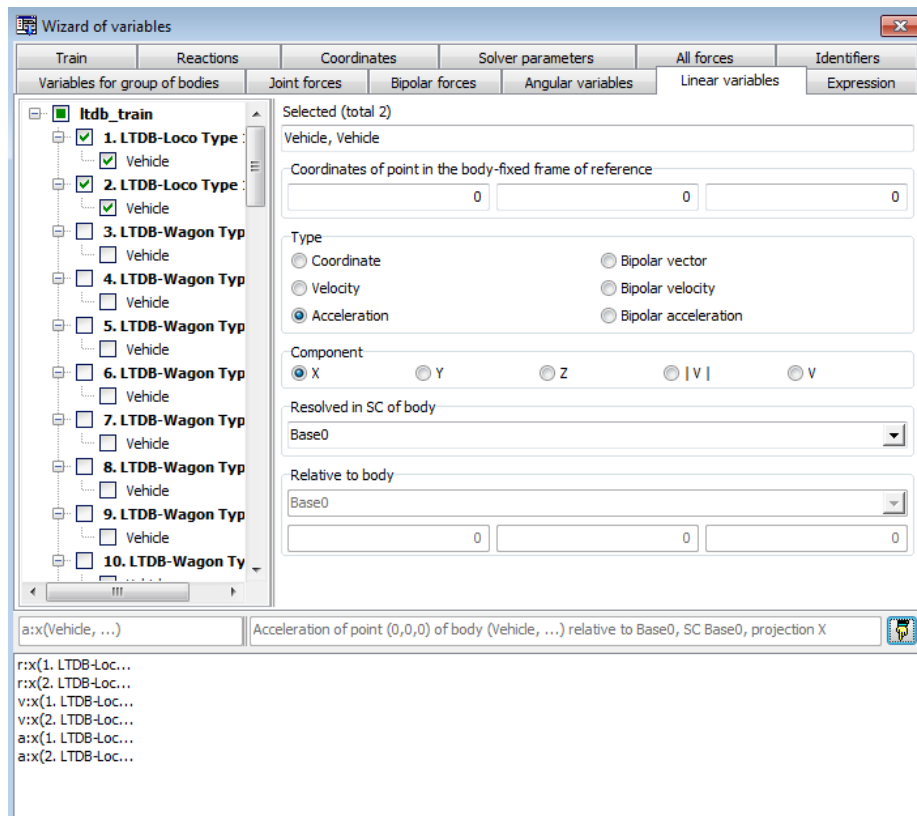


Figure 2.24. Wizard of variables. Linear variables

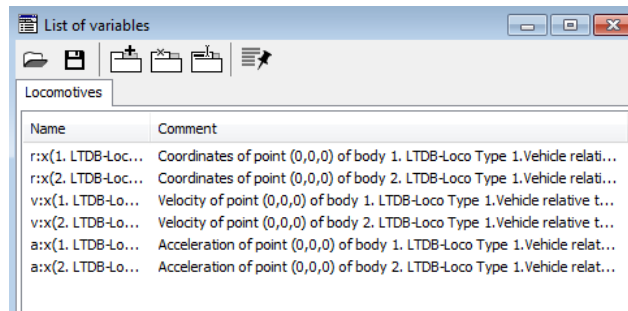


Figure 2.25. List of variables with **locomotives** tab filled in

Create another tab **Coupler forces** in the **List of variables**. To fill it in go to the **Train** tab in **Wizard of variables**, select the bodies of **Vehicle 2**, **Vehicle 25** and **Vehicle 51**. Create variables for the force in wagon connection (Figure 2.26) and move them to the **Coupler forces** tab, Figure 2.27.

