core transport network; logistic system; logistic center allocation; renewable energy; fuzzy set theory; genetic algorithm

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FORMING OF THE REGIONAL CORE TRANSPORT NETWORK TAKING INTO ACCOUNT THE ALLOCATION OF ALTERNATIVE ENERGY SOURCES BASED ON ARTIFICIAL INTELLIGENCE METHODS

Summary. In the modern world the alternative energy sources, which considerably depend on a region, play more and more significant role. However, the transition of regions to new energy sources lead to the change of transport and logistic network configuration. The formation of optimal core transport network today is a guarantee of the successful economic development of a region tomorrow.

The present article studies the issue of advanced core transport network development in a region based on the experience of European and Asian countries and the opportunity to adapt the best foreign experience to Russian conditions.

On the basis of artificial intelligence methods for forest industry complex of Sverdlovskaya Oblast the algorithm of problem solution of an optimal logistic infrastructure allocation is offered and some results of a regional transport network are presented. These methods allowed to solve the set task in the conditions of information uncertainty. There are suggestions on the improvement of transport and logistic network in the territory of Sverdlovskaya Oblast.

Traditionally the logistics of mineral fuel plays main role in regions development. Actually it is required to develop logistic strategic plans to be able to provide different possibilities of power-supply, flexible enough to change with the population density, transport infrastructure and demographics of different regions.

The problem of logistic centers allocation was studied by many authors. The approach, offered by the authors of this paper is to solve the set of tasks by applying artificial intelligence methods, such as fuzzy set theory and genetic algorithms.

ФОРМИРОВАНИЕ ОПОРНОЙ ТРАНСПОРТНОЙ СЕТИ РЕГИОНА С УЧЕТОМ РАЗМЕЩЕНИЯ АЛЬТЕРНАТИВНЫХ ИСТОЧНИКОВ ЭНЕРГИИ НА ОСНОВЕ МЕТОДОВ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА

Аннотация. В современном мире альтернативные источники энергии, которые в значительной степени зависят от региона, играют все более значимую роль. Однако переход регионов к новым источникам энергии приведет к изменению транспортно-логистического конфигурации сети. Формирование оптимальной опорной транспортной сети сегодня является залогом успешного экономического развития региона завтра.

Настоящая статья изучает вопрос опережающего развития опорной транспортной сети региона на основе опыта стран Европы и Азии, а также возможность адаптировать лучший зарубежный опыт к российским условиям.

На основе методов искусственного интеллекта для лесопромышленного комплекса Свердловской области предлагается алгоритм решения задачи оптимального логистического распределения инфраструктуры и представлены некоторые результаты моделирования региональной транспортной сети. Эти методы позволили решить поставленную задачу в условиях информационной неопределенности. Дать предложения по совершенствованию транспортной и логистической сети на территории Свердловской области.

Зависимость логистики от минерального топлива, является устойчивой тенденцией развития регионов, однако при составлении стратегических планов необходимо на ряду, с плотностью населения, особенностями транспортной инфраструктуры и прогнозом демографических изменений, также предусмотреть альтернативные возможности смены источников энергоресурсов.

К проблеме размещения логистических центров обращались многие авторы. Особенностью подхода, предлагаемого авторами этой статьи является применение методов искусственного интеллекта, в частности, теории нечетких множеств и генетических алгоритмов.

1. SISGNIFICANCE OF REGIONS TRANSITION TO ALTERNATE ENERGY SOURCES

Currently the bioenergy fraction amounts to 13% in world primary energy and biomass is the fourth largest energy source (after oil, coal and gas) (fig. 1).

Biomass is considered to be one of the key renewable energy resources of the future. The markets of energy biomass are developing rapidly and becoming more international [1]. Biomass is called all vegetable matters and animal sources, human and organic wastes, generated during production processes, goods consumption and on the stages of wastes technological cycle [2].

