FORMATION OF TERRITORIAL – INDUSTRIAL CLUSTERS BASED ON ADAPTIVE TRANSPORT INFRASTRUCTURE

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ABSTRACT

A method for formation of territorial-regional industrial clusters on the basis of flexibly changed and created transport infrastructure was developed. Objective functions and quantitative criteria, allowing to establish the position of transport units of the system at the local level were formulated. It is shown that location of a transport junction depends on whether it is active or passive. Calculated dependences were offered, allowing to solve the problem of structural synthesis in the framework of regional transport system.

Keywords: transport, system, synthesis, infrastructure, optimization, clusters, territory, production.

Background. *Known methods for the synthesis of logistics transport systems in a number of cases do not allow to solve the task of forming their optimal structure, which is connected with contradictory conditions and restrictions that must be met during its implementation, and the complexity of computational procedure, conditioned with the presence of a large number of operational factors [1–6].*

If a production cluster is formed in the new territory, and transport network and corresponding infrastructure are created for the expected demand for freight transportation, the process of formation of a local level of such a system requires consideration of a number of specific features [7]. Let's consider this question in more detail.

Objective. *The objective of the author is to consider formation of territorial – industrial clusters based on adaptive transport infrastructure.*

Methods. *The author uses general scinetific methods, comparative analysis, mathematical calculation, graph construction, evaluation approach, desriptive method.*

Results. *Let's assume that a production cluster consists of six dots M_1, ... M_6, which arrangement is schematically shown in Pic. 1a. We assume that there are transport routes between each pair of elements, and over a period between all elements freight transportation of unit volume is performed ($q_{i,j}$ = 1 t / day for any combination $i \neq j$).*

Based on the condition of minimization of transport work performed, then each pair of cluster elements should be interconnected via transport routes in a form of straight line segments. In this case, the total length of the transport network:

$$L_\Sigma = 0,5 \cdot \sum_{i=1}^{6} \sum_{j=1}^{6} l_{i,j} .$$

The total transport work within the boundaries of the cluster formed in this way:

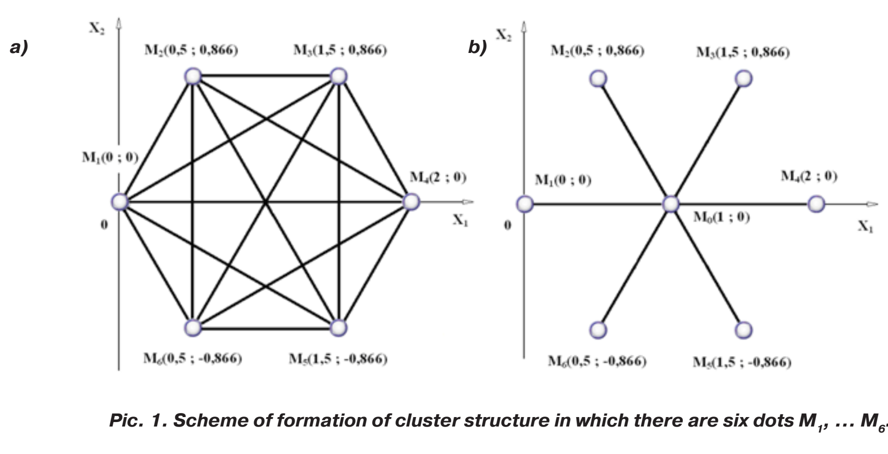
$$Q_W = \sum_{i=1}^{6} \sum_{j=1}^{6} q_{i,j} \cdot l_{i,j} .$$

The adopted version of formation of the transport network achieves a minimum of total transport work Q_W. However, it should also be recognized that such a decision entails an unjustified increase in the total length of transport routes used.