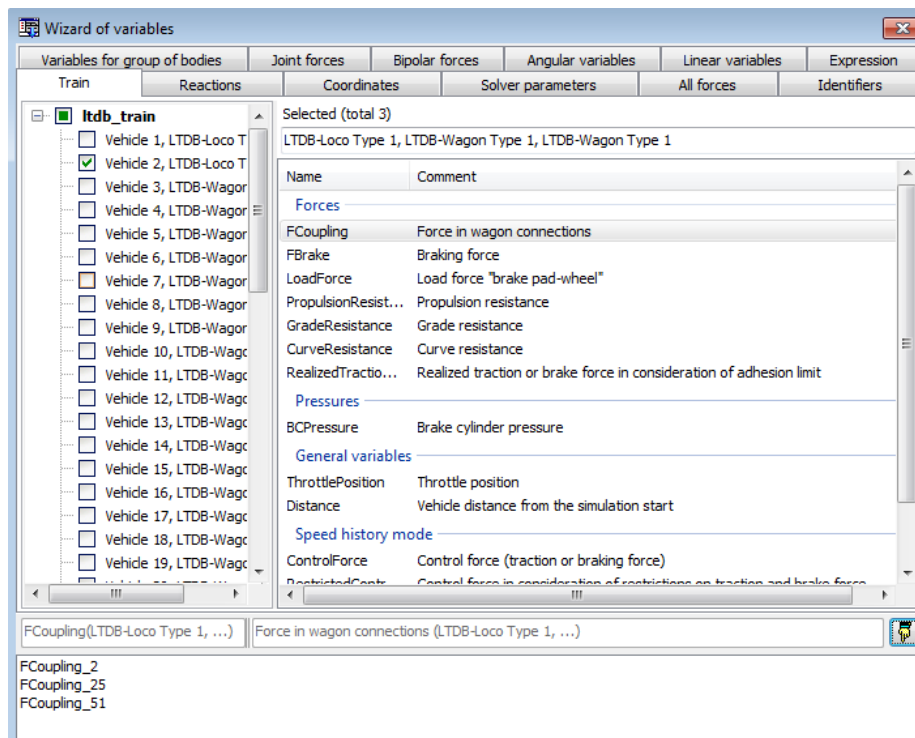


Figure 2.26. Force in wagon connections

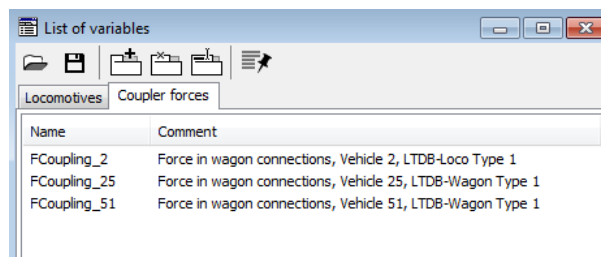


Figure 2.27. List of variables. Coupler forces

We will create three more tabs in list of variables: **Traction Force**, **Resistance**, **Throttle position** and populate them.

Realized traction or braking force with regard to the limit on the clutch, as shown in Figure 2.28. These variables will be added to the **Traction Force** tab.

