

# SUSTAINABLE DEVELOPMENT OF TERRITORIES, BRANCHES, AND PRODUCTION COMPLEXES

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## SPATIAL SELF-ORGANIZATION OF INDUSTRY CLUSTERS: METHODOLOGY AND APPROBATION



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*Understanding the dynamics of cluster process measurement is impossible without relying on the fundamental developments of the Russian scientific school, which has shaped the modern scientific paradigm of spatial analysis in Russia. Therefore, this study addresses the pressing issue of spatial cluster analysis from the perspective of the theory of self-organization of complex adaptive systems. The aim of the study is to develop and test a methodology for identifying and assessing spatial patterns of self-organization using the example of the shipbuilding and ship repair industry in the Kaliningrad Region. Analysis of the spatial distribution of clusters requires an interdisciplinary synthesis of economic geography, regional economics, and network theory, as it is at the intersection of these fields that the most productive tools for identifying patterns in the localization of cluster formations emerge. The methodological framework is based on the integrated application of spatial statistics tools in a geographic information systems environment. Using the example of shipbuilding and ship repair in the Kaliningrad Region, it was demonstrated that the traditional view of a cluster as a simple geographic agglomeration is insufficient. The use of a combination of spatial statistics methods has proven effective for multi-level diagnostics. The study's results demonstrate that, at the regional scale, the distribution of enterprises is statistically indistinguishable from random. However, at the level of the Kaliningrad urban district, statistically significant spatial clustering was identified, forming*

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*the core of a potential self-organizing cluster. It was established that enterprise concentration gravitates toward key infrastructure and manifests itself at specific spatial scales, i.e., radii, confirming the operation of agglomeration effects and the existence of conditions for synergistic interactions. The results also demonstrate that the proposed methodological approach enables a qualitative shift from the recognition of geographic concentration to the diagnosis of self-organization processes, which has important practical implications for the development of targeted territorial policies aimed at the targeted development of clusters at the regional scale.*

*Space, distribution, industry, cluster, location, shipbuilding, ship repair, self-organization.*

## Introduction

The spatial dimension of cluster processes cannot be understood without drawing on the foundational studies that have shaped the modern scientific paradigm of spatial analysis in Russia (Shirov et al., 2025). Of particular importance in this respect is the three-year cycle of fundamental research programs of the Presidium of the Russian Academy of Sciences, completed in 2011. A central place among these was occupied by the program “Fundamental Problems of the Spatial Development of the Russian Federation: An Interdisciplinary Synthesis”, coordinated by Academician A.G. Granberg (Granberg, 2009). This program laid the theoretical and methodological foundations for viewing space not as a static geographical backdrop but as an active, dynamic, and multi-dimensional factor of socio-economic development – an approach that fully aligns with the ecosystem logic of cluster self-organization.

In the subsequent cycle of 2012–2014, the program “The Role of Space in Russia’s Modernization: Natural and Socio-Economic Potential” was approved, building on the ideas of its predecessor but with a focus on the geographical aspects of the transformation of the country’s spatial structure in the

context of nationwide modernization. The monograph summarizing the results of the first program (Avksent’ev et al., 2013) presents an interdisciplinary synthesis encompassing the conceptual foundations of the spatial approach, the influence of the natural and socio-cultural environment, the transformation of economic and innovation space (Yu et al., 2025), as well as the methodology for analyzing and forecasting territorial structure. Particularly significant for our study is the proposition that the concept of space in economics goes beyond the traditional boundaries of its predominantly geographical definition. Regional economics research is acquiring new features precisely because of the inclusion in the analysis of a broader range of factors – social, political, legal, and technological (Fetisov et al., 2012; Mikheeva, 2025).

The experience of the interdisciplinary synthesis and of research on Russia’s space served as the foundation that was integrated into the development of the “Strategy for the Spatial Development of the Russian Federation for the Period up to 2025”<sup>1</sup>, the “Strategy for the Spatial Development of the Russian Federation for the Period up to 2030, with a Forecast up to 2036”<sup>2</sup> and related documents (Shirov et al., 2024; Kuznetsova, Druzhinin, 2024).

<sup>1</sup> On the Approval of the Strategy for the Spatial Development of the Russian Federation for the Period up to 2025: Resolution of the Government of the Russian Federation 207-r of February 13, 2019.

<sup>2</sup> On the Approval of the Strategy for the Spatial Development of the Russian Federation for the Period up to 2030, with a Forecast up to 2036: Resolution of the Government of the Russian Federation 4146-r of December 28, 2024.

This approach, which broadens the content of “space” as a scientific category, makes it possible to view cluster ecosystems not only as geographically localized entities but also as complex adaptive systems whose self-organization is shaped by the interplay of numerous non-linear, often intangible, factors – ranging from the density of network ties to the level of institutional trust and the cognitive proximity of participants. It is precisely in this context that the application of spatial analysis tools, capable of capturing not only the physical concentration of actors but also the hidden factors of their interdependence, becomes methodologically justified (Shirov et al., 2025; Foutakis, 2025).

At the same time, the analysis of the spatial distribution of clusters requires an interdisciplinary synthesis of economic geography, regional economics, and network theory, since it is at the intersection of these fields that the most productive tools for identifying the patterns of localization of cluster formations emerge (Park et al., 2019). Contemporary approaches to studying the geographic location of clusters increasingly rely not only on traditional statistical and cartographic methods but also on geographic information technologies (QGIS, ArcGIS, etc.), spatial econometrics, and the analysis of big data on the locations of enterprises and infrastructure nodes (Park et al., 2019; Zeng et al., 2023). This makes it possible not only to record existing patterns of concentration but also to model potential scenarios of their transformation under the influence of technological, institutional, and global economic shifts (Qi et al., 2024).

### Materials and methods

Within the ecosystem approach to the analysis of cluster self-organization, one of the key methodological challenges is working with multidimensional data that reflect the complex,

nonlinear interrelationships among economic, technological, institutional, and spatial factors (Popov et al., 2021; Popov, 2023). Although an adequate description of cluster dynamics objectively requires taking into account a broad range of variables – from the density of innovation activity to the level of network cooperation and infrastructure accessibility – the growth in the dimensionality of the feature space inevitably gives rise to serious analytical difficulties (Purbasari et al., 2023).

To minimize these difficulties, the author has developed an algorithm for conducting a comprehensive analysis of a cluster ecosystem (Fig. 1). This algorithm visualizes the linear model and reflects the sequential research process, beginning with the collection and preparation of data, followed by stages of spatial analysis and network analysis, the integration of the results, and concluding with the formulation of conclusions and recommendations.

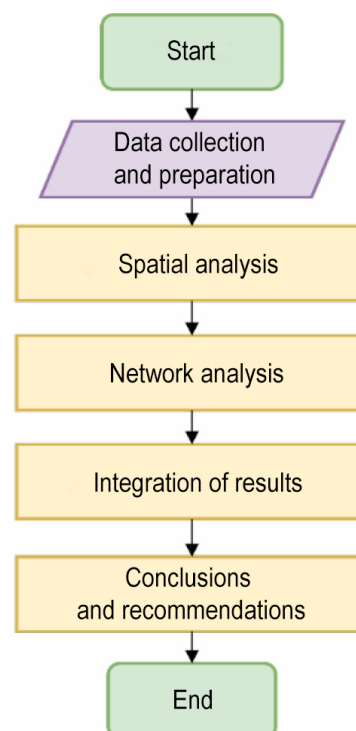


Figure 1. Algorithm for the comprehensive analysis of a cluster ecosystem

Source: own compilation.