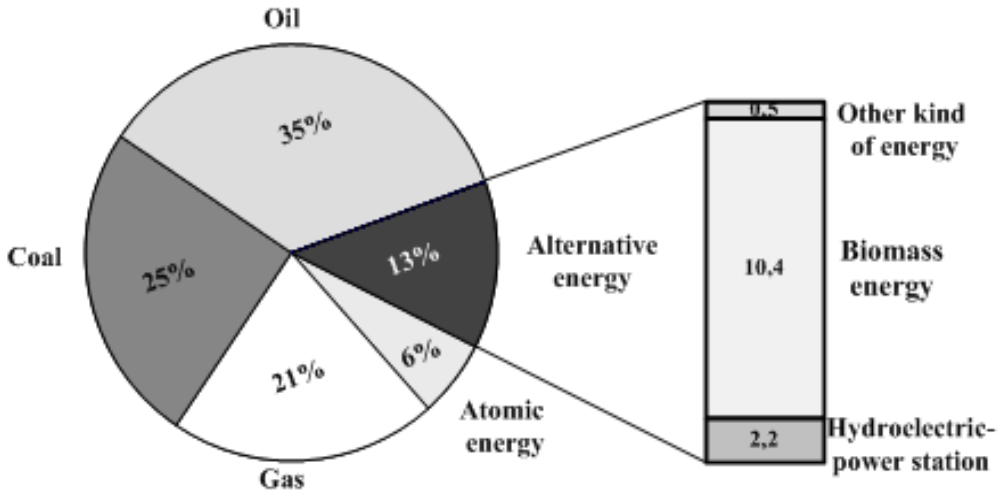


Fig. 1. Biomass fraction in world primary energy [3]
Рис. 1. Доля биомассы в мировой первичной энергии [3]

All biomass sources are divided into three main groups [4]:
- waste and remains;
- specially grown energoculture;
- natural vegetation.

As the subject of the research the authors have chosen waste from enterprises of timber processing complex, which plays an important role in the economy of the Ural Region and Sverdlovskaya Oblast in particular. It is presented in more details in the paper [5]. However, the transition of regions to new energy sources lead to the change of transport and logistic network configuration. The formation of

optimal mezologistic transport network today is a guarantee of successful economic development of a region tomorrow.

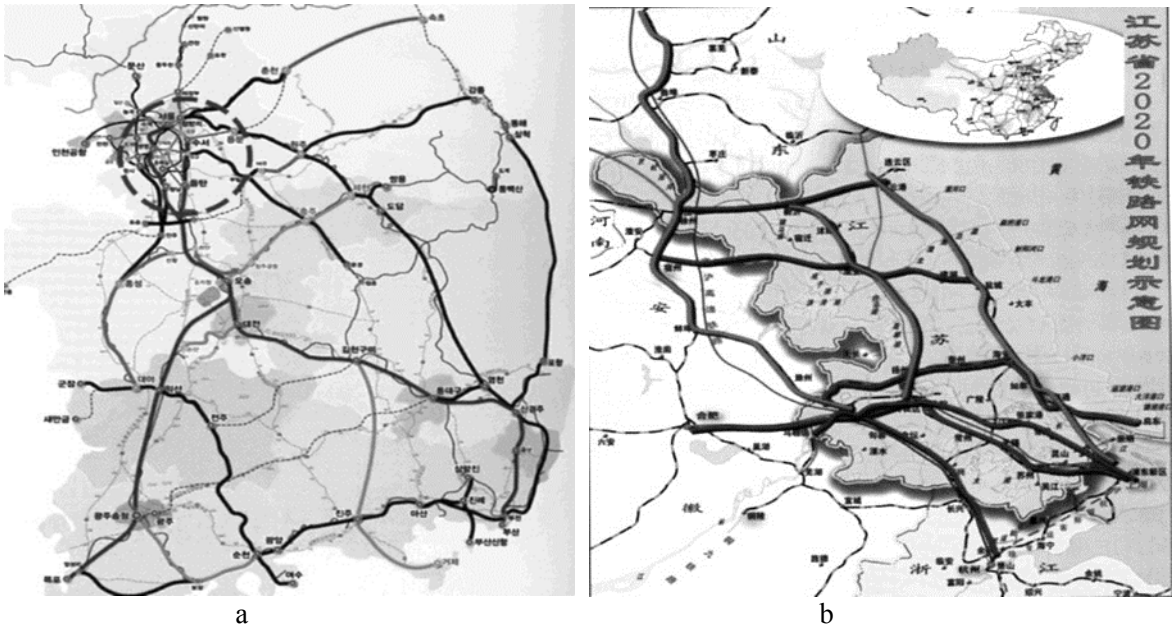
The authors of the paper have studied the issue of advanced development of the regional core transport network by the experience of countries in Europe and Asia and the opportunity to adapt the best foreign experience to Russian conditions.

