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IDENTIFYING CLUSTERS IN INNOVATIVE ENGINEERING ON THE BASE OF DATA MINING AND CHAOS THEORY

Abstract: *The study is based on hypotheses that the formation of clusters in engineering occurs spontaneously, and their life cycle passes through different stages. In this regard, formed clusters affect other clusters and economic structures, including the yield of products in them.Results: 1) A set of indicators for the identification of innovative engineering clusters and determining the stage of their life cycle was developed. 2) The regularities of the functioning of innovative engineering clusters at each stage of its life cycle are determined. 3) The values of the indicators for each stage of the lifecycle of innovative industrial clusters.A set of indicators developed by the authors to identify clusters of innovative engineering and determine the stage of their life cycle allows with sufficient accuracy to solve the task of pattern recognition in the study of the processes and management of development of cluster structures in the study area.*

Keywords: *Innovative engineering clusters; Stage of cluster life cycle; Data mining; Chaos theory.*

1. Introduction

At present, the global industry is following the path of creation and development of cluster structures. According to the European Cluster Observatory in Europe, more than two thousand clusters function in various sectors of the economy. Countries actively using cluster strategies were able to achieve GDP growth in the range from 75 to 90%. These include France, Germany, the United Kingdom and others (Boush et al. 2016).

Thus, the use of the cluster development strategy in the modern economy contributes to an increase in the level of competitiveness of enterprises, an intensification of innovation processes, and an increase in the standard of living of the population (Cooke, 2001; Boush et al. 2016, Spencer et al., 2010, etc.).

Moreover, a special place in the modern economy belongs to innovative machine-building clusters (Sharipov, 2015; Isaksen, 2009; Cooke & Memedovic, 2003, etc.). Because they are one of the key elements of the development of territories, since they form a platform for enhancing production processes of various types of products and creating disruptive innovation (Guly & Maklakhov, 2009; Lavrikova et al., 2014, etc.).

All mentioned above actualizes the issues of developing effective tools for managing the formation and development of clusters in the field of innovative engineering.

At present, the existing methods and technologies in management are not capable of solving the tasks of adaptive management of innovative cluster structures at a sufficient level of efficiency, since clusters are formed

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and are functioning under conditions of high uncertainty, are self-organizing structures largely dependent on environmental conditions (Cooke, 2001; Boush, et al. 2016).

It goes without saying, that one of the areas of tools' development for adaptive management of innovative clusters is solving the problem of identifying these clusters from the variety of economic structures, and determining the stage of their life cycle. This is due to the fact that for each stage of the clusters' life cycle, their most effective approaches and management tools are being applied.

The research was addressed to the issue of developing criteria for identifying innovative engineering clusters.

It is a well known fact, that in modern science, in spite of the high popularity of the cluster approach and the presence of a significant number of scientific publications on this topic, the optimal method for identifying clusters from a variety of economic structures has not been found yet.

In order to solve the problem, a bibliographic search has been performed.

Analysis of scientific publications allows treating a cluster either as a group of geographically close interconnected enterprises belonging to one of them or a set of related industries and complementary to each other (Babkin & Novikov, 2016; Nesmachnykh & Litovchenko, 2013; Marshall, 1993; Sorenson & Audia, 2000; Delgado et al., 2015, etc.), or as a localized network of enterprises in the absence of a single control center and managed using network technologies (Tichy et al., 1979; Jackson et al., 2017; and others.), or as a group of interrelated industries, a segment of industry (Mindlin et al., 2016; Ortuzar 2015, etc.).

Generally most scientists agree that the cluster is based on the core of a set of enterprises producing similar products in terms of parameters - cluster products (Boush et al., 2016; Babkin & Novikov, 2016; Sozinova et al., 2016 and others). The activities of enterprises belonging to the core of the cluster are ensured by their interaction with enterprises that perform supporting functions: formation of a resource base, creation of innovations, etc. (Boush et al., 2016).

Moreover, the bibliographic search made it possible to identify patterns in the emergence and development of cluster structures in the modern economy.