The central tool for the quantitative assessment of these processes is the analysis of spatial autocorrelation, based on the application of the global Moran's I statistic (Krasnykh, 2025). This method makes it possible to assess the degree of spatial dependence among entities (for example, enterprises, research centers, or infrastructure nodes), taking into account both their geographic location and the values of associated attributes, such as the volume of investment, the level of innovation activity, the density of cooperation, and so on. Moran's I formalizes the hypothesis that "like attracts like" – a principle that, within the ecosystem approach, is interpreted as a manifestation of the self-organizing forces that promote the concentration of resources, knowledge, and competencies in specific territorial nodes (Sun et al., 2022).

Formally, Moran's I is calculated using formula (1) (Griffith, 1987):

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^n \sum_{j=1}^n w_{i,j} z_i z_j}{\sum_{i=1}^n z_i^2}, \quad (1)$$

where:

$z_i$  is the deviation of the attribute for feature  $i$  from its mean value ( $x_i - \bar{X}$ );

$w_{i,j}$  is the spatial weight between features  $i$  and  $j$ ;

$n$  is the total number of features;

$S_0$  is the sum of all spatial weights.

Within the approach to the analysis of cluster self-organization we describe, a key role is played by the identification of local "anchor zones" – territorial nodes where high (or, conversely, low) values of innovation activity, investment, or network density are concentrated. To this end, the High/Low Clustering tool (the Getis-Ord General G statistic, calculated in ArcGIS) is employed (Mitchell, 2005), a statistical instrument designed to detect anomalous clusters of extreme values in space.

The degree of clustering is determined on the basis of the General G index, which is calculated using the following formula:

$$G = \frac{\sum_{i=1}^n \sum_{j=1}^n w_{i,j} x_i x_j}{\sum_{i=1}^n \sum_{j=1}^n x_i x_j}, \quad \forall j \neq i, \quad (2)$$

where:

$x_i$  and  $x_j$  are the attribute values for features  $i$  and  $j$ ;

$w_{i,j}$  is the spatial weight for the pair of features  $i$  and  $j$ ;

$n$  denotes the total number of features in the dataset;

$\forall j \neq i$  indicates that features  $i$  and  $j$  cannot be the same entity.

The next method we examined is incremental spatial autocorrelation, which makes it possible to identify the optimal spatial scale at which clustering processes manifest themselves. The tool successively applies Moran's I at increasing distances, recording the corresponding z-scores. Z. Zhao and N. Levine recommend using these "critical distances" in other analytical tools – for example, when setting the search radius for neighbors, which is calculated on the basis of the standard deviational ellipse. The presence of one or more peaks reflects the multi-level structure of the cluster ecosystem, ranging from local nodes to interregional networks (Levine, 2004; Zhao et al., 2023).

The quantitative patterns presented in this section acquire profound meaning only in the context of the evolutionary dynamics of clusters as adaptive systems (Mitchell, 1999; Martin, Sunley, 2020). Indeed, within the paradigm of regional economic development, clusters have become firmly established as key drivers of innovation growth, enhanced competitiveness, and the resilience of national economies, demanding the development of new approaches to their identification and analysis (Shirov, 2020; Smorodinskaya, Katukov, 2019).

Today, the formation and development of clusters is recognized as an effective tool for stimulating economic growth and enhancing the international competitiveness of any country. The proliferation of cluster initiatives across various sectors and geographic zones around the world testifies to the high effectiveness of this development model. At the same time, the functioning of a mature cluster creates a favorable environment for the development of small and medium-sized enterprises, contributing to the formation of a comprehensive ecosystem that includes new opportunities and infrastructure solutions.

Thus, an analysis of data from the State Information System of Industry (GISP) of the Russian Ministry of Industry and Trade shows that industrial parks currently occupy a dominant position in Russia, numbering 380 units as of June 2025, while technology parks number 137 units and entry-level clusters number only 43 units, indicating the early stages of the formation of an innovation base in the country. At the same time, only 8 units have reached a medium level of development, pointing to the difficulties of scaling up initial projects and the relevance of the problem under study.

The consideration of production clusters within the structure of economic planning is of great importance for optimizing the allocation of resources and for building sustainable regional competitive advantages. At the same time, under the conditions of mounting turbulence in the global environment, sanctions pressure, and the industrial revolution in the field of artificial intelligence, traditional deterministic approaches to managing economic systems are revealing their limitations. This, in turn, makes it especially urgent to study clusters that exhibit the properties of self-organizing systems – complex, open, nonlinear structures capable of spontaneous ordering, adaptation, and co-evolution in response to the challenges

of the external environment (Polyakov, Brizhak, 2023).

### Research results

In addressing the methodological problem outlined above, particular interest attaches to the study of specific industry complexes (Druzhinin et al., 2025) that display signs of self-organization. A vivid example for such an analysis is the shipbuilding and ship repair industry. The empirical basis for identifying cluster potential in the country rests on data on the spatial distribution of enterprises in the sector (Polyakov, Brizhak, 2024).

Ship repair and shipbuilding enterprises form one of the most important sectors of the Russian Federation's economy. This sector creates jobs, generates tax revenues, and makes a substantial contribution to the economic future of the region concerned. Despite all these advantages, however, shipbuilding and ship repair enterprises face major difficulties associated with the high cost of equipment and resources (especially under sanctions), complicated certification and licensing procedures, and insufficient funding and support (Polyakov, Brizhak, 2024).

In order to address the current problems, measures are being taken within the framework of state economic development policy to provide support to enterprises in the shipbuilding and ship repair sector. Shipbuilding, as an integral part of Russia's machine-building complex and its military-industrial complex, plays a strategically important role in ensuring national security and economic sovereignty. Today, the largest centers of shipbuilding in the Russian Federation are Saint Petersburg, Severodvinsk, Nizhny Novgorod, and the Kaliningrad Region. According to data for 2024, more than 180 large shipbuilding enterprises were operating in the country, of which about 87 were state-owned. This structure reflects the state's significant role in the development and regulation of the shipbuilding industry.

*Table 1* presents the dynamics of the output of selected types of shipbuilding products and equipment.

The analysis of the data in *Table 1* reveals a number of ambiguous trends in the river passenger vessel segment. Since the beginning of the period under review, an overall positive dynamic has been observed, with a peak value reached in 2020, after which output declined and then stabilized. The output of mixed river-sea vessels exhibits volatility, with a sharp increase in 2022, followed, however, by a return to minimal values.

In the cargo vessel segment, the production of sea-going tankers is marked by instability. The output of sea-going dry cargo vessels shows an upward trend over the period under review. The production of pleasure and sporting vessels is experiencing steady growth. The data point to the development potential of the small-tonnage shipbuilding sector.