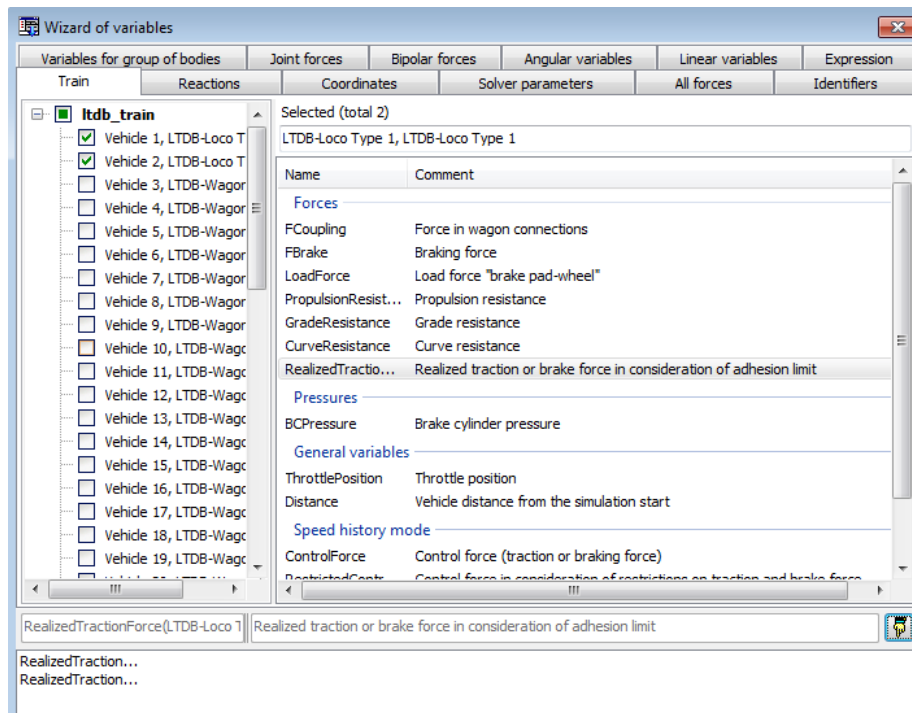


Figure 2.28. Wizard of variables. Realized traction force

Move the next forces on the **Resistance** tab: propulsion resistance, grade resistance, curve resistance, Figure 2.29.

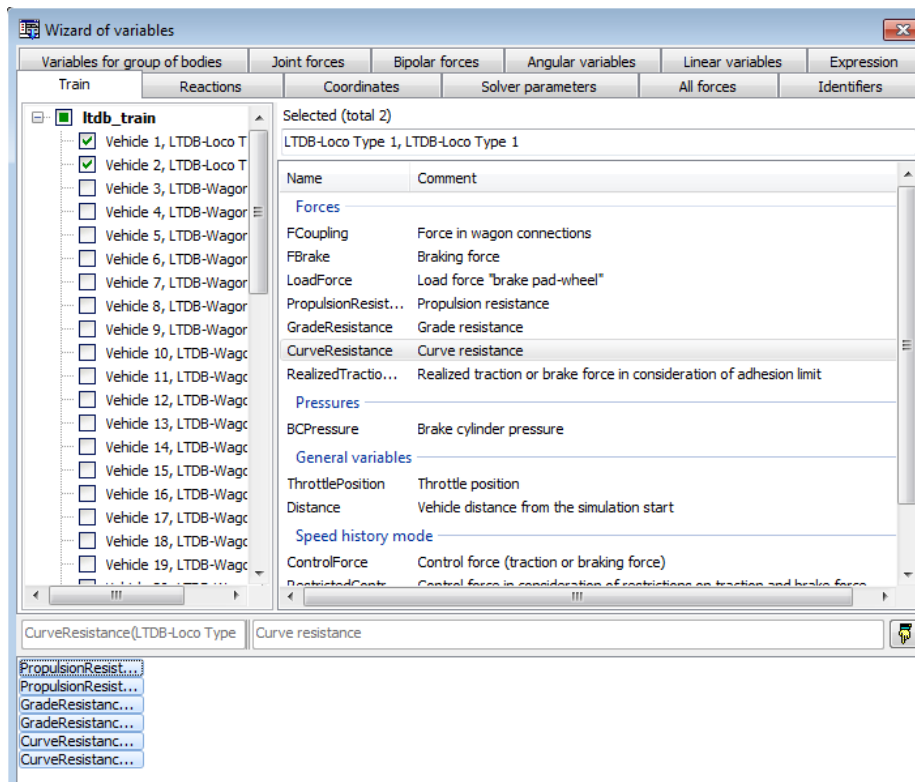


Figure 2.29. Resistance forces

The last variables for tab **Throttle position** we will create from **Identifiers** tab by choosing for **LTDB-Loco Type 1** and **LTDB-Loco Type 2 throttle position** and **dynamic brake position**, Figure 2.30.