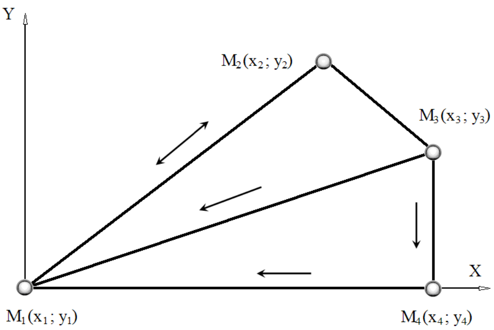
So, it is easy to show that for this example of formation of the network the total length of transport routes is as follows: L_Σ = 22,39 km, and total transport work performed Q_W = 44,78 t km. If in the cluster is added the transport junction M_0 (Pic. 1b), the total length of the tracks used will be: L_Σ^* = 6 km, and the total transport work will be Q_W^* = 60 t km.

This means that the use of the transport junction on the one hand leads to a reduction in the overall length of the transport network (in this example, more than 3,7 times), and on the other hand is accompanied by a slight increase in the transport work performed (in this case about 25%). Given the fact that the construction of transport routes, the appropriate infrastructure and their further maintenance in working condition is very costly from a financial point of view, the requirement associated with providing the absolute minimum of the transport work carried out within the boundaries of a newly created territorial – industrial cluster can not be considered justified.

The most suitable are the requirements for the synthesis of such structures in these conditions, which can ensure a minimum level of transport work performed in conjunction with the smallest total length of all used transport routes.



Pic. 1. Scheme of formation of cluster structure in which there are six dots M_1, ... M_6.



Pic. 2. The scheme of mutual arrangement of individual structural elements of the cluster, and direction of performed freight transportation.

Table 1

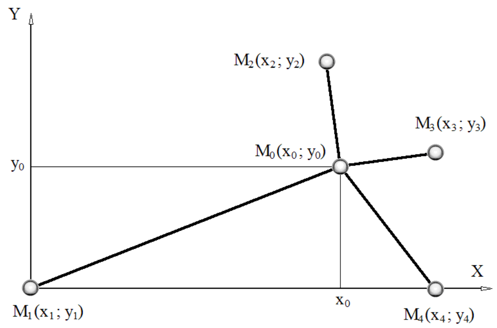
The coordinates of dots of the production cluster

Coordinates of elements of the cluster M_i	Value of index i			
	1	2	3	4
x_i, km	0	16	22	22
y_i, km	0	15	8	0

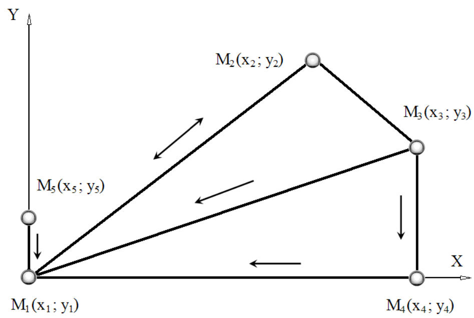
Then, the objective function, which determines the requirements for the structure of the system at the loal level is formulated as follows:

$$I_z = Q_w \cdot L_\Sigma \to min \quad (1)$$

Thus, the considered example demonstrates that the formation of cluster structure, based on a newly created infrastructure is associated with the necessity of using a respective target function (1) and with the definition of the transport junction position if its inclusion in a cluster is appropriate. In this case the definition of the coordinate of the junction M_0 is an independent task that needs to be considered and solved separately.



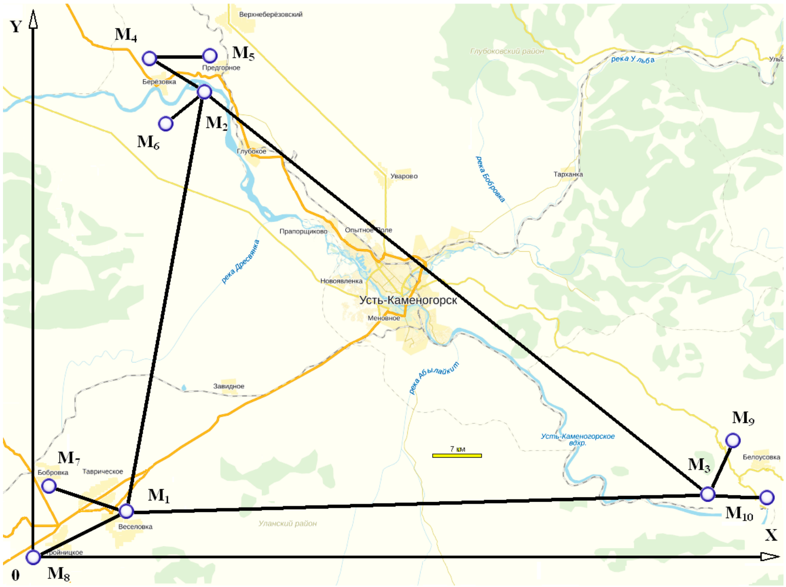
Pic. 3. The scheme of arrangement of elements of the cluster and the transport junction M_0.