At the same time, many companies in the sector are engaged not only in shipbuilding and ship repair but also in related fields, such as the production of propulsion, hydroacoustic, navigation, auxiliary, deck, and other equipment; materials and components for vessels; and scientific research in the area of shipbuilding and marine technology.

*Table 2* presents the distribution of shipbuilding and ship repair enterprises across the federal districts of the Russian Federation.

An analysis of the distribution of shipbuilding and ship repair enterprises across the federal districts of the Russian Federation in 2023 reveals a pronounced territorial unevenness. The highest concentration is observed in the Northwestern Federal District, which accounts for 625 enterprises (35% of the total). These enterprises generated 48% of total revenue – amounting to 146.7 billion rubles – and employed 54% of the workforce in the sector

**Table 1. Output of major product types in physical terms, 2017–2023**

Product type	Year						
	2017	2018	2019	2020	2021	2022	2023
River passenger vessels, units	12	9	17	29	19	23	22
Mixed river-sea passenger vessels, units	1	2	2	1	1	7	1
Sea-going tankers, units	2				1		
River tankers, units		7	1				
Mixed river-sea tankers, units	7	3					14
Sea-going dry cargo vessels, units	1		8		2	3	4
Sea-going cargo-passenger vessels, units	1				1		
River dry cargo vessels, units	2	1	1	2	1	6	1
Mixed river-sea dry cargo vessels, units		5	9	18	15	5	8
Sea-going tugboats, units	8	1	1	4	36		1
Pleasure and sporting vessels, thousand units	76.3	74.2	79.7	88.3	117.4	132.5	167.4
Other pleasure or sporting vessels; rowing boats, dinghies, and canoes, thousand units	10.9	7.8	6.9	4.9	7.0	12.8	15.3

Compiled from: Output of major product types in physical terms from 2017. Available at: <https://fedstat.ru/indicator/58636>; Industrial production in Russia. 2023. Federal State Statistics Service. Available at: [https://rosstat.gov.ru/storage/2024/03-21/99jTVcC9/Sbornik\\_prom\\_proiz\\_2023/Prom\\_proiz\\_06-02-2023.xlsx](https://rosstat.gov.ru/storage/2024/03-21/99jTVcC9/Sbornik_prom_proiz_2023/Prom_proiz_06-02-2023.xlsx); Output of major product types in physical terms. Federal State Statistics Service. Available at: [https://rosstat.gov.ru/storage/mediabank/Proizvodstvo\\_god\\_s\\_2017.xlsx](https://rosstat.gov.ru/storage/mediabank/Proizvodstvo_god_s_2017.xlsx)

**Table 2. Distribution of shipbuilding and ship repair enterprises by federal district of the Russian Federation, 2023**

Federal district	Number of firms, units	Revenue, thousand rubles	Number of employees, persons
Far Eastern Federal District	290	21563228	22042
Volga Federal District	252	98703026	19997
Northwestern Federal District	625	146715235	66006
North Caucasus Federal District	10	91377	50
Siberian Federal District	83	3438417	892
Ural Federal District	27	1743301	764
Central Federal District	164	14650194	4959
Southern Federal District	337	18669752	7585
Total	1788	305574530	122295

Compiled from: data from the List-Org counterparty verification service. Available at: <https://www.list-org.com/>

(66,000 people). This is due to the presence of a developed industrial infrastructure and key shipbuilding centers located in the Leningrad, Kaliningrad, Arkhangelsk, and Murmansk regions, as well as in the city of Saint Petersburg. The remaining districts (especially the North Caucasus) play a negligible role. The sectors under study clearly display a high degree of geographic concentration that is contingent on historically formed industrial clusters and on access to maritime routes of communication.

Figure 2 shows the geography of the location of shipbuilding and ship repair enterprises in the Russian Federation. According to the data presented, these enterprises are mainly concentrated in locations that are geographically situated near major bodies of water, rivers, and seas.

Table 3 presents the output data from the analysis of the spatial concentration of shipbuilding and ship repair enterprises in the Russian Federation.

**Figure 2. Location of shipbuilding and ship repair enterprises in the Russian Federation**

Compiled from: data from the List-Org counterparty verification service. Available at: <https://www.list-org.com/>

**Table 3. Analysis of the spatial concentration of shipbuilding and ship repair enterprises in the Russian Federation**

Concentration / dispersion measure	OKVED2			
	30.1	30.11	30.12	33.15
Gini	0.969345	0.95515	0.935518	0.920427
Gini n	0.972936	0.95869	0.938983	0.923836
Gini w	0.957014	0.96046	0.930128	0.921742
Gini w n	0.960558	0.96402	0.933573	0.925156
HHI	0.210652	0.17050	0.088742	0.061625
HHI n	0.207729	0.16743	0.085367	0.058150
HHI eq	4.747162	5.86508	11.268654	16.227133
Hoover	0.888081	0.85717	0.826128	0.810508
Hoover w	0.003934	0.00426	0.004719	0.003763
Coulter	0.324674	0.29208	0.204714	0.175447
Atkinson	0.931474	0.87999	0.862611	0.812610
SD	40.532619	2466.03171	33.739741	288.821821
SD w	32.672611	1952.23772	44.440551	256.802381
CV	7.502964	6.73596	4.809821	3.969707
CV n	0.456616	0.40994	0.292716	0.241589
Williamson	7.317183	6.39616	4.174318	4.110894
Compiled from: data from the List-Org counterparty verification service. Available at: <a href="https://www.list-org.com/">https://www.list-org.com/</a>				

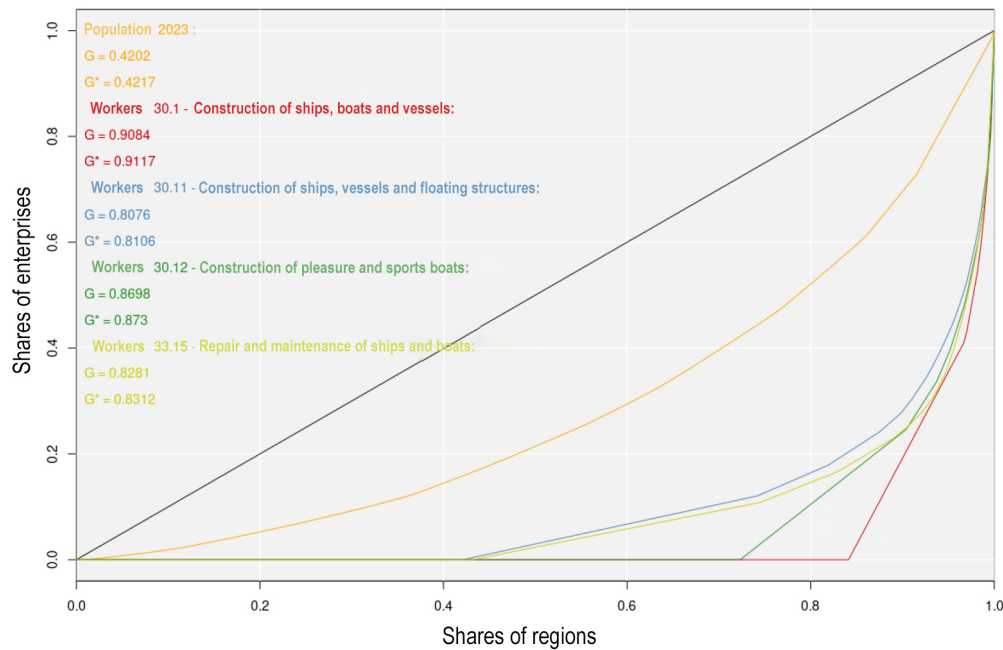
The results of the analysis point to a pronounced tendency toward spatial concentration in the shipbuilding and ship repair industries. The high values of the Gini coefficients, ranging from 0.92 to 0.97, indicate a considerable degree of inequality in the distribution of enterprises across the subjects of the Russian Federation. This suggests that the bulk of the existing economic activity in the industries under study is confined to a relatively small number of regions, which is fully consistent with the cartographic picture of the enterprises' location. At the same time, it should be noted that such a configuration carries risks for the long-term resilience not only of the industries in question but also of the national economy as a whole.

