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# User view on the Mix PROSTOR system

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**Abstract.** The system of automation of scientific research is considered in application to the problem of forecasting the development of the core transport network of Russia. Particular attention is paid to the visual and interactive presentation of modeling results. To support the simulation, stochastic methods are used, based on the massive solution of an optimization transport problem for many variable parameters.

**Keywords:** transportation problem, modeling, research automation system

## Introduction

The Mix PROSTOR system is a tool for developing solutions for the formation and development of the core transport network of Russia [1], [2]. For example,

- to analyze the impact on the development of the transport network and the transport complex of the country as a whole of possible changes in tariff policy, in the geography of the origin and destination of cargo flows, etc.;
- to determine favorable intervals for the scale of the load on the Russian transport network with different options for including it in the system of international transport corridors (ITC).

The main criterion for calculations using the model is the minimal total current costs necessary for the development of the supporting transport system at the end of the forecast period. In the generalized structure, the functionality includes four groups of terms (in the context of transport hubs and types of transport). Each of them reflects the formation of costs associated with the provision of services in a certain area of the transport process and takes into account the investment component in strengthening the regional transport complexes:

- with cargo processing directly at the hubs;
- ensuring the transportation of products between adjacent hubs;
- with the creation of additional capacities of regional transport complex facilities; and
- with the preparation of other resources necessary to strengthen the elements of regional transport complexes.

To expand the range and clarify the information justifying these results, it is necessary to perform a series of scenario calculations using the model.

Note that there are several obvious consequences of this formulation of the problem.

Firstly, the solution is optimal only “as a whole”, but for the transportation of any individual product and/or pair of hubs, the manufacturer-consumer can come up with a better solution. The solution optimizes the costs associated with the transportation of goods, rather than the income of carriers.

Secondly, the assumption that the optimality criterion used – generalized cost minimum for all participants in the transportation process – is very strong. It is assumed in advance that the full effect will be received by the end consumers, who will not have to overpay for additional transport costs. The interests of transport companies, which are often the opposite, are expected to be satisfied by the normal (average for the world economy or the economy of individual countries) profit contained in the proposed tariffs for different types of transport work: loading, unloading, transshipment, transit, and transportation itself.

**Mathematical model.** Below is a simplified version of the model implemented in the system Mix PROSTOR [3], [4], operating on the following sets**:**

*P* – multitude of all kinds of cargo;
*T* – multitude of all types of transport; and
*R* – set of all transport hubs.

Each transport shoulder is defined by the type of transport and a pair of hubs: (*t*, *r*, *r*').
Let us introduce the following notation:

- $A_r^p$ – volume of the product *p* produced in the hub *r*;
- $X_r^p$ – volume of the product *p* immersed on the transport view *t* at the hub *r*;
- $B_r^p$ – volume of the product *p* consumed in the hub *r*;
- $Y_{tr}^p$ – volume of the product *p* unloaded from the transport type *t* at the hub *r*;
- $Z_{tr}^p$ – volume of the product *p* carried in transit on *t* through the hub *r*;
- $V_{tt'r}^p$ – volume of the product *p* overloaded from the transport *t* for the transport *t*' at the hub *r*;
- $W_{tt'r}^p$ – volume of the product *p*c brought to the r-hub along the shoulder (*t*, *r*', *r*);
- $W_{trr'}^p$– volume of the product *pp* taken from hub *r* along the shoulder (*t*, *r*, *r*');
- $C_{tr}$ – transport capacity *t* at the hub *r*; and
- $P_{trr'}$ – shoulder Capacity (*t*, *r*, *r*') which takes into account shoulder transportation in both directions: $P_{trr'} = P_{tr'r}$.

The following restrictions apply to network parameters:

- on the volume of products produced in the unit and accepted by different types of transport to be loaded for export outside the unit, as well as restrictions on the volume accepted to be unloaded for the consumption inside the unit:

$$\sum_t X_{tr}^p \le A_r^p, \quad \sum_t Y_{tr}^p \ge B_r^p$$

- on the volume of the individual product type loaded, unloaded, transited and transshipped to another type of transport at the hub:

$$\sum_{r'} W_{tr'r}^p = Y_{tr}^p + \sum_{t'} V_{tt'r}^p + Z_{tr}^p, \quad X_{tr}^p + \sum_{t'} V_{tt'r}^p + Z_{tr}^p = \sum_{r'} W_{trr'}^p$$

- on the volume of products processed in the unit *r* a certain type of transport *t*

$$\sum_{p}\left(X_{tr}^{p}+Y_{tr}^{p}\right)+\sum_{p,t\prime}(V_{tt\prime r}^{p}+V_{t\prime t\prime r}^{p})\leq \mathrm{C}_{tr}$$

- on the volume of products transported on the shoulder with a given carrying capacity

$$\sum_{p}(W_{trr\prime}^{p}+W_{tr\prime r}^{p})\leq P_{trr\prime}$$

The target function of the model is the sum of the costs associated with cargo processing in transport hubs and with the transportation of goods over the shoulders

$$\sum_{t,r,p}\vec{c}_{t,r}^{p}\,X_{tr}^{p}+\sum_{t,r,p}\overleftarrow{c}_{t,r}^{p}\,Y_{tr}^{p}+\sum_{t,r,p}\breve{c}_{t,r}^{p}\,Z_{tr}^{p}+$$
$$\sum_{t,t\prime,r,p}c_{tt\prime r}^{p}V_{tt\prime r}^{p}+,\sum_{t,r,r\prime,p}\varphi_{trr\prime}^{p}l_{trr\prime}\,W_{trr\prime}^{p}\rightarrow min,$$

with the following coefficients:

- $\vec{c}_{t,r}^{p}$– loading of the product *p* for the transport *t* at the hub *r*;
- $\overleftarrow{c}_{t,r}^{p}$ – loading of the product *p* for the transport *t* at the hub *r*;
- $\breve{c}_{t,r}^{p}$ – transit of the product *p* by the transport *t* at the hub *r*;
- $c_{tt\prime r}^{p}$ – product overload *p* from the transport *t* on the *t'* at the hub *r* are specific (in terms of per unit of cargo),
- $l_{trr\prime}$ – length of the shoulder (*t*, *r*, *r'*); and
- $\varphi_{trr\prime}^{p}$ – the cost of transportation along the shoulder of a unit volume of product per unit distance.

Thus, we have a simplified formulation where the coefficients for the variables $X_{tr}^{p},Y_{tr}^{p},Z_{tr}^{p},\ V_{tt\prime r}^{p},\ W_{trr\prime}^{p}$ are considered constant, and such a problem is solved by a suitable linear programming package. The ability to vary tariffs has to be sacrificed already at this stage, since in the nonlinear case the model turns out to be unnecessarily complex to solve.