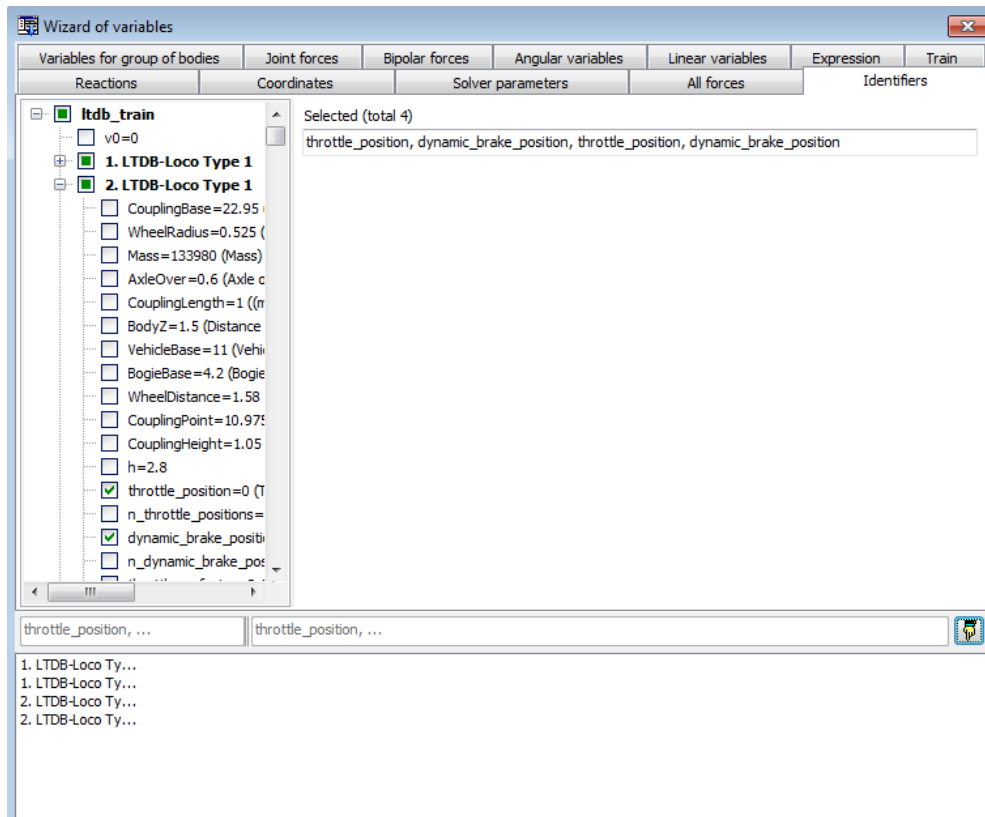


Figure 2.30. Wizard of variables. Identifiers

So we have finished creating **List of variables**, save it. Now, before you start integration in the **Object simulation inspector**, you need to go to the **Object variables** tab, load the **List of variables** and tick the box **Automatic saving of variables**, otherwise the simulation results will not be saved.

For clarity of the process, let us create five graphical windows and add variables to them. In the first graphic window add the speeds of locomotives, in the second – resistance forces for the first locomotive, in the third – the realized traction or braking force taking into account a limit on coupling, in the fourth – the position of the dynamic brake and the position of the driver controller for the first locomotive, and in the fifth – the forces in couplers.

2.4. Simulation of train dynamics

Now everything is ready for simulation. The program desktop looks like shown in Figure 2.31.