The high values of the other coefficients presented in Table 3 confirm the conclusion that a very limited number of regions accumulate the lion's share of economic activity in the sectors

under study. At the same time, the elevated values of the Williamson coefficient further highlight the depth of interregional contrasts in levels of economic development – for all the industries without exception – and once again point to the existing regional asymmetry of current industrial development.

*Figure 3* presents a chart that reflects the level of spatial concentration of shipbuilding and ship repair enterprises in the Russian Federation, using Lorenz curves and Gini coefficients ( $G$  and  $G^*$ ).

The analysis of the spatial concentration of shipbuilding and ship repair enterprises in the Russian Federation shows that most segments of the industry exhibit a high degree of territorial concentration. This means that enterprises engaged in the construction and repair of vessels are concentrated in a relatively small number of the country's regions. A particularly high degree of concentration is observed in the



**Figure 3. Spatial concentration of shipbuilding and ship repair enterprises in the Russian Federation**

Compiled from: data from the List-Org counterparty verification service. Available at: <https://www.list-org.com/>

segment of the construction of ships, vessels, and boats (30.1), as well as in the construction of pleasure and sporting boats (30.12) and in ship repair (33.15). This may be attributable to historical, infrastructural, or resource factors, as well as to the presence of shipbuilding clusters (for example, in Saint Petersburg, Kaliningrad, and the Russian Far East) and to the logistical advantages enjoyed by coastal regions.

Thus, according to data for 2023 (Tab. 4), a pronounced territorial concentration of specialized enterprises is observed in the Kaliningrad Region. This distribution not only makes it possible to register the fact of geographic agglomeration (Strano et al., 2021) but also serves as a starting point for a deeper analysis of the manifestations of self-organization – an analysis of cooperative ties, value chains, and institutional interactions among geographically proximate enterprises, which forms the basis for identifying a self-organizing cluster in the region’s shipbuilding sector.

An analysis of the data in Table 4 shows that the regional center – the City of Kaliningrad

Urban Okrug – is the clear leader across all indicators. It accounts for the largest number of employees – 1,658 persons, or 59.5% of the total number employed in the sector; the largest number of firms – 63 units; and 83.4% of all revenue, which points to the concentration of the industry’s main production capacities and economic resources in the regional center.

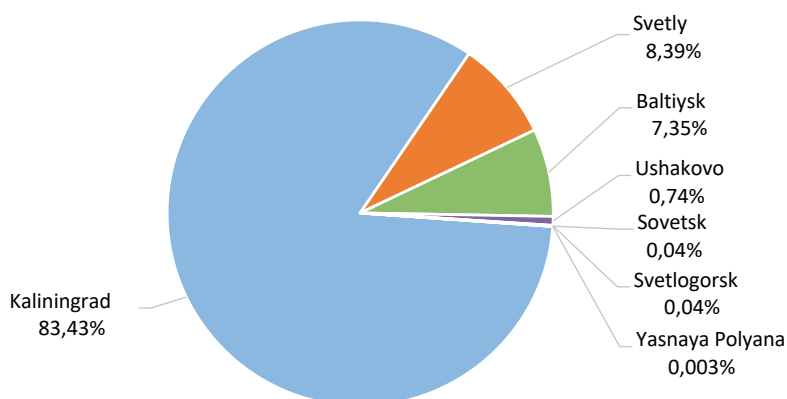
The structure of the distribution of shipbuilding and ship repair enterprises across the cities of the Kaliningrad Region in 2023 is presented in Figure 4. According to this figure, the Svetly and Baltiysk Urban Okrugs are also important centers of the shipbuilding industry beyond the regional center, specializing mainly in ship repair in the port zone.

At the same time, a substantial share of the municipal okrugs show zero values for both revenue and the presence of enterprises in the industry under study. This indicates that beyond Kaliningrad, industry activity is dispersed in a fragmentary fashion, lacking stable spatial structures, which may limit the synergistic potential of the regional cluster ecosystem.

**Table 4. Distribution of shipbuilding and ship repair enterprises by municipal okrug in the Kaliningrad Region, 2023**

Okrug No.	Municipal okrug	Revenue, thousand rubles	Number of firms, units	Number of employees, persons
0	Ozersk Municipal Okrug	0	0	0
1	Nesterov Municipal Okrug	499	1	5
2	Yantarny Urban Okrug	0	0	0
3	Gusev Urban Okrug	0	0	0
4	Krasnoznamensk Municipal Okrug	0	0	0
5	Ladushkin Urban Okrug	0	0	0
6	Svetlogorsk Urban Okrug	8118	2	4
7	City of Kaliningrad Urban Okrug	15113538	63	1658
8	Pionersky Urban Okrug	0	0	0
9	Zelenogradsk Municipal Okrug	0	0	0
10	Svetly Urban Okrug	1520079	11	401
11	Gvardeysk Municipal Okrug	0	0	0
12	Bagrationovsk Municipal Okrug	0	0	0
13	Chernyakhovsk Municipal Okrug	0	1	1
14	Neman Municipal Okrug	0	0	0
15	Polesk Municipal Okrug	0	0	0
16	Sovetsk Urban Okrug	6707	1	7
17	Slavsk Municipal Okrug	0	0	0
18	Pravdinsk Municipal Okrug	0	0	0
19	Baltiysk Urban Okrug	1330958	5	684
20	Guryevsk Municipal Okrug	134310	3	28
21	Mamonovo Urban Okrug	0	0	0

Compiled from: data from the List-Org counterparty verification service. Available at: <https://www.list-org.com/>

**Figure 4. Structure of the distribution of shipbuilding and ship repair enterprises across the cities of the Kaliningrad Region, 2023, %**

Source: own compilation.