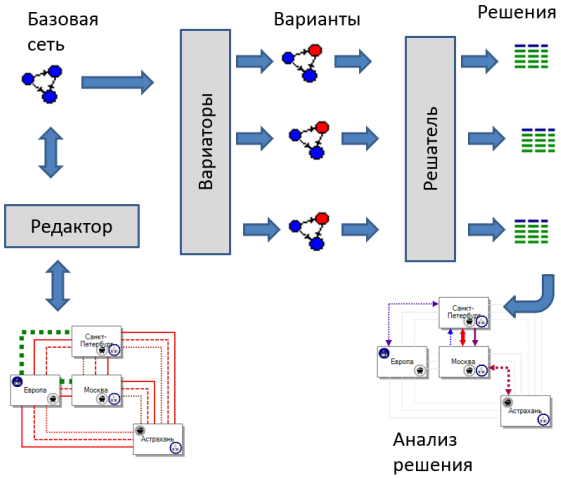


**Figure 1**. Operation scheme in the Mix PROSTOR system

**General work scenario.** Working in Mix PROSTOR is divided into several steps, depicted in Figure 1:

*Editing the description of the transport network*. At this step, a network description is created which specifies the types of transport, products, hubs, shoulders, etc. The network described is called *basic*.

*Creating a new or selecting a previously defined experiment*. Each experiment consists of varying some parameters of the core network, such as tariffs, shoulder capacity, production/consumption volumes, etc. Variations occur virtually – the basic network does not change.

*Setting experimental parameters and finding many solutions*. Parameter variation allows ranges of values. For each variable parameter, a so-called variator is specified, which indicates the boundaries of the parameter change. In the experiment, several variators can be specified. Moving on to the next step, the solver for each variation is triggered, resulting in a large number of solutions.

*Analysis of the decisions obtained*, including comparing them, finding "typical" cases, dependence on variators, etc.

## 1. General organization of the interface

The interface of Mix PROSTOR has

- the main menu;
- a toolbar containing buttons that depend on the current activity;
- a status bar that displays current state parameters such as a selected map, solution, product, and the like; and
- windows that display the transport network in various ways and allow you to determine the network and carry out calculations with it.

The Mix PROSTOR interface is organized in the form of a set of communicating windows, each of which displays information about the transport network in a special way (Figure 2).

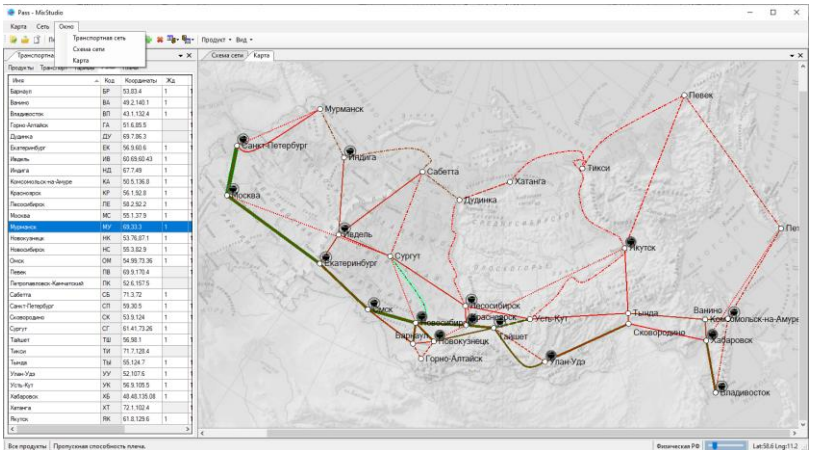


**Figure 2**. Windows in the Mix PROSTOR system

**Map** displays the transport network on a geographical map;

**Network Scheme** displays the transport network in a schematic view, where hubs are displayed as rectangles and shoulders as broken lines;

**Transport network** is the main "control panel" through which the transport network is set and experiments are carried out.

The set of visible windows and their location can be changed. In order to make a window visible, the user needs to select it through the **Window** item in the main menu. For example, **Window | Transport network**. To "hide" the window, press the cross ✕ in the upper right corner of the window.

To move a window, the user needs to "take" the window title with left mouse button or by the corresponding bookmark and start dragging the window to another place. During drag and drop, *anchor points*, which are the ultimate drag target, will appear on the screen. The view of the screen at this moment is shown in Figure 3.

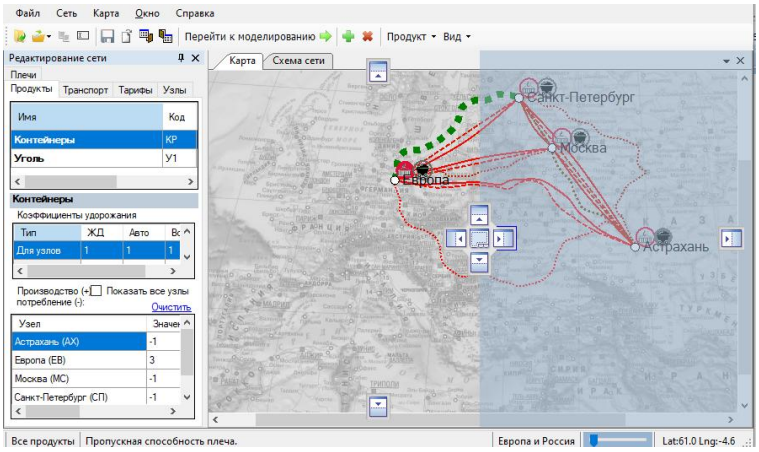


**Figure 3.** Dragging a window

## 1.1. Window "Map"

In the **Map** window, the transport network is displayed on top of the background map.

Mix PROSTOR provides several maps, the set of which depends on the specific installation and version. The currently selected map is displayed in the Mix PROSTOR status bar (Figure 4).


**Figure 4**. Display of the selected map in the status bar

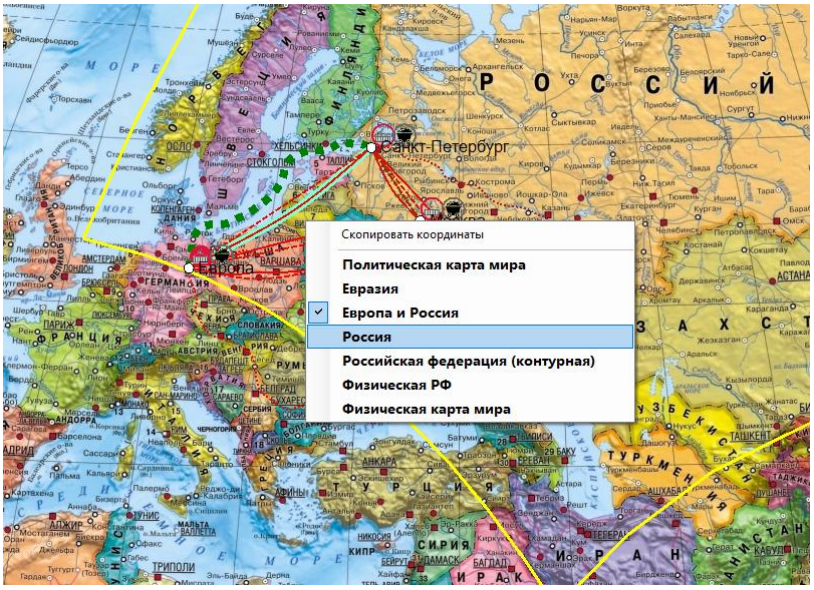


**Figure 5**. Selecting an available map in the **Map** window

You can select any of the background maps either through the **Map** item on the main menu, or by right-clicking on a point on the map, as shown in Figure 5. A list of those maps on which this point is present will appear in the drop-down menu. In this case, during the selection process, the boundaries of the map corresponding to the specified menu item will be highlighted with a yellow line.