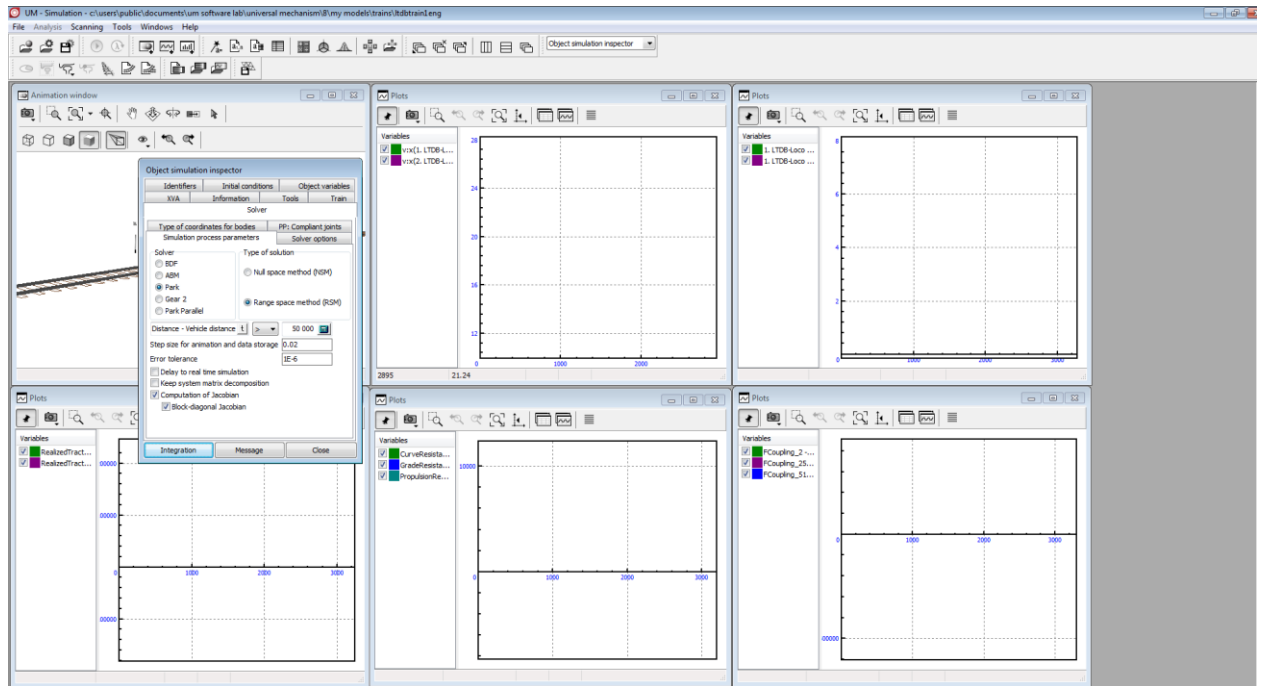


Figure 2.31. Desktop of the program. Everything is ready for simulation

Start the simulation process either *F9* hot key or **Integration** in **Object simulation inspector**.

After first starting simulation process the message window (Figure 2.32) appears. Every wagon has only one connection with the next wagon obviously last wagon has not such connection. So this wagon coupling force is not considered. Press **Continue** to start simulation process. In order to remove this message activate options **Do not show this window anymore**.

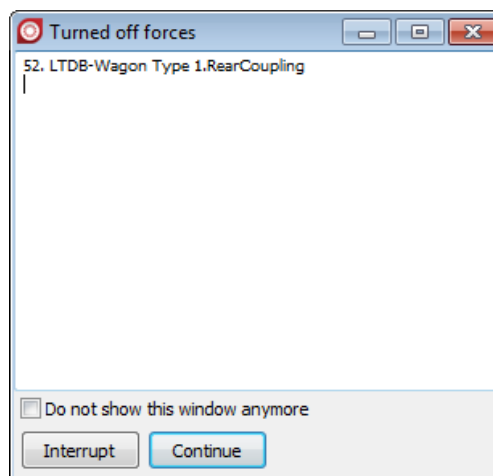


Figure 2.32 Message window

2.5. Simulation results

The plot of the speed change of the first and second vehicles is shown in Figure 2.33.