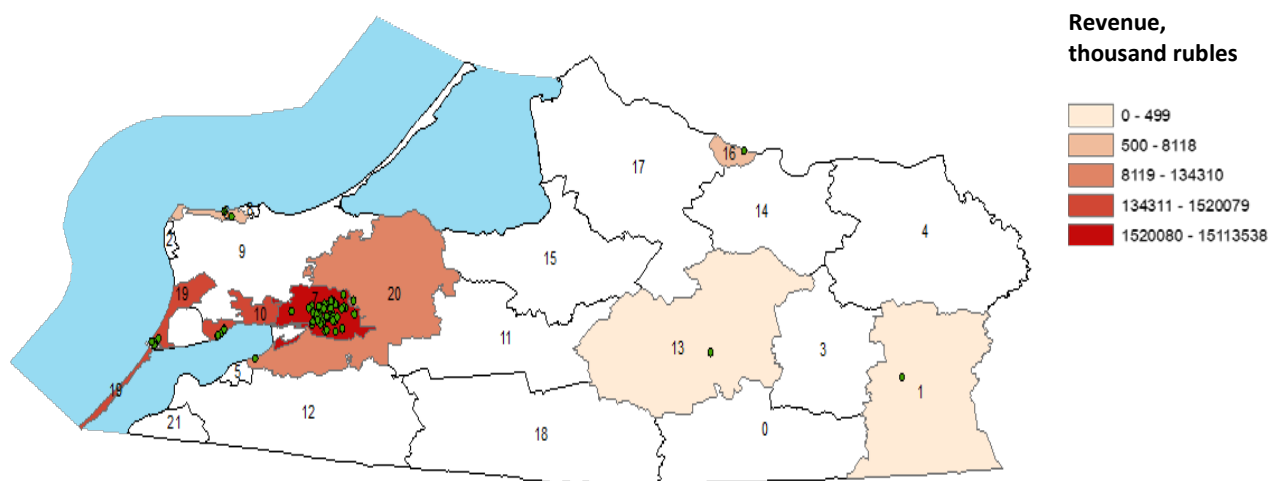
### Spatial analysis of the Kaliningrad Region

Let us now draw on the author's dataset DatsetOKVED, which contains information on 1,788 companies in the shipbuilding and ship repair industry of the Russian Federation (OKVED 30.1, 30.11, 30.12, 33.15), and carry out a comprehensive spatial analysis of these industries using the example of the Kaliningrad Region. To do this, we plot the data on a map and analyze the distribution of shipbuilding and ship repair enterprises across the districts of the Kaliningrad Region (Fig. 5).

The distribution of shipbuilding and ship repair enterprises in the Kaliningrad Region corroborates the data analyzed earlier and demonstrates pronounced local clustering within the City of Kaliningrad Urban Okrug, which once again testifies to the concentration of production and innovation potential in the regional center. At the same time, these enterprises give rise to the dominance of agglomeration effects, which are manifested in the developed infrastructure, the availability of skilled personnel, and a favorable investment climate.

However, the data in Figure 5 point to the absence of statistically significant spatial autocorrelation in the distribution of

shipbuilding and ship repair enterprises across the territory of the Kaliningrad Region, with the pattern being essentially random. The values obtained for Moran's I, the z-score, and the p-value likewise indicate that the spatial distribution of the enterprises displays no pronounced clustering or dispersion, leaning rather toward a random pattern, since there are no statistically significant signs of spatial autocorrelation. This may be attributable to several factors. First, at the scale of the Kaliningrad Region – which encompasses a large territory with diverse economic and geographic conditions – the local clusters observed within the city are leveled out. Second, the presence of the enterprises under study in locations outside the city may be shaped by other factors that are unrelated to the agglomeration effects typical of the city – for instance, proximity to the ports of Kaliningrad (the commercial and fishing ports), Svetly, Baltiysk, and Pionersky, to ship repair bases, to raw-material sources, or to logistical nodes. Third, the analysis covers the entire territory of the region, including districts where shipbuilding and ship repair enterprises are either present in single instances or entirely absent, a fact that affects the overall picture of spatial distribution.



**Figure 5. Distribution of the revenue of shipbuilding and ship repair enterprises across the districts of the Kaliningrad Region, 2023**

Source: own compilation using ArcMap software (Esri Inc. (2019). ArcMap 10.8. Available at: <https://www.esri.com/en-us/arcgis>).

Given the identified concentration of industry activity within the City of Kaliningrad Urban Okrug, the subsequent study will focus on its territorial boundaries. This stage envisages a detailed spatial analysis aimed at identifying the key factors that give rise to the formation and functioning of the cluster ecosystem in the urban environment, with a particular emphasis on the specificities of the shipbuilding and ship repair industries. Such an approach will make it possible to uncover the local mechanisms of self-organization, the institutional and infrastructural conditions, and the spatial patterns of interaction among economic agents that either facilitate or, conversely, constrain the development of the sector's potential at the micro level (Druzhinin et al., 2025; Chen et al., 2024).

### **Spatial analysis of the City of Kaliningrad Urban Okrug**

Using the data in *Table 5*, let us analyze the concentration indicators for shipbuilding and ship repair enterprises across the districts of the City of Kaliningrad Urban Okrug. This analysis will make it possible to identify the specific features of the sector's location within the city, to assess the contribution of each district to the overall picture, and to pinpoint possible development trends.

Moskovsky District exhibits an overwhelming superiority across all three indicators: revenue, costs, and number of employees. The values of these indicators point to the concentration of

the industry's main production capacities and employment in this district. It is here that the Yantar Baltic Shipyard (hereinafter referred to as PSZ Yantar JSC) is located – the leading enterprise in the sector, which specializes in military and civil shipbuilding, ship repair, as well as the production of metal structures and products in the sphere of machine building. In addition, Moskovsky District is home to the key transport and logistical infrastructure: the Kaliningrad Commercial Sea Port, which handles freight and passenger traffic; the Kaliningrad Sea Fishing Port; and the Kaliningrad River Port, situated on the Pregolya River and servicing inland freight transportation.

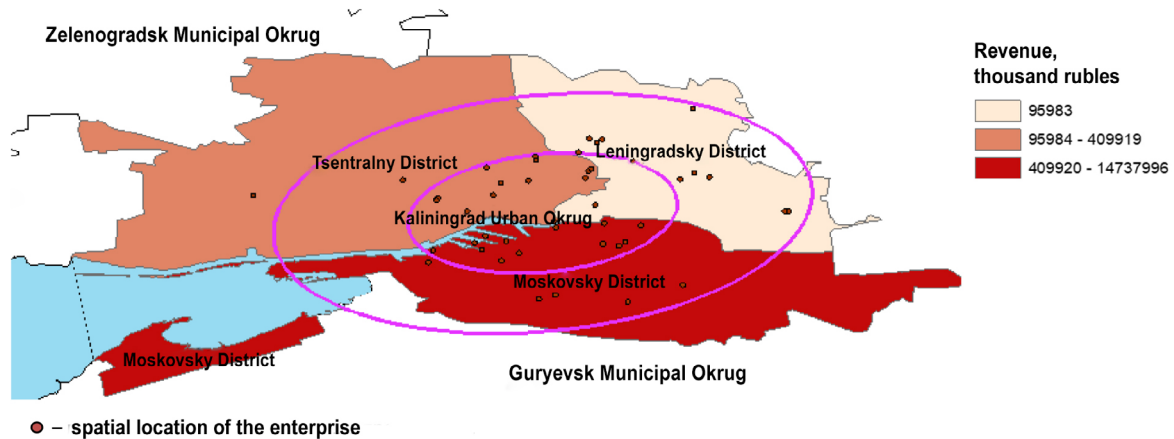
The combination of a favorable geographic location – at the mouth of the river and at the junction of sea and river routes – together with the developed infrastructural base, forms the spatial core of attraction for enterprises in the sector, promoting the concentration of production capacities, logistical links, and human resources. This, in turn, reinforces the agglomeration effects and has a substantial influence on the self-organization of the ecosystem of this industry cluster.

