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The use tensor method of dual networks for analysis of the transport and tourist components of sustainable development of territories

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Abstract. The article explores the possibility of applying tensor method of dual networks for analysis of transport and tourism components in sustainable development of territories. The tensor method of dual networks, in contrast to other methods allows to consider the structure of the large-scale intelligence system and the processes occurring in it as one whole. Thus, we have the possible to complex analyze all the components of a large-scale system even when its structure, the number of its elements and the connections between them will be changed. Tensor equations make it possible to accurately calculate the parameters of a system when simulating various ways of connecting its elements. On the example of the analysis of the tourist transport system, the advantages of using the method of double networks to assess the impact of the system on the sustainable development of the territory are shown.

1 Introduction

Sustainable development is one of the most important factors in the modern world SDG (Sustainable Development Goals) indicators are used to assess the sustainable development of the territory, for which the Sustainable Development report is drawn up. Tourism is closely related to economic, social and other indicators [1]. As we can see the indicator SDG 3 (Good health and well-being) or indicators SDG 6 (clean water and sanitation), SDG7 (affordable & clean energy), SDG 8 (decent work and economic growth), SDG 9 (industry, innovation & infrastructure), SDG 11 (sustainable cities & communities), SDG 13 (climate action), etc. We see a strong spheres relationship between tourism and many of the indicators that are included in the Sustainable Development Goals, depicted in Fig. 1.

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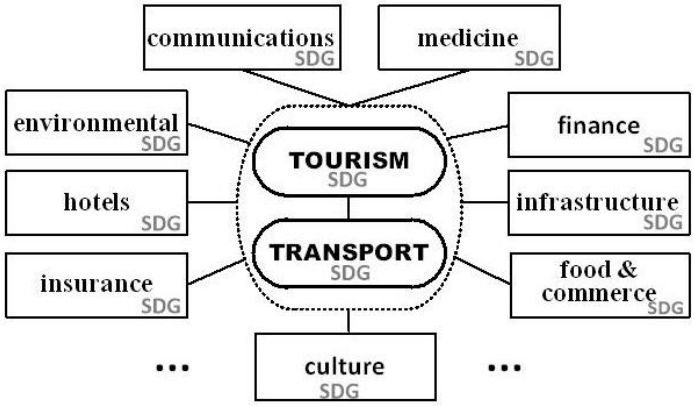

Fig. 1. SDG: tourism, transport & other spheres

In the SDG9 and SDG11 indicators we see the transport component. Transport is an important part of the infrastructure of any territory. And, of course, it is an important factor for the development of tourism in this territory. Tourism is associated with air transport, water transport, land transport and others [2][3]. Together with tourist flows, transport forms a complex system (see Fig 2).