Pic. 4. Scheme of a cluster, consisting of five dots.

Let's consider in this context the task of determining the position of the transport junction of the cluster to be formed on the basis of four dots (Pic. 2). The corresponding coordinates of these elements in Y0X system are presented in Table 1.

The volume of transportation between separate points is set by a matrix $\| Q \|$ [7] with elements $q_{i, j}$, [tonnes / day.]:



Pic. 5. The scheme of mutual arrangement of dots of the production cluster.

Table 2

The coordinates of individual structural elements of the cluster

Coordinates of dots $M_i(x_i; y_i)$	Value of the index i									
	1	2	3	4	5	6	7	8	9	10
x_i, km	13	21	80	17	24	18	0,5	0	86	95
y_i, km	4	53	6	58	58	48	7	0	13	5

Table 3

Freight flows between individual elements of the cluster $q_{i,j}$ [thous. t km / day]

Values of indices i and j 1		Index i									
		2	3	4	5	6	7	8	9	10	
Index j	1	0	0	1,16	0	0	0	0	0	0	0
	2	0,52	0	2,2	0	0	0	0	0	0	0
	3	0	0,86	0	0	0	0	0	0	0	0
	4	0	0,12	0	0	0	0	0	0	0	0
	5	0	0	0	0,12	0	0	0	0	0	0
	6	0	0,22	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0
	9	0	0	0,16	0	0	0	0	0	0	0
	10	0	0	0,22	0	0	0	0	0	0	0

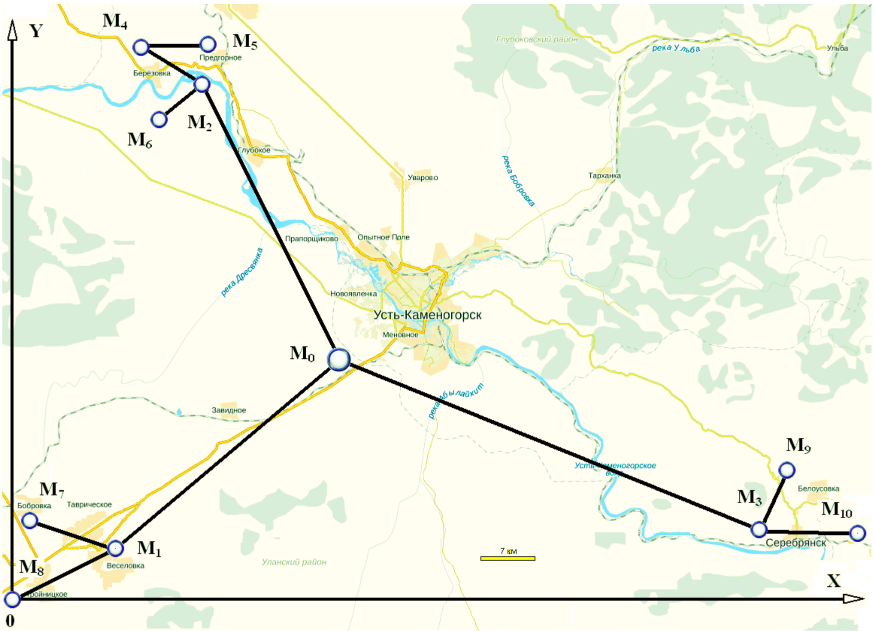
$$\| Q \| = \left\| \begin{matrix} 0 & 1{,}6 & 0 & 0 \\ 0{,}2 & 0 & 1{,}8 & 0 \\ 1{,}52 & 0 & 0 & 1{,}2 \\ 0{,}7 & 0 & 0 & 0 \end{matrix} \right\| .$$

Let us further assume that the cluster contains an additional element M_0, acting as a transport junction (Pic. 3).