Next, the map (*Fig. 6*) pinpoints the locations of the enterprises in the sector, while the aggregate revenue by district is marked in color. The concentration of objects in Moskovsky District, as well as the high revenue values in this zone, testify to the formation of an economic core of the cluster that brings together production capacities and infrastructural nodes.

**Table 5. Concentration indicators for shipbuilding and ship repair enterprises across the districts of the City of Kaliningrad Urban Okrug, 2023**

District ID	District name	Total revenue, thousand rubles	Total costs, thousand rubles	Number of employees, persons
0	Leningradsky District	95983	67737	18
1	Tsentralny District	279559	128240	182
2	Moskovsky District	14737996	1697620	1458
Total		15113538	1893597	1658

Compiled from: data from the List-Org counterparty verification service. Available at: <https://www.list-org.com/>



**Figure 6. Standard deviational ellipse reflecting the spatial concentration and direction of the distribution of shipbuilding and ship repair enterprises in the City of Kaliningrad Urban Okrug, 2023**

Source: own compilation using ArcMap software (Esri Inc. (2019). ArcMap 10.8. Available at: <https://www.esri.com/en-us/arcgis>).

Tsentralny District ranks second in terms of revenue (279,559 thousand rubles), costs, and number of employees (182 persons). It plays a substantial role, although it trails Moskovsky District considerably in terms of the scale of activity. Research shows that Tsentralny District in Kaliningrad – on Pravaya Naberezhnaya Street – hosts a concentration of enterprises that perform functions such as design, repair, and supply, as well as smaller-scale enterprises likewise specializing in shipbuilding and ship repair (for instance, Baltiyskaya Sudoremontnaya Kompaniya LLC and other ship repair companies).

A standard deviational ellipse has also been constructed on the map around the enterprises' locations, showing the dominant direction and degree of dispersal of the objects. The elongation

of the ellipse along the coastline points to an anisotropy in the distribution that is shaped by transport, logistical, and infrastructural factors of importance to the sector.

By default, the size of the ellipse is set to 1, which corresponds to the cluster core. In addition, a second ellipse was constructed covering two standard deviations, which supports the hypothesis advanced regarding the homogeneity of the input class of all the spatial objects selected. These geometric characteristics of the distribution find quantitative confirmation in the results of the nearest neighbor analysis.

The author then carried out an analysis of the spatial distribution of shipbuilding and ship repair enterprises in the City of Kaliningrad Urban Okrug using the nearest neighbor method (Tab. 6).

**Table 6. Nearest neighbor summary for shipbuilding and ship repair enterprises in the City of Kaliningrad Urban Okrug, 2023**

Indicator	Value
Observed mean distance	423.4645 m
Expected mean distance	673.6942 m
Nearest neighbor ratio	0.628571
z-score	-5.639976
p-value	0.000000

Source: own compilation using ArcMap software (Esri Inc. (2019). ArcMap 10.8. Available at: <https://www.esri.com/en-us/arcgis>).

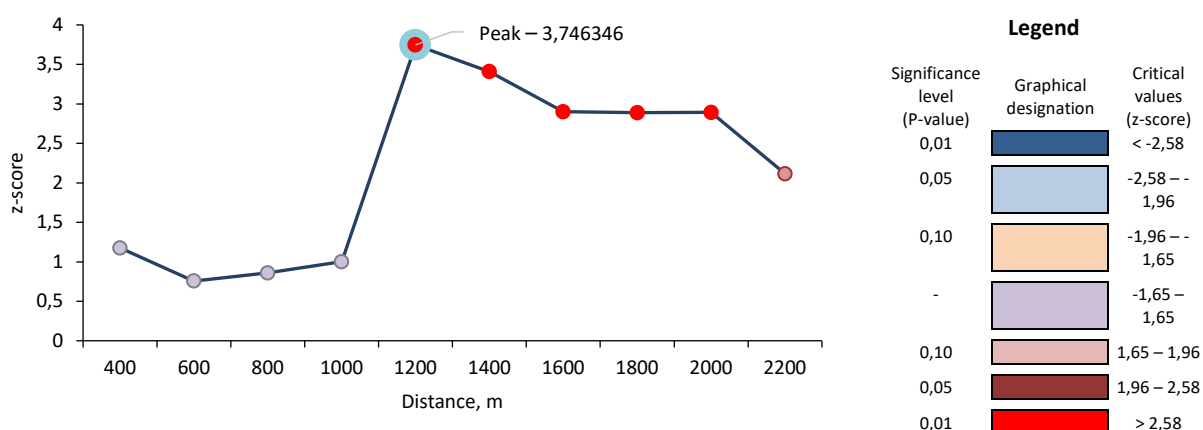
The results of the nearest neighbor analysis confirm the presence of statistically significant spatial clustering of shipbuilding and ship repair enterprises in Kaliningrad. The nearest neighbor ratio, which stands at 0.629 (substantially below one), points to a tighter clustering of the enterprises than would be observed under a random distribution. The high negative z-score (-5.64) and a p-value close to zero (0.001) testify to the presence of stable local agglomeration effects and the functional interconnectedness of the industry's participants, which form the core of the cluster ecosystem.

The observed mean distance between each enterprise and its nearest neighbor is 423.46 m, which is substantially below the expected value of 673.69 m under a random distribution. The corresponding nearest neighbor ratio is 0.6286, which unequivocally points to a tendency toward the concentration of objects in space. The clustering identified reflects not only geographic concentration but also the functional interdependence of the industry's participants, which forms the basis for the self-organization of the cluster ecosystem at the local level.

The results of the spatial autocorrelation analysis for the shipbuilding and ship repair enterprises in the City of Kaliningrad Urban Okrug, using the Global Moran's I summary by distance, are presented next (Fig. 7).

The results show that at short distances (400 to 1,000 m), Moran's I takes low positive values – from 0.0227 to 0.0247. The high p-values, however, which lie in the range of 0.24 to 0.32, point to the absence of statistically significant autocorrelation. At the same time, at intermediate distances of 1,200 to 2,000 m, a clear and statistically reliable clustering is observed: Moran's I reaches a maximum of 0.1245 at 1,200 m ( $p = 0.0002$ ), and the values at the remaining distances in this range are also significant ( $p < 0.01$ ).

These findings indicate that enterprises in the sector show a tendency toward localization and tend to group within a radius of 1.2 to 2.0 km around key infrastructural centers – port zones, industrial clusters, or transport arteries. At a distance of 2,200 meters, the index drops to 0.0339 but retains statistical significance at  $p = 0.0344$ , which points to a weakening of the spatial ties, though by no means to their complete disappearance.