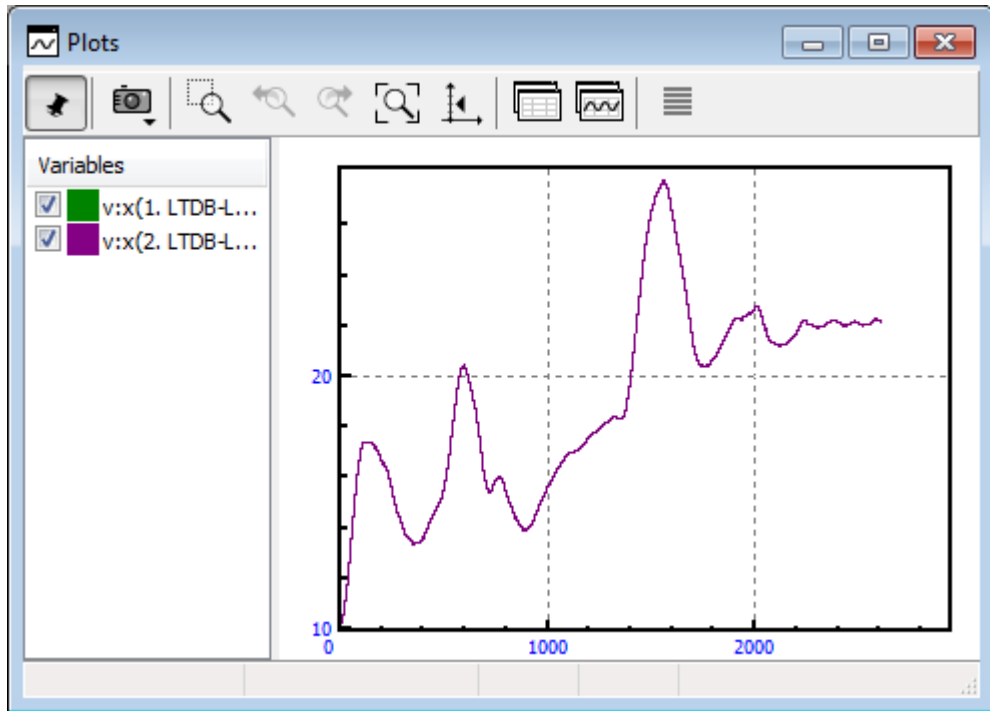


Figure 2.33. Speed of the first two vehicles

The plot of the realized traction or braking force taking into account a limit on coupling from time is shown in Figure 2.34.

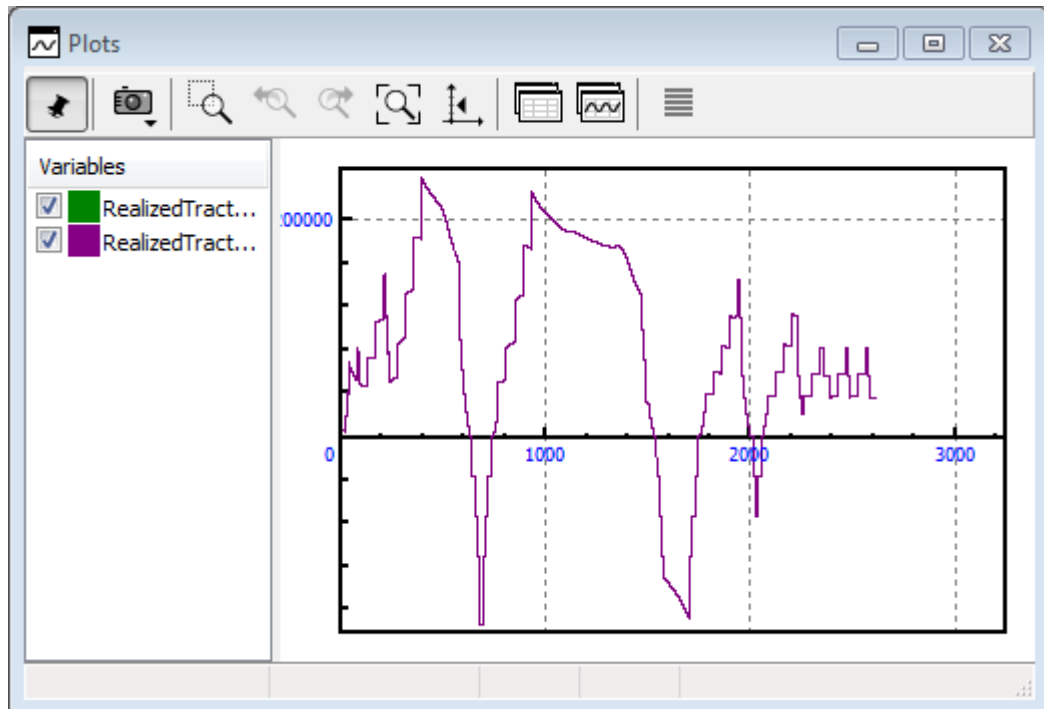


Figure 2.34. Realized traction or braking force with regard to the limit of maximum traction force for the first two vehicles

Resistance forces vs. time are shown in Figure 2.35.