As research has globalised, formation of clusters is accompanied by the emergence and then successive enhancement of the synergistic effect, which contributes to the increase in the volume of output in the cluster, while the level of similarity of output in the cluster is consistently increasing. This effect can be detected using statistical methods and simulation methods (Boush et al., 2016).

In the course of their development, clusters shift the production in their own direction, becoming one of the key factors for the development of the territory (region) in which they are located (Cooke, 2001; Boush et al., 2016, etc.). This contributes to the fact that clusters influence economic structures created by enterprises producing similar products in other territories (regions) (Boush et al., 2016).

As it is stated in the works of Menzel & Fornahl (2009), Ron & Sunley (2011), Daddi et al. (2017) and others devoted to the development of cluster evolution and the structure of the clusters life cycle, formation of the stages of the life cycle of clusters is influenced by the technological heterogeneity of enterprises that form these economic structures, their potential. Studies have shown that economic clusters go through stages like emergence, growth, decline, extinction or renewal. The evolution of clusters is accompanied by the interrelation of clustering processes with information processes implemented in the territory (region) in which they are located (Boush et al., 2016).

Some scientists find a positive trend and memory effect (Boush et al., 2016) at the stages of the clusters life cycles characterizing their growth and development in the time series that specify their indicators in most cases.

The above patterns of occurrence and development are specific for innovative machine-building clusters. The difference of these clusters from other cluster structures is their interconnection with the innovation processes of regional, state and world level (Feldman & Audretsch, 1999, etc.).

To solve the aroused problem it is urgent to find methods of identifying clusters and determining the stage of their life cycle, including innovative ones. To date, expert methods are used in combination with cartographic, network analysis, statistical analysis methods, data mining methods, and simulation methods.

It is known, that one of the first approaches to solving the problem of identifying clusters from a variety of economic structures was developed by M. Porter, and improved by Kovaleva (2011). The methodology of M. Porter was refined and implemented to identification and mapping clusters in the (EU) European Cluster Observatory. To solve the problem of cluster identification such indicators as the coefficient of localization, size of the cluster group, focus of the cluster group are used.

Thus, implementation of network analysis to identify clusters involves finding the cluster core, building value chains, which are created in a cluster, identifying primary and secondary industries in cluster structures (Kovaleva, 2011).

Statistical methods and methods of intellectual analysis are among the most informative, allowing with sufficient accuracy to identify patterns of clusters functioning, determine key performance indicators of their development, predict trends and tendencies of clustering processes in the modern economy, and therefore develop criteria for solving the problem of cluster identification from sets of economic structures (Markov & Petukhova, 2013; Brenner, 2000; etc.).

But bibliographic search has also shown that cluster analysis methods, neural networks, taxonomy building methods, etc. are used to solve the above problems (Spencer et al., 2010; Feser & Sweeney, 2000; Hanks et al., 1994; Goetzmann & Wachter, 1995; Veselovsky et al., 2015; and others.).

These methods make it possible to solve the problem of identifying clusters, research of patterns of their functioning.

Using statistical methods, it has been shown that the functioning of cluster structures in the region leads to an increase in the level of employment and income of the population (Spencer et al., 2010). It was determined that the interaction of the participants is one of the key factors triggering clustering processes (Feser & Sweeney, 2000).

The article (Hanks et al., 1994) describes the use of mathematical cluster analysis for constructing taxonomy of growth configurations of high-tech organizations and a taxonomy of growth stage configurations in a sample of 126 high-technology organizations. The derived configurations suggest a sequence of four growth stages.

Neural networks are actively used in the study of clustering processes, including the study of cluster structures of territorial-administrative entities (for example, one of the regions of the Russian Federation) (Karminskaya, 2013).

Despite a significant number of publications on the above topics, as shown by the bibliographic analysis, the solution of the above problems is local, the use of statistical methods is fragmentary, only certain aspects of cluster functioning are investigated which makes it difficult to develop a set of criteria for identifying clusters, the use of which will allow with sufficient accuracy to identify clusters from a variety of economic structures.