**Figure 7. Result of the spatial autocorrelation analysis using the global Moran's I summary for shipbuilding and ship repair enterprises in the City of Kaliningrad Urban Okrug, 2023**

Source: own compilation using ArcMap software (Esri Inc. (2019). ArcMap 10.8. Available at: <https://www.esri.com/en-us/arcgis>).

To verify the quantitative estimates obtained, the author performed an analysis of the spatial distribution of the enterprises in the industry under study using the General G statistic (Getis-Ord). The calculation showed that the observed value of G is 0.0888, which is noticeably higher than the expected value under a random distribution (0.0162). Consequently, a purposeful concentration of enterprises in certain urban zones is taking place.

The spatial concentration and the direction of the distribution of shipbuilding and ship repair enterprises in the cluster within the City of Kaliningrad Urban Okrug are presented in Figure 8.

An analysis of the results shows that the threshold distance (3,948.92 m) defines the radius within which enterprises are treated as spatial neighbors when calculating the index. Thus, shipbuilding and ship repair enterprises are not randomly distributed but are concentrated in local clusters, which is consistent with the hypothesis of the territorial agglomeration of the

sector, driven by the presence of infrastructure, logistical, and production factors.

It is worth noting that the “high-low” (HL) outlier clearly points to an area with a high level of concentration / productivity. The region’s largest enterprise, PSZ Yantar JSC, is located here, yet it is surrounded by territories with low concentration/productivity. The value identified also points to a local center of activity that has so far not exerted a substantial positive influence on neighboring enterprises owing to its low cooperative activity.

The second outlier, “low-high” (LH), reflects an opposite site, where an area with a low concentration of enterprises is surrounded by areas with a high concentration. This is a depressed area within a developed cluster, which points to the heterogeneity of the development of the territory under study.

A graphical analysis of the spatial clustering of shipbuilding and ship repair enterprises in the City of Kaliningrad Urban Okrug, using the General G statistic, is presented next (Fig. 9).

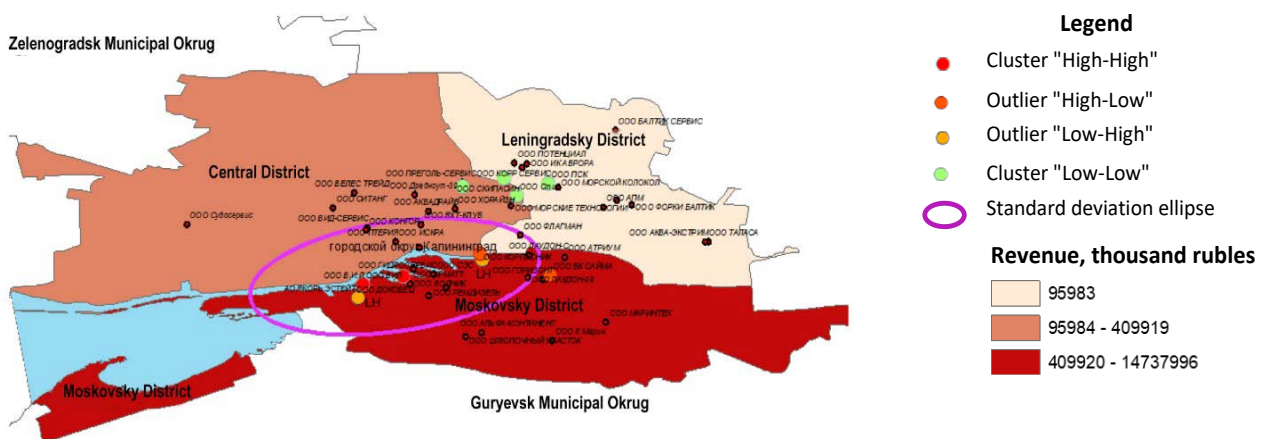
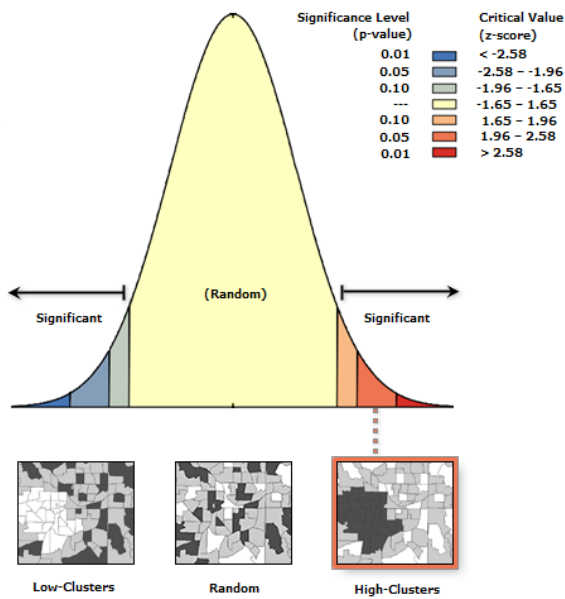


Figure 8. Spatial concentration and direction of distribution of shipbuilding and ship repair enterprises in the cluster in the City of Kaliningrad Urban Okrug, 2023

Source: own compilation using ArcMap software (Esri Inc. (2019). ArcMap 10.8. Available at: <https://www.esri.com/en-us/arcgis>).



**Figure 9. Analysis of the spatial clustering of shipbuilding and ship repair enterprises in the City of Kaliningrad Urban Okrug using the General G statistic, 2023**

Source: own compilation using ArcMap software (Esri Inc. (2019). ArcMap 10.8. Available at: <https://www.esri.com/en-us/arcgis>).

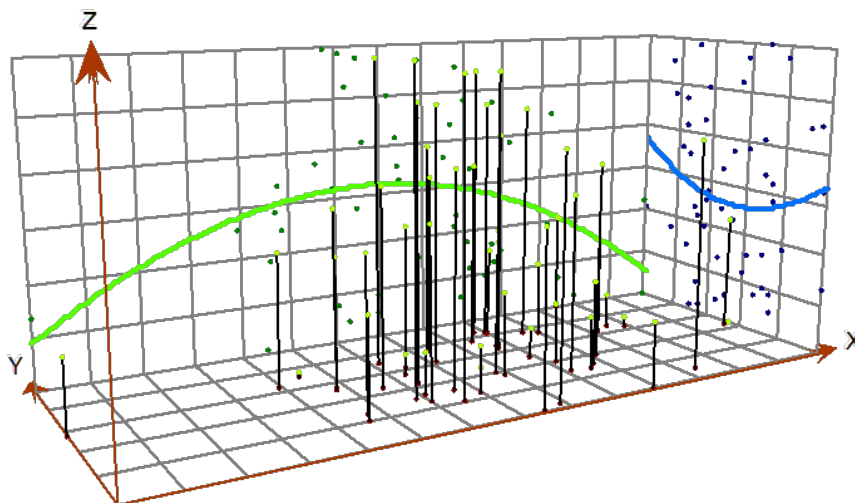
The results in Figure 9 are consistent with the conclusions drawn earlier in the nearest neighbor analysis and confirm the tendency

toward the concentration of enterprises in certain districts of the city. Further research can be directed toward a more detailed analysis of the factors influencing the spatial clustering of shipbuilding and ship repair enterprises, as well as toward an assessment of the consequences of this clustering for the economy of the city and of the region under study.