The user can change the map scale either by rotating the mouse wheel when the **Ctrl** button is pressed or by moving the slider on the Mix PROSTOR status bar. If the selected map does not fit entirely in the window, you can move it with the left mouse button.

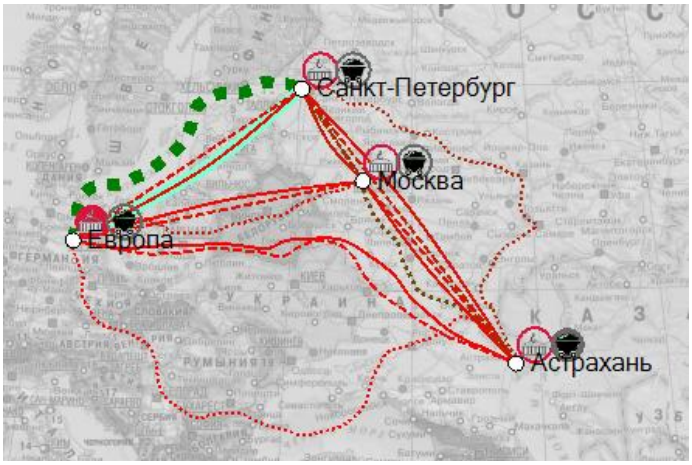


**Figure 6**. Background map in gray scale

To ensure that the information in the background does not interfere with perception, it can be made less bright. To do this, it is recommended to mark the item **Map | Shades of Gray** in the main menu. After this, the map will take the form shown in Figure 6.

This type is convenient to use after all hubs of the transport network have already been specified.

## 1.2. Window "Network Scheme"

Displaying on a map is not always convenient for the following reasons:

- if the hubs are distributed unevenly, in some part of the map the hubs can be crowded. This problem cannot be solved by changing the map scale, since other hubs go beyond the window and the map has to be constantly scrolled;
- if there are several parallel shoulders between some two hubs (for example, a railway and a road), they overlap each other. In this case, you have to artificially "push them apart".

To solve these problems, Mix PROSTOR allows you to display information in the form of a *network scheme*, where hubs can be randomly arranged to maintain an overall view of the network topology:

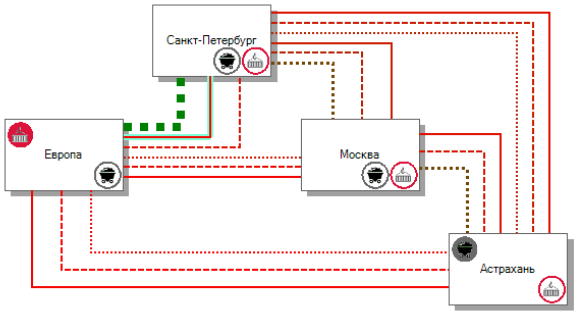


**Figure 7**. Transport network scheme

Each hub is displayed in a rectangle, inside which, in addition to the name, the products produced/consumed in this hub are indicated. Line type — dotted, dashed, etc. – reflects the type of transport. All these display elements can be specified when the transport network is described.

The location of hubs in the scheme can be changed either manually or automatically.

## 1.3. Window "Transport Network"

The **Transport Network** window provides basic tools for describing the network and making calculations. The information displayed in it depends on current activities: editing the network, setting experiments, analyzing results, etc. All these possibilities will be described below.

# 2. Editing the transport network

Mix PROSTOR provides several examples of networks that can be used both for the demonstration of the system capabilities and as templates for creating new networks. To select an existing network, the user needs to click the **Open Network Description** button on the toolbar; then select the desired network from the drop-down menu. As new networks are created, the list of available networks will be expanded. Networks can be renamed and copied, and new ones can be created.

The newly created network does not contain any hubs or shoulders. However, Mix PROSTOR defines by default several types of transport – rail, road, aviation, etc., as well as several products – containers, coal, timber, building materials, etc. If the new network does not use any of them, they can be removed, although their presence does not affect either the complexity of the problem being solved or the display of information.

Each network is represented in the file system by a separate directory that has the same name as the network. The directory must contain a net.xml. file, which stores the network description. In addition to this directory, there may be additional files that store, for example, calculation results, etc. Thus, the network operations described above in this section can be performed by operations on directories in the file system.

To describe the transport network, the user needs to go to the window **Transport Network** and change the activity to **Network editing** by clicking the required number of times on the toolbar.

In the **Network Edit** mode, the window contains the following pages:

- **Products**,
- **Transport**,
- **Tariffs**,
- **Hubs**, and
- **Shoulders**.

By filling out the information on these pages, the user will fully define the description of the transport network. Some pages may have to be visited several times and not in the order listed above. The general outline for the description of the transport network is as follows:

1. definition of the types of transport;
2. specifying hubs;
3. shoulder assignment;
4. defining a set of products;
5. task of loading/unloading products at network hubs; and
6. determination of tariffs.

## 2.1. Types of transport

Types of transport are used to define transport shoulders. The transport is identified by its one-character code, which is then used to transmit data to the solver, import/export data, and the like. To display information to the user, the full and short names of the transport are used, which (unlike the code) can be further changed. For example, for icebreaker transport you can choose the full name “Icebreaker”, short – “Ice” and code “I”.

The assignment of a new type of transport takes place on the **Transport** page. To do this, the user clicks the **Add** button on the toolbar, in the **New type of transport** dialog, enters a unique single-character type code and clicks **OK**. There, if required, the

user can change the full and short name of the type of transport, as well as select the type of line with which the shoulders using this type of transport will be displayed on the map and the network scheme.

To delete the type of transport selected on the same page, the user needs to click the **Delete** button  on the toolbar and confirm deletion by clicking **OK**.

It should be noted that deleting the type of transport removes all shoulders using it from the transport network.

### 2.2. Hubs

Each hub is identified by its two-character code, which is then used to transmit data to the solver, import/export data, and the like. To display information to the user, the name of the transport is used, which, unlike the code, can be changed in the future. For example, for a transport hub "Moscow" you can select the code "MS".

Adding hubs occurs on the **Hubs** page using the **Add** button  on the toolbar. In the **New Hub** dialog, the user needs to enter a unique two-character hub code and click **OK**. If required, the user can change the hub name. Mix PROSTOR "knows" the main cities of Russia and the capitals of other states. When you enter a name, the user can select it from the drop-down list. Next, it is recommended to set the hub **Capacity** – parameter $C_{tr}$ – having previously selected **Capacity** in the field with the list, which is located above the list of hubs.