2. TRANSPORT AND LOGISTIC NETWORK CONFIGURATION IN SOME COUNTRIES OF THE WORLD

Transport infrastructure must correspond to regional facilities and demands, however, the modernization and growth of roads network, railways in particular, may establish the necessary conditions for economic advance. A good example can be the economics of such countries of Asian and Pacific region as South Korea and China, in which in order to decrease the imbalance of economics development of different regions in a country, the government made a decision about advanced transport network development.

Nowadays the transport of Korea is developing in the second plan of the National railways network, in which the strategic 'grid' of railway network provides the connection of any two destination points of the country for less than 1,5 hours (fig. 2a) [6].

In China the strategic transport 'grid' [fig. 2b] consists of three vertical and four cross railway lines, including the high-speed lines. And today one third of world high-speed lines run across the territory of this country and 30 largest cities of China in which the economics of the state is concentrated are integrated into the high-speed lines system. The transport networks of the Asian countries in particular, having the configuration of a grid, contributed to the high level of land development and more favorable conditions of enterprises allocation in the rim land [6, 7].



a b

Fig. 2. Strategic transport 'grids' of Korea (a) and China (b)
Рис. 2. Стратегическая транспортная «решетка» Кореи (а) и Китая (б)

Thus, the experience of the countries mentioned above, showed the success of the advanced transport network development for the economics both of a particular region and the state as a whole. The reliability of transport networks is important as well as the speeds that they offer [8].

Transport networks of the European countries have either radial (one center) configuration like in France, where ‘all the roads bring to Paris’, or multicenter configuration like in Germany. And if to consider not just the territory of one particular country but also the territory of Europe as a whole, it is obvious that there is also a grid transport network. A relation between the quantity and quality of transport infrastructure and the level of economic development is apparent. High density transport infrastructure and highly connected networks are commonly associated with high levels of development [9].

The new transport policy (for the period 2014 – 2020) establishes a core transport network built on nine major corridors: two North-South corridors, three East-West corridors and four diagonal corridors. Member states may pool their scarce resources to achieve the best results. The core network will remove bottlenecks and upgrade infrastructure (fig. 3) [10].

Fig. 3. Transport network of Europe [10]
Рис. 3. Транспортная сеть Европы [10]

The paper authors’ objective is to apply the best world experience when working on the problem of constructing the optimal configuration of Sverdlovskaya Oblast core transport network on the basis of artificial intelligence.

3. ANALYSIS OF ROAD NETWORK IN SVERDLOVSK OBLAST

Sverdlovsk Oblast is included into Ural Federal District. The population is 4545 thousand people. The area of the region is 194,8 thousand square kilometers. Ekaterinburg is the third largest transportation hub in Russia, which includes 7 trunk lines and 6 federal highways. According to the data for 2012 there are 11455 kilometers of motor roads for general use, including hard surface roads 10834 km (or 94%, against 91,3% in whole Russia) [11].

Density of motor roads for general use is 55,2 km per 1 thousand square kilometers, which exceeds the index in Russia more than 1,7 times greater and in the Ural Federal District 2,7 times. Among 1705 rustic units in the region there are 1403 or 82,3% which are connected by hard surface roads with the network of motor roads for general use. The similar index in the district is 70,6%, and in Russia as a whole is 66,1%.

But despite the fact that motor roads density in Sverdlovsk Oblast is higher than in Russia in average it is not enough for the efficient functioning of regional logistic system.

The article authors have worked the issue of transport network optimization on the basis of artificial intelligence application.

4. SOLUTION ALGORITHM

The issue of the optimal production forces allocation always played an important role in the regional logistics. To solve the problem of the optimal territory division into logistic zones the authors' approach described in [12-14, 18] was used. The problem of defining the optimal number of logistic service zones and their allocation is in fact the problem of market segmentation. From the mathematical standpoint such task reduces to the problem of defining set clustering, in other words its partition to some number of disjoint subsets. By this approach the clustering analysis is use, based on optimization of some objective function, defining the optimal in a sense partition of many objects into clusters.

The solution algorithm for the optimal allocation of the logistic network under conditions of transition to the alternative energy sources consists of several stages:

1) Forecast of biomass volume on the basis of the analysis of timber industry volume and clients' environment analysis.
2) Defining the necessary quantity of logistic platforms on the territory of Sverdlovsk Oblast.
3) Dividing the region into zones (clusters) using artificial intelligence methods.
4) Building a transport network model.
5) Verifying the mathematical model to the real regional transport and logistic network.
6) Developing concrete suggestions on transport network improvement.