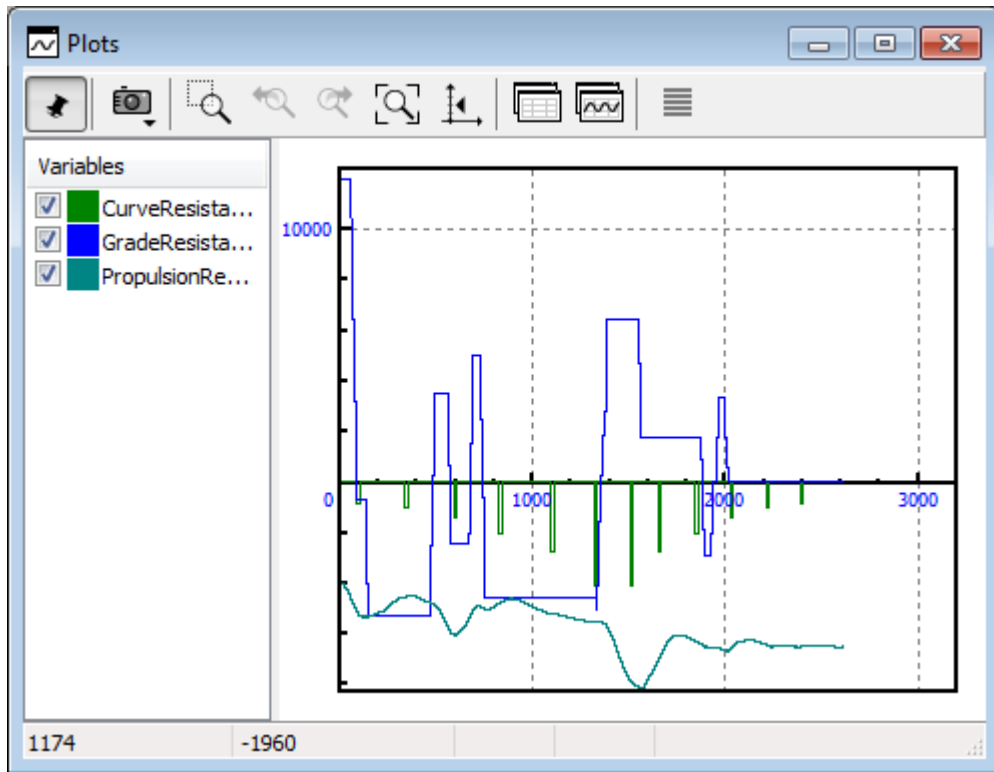


Figure 2.35. Resistance

The position of the driver controller and the position of the dynamic brake are shown in Figure 2.36.

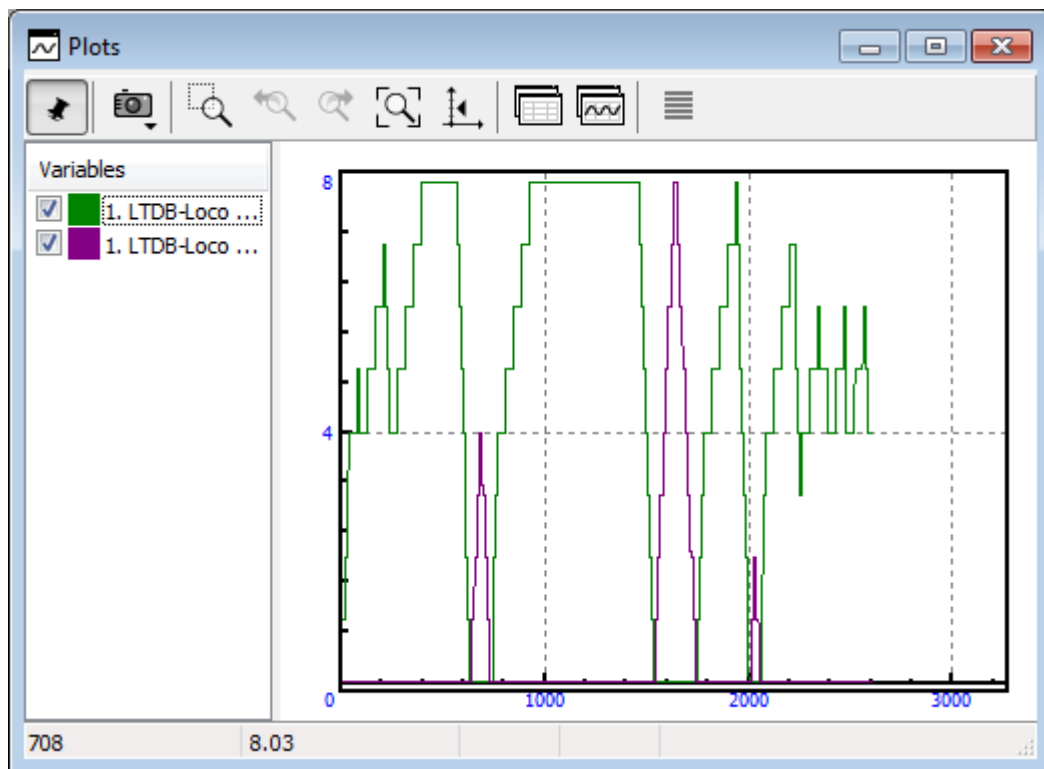


Figure 2.36. Dynamics

The forces arising in the inter-car connections are shown in Figure 2.37.