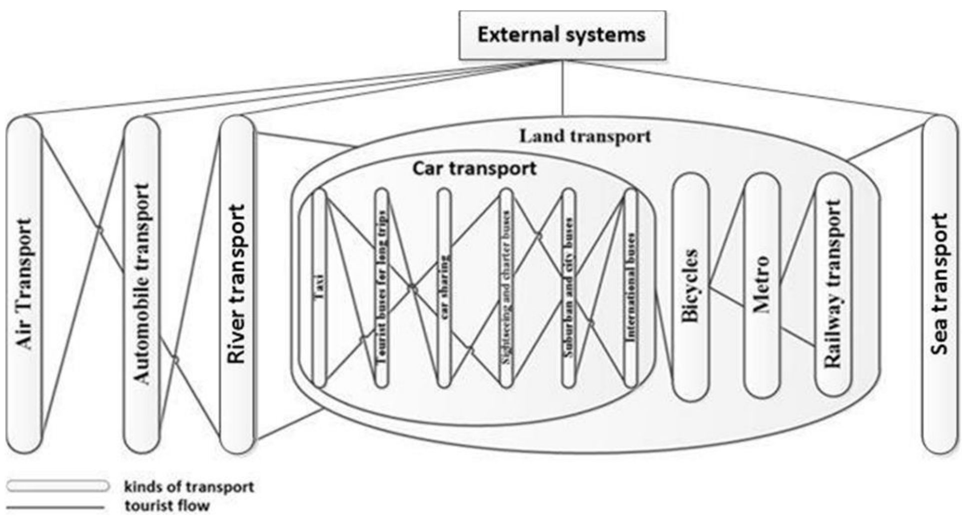

Fig. 2. Transport and tourist flows

This system has a complex structure [4] and a large number of parameters (passenger turnover, traffic volume [5], cost of traffic, number of traffic, network density, route coefficient, coefficient of straightness of the route network, transfer coefficient, passenger time spent on travel, etc.). Calculation and analysis of all parameters of the system optimization of connections between the components of the system and external connections when changing the structure is a complex computational task. To solve it, you can use parallel computing. But even in this case, we do not have the opportunity to combine the structure of the system and the processes in the system in a mathematical model [6][7][8]. To solve this problem, you can apply the tensor method of dual networks [9]. Consider the advantages of using this method to analyze the sustainability of a complex system that combines transport and tourism.

2 Tensor method of dual networks

Let us imagine that this system is a projection of some abstract system in a specific coordinate system, where the coordinates are the connections between the elements of the system [4]. Then we get the network in Fig. 3.

This network consists of:

Elements - kind of transport. Each element has an entrance and an exit.

Processes - tourist flow, resources flow. The tourist flow can be main or intermediate. The main tourist flow is twofold. At the entry of the element, it determines the flow of tourists who have switched from other modes of transport. At the output of an element, this is a flow as a result of the pooling of resources and the flow of tourists who have switched from other modes of transport. Intermediate tourist flow - the flow of tourists between modes of transport.

Resources - this is what comes from the external environment and is necessary to ensure the transport of tourists. Resource 1 (Res1) – people, Resource 2 (Res2) - technics.

Plan - planned tourist flow.

Legend :

A, **B** – number of transport (1 - Air Transport, 2 - Automobile transport, 3 - Water transport, 4 - Land transport, 5 - International buses)

$\mathbf{r^{kA}}$ – resource k for the transportation of one tourist by transport A, k – resource number (1 or 2 in our example)

Res1 – resource 1

Res2 – resource 2

$\mathbf{res^{kA}}$ – the coefficient that determines the amount of resource k for the transportation of tourists by transport A

$\mathbf{T_A}$ – tourist flow for A

$\mathbf{T^A}$ – result of merging the tourist flow for A and resources for A

$\mathbf{T_B}$ – flow of tourists who changed transport A to other types of transport

$\mathbf{pl_{AB}}$ – planned flow of tourists transport n

$\mathbf{t^{AB}}$ – coefficient of distribution of the tourist flow from transport A relative to the tourist flow of transport B

$\mathbf{tour_{AB}}$ – the number of tourists from transport A, who changed transport A to transport B.

Superscript - a variable affects the value of another variable.

Subscript - the variable is a response to the influence of another variable.

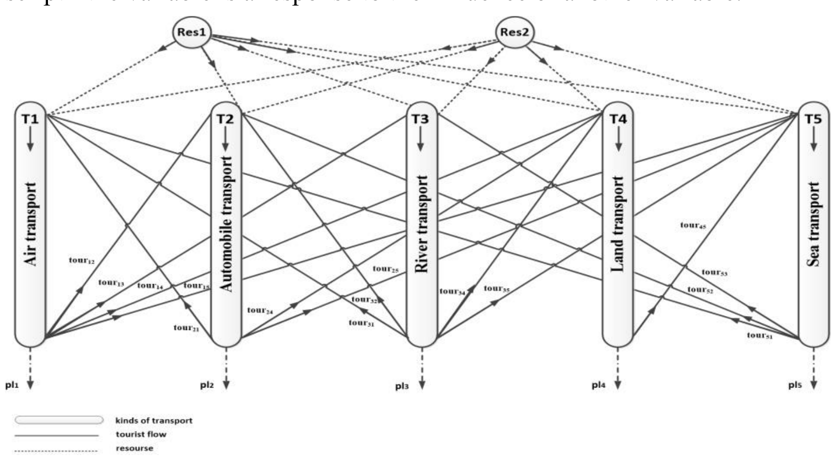

Fig. 3. Network model of the tourist-transport system

The equations describing the system have a tensor form:

$$T_A = pl_A + \sum_B tour_{AB} \tag{1}$$

$$tour^{AB} = t^{AB} \cdot T_B \tag{2}$$

$$res^{kA} = r^{kA} \cdot T_B \tag{3}$$

$$pl^A = (\delta^{AB} - t^{AB}) \cdot T_B,\ (\delta^{AB} - t^{AB}) = (I - \propto), \propto - matrix\ of\ t^{AB} \tag{4}$$