To remove a hub from the network, the user needs to go to the page **Hubs**, select the desired hub, click the **Delete** button  on the toolbar and confirm the deletion by pressing **OK**.

It needs to be remembered that the removal of a hub removes from the transport network all the information associated with it and, in particular, all the shoulders connecting this hub to other hubs.

If Mix PROSTOR knows the name of the hub, it also knows its coordinates, filling them out automatically when editing the name of the hub. However, if this information is unavailable or erroneous, the user can correct it manually by entering the coordinates in the format "latitude, longitude". If the coordinates of the hub are unknown, their approximate values can be obtained as follows: go to the window **Map**; if the point of interest is not on the map, select the appropriate map through the item **Map** of the main menu, for example, **Map | World | Eurasia**; right-click on the point of interest and select **Copy coordinates** from the pop-up menu. The coordinates of the dot will be copied to the **Windows** clipboard. Next, the user should return, if necessary, to the transport network window, select the page **Hubs** and fill in the field in the **Coordinates** column for the desired hub in the list by inserting the contents of the clipboard by pressing **Ctrl-V** or **Shift-Insert**.

### 2.3. Shoulders

The shoulder is defined by two hubs and the type of transport. If the required hubs or type of transport have not yet been specified, they must first be specified by returning to adding hubs or adding the types of transport.

To add a shoulder on the **Shoulders** page, the user clicks the **Add** button  on the toolbar, in the **New Shoulder** dialog, selects two different hubs and type of transport, and then clicks **OK**. After this, the user needs to set the shoulder **Capacity** – parameter $P_{trr\prime}$.

Which hub is the first and which is the second does not matter from the point of view of describing the transport network and solving the optimization problem. However, in the list of shoulders they will be shown exactly in the same order in which they were indicated when the shoulder was created.

Since the coordinates of the hubs are already known, Mix PROSTOR automatically fills the field **Distance** — the parameter $l_{trr'}$, assuming that the hubs are connected along a geodesic line. The user can manually enter more realistic values. The length of the shoulder is also automatically edited when its path is specified on the map.

To remove a shoulder on the **Shoulders** page, the user selects the shoulder to delete from the list, clicks the **Delete** button  on the toolbar and confirms the deletion by pressing **OK**.

### 2.4. Products

Each product is identified by its two-character code, which is then used to transmit data to the solver, import/export data, and the like. To display information to the user, the product name is used, which (unlike the code) can be further changed. For example, for the product "Containers", you can select the code "CT".

Mix PROSTOR defines by default several products – containers, coal, timber, building materials, etc. If any of them are not used in your network, they can be removed, although their presence does not affect either the complexity of the problem being solved or the display of information.

To specify a new product on the **Products** page, the user clicks the **Add** button  on the toolbar, in the **New Product** dialog, enters a unique two-character product code and clicks **OK**. Next, if required, the user can change the name of the product. If necessary, the user may select the color to be used for this product.

Mix PROSTOR allows for choosing distinct colors for products. When all the products have already been described, the user needs to click on the list of products and press **Ctrl-U**.

To delete a product on the **Products** page, the user needs to select it, click the **Delete** button  on the toolbar and confirm the deletion by clicking **OK**.

### 2.5. Production and consumption volumes

To set production/consumption volumes — the values $A_r^p$ and $B_r^p$ used in the model — the user needs to

1. go to the page **Products**;
2. select a product from the list of products;
3. in the bottom bar, mark (check the box) **Show all hubs**;
4. in the table **Production (+) /Consumption (–),** enter the volumes, counting the positive values for production $A_r^p$, and negative for consumption $B_r^p$; at the bottom of the list is the balance, which should be positive in the end; and
5. repeat steps 3-4 until all volumes are specified.

In the list of products, the products for which volumes are specified will be highlighted in bold, and those for which the balance is negative will be highlighted in red, which means that they require correction.

## 2.6. Tariffs

Tariffs determine the coefficients in the objective function of the linear programming problem (1).

Since there are a very large number of these coefficients, entering them manually would be extremely labor-intensive. So, for example, if a network has 20 hubs, 4 types of transport and 10 products, it will be necessary to set 20 · 4 ·10 = 800 coefficients $\vec{c}_{t,r}^{p}$ alone. Mix PROSTOR solves this problem by limiting the freedom to set tariffs, allowing the user to set the so-called *basic tariff* for the type of work. Then $\vec{c}_{t,r}^{p}$ is obtained by multiplying the basic tariff by the so-called *price coefficients*. Thus, instead of 1500 coefficients, the user will need to set only 20 + 4 + 10 = 34 coefficients. Mix PROSTOR sets them to default values that can be changed if necessary.

### Processing rates in hubs

Loading the rate product *p* for the transport *t* at the hub *r* is defined as

$$\vec{c}_{t,r}^{p} = \vec{Q}_t * \gamma_t^p * \rho_{tr,}$$

where

$\vec{Q}_t$ is the basic tariff for loading on transport *t*;

$\gamma_t^p$ is the appreciation factor for the product processing *p* by the transport *t*; and

$\rho_{tr}$ is the coefficient of increase in the cost of the transport processing *t* at the hub *r*.

For unloading and transit, tariffs are determined similarly.

To set the base tariff $\vec{Q}_t$ to load onto transport on the **Tariffs** page, the user needs to enter the tariff value in the table **Types of work** in the **Loading** line.

To set the price increase coefficient $\gamma_t^p$ for loading the product *p* for the transport *t* on the **Products** page, the user needs to select a product *p* in the list of products, select **Hubs – price increase coefficient** in the drop-down list located above the list of products, and fill out the cell corresponding to the transport *t*.

The coefficient $\rho_{tr}$ - the price increase of the transport processing *t* at the hub *r* – can be set on the **Hubs** page by selecting **Price coefficients** in the drop-down list located above the list of the hubs. Next, the user should select the desired product type in the product list, in the column corresponding to the transport *t* and enter the coefficient value.

### Transportation rates by shoulder

Transportation tariff for the product *p* on the shoulder (*t, r, r*') over a distance of 1 km is defined as

$\varphi_{trr'}^{p} = S_{trr'} \cdot \theta_t^p$,

where

$S_{trr'}$ is the basic tariff for transport on the shoulder (*t, r, r*') over a distance of 1 km, and

$\theta_t^p$ is the price coefficient for the transportation of the product over the shoulders *p* transport *t*.

To set the base tariff $S_{trr'}$ for the shoulder (*t, r, r*') for a distance of 1 km on the **Shoulders** page, the user needs to select the required shoulder and enter the tariff value in the column **Tariff (Rub/km).**

To set the price increase coefficient $\theta_t^p$ for the transport over the shoulders of the product *p* transport *t* on the **Products** page, the user needs to select a product *p*. In the

drop-down list located above the list of products, the user needs to select **Shoulders – price coefficient** and fill in the cell corresponding to the transport *t*.