On contrary, to solve the development problem of criteria for identifying clusters from a variety of economic structures we suggest data mining methods and chaos theory, which allow describing a cluster and its functioning with varying environmental conditions, as well as the processes of creation and diffusion of innovations with sufficient accuracy.

Our investigation involves innovative engineering clusters.

2. The purpose of the study

The factors mentioned above allowed us to define the aim of this study as development and testing a set of indicators used to identify innovative engineering clusters among economic structures and to determine their life cycle stage.

3. Theory and methodology

Based on the foregoing, we formulate the main provisions of the theory and methodology of the study.
We consider a cluster a non-institutionalized association of independent economic entities engaged in joint activities based on proximity (territorial, sectoral, cultural), complementarity (product, resource, process), interconnectedness of flows (tangible, intangible, informational. The cluster is limited by territorial location: all cluster subjects are located on the same territory, defined, for example, by one region.

Clustering is the process of cluster emergence and development (Boush, 2011). This is a spontaneous process characterized by significant dependence on external conditions and is consequently poorly managed. Being a result of this process, clusters are emergent self-organized systems with a synergistic effect, which increases as clusters develop.

The formed cluster has a core, which is represented by enterprises producing goods in the cluster. The other agents interact with the core in the cluster through communication channels: producers of resources, providers (in particular, involved in sales processes), and consumers of the cluster products. This means that informational processes intensify in the generated clusters, their base being communication between cluster agents.

Since clusters in the process of their formation become the production centre and one of the key elements in regional development, their distinctive feature is the significant increase in production volumes compared to the other economic organisations. Consequently, the volume of goods produced is the key indicator to characterise the cluster.

In terms of this relation the formed clusters affect the other clusters and economic organisations, including their output.

Another clustering feature is appearance of relations between production processes and the other processes which have an impact on clustering and its resource potential. Moreover, the implementation of these relationships can be delayed, with a gap of no more than one third of the cluster's life cycle stage, depending on the possibility to develop resource potential for cluster functioning. This peculiarity can serve as a trigger effect for numerous clustering processes.

During their life cycle clusters go through a series of stages:

- diffuse group (this stage is characterized by non-interacting agents at innovative market, the absence of clustering processes, the absence of conditions for their emergence);
- latent cluster (this life cycle stage is characterized by the start of clustering processes; the cluster core is being formed; the relationships between manufacturing processes and those affecting the resource potential are being developed. At this stage it is quite difficult to identify clustering processes, so data mining techniques are needed);

- evolving cluster (this phase of the cluster life cycle is easily identified with the use of data mining techniques; the volumes of the products produced (sold) differ substantially from those produced by other economic structures, the values of this parameter being rapidly increased, i.e. a positive trend is observed, "the past" affects “the future”, which can be studied by means of chaos theory methods; at this stage the cluster resource potential has already been formed and continues to develop, i.e. the relationships between production processes and those affecting this potential can be identified; information exchange between the cluster agents is also enhanced, which can be determined by the use of data mining techniques);
- mature cluster (this stage of the cluster life cycle has the same peculiarities as the previous one, its difference being in the growth of production volumes in the cluster which is either reduced or stopped, and the volume of goods produced remains at the same level);
- collapsing cluster (the volume of production and the intensity of information flows are reduced; relationships between the processes are disrupted; finally, when the cluster is almost destroyed, it cannot be distinguished among the other economic structures).

In the process of clustering a cluster sequentially passes through all the stages described. Depending on the cluster type each stage may differ in time.

Thus the following conclusions can be made.

A cluster has a core in its base, consisting of enterprises producing the products of the cluster. This core is formed at the stage of emerging cluster; it forms the relationships between the other processes, affecting the resource potential of the cluster. A delay effect may occur when the cluster core interacts with these processes, its duration can be no more than one third of the cluster life cycle stage. The core develops relations with suppliers of resources, which produce goods in the cluster, and relations with products consumers in the cluster. The cluster is constrained by territory.

The key indicator characterizing a cluster is its output.

A cluster differs significantly from other economic structures in its productivity as a key indicator. This can be investigated with the use of data mining, in particular, pattern recognition methods. This characteristic can be revealed at the following life cycle stages: emerging cluster, growing cluster mature cluster.