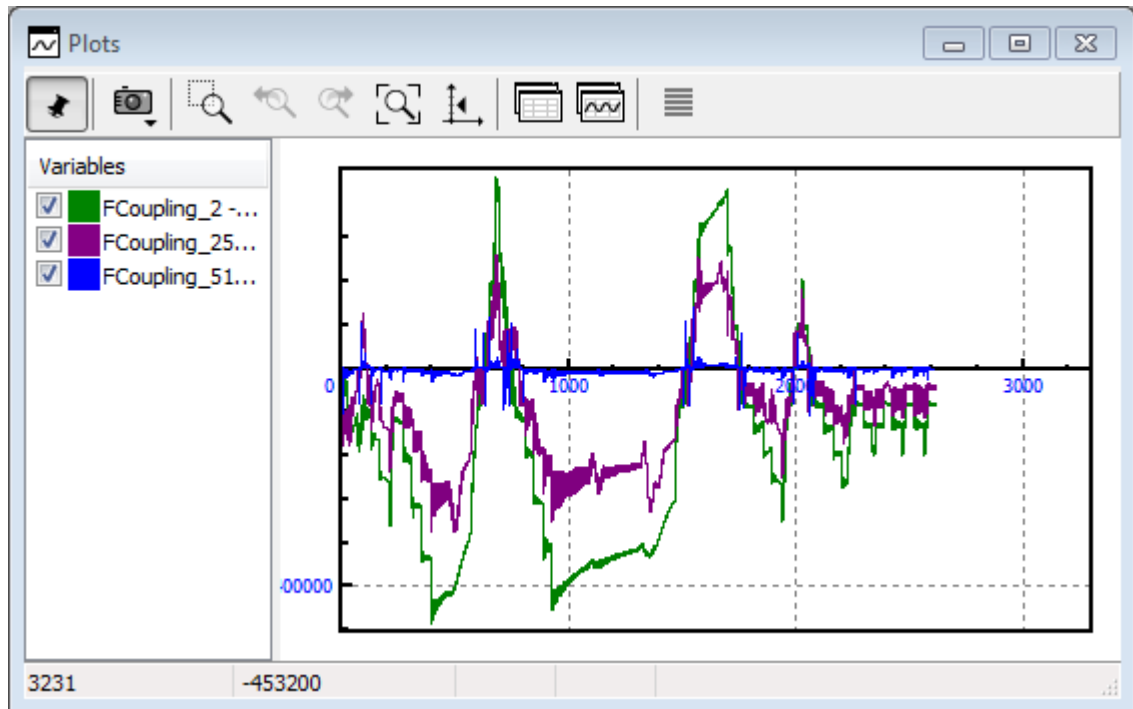


Figure 2.37. Coupling forces

References

- [1] Maksym Spiryagin, Qing Wu & Colin Cole, (2017) Longitudinal train dynamics, *Vehicle System Dynamics*, 55:4, 449-449, DOI: 10.1080/00423114.2017.1285510.
- [2] Maksym Spiryagin, Qing Wu, Colin Cole., (2017) International benchmarking of longitudinal train dynamics simulators: benchmarking questions. *Vehicle System Dynamics* 55:4, pages 450-463.
- [3] Qing Wu, Maksym Spiryagin, Colin Cole, Chongyi Chang, Gang Guo, Alexey Sakalo, Wei Wei, Xubao Zhao, Nico Burgelman, Pier Wiersma, Hugues Chollet, Michel Sebes, Amir Shamdani, Stefano Melzi, Federico Cheli, Egidio di Gialleonardo, Nicola Bosso et al., (2018) International benchmarking of longitudinal train dynamics simulators: results, *Vehicle System Dynamics*, 56:3, 343-365, DOI: 10.1080/00423114.2017.1377840.