To conclude our investigation, we make use of the Trend Analysis tool in ArcGIS to visualize the spatial dynamics of the coordination of ties among shipbuilding and ship repair enterprises in the City of Kaliningrad Urban Okrug (Fig. 10).

The figure depicts a three-dimensional surface on which the X and Y axes plot the geographic coordinates of the spatial location of the enterprises in the industry under study, while the Z axis plots an integral coordination indicator that accumulates the number of enterprises, their revenue, and the number of employees.

This analysis serves, on the one hand, as a basis for the subsequent study of network interconnections among the enterprises – an investigation the author plans to present in



**Figure 10. Three-dimensional trend surface analysis reflecting the spatial dynamics of the coordination of ties among shipbuilding and ship repair enterprises in the City of Kaliningrad Urban Okrug, 2023**

Source: own compilation using ArcMap software (Esri Inc. (2019). ArcMap 10.8. Available at: <https://www.esri.com/en-us/arcgis>).

the next cycle of works – and, on the other, for identifying the potential factors that shape their location. Among such factors are access to infrastructure, logistical nodes, skilled personnel, and the institutional environment, which together create the conditions for the self-organization of the cluster ecosystem.

### Conclusion

Drawing on an interdisciplinary synthesis of economic geography, regional economics, and network theory, the present study has not only tested the author's methodology of spatial analysis but has also yielded a number of substantive conclusions of both theoretical and applied significance.

First and foremost, it has been empirically confirmed that the traditional interpretation of an industrial cluster as a simple geographic agglomeration of enterprises is insufficient for understanding the processes that actually take place in space. Using the example of the shipbuilding and ship repair industry of the Kaliningrad Region, it has been convincingly demonstrated that the key characteristic of the emerging cluster ecosystem is not so much the very fact of territorial proximity as the presence of statistically significant spatial patterns of self-organization – that is, of ordered structures that can be revealed only through the multi-level application of spatial statistics instruments.

One of the most substantial findings is the opposing directionality of the spatial dynamics, depending on the chosen scale of analysis. At the level of the whole of the Kaliningrad Region, the distribution of enterprises is statistically indistinguishable from random, pointing to the fragmentation of the industrial landscape and the absence of stable inter-municipal cooperative ties. When the level is shifted to that of the City of Kaliningrad Urban Okrug, however, the picture changes fundamentally: here, a stable and statistically significant spatial

clustering is registered, forming a compact core with a high density of enterprise location.

Of particular note is the “critical” clustering radius that was identified – between 1.2 and 2.0 km – within which the enterprises display the greatest spatial interdependence. This interval most likely reflects the actual radius of economic interaction, which is shaped by transport and logistical accessibility, the possibility of the prompt exchange of services and components, and the shared use of port and industrial infrastructure. The fact that, at a distance of 2.2 km, spatial autocorrelation, while weakening, nonetheless retains its statistical significance, points to the gradual, rather than abrupt, nature of the attenuation of the agglomeration effects.

It is important to stress that the spatial concentration of enterprises does not in itself constitute sufficient evidence of the existence of a cluster in the ecosystem sense of the term. The results obtained in the paper – the high values of the Gini coefficients, the statistically significant indicators of the General G statistic, the confirmed clustering at the level of the nearest neighbor analysis – provide a necessary but not a sufficient basis for a definitive conclusion regarding the presence of a self-organizing ecosystem. It is noted that the next cycle of research should be devoted to the analysis of the network interconnections among enterprises, since it is the density of cooperative ties, the intensity of knowledge exchange, and the level of institutional trust that transform a geographic agglomeration into a genuine cluster.

From a practical perspective, the methodology proposed here – which combines quantitative GIS methods with ecosystem logic – can be viewed as a tool for the targeted adjustment of regional industrial policy. The spatial core that was identified within the boundaries of Moskovsky District of

Kaliningrad, coinciding with the zone where PSZ Yantar JSC and the key port facilities are located, represents a natural proving ground for targeted institutional and infrastructural interventions. In contrast to the “diffuse” support of the entire industry across the region, the concentration of measures precisely within the boundaries of the identified cluster core is capable of yielding a higher multiplier effect.

In a broader context, the present paper contributes to the debate on the limits of the

applicability of spatial analysis in regional economic research. It has been demonstrated that the absence of clustering at one territorial level by no means precludes its presence at another, more local level – a fact that requires both the researcher and the practitioner to forego the search for a single “correct” scale of analysis in favor of a multi-level diagnostic approach. It is precisely in this capacity to capture the heterogeneity of spatial processes that, in our view, the main value of the proposed approach lies.

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## ПРОСТРАНСТВЕННАЯ САМООРГАНИЗАЦИЯ ОТРАСЛЕВЫХ КЛАСТЕРОВ: МЕТОДОЛОГИЯ И АПРОБАЦИЯ

*Осмысление динамики измерения кластерных процессов невозможно без опоры на фундаментальные разработки российской научной школы, в рамках которой сформировалась современная научная парадигма пространственного анализа России. В связи с этим данное исследование посвящено актуальной проблеме пространственного анализа кластеров с позиции теории самоорганизации сложных адаптивных систем. Его цель состоит в разработке и апробации методологии выявления и оценки пространственных паттернов самоорганизации на примере судостроительной и судоремонтной отрасли Калининградской области. Анализ пространственного распределения кластеров требует междисциплинарного синтеза экономической географии, региональной экономики и теории сетей, поскольку именно при пересечении этих направлений возникают наиболее продуктивные инструменты для выявления закономерностей локализации кластерных образований. Методологический аппарат базируется на комплексном применении инструментов пространственной статистики в среде геоинформационных систем. На примере судостроения и судоремонта Калининградской области было продемонстрировано, что традиционный взгляд на кластер как на простую географическую агломерацию является недостаточным. Применение комплекса методов пространственной статистики показало свою эффективность для многоуровневой диагностики. Результаты исследования демонстрируют, что в региональном масштабе распределение предприятий статистически не отличается от случайного, однако на уровне городского округа «Город Калининград» выявлена статистически значимая пространственная кластеризация, формирующая ядро потенциального самоорганизующегося кластера. Установлено, что концентрация предприятий тяготеет к ключевой инфраструктуре и проявляется на определенных пространственных масштабах, т. е. радиусах, что подтверждает действие агломерационных эффектов и наличие условий для синергетического взаимодействия. Полученные результаты показывают, что предлагаемый методический подход позволяет осуществить качественный переход от констатации географической концентрации к диагностике процессов самоорганизации. Это имеет важное практическое значение для формирования адресной территориальной политики целенаправленного развития кластеров в региональном масштабе.*

*Пространство, распределение, промышленность, кластер, местоположение, судостроение, судоремонт, самоорганизация.*

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