Cluster development is accompanied by increased communication and information processes that affect its key indicators.

In cluster functioning there is an effect of the past on the future within the cluster life cycle stage that can be studied by means of chaos theory methods.

In the cluster life cycle the focus in production processes is shifted towards the cluster thus there is an effect of the cluster on the other similar clusters and economic structures.

Clusters unlike other economic structures should possess all the above characteristics. A situation is possible when some economic structures differ significantly from the other economic structures, but cannot be considered clusters. This is due to the absence of clustering processes that form the cluster core, the absence of synergy effect as well as proper communication channels. Such economic structures are called chimerical structures. They are located in areas geographically limited to a single economic entity.

4. Development of a set of indicators to solve the problem of identifying the innovative engineering clusters and determining their life cycle stage

Based on the theoretical analysis it made us possible to select key performance indicators needed to solve the problem of identifying innovative engineering clusters and determining their life cycle stage.

To accomplish this task a finite set of economic structures is considered which is represented by a set of enterprises and other organizations working in the field of innovative engineering, and located in one region. The location of these economic structures is geographically limited to the same region. These structures are involved in corresponding innovative processes. The main indicator is the time needed to produce innovative products in the field of innovative engineering. It is also necessary to use indicators that characterize innovative processes at macro level, i.e. in all research fields at the state level or at the global level, and indicators that characterize information processes in the economic structures under investigation.

On the basis of the given above statements to solve the problem of identifying innovative engineering clusters a set of indicators was developed. It includes the following indicators:

- Significant difference observed economic structure economic between structures included in the test set (the volume of innovative engineering products);
- The interconnection of production in the examined economic structure of innovation processes implemented at the macro level;
- The linkage of the production volume in the study of economic structure implemented in it information processes;
- The influence of the studied economic structure on other economic entities included in the test set (on the volumes of innovative engineering goods produced);
- A positive trend in the time series that specifies the output in the study of economic structure;
- The presence of memory in the time series that specifies the output in the study of economic structure.

Table 1 (see Appendix) shows methods and algorithms of calculation of the above indicators.

The values of these parameters for each stage of the life cycle of innovative engineering cluster are given in table 2.

On applying the set of indicators it is possible to solve the problem of identifying innovative engineering clusters and determining their life cycle stage, the regions of the Russian Federation taken as examples.

Table 2. Values of indicators for each stage of the life cycle of innovative engineering clusters

Indicator	Life cycle stages of the innovative engineering cluster				
	Diffuse group	Latent cluster	Evolving cluster	Mature cluster	Collapsing cluster
Significant difference observed economic structure economic between structures included in the test set, Yes/No	No, Yes*	No, Yes	Yes	Yes	No
The interconnection of production in the examined economic structure of innovation processes implemented at the macro level, Yes/No	No	Yes **	Yes **	Yes **	No
The linkage of the production volume in the study of economic structure implemented in it information processes, Yes/No	No	No, Yes **	Yes **	Yes **	No
The influence of the studied economic structure on other economic entities included in the test set, Yes/No	No, Yes *	No, Yes	No, Yes	Yes	Yes, No

Table 2. Values of indicators for each stage of the life cycle of innovative engineering clusters (continued)

Indicator	Life cycle stages of the innovative engineering cluster				
	Diffuse group	Latent cluster	Evolving cluster	Mature cluster	Collapsing cluster
A positive trend in the time series that specifies the output in the study of economic structure, Yes/No	No, Yes	No, Yes	Yes	No	No
The presence of memory in the time series that specifies the output in the study of economic structure, Yes/No	No, Yes	No, Yes	Yes	Yes	No
* – Typical for chimerical structures. ** – Lag can't be more than one third of the duration of the life cycle stages of innovative engineering cluster.					

5. Solution of the problem of the identifying innovative engineering clusters and determining their life cycle stage, the regions of the Russian Federation taken as an example

As economic structures the regions of the Russian Federation are considered, which produce innovative products in the field of mechanical engineering.

To solve the problem an assumption was made that in one region of the Russian Federation only one innovative engineering cluster can appear and function.