5. PROBLEM SOLUTION USING ARTIFICIAL INTELLIGENCE

To solve the task the authors used their own method [5, 15-17]. It is based on FCM-method (Fuzzy C-means method) of J.C. Bezdek [19]. The use of artificial intelligence method, in particular, fuzzy set theory in conformity to clustering analysis, based on the following property: when solving the problems of complex systems structuring the majority of set up object classes have a high degree of uncertainty. The requirement of finding one-to-one elements clustering of the studied problem area is rough and stiff. The task of fuzzy clustering is to find fuzzy partition of the set of the studied population elements, which form the structure of fuzzy clusters, presented in the studied data. This task is solved by finding degree of membership of elements set to the desired fuzzy clusters, which in total define the fuzzy partition of the studied elements assumed set. In a general way the set of fuzzy clustering is set in the following way.

Let the studied population of data present the finite elements set $A=\{a_1, a_2, ..., a_n\}$, which is called the set of clustering objects. In addition the natural n defines the total amount of data objects.

It is assumed that desired fuzzy clusters represent fuzzy sets A_k, forming fuzzy cover of assumed clustering objects set $\mathsf{A} = \mathsf{U}\mathsf{A}_k = A$ for which the following condition is met

$$\forall a_i \in A : \sum_{k=1}^{c} \mu_{\mathsf{A}_k}(a_i) = 1, \tag{1}$$

where: c - predetermined number of fuzzy clusters A_k, $k = 2, ..., c$.

For each cluster there are so called typical samples or centers v_k of the desired fuzzy clusters A_k, $k = 2, ..., c$, which are calculated for each cluster from the formula

$$v_k = \frac{\sum_{i=1}^{n} \left(\mu_{\mathsf{A}_k}(a_i)\right)^m \cdot x_i}{\sum_{i=1}^{n} \left(\mu_{\mathsf{A}_k}(a_i)\right)^m}, \tag{2}$$

where: $m \geq 1$ - is some real parameter, called exponential weighting coefficient.

As the objective function it is considered sum of squares of distances from clustering objects to cluster centers,

$$f\left(\mathsf{A}_k, v_k\right) = \sum_{i=1}^{n}\sum_{k=1}^{c}\left(\mu_{\mathsf{A}_k}\left(a_i\right)\right)^m \left(x_i - v_k\right)^2 . \tag{3}$$

In a general case in such arrangement the problem of fuzzy clustering refers to the problems of non-linear programming.

The independent question, which solution is preceded by defining the borders of logistic zones, is defining the number of these zones on the service ground. The number of zones and their geographic allocation are defined by location of consumers and producers. The main criteria of service zone organization are ensuring proper service quality and minimizing logistic expenses. If minimum and maximum prices on warehousing and transportation are included into a design model, the obtained result doesn't have pointwise value but some set of permissible values.

In the fig. 4 there is a dotted graph of cost for wooden pellets transportation by obtained clusters, supposing that the storage of finished products is in the center of the cluster. The straight lines show the expenses for warehousing with minimum and maximum costs on warehouses. Hence, two upper bold curves show the total spending on product transportation and warehousing by minimum and maximum costs on warehouses. Number of clusters is plotted along X-axis and the cost in thousands of rubles is along Y-axis.