$$T^A = \sum_B tour^{BA} + \sum_k res^{kA} \tag{5}$$

Let's connect the elements of the system differently (see Fig. 4). Then the equation for our system with a new connection of elements:

$$pl^{A'} = \left(\delta^{A'B'} - t^{A'B'}\right) * T_{B'} \tag{6}$$

Since the system parameters did not change, then:

$$pl^A = pl^{A'} \tag{7}$$

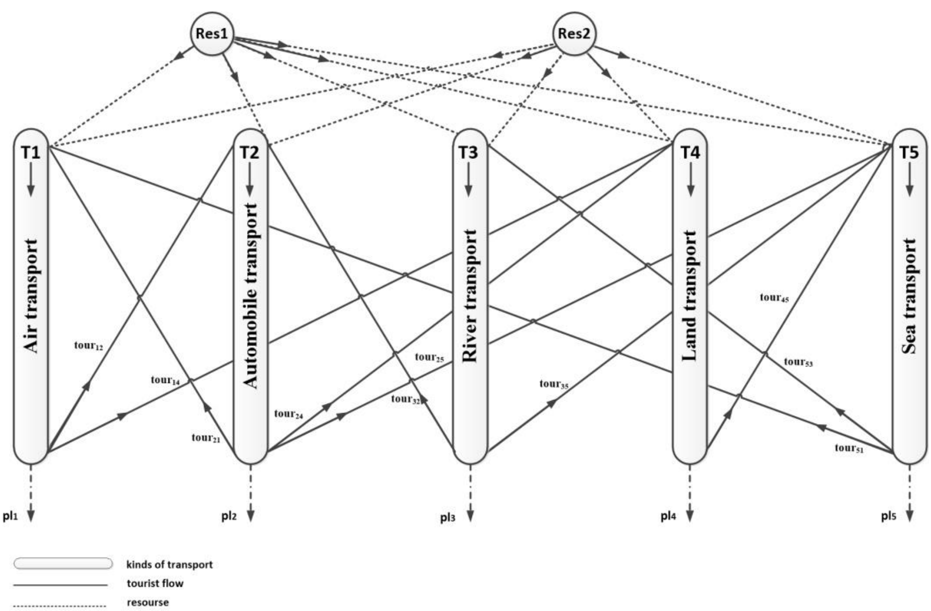

Fig. 4. New network model of the tourist-transport system

From (4) and (7) we obtain:

$$T_B = G_B^{B'} * T_{B'} \tag{8}$$

$$G_B^{B'} = (\delta^{AB} - t^{AB})^{-1} \cdot \left(\delta^{A'B'} - t^{A'B'}\right) \tag{9}$$

$$T_{A'} = G_{A'}^{A} \cdot T_A \tag{10}$$

$$\left(\sum_{B'} tour^{B'A'} + \sum_{k'} res^{k'A'}\right) = G_{A'}^{A}\left(\sum_B tour^{BA} + \sum_k res^{kA}\right) \tag{11}$$

The equation (8), (10), (11) define transformations for (1), (2), (3), (4).

The equation (11) is the conversion formula for (5) provided that all *res* and all *tour* are given.

3 Results of Analysis of tourist flows and traffic in St. Petersburg using the tensor method of dual networks

Consider the application of the tensor method of dual networks on the example of the analysis of tourist flows in St. Petersburg. For example, Tab. 1 shows the planned flows of tourists by type of transport in St. Petersburg [10] and we use the network in Fig. 4.

Tab. 1. Annual traffic volume (million people)

Air transport ($\mathbf{pl^1}$)	Automobile transport ($\mathbf{pl^2}$)	River transport ($\mathbf{pl^3}$)	Land transport ($\mathbf{pl^4}$)	Sea transport ($\mathbf{pl^5}$)
13.06	385.9	2.7	1333.3	0.8764

Tab. 2 shows the matrix $(\delta^{AB} - t^{AB})$ which is filled in accordance with Fig. 4. The rows and columns of the matrix are transport numbers. If there is 0 at the intersection of a row and a column, then there is no flow between these modes of transport. For example transport (2) - line 2 and transport (3) - column 3 are not connected by the tourist flow. For calculations $\mathbf{tour^{AB}}$, we use the equation (4). It is also necessary to calculate the inverse matrix (Tab. 3).