### 2.7. Location of hubs and shoulders

After setting the coordinates of the hubs, Mix PROSTOR automatically places hubs on the map and on the network scheme. However, the shoulders on the map are displayed in straight lines, so if there are several shoulders between two hubs corresponding to different types of transport, they overlap each other. Also, the location of hubs in the network scheme may not be the best, which causes the shoulders to intersect with each other and the hubs. Mix PROSTOR makes it possible to eliminate these drawbacks to a large extent in the manual mode.

When setting a path, you can draw a line from the first hub to the second or vice versa.

Changing the path automatically changes the length of the shoulder. If necessary, the user can correct it by changing the value in the column **Distance (km).**

Mix PROSTOR automatically places hubs on the network scheme when changing from coordinates. The hubs are placed on the grid so that they are aligned both horizontally and vertically.

Generally, a good layout of hubs in the network scheme is a very difficult task, due, in particular, to the subjectivity of the concept "good". Mix PROSTOR implements heuristic method for placing hubs, which seeks to provide the following conditions:

- hubs should have different coordinates in the network scheme;
- if one hub has geographic coordinates north of the other hub, then on the network scheme the first hub should be at least as high as the second; the same goes for other directions; and
- lines corresponding to the shoulders should not intersect firstly the rectangles of hubs and secondly other lines.

To call automatic placement, the user needs to press **Ctrl-U**.

The user can then correct the location by simply dragging the hubs from one place to another. Moreover, if a free row (column) is formed in the grid, it collapses automatically. Dragging a hub with the **Shift** button pressed moves along with the hub everything that is no higher than it (below, right, left), depending on the direction of dragging.

## 3. Conducting an experiment

The next step after setting the core network is the description of *experiments*. Each experiment consists of some varying parameters of the core network, such as tariffs, shoulder capacity, production/consumption volumes, etc. Variations occur virtually – the core network does not change.

In order to move on to experiments, the user needs to press the **Go to modeling** button  on the toolbar. The **Transport Network** window will display a list of experiments already specified, which is initially empty, of course.

### 3.1. Calculation of the basic option

In the simplest case, the experiment does not contain any variators and you just need to find a solution for the core network. To do this, the user needs to create a new experiment by clicking the **Create...** button  on the toolbar and selecting **Stochastic experiment**

from the drop-down menu. Next, the user needs to enter the name of the experiment, for example, **Basic** and click **OK**. An element named **Basic** with the icon  will appear in the list of experiments. The user should select a new item in the list by clicking on it with the mouse button, then click the **Select Experiment** button on the toolbar, and then click the **Show Solutions** button on the toolbar.

At this point, the solver starts and finds a solution to the transport problem, if it exists. After that, the user can proceed to analyze the resulting solution.

### 3.2. Creating an experiment

Mix PROSTOR supports two types of experiments, differing in the way values are selected:

***An enumeration experiment***, denoted by the icon  , assumes that the ranges of all variators are divided into the same number of segments, and when the next set of values is chosen, the value in each interval increases by the corresponding step. This is useful if the selected parameters are to increase synchronously. For example, let the task be to vary transportation tariffs along the Trans-Siberian Railway, which is represented in the model by the three shoulders: "Moscow-Novosibirsk", "Novosibirsk-Taishet", and "Taishet-Vladivostok". Let an interval of transportation tariff $S_{trr'}$. be defined for each of these shoulders Then the enumeration will begin with the minimum values in all the three ranges and end with the maximum values.

***A Stochastic experiment***, denoted by the icon  , assumes, in contrast, that the parameters chosen for variation are not related. Essentially, each parameter can be considered to correspond to some dimension in multidimensional space, and the search consists of randomly selecting a given number of points in the parallelepiped, the dimensions of which are determined by the ranges of variators.

To create an experiment, the user needs to click the **Create** button...  on the toolbar and select the desired type of experiment from the drop-down menu. Then the user needs to enter the name of the experiment, for example, **Trans-Siberian Railway – tariff** and click **OK**. An element with the corresponding icon will appear in the list of experiments. The user needs to select a new element in the list by clicking on it with the mouse button, and then click the **Select Experiment** button on the toolbar. In the text field, **Number of solutions**, the user needs to indicate the number of options that he/she plans to create. (This value is subject to change at a later date.)

### 3.3. Setting the variator

Mix PROSTOR allows the user to vary the following network settings.

<u>for hubs</u>

$A_r^p$ , $B_r^p$ – volume of the product *p* produced/consumed in the hub *r*;

$C_{tr}$ – transport capacity *t* at the hub *r*;

$\gamma_t^p$ – price coefficient for the product processing *p* by the transport *t*;

$\rho_{tr}$ – price coefficient for the cost of the transport processing *t* at the hub *r*;

<u>for shoulders</u>

$S_{trr'}$ – basic tariff for the transport on the shoulder (*t*, *r*, *r*') over a distance of 1 km;

$P_{trr'}$ – shoulder Capacity (*t*, *r*, *r*');

$\theta_t^p$ –price coefficient for the transport over the shoulders of the product *p* transport *t*.

To determine the experiment variators, the user needs to select them in the list of experiments and go to the step **Editing variators** by clicking the **Selecting an experiment** button on the toolbar.

When specifying any type of a variator, the user needs to set the range of values of the corresponding parameter. To do this, the user needs to fill out a cell in the **Range** column. When creating a variator, this cell is filled with the parameter value specified in the core network.

The range is specified by a pair of values – initial and final — through a dash, for example,

-20–20, – 1.5 - -1.2, -5 – -10.

If the initial and final values coincide, you can simply indicate this value as a range.

### 3.4. Variators for the hub

Let, for certainty, the hub *r* be "Taishet", the transport *t* be "Railway", and the product *p* be "Coal".

**Production-consumption.** The production (consumption) $A_r^p$ ( $B_r^p$) at the hub *r* can be set in two ways:

*Method 1*. In the window **Network Scheme**, right-click on the required hub, for example, **Taishet**, select **Loading/Unloading | Coal** from the drop-down menu. A new element corresponding to the new variator will appear in the **Transport Network** window. To do this, the user needs to fill in a range of values. As usual, positive values correspond to production and negative, to consumption. For example, the range **-20 – 10** means that the variants will vary from the case where 20 units of product are consumed in a hub to the case where 10 units of product are produced.

*Method 2*. Click the **Create...** button on the toolbar and select **Taishet | Loading/Unloading | Coal** from the drop-down menu, then fill in the range of values in the same way as in method 1.

**Capacity**. There are two ways to set the hub capacity variator $C_{tr}$:

*Method* 1. In the window **Network scheme** right-click on the required hub, select from the drop-down menu **Capacity | Railway**. A new element corresponding to the new variator will appear in the **Transport Network** window. To do this, the user needs to fill in a range of values.

*Method* 2. Press the button **Create...** on the toolbar and select **Taishet| Capacity | Railway** from the drop-down menu, then fill in the range of values.

**The price coefficient for product processing.** Mix PROSTOR doesn't allow for setting the variator price increase coefficient $\gamma_t^p$ for a specific product, but only for all the products and specific type of transport. To do this, the user needs to press the button **Create...** on the toolbar and select **Railway |Increase in price for hubs** from the drop-down menu and set range values.