Since all transport routes within the boundaries of the cluster will pass through the junction $M_0(x_0; y_0)$, it leads to the appearance of bypass routes and changing delivery routes. The position of the point M_0 on the plane Y0X is defined from the condition:

$$I_z(x_0; y_0) \to \min \qquad (2)$$

To do this, it is necessary to solve the following system of equations:

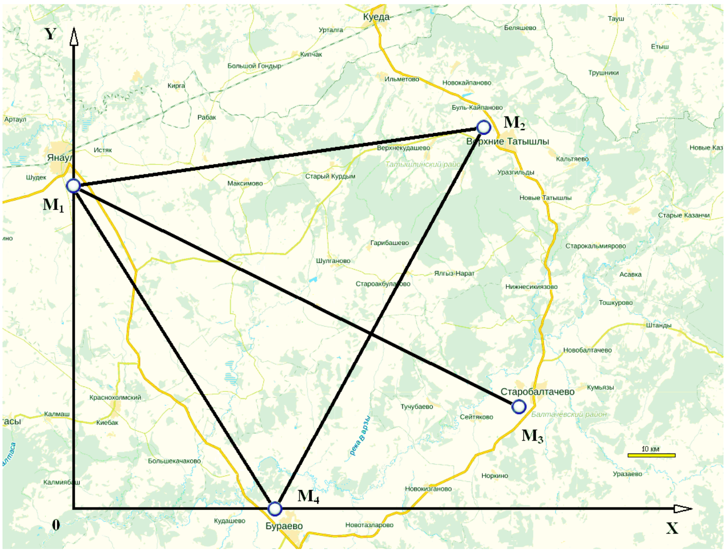


Pic. 6. The structure of the cluster with the transport junction M_0 and three groups of elements – satellites.

Table 4

The coordinates of individual structural elements of the cluster

Coordinates of dots $M_i(x_i; y_i)$	Value of index i			
	1	2	3	4
x_i, km	0	81,1	88,4	40,2
y_i, km	64,3	77,1	20,1	0



Pic. 7. The scheme of mutual arrangement of structural elements of the cluster.

$$\begin{cases} \dfrac{\partial I_Z(x_0, y_0)}{\partial x} = 0 \\ \dfrac{\partial I_Z(x_0, y_0)}{\partial y} = 0 \end{cases}. \qquad (3)$$

For the adopted system of input data (Table 1) coordinates of the junction M_0 on the plane Y0X:

$$\begin{cases} x_0 = 19{,}2\ km \\ y_0 = 7{,}5\ km \end{cases}.$$

It is easy to show that the total length of transport routes within the boundaries of a cluster with the junction M_0(19,2; 7,5) is as follows: $L_\Sigma^* = 39{,}6$ km, and transport work performed: $Q_T^* = 140{,}3$ thous. t km / day. If the cluster does not have a single junction, the total length of transport routes for a given version of arrangement of elements M_1, ... M_4: $L_\Sigma = 84{,}6$ km, and performed within the boundaries of the cluster transport work is: $Q_T = 116{,}7$ thous.t km / day.

Thus, the obtained results suggest that the inclusion of an additional element M_0 in this cluster leads to increases in the volume of transport work performed by about 20% and a simultaneous decrease in the total length of transport routes by more than 2 times.

In general, a developed method based on the use of the objective function (2) allows to set the position of the additional structural element M_0 on the plane

However, some features associated with the solution of such problems should also be noted. So if in the cluster shown in Pic. 2 an element M_5 is added, located near the point M_1 and technologically associated only with this point (Pic. 4), then freight transportation between these elements via the junction M_0 is unreasonable to be performed because of excessively increasing length of the transport route.

Such structural elements – satellites, should be excluded from consideration before the search procedure of location of the point M_0. Later, at the stage of cluster formation, satellites should be included in its composition, in spite of virtual absence of transportation through the junction M_0.