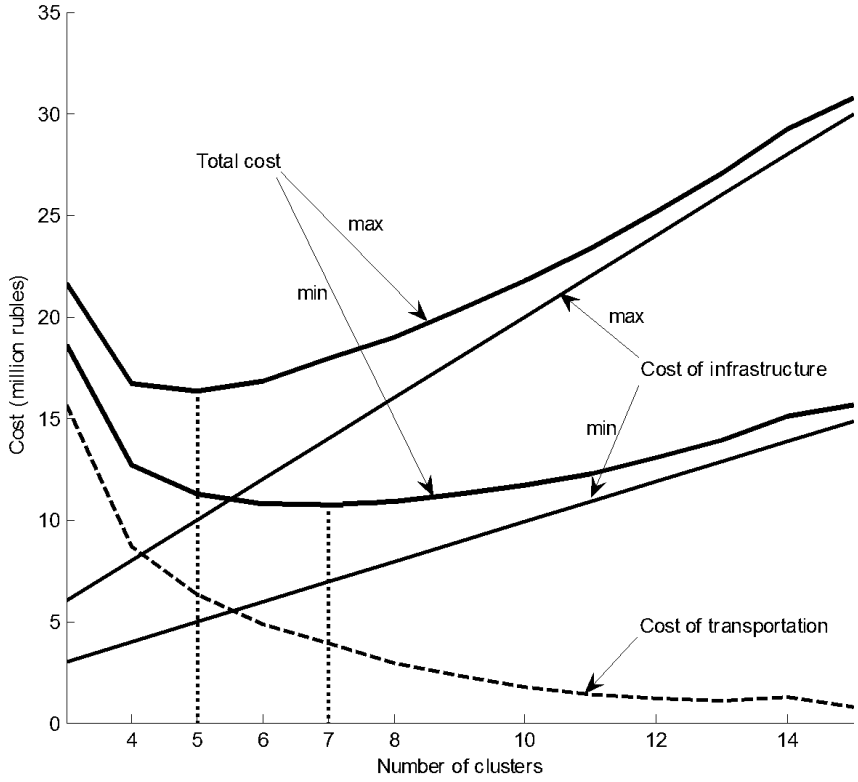


Fig. 4. Defining the optimal number of logistic platforms
Рис. 4. Определение оптимального количества логистических платформ

By this setting of the problem the number of logistic platforms in Sverdlovsk Oblast is within the range from 5 to 7.

In fig. 5-7 for each value from the obtained range the optimal partition of Sverdlovsk Oblast to clusters has been done and the transportation network has been modeled. In the left figures by the big stairs the centers of clusters are signed. And by different geometric shapes the elements of clusters are signed.

For the creating of road maps we used the genetic algorithms [20]. The main advantage of GA is possible to use them in solving of problems with a large amount of data in future research. By imposing

the road maps, when there is different number of clusters, it is seen that the clusters' centers slide a bit, making necessary to build new roads (Fig. 8). Ii this picture we can see that some roads are constant in all three models. On this base we can create skeleton diagram: neat line – 1 time, bold line – 2 times, thickened line – 3 times. Absence of connections in some cities mean that the roads from them should be built straight into clusters' centers (Fig. 9). This skeleton diagram we can use for the analysis and optimization of the road network of region.

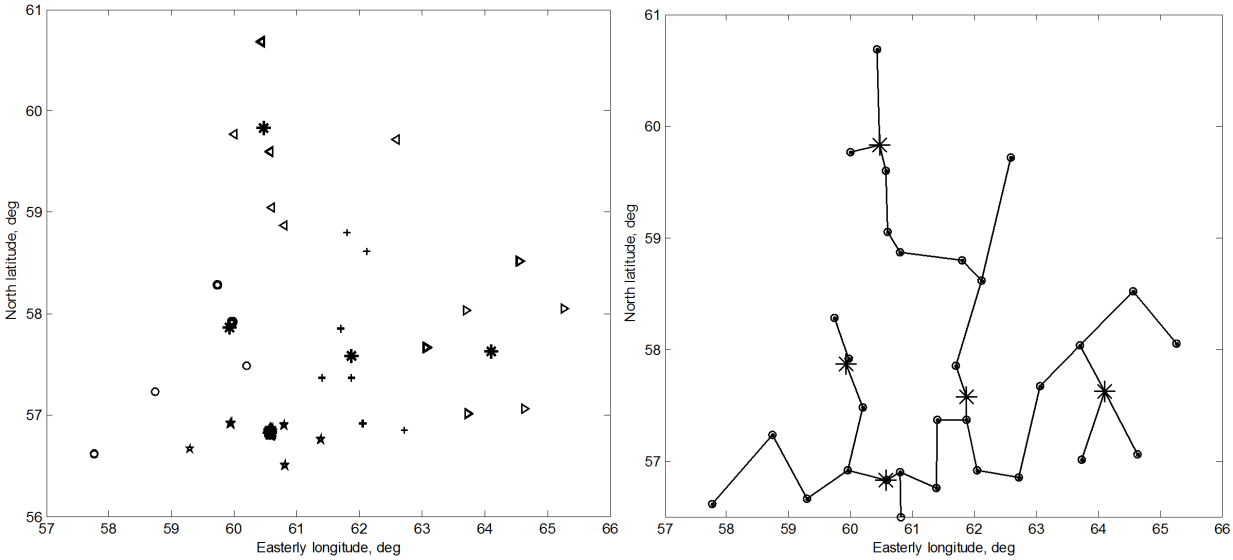


Fig. 5. Model for 5 logistic platforms
Рис. 5. Модель для 5 логистических платформ