**The price coefficient for transport processing**. The variator of the coefficient of increase in the cost of transport processing $\rho_{tr}$ at the hub can be set in two ways:

*Method* 1. In the window **Network Scheme**, right-click on the required hub, select **Rise factor /Railway** from the drop-down menu. A new element corresponding to the new variator will appear in the **Transport Network** window. To do this, the user needs to fill in a range of values.

*Method* 2. Press the button **Create...** on the toolbar and select **Taishet| The coefficient of appreciation | Railway** from the drop-down menu, then fill in the range of values.

### 3.5. Variators for the shoulder

Let, for certainty, the hub *r* be "Taishet", the transport *t* be "Railway", and the product *p* be "Coal".

**Capacity limitation**. The capacity variator $P_{trr'}$ for the shoulder *(t,r,r')* can be set in two ways**:**

*Method* 1. In the window **Network Scheme** the user needs to right-click on the required shoulder and select from the drop-down menu **Taishet-Krasnoyarsk (Railway) | Capacity**. A new element corresponding to the new variator will appear in the **Transport Network** window. Then the range of values needs to be filled.

*Method* 2. Press the button **Create...** on the toolbar and select **Taishet | Taishet-Krasnoyarsk (Railway)|Capacity** from the drop-down menu, then fill in the range of values.

**Tariff.** There are two ways to set a variator of the basic transportation tariff $S_{trr'}$ on the shoulder:

*Method* 1. In the window **Network Scheme**, the user needs to right-click on the required shoulder and select from the drop-down menu **Taishet-Krasnoyarsk (Railway) | Tariff**. A new element corresponding to the new variator will appear in the **Transport Network** window. The user needs to fill in the range of values.

*Method* 2. Press the button **Create...** on the toolbar and select **Taishet | Taishet-Krasnoyarsk (Railway) | Tariff** from the drop-down menu, then fill in the range of values.

**Coefficient for transportation over shoulders.** Mix PROSTOR doesn't allow for setting a variator for the price coefficient $\theta_t^p$ that specifies the price for transporting the product over the shoulders *p* by the transport *t.* Instead, the price coefficient applies to all products and specific type of transport. The user needs to click the **Create...** button on the toolbar and select **Railway | Shoulder Increase** from the drop-down menu, and then fill in the range of values.

### 3.6. Calculation of variants

Before calculating the variants, the user needs to make sure that the desired value is entered in the **Number of solutions** field. The value of this field will be ignored if all variators define a range from a single value.

To calculate options, the user needs to click the **Show solutions** button on the toolbar. Computing may take some time. In order not to repeat the calculations many times, Mix PROSTOR remembers the results obtained, and when this step is performed

again, it does not repeat the calculations. This may be essential for a stochastic experiment in which repeated calculations will lead to a random selection of the new values of variable parameters.

Evidently, with any changes in the core network or in the description of the experiment, the calculations will be carried out anew.

## 4. Analysis of results

When the user proceeds to the step of analyzing the results in the window **Network Scheme**, the shoulders are displayed according to the selected method, which can correspond to the volume of transportation, load of the shoulder, percentage of the use of the shoulder in all solutions received, etc.

The window **Transport network** contains four pages:

1. **List of solutions** lists all solutions specifying the values of the variable parameters and the values of the objective function;
2. **Clusters** are groups decisions based on their similarity, indicating the number of decisions in each group;
3. **Shoulders** page provides complete information about all the shoulders of the transport network for the currently selected solution; and
4. **Correlation of roads**.

### 4.1. Shoulder display method

The method for displaying the shoulder can reflect either the characteristic of the shoulder in the selected solution, for example, the total volume of transportation for a given shoulder, or the average value for all solutions.

The display may depend on whether a particular product is specified. To select a product to display, click the **Product** button on the toolbar and select the desired product or **(all products).**

To select a display method, the user needs to click the **View** button on the toolbar and select the desired display type. Some display types may not be available. For example, **Average volume** does not make sense if there is only one solution.

The number of the current solution, the selected product and the display method are shown on the Mix PROSTOR status bar (Figure 8):

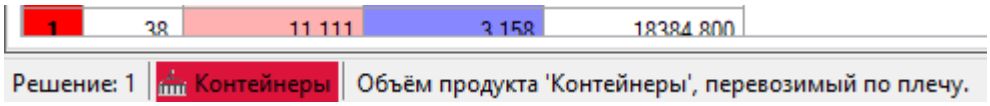


**Figure 8**. Display the current solution in the status bar

A list of mappings implemented in Mix PROSTOR is shown in Table 1.

Here

$N$ is the number of solutions;

$L^p_{tr'r} = W^p_{tr'r} + W^p_{trr'}$ is the volume of the product $p$ “shouldered” in both directions;

$\bar{v}$ is the vector of values of the selected variator for all solutions;

*avg* is the average of all solutions;
*count* is the number of solutions with a given property; and
*corr* is the correlation of two dimension vectors *N*.
The meaning of the other variables is described in the *Mathematical model* section.

**Table 1.** A list of mappings implemented in Mix PROSTOR

| Display name | Value at selected product $p$ | Value at (all products) | Color min. | Color max. |
|---|---|---|---|---|
| Capacity | $P_{trr'}$ | $P_{trr'}$ | | |
| Volume | $L^p_{tr'r}$ | $\sum_p L^p_{tr'r}$ | | |
| Average volume | $avg(L^p_{tr'r})$ | $avg(\sum_p L^p_{tr'r})$ | | |
| Basic price per 1 km | $\varphi^p_{trr'}$ | | | |
| Price per 1 km | $\varphi^p_{trr'} * (L^p_{tr'r})$ | $\sum_p \varphi^p_{trr'} * L^p_{tr'r}$ | | |
| Average price per 1 km | $avg(\varphi^p_{trr'} * L^p_{tr'r})$ | $avg(\sum_p \varphi^p_{trr'} * L^p_{tr'r})$ | | |
| Usage (%) | $\frac{count(L^p_{tr'r} \neq 0)}{N}$ | $\frac{count(\sum_p L^p_{tr'r}) \neq 0)}{N}$ | | |
| Workload | | $\frac{\sum_p L^p_{tr'r}}{P_{trr'}}$ | | |
| Average workload | | $avg(\frac{\sum_p L^p_{tr'r}}{P_{trr'}})$ | | |
| Dependence on the variator... | $corr(\overline{L^p_{tr'r}}, \bar{v})$ | $corr(\overline{\sum_p L^p_{tr'r}}, \bar{v})$ | | |

Also note that
- shoulder capacity is independent of the product;
- the base price per 1 km is taken based on the core network, not on a specific solution;
- workload and average workload do not make sense for an individual product.

### 4.2. List of solutions

The page **List of solutions** provides information about all solutions received. An example of such a page is shown in Figure 9.

When you select a solution in the list, it becomes current – this is what is displayed on the map, network scheme, etc. The first column indicates the cluster (i.e., a group of similar solutions) to which this solution belongs. For each solution, the list contains the values of the variators and the objective function. The table can be ordered by clicking with the mouse on the column headings.