Tab. 2. The matrix $(\delta^{AB} - t^{AB})$ for the network in Fig. 4

	1	2	3	4	5
1	1	-0.03	0	-0.01	0
2	-0.5	1	0	-0.3	-0.001
3	0	-0.006	1	0	-0.451
4	0	0	0	1	-0.5
5	-0.07	0	-0.3	0	1

Tab. 3. The matrix $(\delta^{AB} - t^{AB})^{-1}$ for the network in Fig. 4

	1	2	3	4	5
1	1.0167	0.0311	0.0036	0.0191	0.0119
2	0.5263	1.0167	0.0550	0.3098	0.1842
3	0.0658	0.0132	0.0550	0.0048	0.5909
4	0.061	0.0036	0.1770	1.0011	0.5897
5	0.12201	0.0072	0.3541	0.0036	1.1782

Then, using formula 4, you can calculate the values of the tourist flow for each type of transport. This is the result of matrix multiplication Tab. 3 and Tab. 1.

Tab. 4. The tourist flow for each kind of transport T^A

$\mathbf{T^1}$	$\mathbf{T^2}$	$\mathbf{T^3}$	$\mathbf{T^4}$	$\mathbf{T^5}$
41.6	**664.6**	**10.7**	**859.6**	**9.4**

Then, using the formulas 2, we can calculate the values $\mathbf{tour_{AB}}$ – the number of tourists of transport A per tourist of transport B, when changing from A to B.

Tab. 5. The number of tourists from transport A, who changed transport A to transport B, for each kind of transport

$\mathbf{tour^{12}}$	$\mathbf{tour^{14}}$	$\mathbf{tour^{21}}$	$\mathbf{tour^{24}}$	$\mathbf{tour^{25}}$	$\mathbf{tour^{32}}$	$\mathbf{tour^{35}}$	$\mathbf{tour^{45}}$	$\mathbf{tour^{51}}$	$\mathbf{tour^{53}}$
19.937	8.596	20.836	257.877	0.009	6.645	4.711	4.711	2.918	3.209

We got the base values of the system, according to which, if necessary, we can calculate the rest of the values.

Then suppose we decide to experiment with the model in Fig. 4 and change its structure (Fig. 3). For this model, we can compose a matrix (Tab. 6) by analogy with the matrix in Tab. 2.

Tab. 6. The matrix $(\delta^{AB} - t^{AB})$ for the network in Fig. 3

	1	2	3	4	5
1	1	-0,03	-0,5	-0,01	-0,5
2	-0,5	1	0	-0,3	-0,001
3	-0,17	-0,1	1	-0,002	-0,5
4	0	0	0	1	-0,5
5	-0,07	-0,002	-0,3	0	1

And using transformation formula (10), we can calculate the flow of tourists for **A'** (Tab.7).

Tab. 7. The tourist flow for each kind of transport $T^{A'}$

$\mathbf{T^{1'}}$	$\mathbf{T^{2'}}$	$\mathbf{T^{3'}}$	$\mathbf{T^{4'}}$	$\mathbf{T^{5'}}$
93,6	**459,5**	**80,9**	**872,5**	**34,5**

So, if necessary, we can calculate resource and tourist flows for any new models. Given the transformation formulas, we do not need to worry about the complexity of the connections of the modeled system and the large number of system parameters. In a similar way, we can calculate any indicators of the sustainability of tourism or transport (passenger traffic, density of the route network, etc.). The dual nature of the constructed network also makes it possible to calculate financial flows in the system. The tensor method allows you to obtain balanced tourist flows for each type of transport. Since the calculation uses the Leontief input-output model. That is, together with a decrease in the computational complexity of the problem, this method allows one to obtain an optimal solution.

4 Conclusions

The application of the tensor double network method for the analysis of a complex tourist - transport system ensures the sustainable development of the system, since:

- allows to jointly simulate tourist flows and their connections with different modes of transport;
- the tensor form of the equations of the transport system allows you to calculate the parameters of different models of the system according to the parameters of the existing system;
- allows you to get an optimal solution, since the Leontief input-output model is used in the calculations;
- is an alternative approach compared to forecast methods.

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