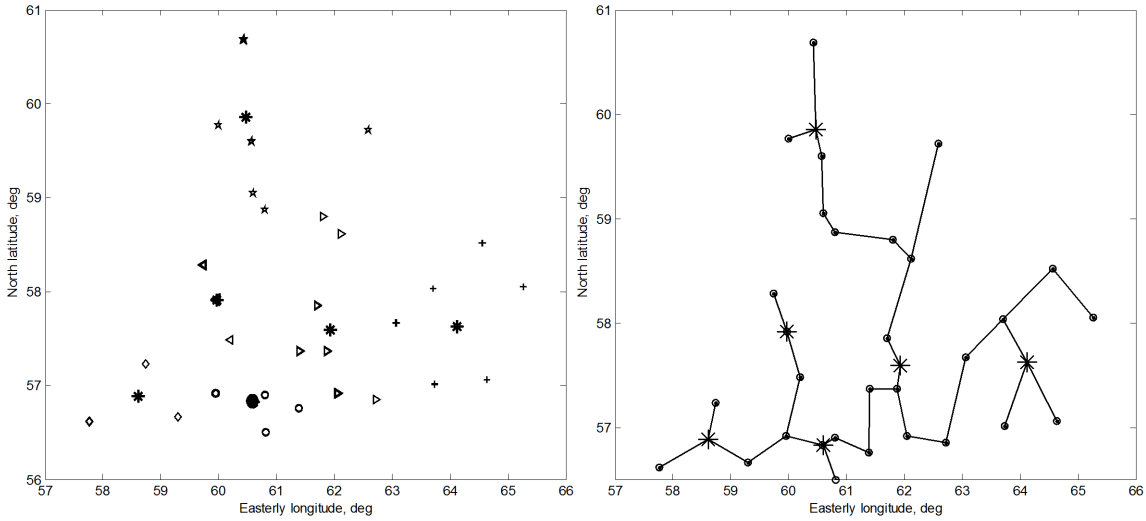


Fig. 6. Model for 6 logistic platforms
Рис. 6. Модель для 6 логистических платформ

It is obvious that when developing the regional core transport system it is necessary to pay attention to those roads which can be met most of the times in different variants of the region segmentation. Matching the scheme of real road network with modeling results will allow to define the narrow sections of regional transport network and come up with recommendations on their elimination. Expanding forest biomass use for biofuels and energy generation will compete with traditional forest products, but it may also produce benefits through competition and market efficiency [21].