Thus, later a satellite is to be understood as an element of a cluster which, when functioning is exclusively associated with a nearby dot in the delivery of goods at a relatively small distance (typically less than 10 ... 20 km).

If there are several satellites, when determining the position M_0 their presence is also not taken into account, and after finding coordinates of M_0, in accordance with the above method, connection of satellites with corresponding structural elements is restored.

Let's consider the process of formation of such clusters using a specific example.

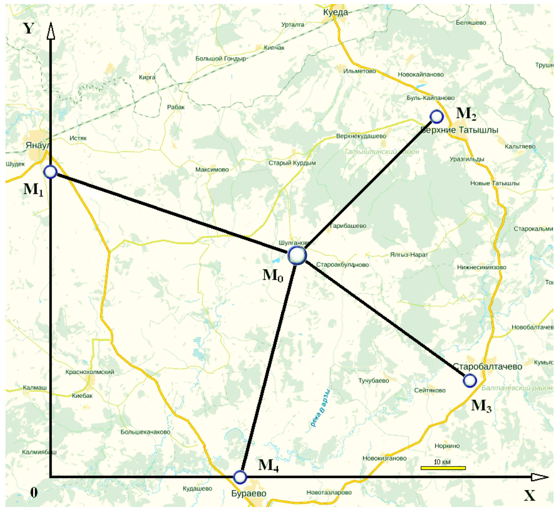
Let's assume that structure formation will be based on the aggregate of ten interrelated elements M_1, ... M_{10}, shown in Pic. 5. The coordinates of these elements on the plane are shown in Table. 2.

It should also be noted that the numbering elements M_i index values are assigned in sequential order only to points that will be involved in the formation of the transport network in the first stage. In this case, these are elements M_1, M_2 and M_3. The other points are treated as elements – satellites and further are indexed arbitrarily because they do not participate directly in the procedure for determining transport junction position.

Data describing freight transportation within cluster boundaries are listed in Table. 3.

According to the results of the calculations we can conclude that for the adopted system of initial data optimal is position of the point M_0 on the plane, which is characterized by the following coordinates:

$$\begin{cases} x_0 = 36\ km \\ y_0 = 24\ km \end{cases}.$$



Pic. 8. Scheme of a cluster with a passive transport junction M_0.

Schematic representation of the synthetic cluster structure composed of ten dots M_1, ... M_{10}, transport junction M_0 and the corresponding transport routes is shown in Pic. 6.

Thus, the transport junction of an individual cluster can act as its structural component, as well as an element belonging to the regional level of the transport system, if such a decision is appropriate [8–11].

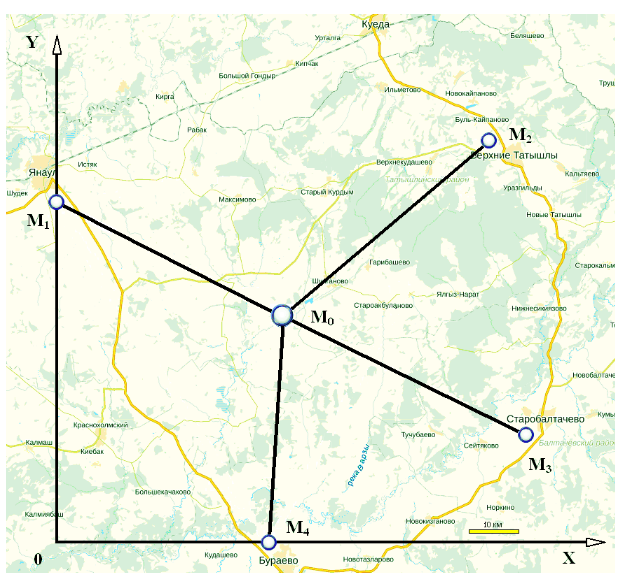
However, there is a feature associated with the fact that if transport junction of the cluster is simultaneously regional structural element, it can function as source or consumer of freight flows. If this is true, then the calculation of additional cargo flows related to the functioning of the regional level of the system can be linked to the need for further clarification of the junction position, for which a relevant procedure should be developed.

Let's consider the specified feature in detail. Let's assume that the analyzed cluster is associated with the other so that freight flows through the transport junction are small and can be disregarded in the calculations, or these flows cannot be regarded as existing stably for a long period of time when delivering goods to individual customers in the cluster.