If in the column **Total freight price** (the value of the objective function) we have 0 in the list of solutions, this means that no solutions have been found for this option. The main reasons may be the following: either the network is disconnected, or there is a negative production/consumption balance for some product, or insufficient shoulder capacity is specified, or the solver does not have enough resources to find a solution.

| Клас | # | Москва (Контейнеры) - Производство | Европа (Контейнеры) - Производство | Санкт-Петербур (Контейнеры) - Производство | Астрахань (Контейнеры) - Производство | Суммарная цена перевозки |
|---|---|---|---|---|---|---|
| 5 | 1 | -3.249 | 21.056 | -3.419 | -2.938 | 8538.362 |
| 1 | 2 | -2.831 | 29.654 | -1.435 | -3.460 | 7618.439 |
| 5 | 3 | -2.838 | 45.880 | -4.057 | -2.827 | 8543.689 |
| 2 | 4 | -4.117 | 34.700 | -1.809 | -4.852 | 9903.149 |
| 1 | 5 | -3.641 | 23.230 | -1.060 | -2.648 | 7182.156 |
| 6 | 6 | -3.766 | 26.556 | -2.890 | -1.852 | 7584.505 |
| 8 | 7 | -4.732 | 44.547 | -2.949 | -2.721 | 9094.171 |
| 8 | 8 | -4.799 | 33.163 | -3.028 | -2.194 | 8715.095 |
| 5 | 9 | -1.978 | 40.467 | -4.725 | -2.845 | 8400.870 |
| 2 | 10 | -4.682 | 47.726 | -4.417 | -4.087 | 11120.092 |
| 3 | 11 | -1.307 | 23.210 | -2.486 | -3.078 | 6917.527 |
| 2 | 12 | -3.873 | 42.721 | -4.804 | -3.908 | 10589.132 |
| 2 | 13 | -4.552 | 15.247 | -4.627 | -4.273 | 11309.512 |
| 2 | 14 | -4.458 | 39.184 | -4.953 | -4.570 | 11691.667 |
| 1 | 15 | -2.419 | 36.287 | -3.207 | -2.208 | 7241.203 |
| 4 | 16 | -1.378 | 26.254 | -3.661 | -4.914 | 9281.632 |
| 1 | 17 | -3.444 | 33.704 | -1.849 | -3.027 | 7848.191 |
| 1 | 18 | -3.025 | 24.062 | -1.171 | -3.381 | 7518.831 |
| 2 | 19 | -4.643 | 41.485 | -2.342 | -4.704 | 10466.563 |
| 4 | 20 | -2.194 | 16.643 | -2.980 | -3.900 | 8493.447 |
| 4 | 21 | -1.820 | 23.397 | -3.169 | -4.827 | 9200.579 |
| 2 | 22 | -3.298 | 25.900 | -2.737 | -4.742 | 9804.379 |
| 3 | 23 | -2.137 | 48.647 | -1.427 | -3.114 | 6867.891 |
| 5 | 24 | -3.054 | 30.674 | -3.710 | -2.593 | 8271.238 |

**Figure 9**. Page **List of solutions**

If the first option is quite easy to determine by analyzing the network layout visually, the reasons for the second and third cases may not be obvious because both production and overhead capacity can be variable values.

Mix PROSTOR allows you to determine the cause based on the analysis of the solver input data. To do this, the user needs to select a problematic solution and press the button **Why is there no solution?** on the toolbar. In case of a negative balance of production, the answer may appear as shown in Figure 10.

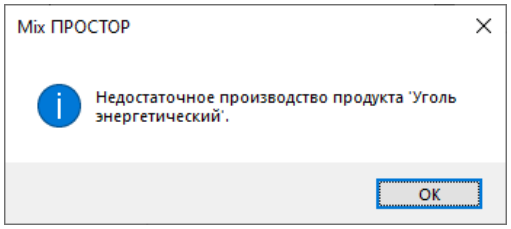


**Figure 10**. Determining the reason why no solution has been found

To determine insufficient Capacity, Mix PROSTOR solves an optimization problem to find the minimum (from some point of view) expansion of shoulder capacity such that a solution exists. The answer may look, for example, as shown in Figure 11.

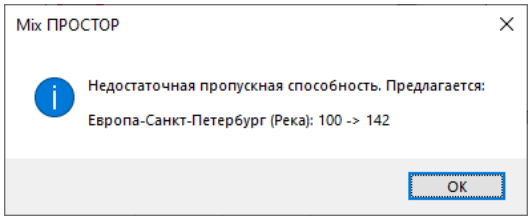


**Figure 11**. Proposing a system to eliminate insufficient shoulder capacity

### 4.3. Clusters

If the number of variants and, accordingly, solutions is in the tens and hundreds, their manual comparison turns out to be very difficult. Mix PROSTOR uses clustering methods to break down the entire set of solutions into groups (*clusters*), consisting of solutions similar to each other. The initial data for clustering are vectors from the values of the variables of the transport network model, which makes it possible to determine the similarity of solutions, for example, as the cosine distance between their corresponding vectors. Mix PROSTOR limits the maximum number of clusters to 8.

Each cluster is automatically assigned some color, which is used to visualize whether the solution belongs to this cluster. For each cluster, Mix PROSTOR finds the *typical representative* as the closest to the average solution with respect to the cluster.

The page **Clusters** contains a table listing the clusters. An example of such a table is given in Figure 12.

| # | Решен в класте | Москва (Контейнеры) - Производство | Европа (Контейнеры) - Производство | Санкт-Петербур (Контейнеры) - Производство | Астрахань (Контейнеры) - Производство | Суммарная цена перевозки |
|---|---|---|---|---|---|---|
| 1 | 21 | -4.095 | 30.037 | -3.679 | -4.141 | 10341.923 |
| 2 | 20 | -2.541 | 34.580 | -2.523 | -2.033 | 6770.861 |
| 3 | 18 | -1.746 | 31.525 | -1.795 | -1.915 | 5753.670 |
| 4 | 16 | -2.615 | 35.029 | -2.142 | -4.387 | 8718.783 |
| 5 | 14 | -3.713 | 34.736 | -2.774 | -2.037 | 7672.230 |
| 6 | 11 | -4.259 | 26.989 | -3.860 | -2.169 | 8770.301 |

**Figure 12**. Clusters

The second column indicates the number of solutions in each cluster. The remaining columns show the values of the variator parameters and objective function for the typical representative.

When you select a cluster in the list, its typical representative becomes the current solution, which is displayed on the map, network scheme, etc.

The column headings and corresponding variators depict graphs of the distribution of solutions in the variator range. For example, the graph shown in Figure 13 means that in the "blue" cluster most solutions have the variator value **Moscow (Containers) – Production** close to the maximum, less – close to the middle, and very little – close to the minimum.


**Figure 13**. Graphs of solutions distribution in the variator range

Mix PROSTOR supports spatial visualization of the distribution of multiple solutions – two- or three-dimensional. Each point corresponds to a certain solution; its color shows belonging to the cluster.