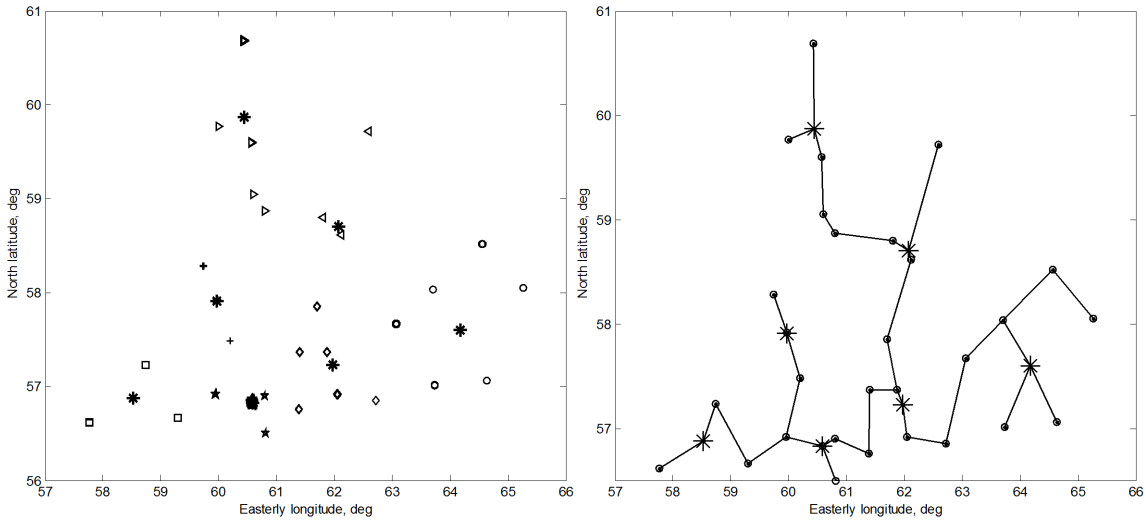


Fig. 7. Model for 7 logistic models
Рис. 7. Модель для 7 логистических платформ

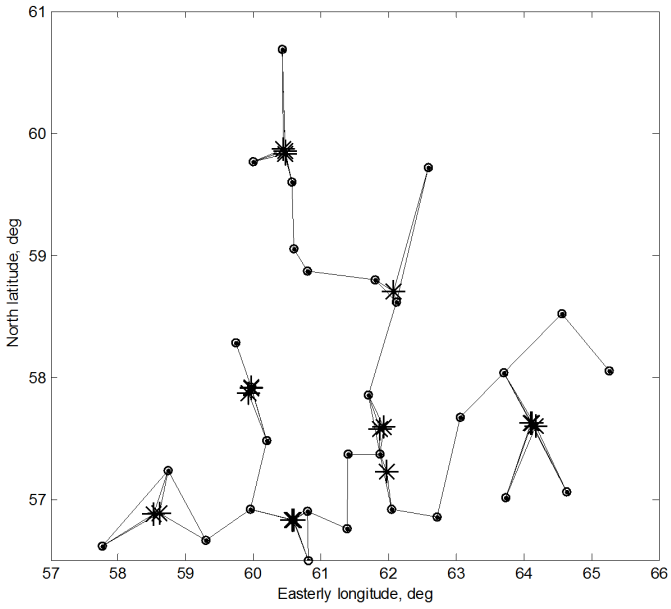


Fig. 8. Superimposed road maps
Рис. 8. Наложенные схемы дорог

CONCLUSION

The authors of the paper specified the success of the advanced transport network development for the economics both of a particular region and the state as a whole. It was concluded that ‘grid’ configuration of the network contributes to the high level of land development and more favorable conditions of enterprises allocation in the rim land.

The authors of the article tried to develop a model of a rational logistic system of environmental management, in which the development of the region and the interests of today’s and future generations are considered. With that end in view the authors analyze possible variants of waste utilization centers allocation on the basis of forest reserves volume and predicted biomass volume, also products distribution centers on the basis of prospective consumers’ location analysis. Peculiarity of the offered approach in the

article is the use of artificial intelligence methods. The authors use fuzzy-set theory, in particular, the method of fuzzy clustering that allows to simulate the optimal transport network of the region, and in prospect to make recommendations to the Ministry of transport and communication of the Sverdlovsk region government how to develop transport network. Research work is performed with the partial financial support by RFBR, project № 14-07-00222 "Intelligent Decision Support System for the problems of logistics infrastructure".

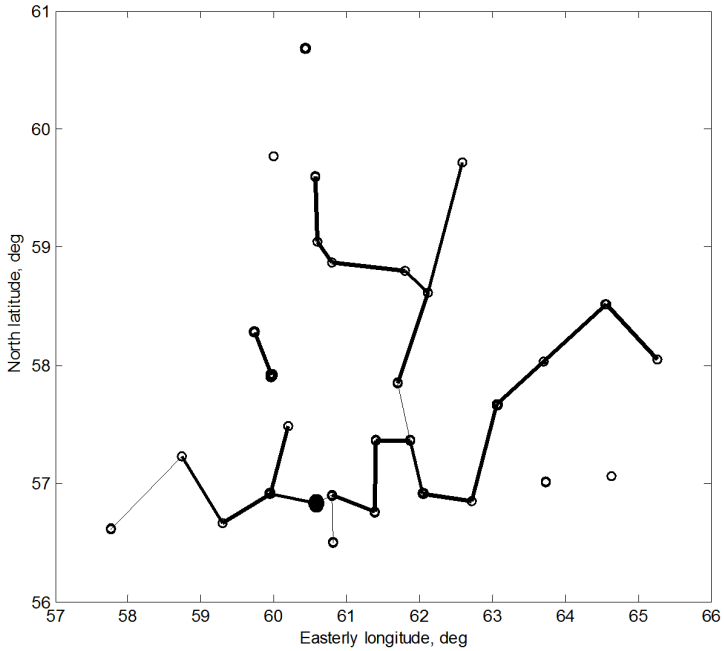


Fig. 9. Regional core transport network taking into account the allocation of alternative energy sources
Рис. 9. Опорная транспортная сеть региона с учетом размещения альтернативных источников энергии

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