If the condition is true, then this transport junction is considered as passive, and its position within cluster boundaries is determined on the basis of the method developed above.

If the transport junction is operated so that over a long period of time through it delivery of goods from outside to the address of specific cluster dots is performed and it is impossible or impractical to neglect such freight transportation, in the future such a junction is called active.

If through the active junction M_0 on a permanent basis delivery of goods is performed to the i-th element of the cluster M_i ($i \neq 0$), the characteristic of the active junction, as an independent source of freight flows in the address of M_i element will be the value of $q_{0,\ i}$. Conversely, if the element M_j ($j \neq 0$) performs sending of goods on a continuous basis through the junction M_0 in the address of other clusters, the activity of this junction as a consumer of transport flows from M_j will be characterized by a value $q_{j,0}$. All this means that the adjustment of transport junction position may be required only in those cases where a junction is active. All its characteristics of activity of $q_{0,\ i}$ and $q_{j,0}$ should be known.



Pic. 9. The scheme of the cluster with the active transport junction.

Let's consider an active transport junction M_0, connecting n elements of the cluster. Unlike a passive junction its operation is connected with the presence of outgoing and incoming flows, characterized by a set of values of $q_{0,i}$ and $q_{i,0}$ (i = 1, 2, … n), some of which may be zero. Additional transport work carried out within the boundaries of the analyzed cluster and associated with activity of transport junction M_0 is defined as follows:

$$Q_D = \sum_{i=1}^{n} (q_{0,i} + q_{i,0}) \cdot l_{i,0} .$$

Then, by analogy with the previously considered case the objective function at a predetermined position of the active junction $M_0(x_0; y_0)$ is defined as follows:

$$I_Z(x_0; y_0) = \{ \sum_{i=1}^{n} \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2} \} \times$$

$$\times \{ \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{q_{i,j} \cdot m_{i,j} \cdot [\sqrt{(x_i - x_0)^2 + (y_i - y_0)^2} +}{\sqrt{(x_j - x_0)^2 + (y_j - y_0)^2}] +}$$

$$+ \sum_{i=1}^{n} (q_{0,i} + q_{i,0}) \cdot \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2} \} .$$

The position of the transport junction on the plane is defined by the condition (2) and connected with the solution of the system of equations (3).

To illustrate the possibilities of the developed method for determining coordinates of the active transport junction, we will consider the example of cluster formation on the basis of data presented in Pic. 7. Coordinates of elements, which are part of this cluster, are shown in Table 4.

The matrix of freight flows with elements $q_{i,j}$ [thous. t / day] is as follows:

$$\| Q \| = \begin{Vmatrix} 0 & 2,2 & 0 & 1,66 \\ 0,65 & 0 & 0 & 0,82 \\ 1,16 & 0 & 0 & 1,2 \\ 0 & 0 & 0 & 0 \end{Vmatrix} .$$

If the transport junction is passive, its coordinates established by the results of calculations:

$$\begin{cases} x_0 = 45,7\,km \\ y_0 = 45\,km. \end{cases}$$

The position of this junction, under the assumption that the level of interaction of dots of cluster with a regional level of the system is negligibly small is shown in Pic. 8.

If the junction is active and has the following characteristics of activity: $q_{0,2}$ = 1,86 thous. t•km / day, $q_{2,0}$ = 0,18 thous. t•km / day, $q_{0,3}$ = 0,22 thous. t•km /day, to determine its position on the plane it is necessary to consider additional volumes of transport work performed, arising in the functioning of the regional level of the system.

The structure of the cluster with the active junction, which location was set using the developed method, for adopted indicators of activity is shown in Pic. 9.

Comparing data presented in Pic. 8 and 9, it can be concluded that the existence of freight flows at the regional level and the interaction between clusters really affect the position of transport junctions, which should be taken into account in solving structural synthesis tasks.

Conclusion. *A method of forming territorial – industrial clusters on the basis of newly established transport infrastructure was developed, which is associated with the need to determine the transport center position on the basis of the formulated objective function.*

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