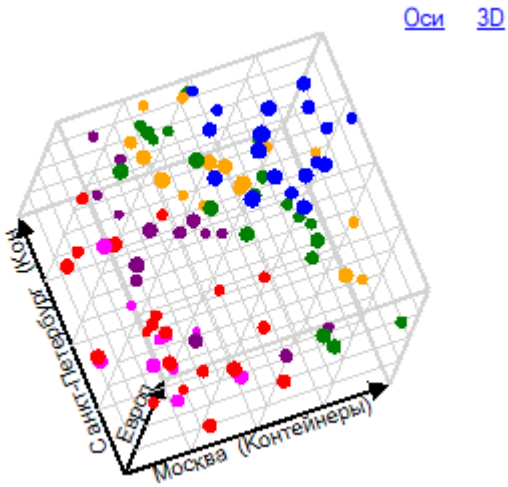


**Figure 14**. Three-dimensional spatial visualization of the distribution of multiple solutions

Figure 14 provides an example of such imaging. The top right corner displays the current visualization dimension – 2D or 3D. In order to change the dimension, the user needs to click on this "link". If you click on the **Axis**, you can select two or three variators that are of interest.

It is possible to twist the cube with the mouse. You can click on a point in a cube to make the solution corresponding to that point current – it appears on the network scheme and on the map.

### 4.4. Shoulders

Transport volumes by shoulder for the current solution – values of the variables $W^{p}_{tr,r}$ and $W^{p}_{trr'}$ — for each shoulder (*t*, *r*, *r*'), as well as other shoulder characteristics, can be found on the page **Shoulders** (Figure 15).

Essentially, the table gives, for each shoulder, the values of all the methods provided by Mix PROSTOR in which the shoulders are displayed. In this case, colors are also determined according to the specific display method.

The table content changes when the current solution or current product changes. The table can be ordered by clicking on the column headings with the mouse.

| Плечо | Вид трансп | Пропуск способн | % использ | Средний объём | Объём | Сред. цена за 1км. | Цена за 1км. | Сред. загруже | Загруже | Зависим от Москва (Контей | Зависим от Европа (Контей | Зависим от Санкт-П (Контей | Зависим от Астраха (Контей |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Европа-Санкт-Петер... | Вода | 46.00 | 100.00 | 9.93 | 10.61 | 1.99 | 2.12 | 0.22 | 0.23 | -0.55 | 0.03 | -0.64 | -0.50 |
| Европа-Санкт-Петер... | Авто | 1.00 | | | | | | | | | | | |
| Европа-Москва | Вода | 4.00 | | | | | | | | | | | |
| Европа-Москва | ЖД | 2.00 | | | | | | | | | | | |
| Европа-Москва | Авто | 1.00 | | | | | | | | | | | |
| Европа-Астрахань | Вода | 1.00 | | | | | | | | | | | |
| Европа-Астрахань | ЖД | 1.00 | | | | | | | | | | | |
| Европа-Астрахань | Авто | 1.00 | | | | | | | | | | | |
| Санкт-Петербург-Мо... | Вода | 15.00 | 24.00 | 0.12 | | 0.01 | | 0.01 | | -0.68 | 0.11 | | 0.02 |
| Санкт-Петербург-Мо... | ЖД | 7.00 | 100.00 | 4.00 | 3.94 | 0.40 | 0.39 | 0.57 | 0.56 | 0.15 | | | -1.00 |
| Санкт-Петербург-Мо... | Авто | 5.00 | 100.00 | 3.83 | 4.25 | 0.77 | 0.85 | 0.77 | 0.85 | -0.98 | 0.08 | | 0.17 |
| Санкт-Петербург-Ас... | Вода | 7.00 | | | | | | | | | | | |
| Санкт-Петербург-Ас... | ЖД | 5.00 | | | | | | | | | | | |
| Санкт-Петербург-Ас... | Авто | 3.00 | | | | | | | | | | | |
| Москва-Астрахань | Вода | 15.00 | 100.00 | 4.00 | 3.94 | 0.80 | 0.79 | 0.27 | 0.26 | 0.15 | | | -1.00 |
| Москва-Астрахань | ЖД | 4.00 | | | | | | | | | | | |
| Москва-Астрахань | Авто | 3.00 | 100.00 | 2.00 | 2.00 | 0.60 | 0.60 | 0.67 | 0.67 | | | | |
| Европа-Санкт-Петер... | ЖД | 3.00 | | | | | | | | | | | |

**Figure 15**. Page view **Shoulders** for the current solution

## 4.5. Correlation of roads

From the resulting set of solutions, it is possible to calculate the correlation between the individual shoulders, displayed on the page **Road correlation** in the form of the matrix shown in Figure 16.

A positive correlation, displayed in red, means that an increase in the volume transported along the first shoulder is associated with an increase along the second shoulder. This may indicate the presence of transport corridors.

A negative correlation displayed in blue can mean alternative routes – transportation is carried out along one of them.


**Figure 16**. Shoulder correlation – transport corridors

## 5. Export/import of data

The transport network description can be saved in the MS Excel (xlsx) format. To save a network description, the user needs to return to editing the network by pressing the appropriate number of times on the arrow on the toolbar, then clicking the **Export** button in the toolbar, selecting the file to save data to and clicking the **Save** (button **Save**).

The saved file has a strictly defined structure. It contains several pages:

- **Products**,
- **Transport**,
- **Tariffs**,
- **Hubs**, and
- **Shoulders**.

Each page contains the information specified when the network was edited. If the network structure is saved and only the values in the tables have been changed, the file can be uploaded back to Mix PROSTOR to the current network. To do this, the user needs to click the **Import** button on the toolbar, select the file to download and click the **Open** button.

Each calculated Mix PROSTOR variant has its own parameters, which can be found by going to the step **Analysis of results**. Sometimes it is useful to obtain input data for a solver corresponding to a specific option, for example, in order to try to feed it to another solver. Currently, Mix PROSTOR uses for this purpose the Google OR solver [5].

There are several standard formats for describing a linear programming problem, such as

1. LP format based on the algebraic notation of the problem [6],
2. MPS format based on the representation of the problem in the matrix form [7].

To save an option, the user needs to go to the step **Analysis of results**, select the page **List of solutions,** select the desired solution in the list, and click the **Save solution** button on the toolbar. In the **Save As** drop-down list, the user needs to select either **Solution** to save information about the received solution for all network shoulders in the xlsx format, or **LP-file** to save the description of the linear programming problem in the LP format, or **MPS-file** to save the description of the linear programming task in the MPS format. Next, the user needs to enter the file name and click the **Save** button.

## Conclusion

The user tools within the Mix PROSTOR transport network development forecasting system cover the entire cycle of conducting experiments, from defining the network and setting parameter ranges to analyzing results. Data exchange with other systems, such as the Optimization Inter-Sector Interregional Model (OIIM) [8], is crucial for serving as input sources and creating tools for comprehensive analysis, where the transport problem is only a component part.

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