The main indicator used to analyse the selected set of economic structures was "The volume of innovative goods, services (per year) in manufacturing machinery and equipment (without ammunition, expressed in thousands of roubles)" with the period from 2006 to 2015 for each RF region.

Since innovations in this field are diverse and their centres are located on the vast territory of Russia, as a characteristic of innovative processes at the macro level an indicator "The volume of innovative goods, services (per year), their total amount, expressed in thousands of roubles" was used for the period from 2006 to 2015 totally for all the RF regions.

To assess the information flows in the economic structures under research the indicator "Investments in information and communication technologies (per year, thousands of roubles)" was used for every region from 2006 to 2015.

The data were obtained at the Unified Interdepartmental Statistical Information system (EMISS, 2016).

The study covered 61 RF regions involved in innovative engineering production. In calculations programming language Python 3 was used. The visualization was made with the program MS Visio.

FRIS-RATING algorithm was used to divide the set of the regions into two groups.

Figure 1 shows profiles of two groups of RF regions.

The first group included regions with a high rate of production of innovative engineering products, such as Tatarstan, Krasnoyarsk Territory, Moscow Region, Perm Territory Region, Sverdlovsk Region, Saint-Petersburg, Lipetsk Region, Rostov Region, Penza Region, the Republic of Bashkortostan. These regions are characterized by a gradual increase in the values of the index which determines the output of innovative products in them in combination with cyclical fluctuations (figure 1).

The second group included the regions of the Russian Federation with the low rates of production of innovative engineering products: Voronezh Region, Yaroslavl Region, Vladimir Region, Orel Region, Republic of Mordovia, Samara Region, Vologda Region, Bryansk Region, Moscow, Saratov Region, Chelyabinsk Region, Kirov Region, Kemerovo Region oblast, Kaluga Region, Chuvash Republic, Kurgan Region, Krasnodar Territory, Novosibirsk Region, Tver Region, Tyumen Region, Tula Region, Nizhny Novgorod Region, the Udmurt Republic, Tambov Region, Kostroma Region, Yamal Nenets Autonomous Okrug, Altai Territory, Volgograd Region, Ulyanovsk Region, Murmansk Region oblast, Orenburg Region, Belgorod Region, Leningrad Region, Ryazan Region, Pskov Region, Tomsk Region, Irkutsk Region, Omsk Region, Khabarovsk Territory, Kaliningrad Region, Ivanovo Region, Novgorod Region, Magadan Region, Amur Region, Republic of Karelia, Republic of Adygea, Stavropol Territory, Astrakhan Region, Smolensk Region, Kabardino-Balkaria Republic, Karachay-Cherkessia Republic. In the regions of the second group, there is a decrease in the volume of manufactured innovative products of the engineering industry (figure 1).

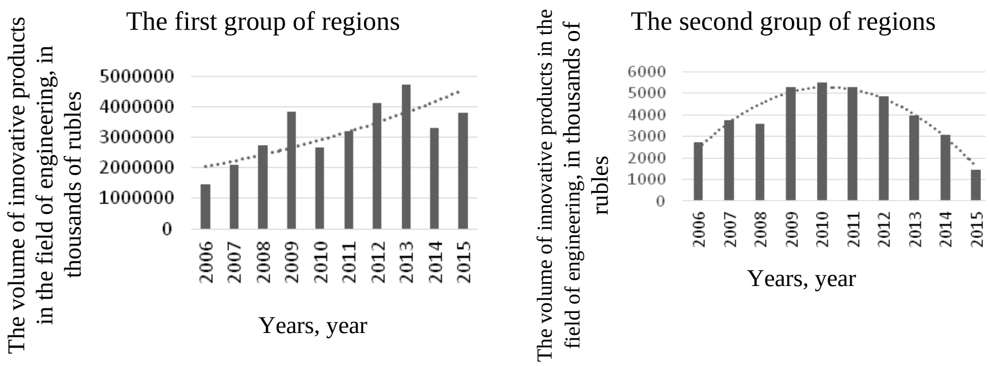

Figure 1. Profiles, built for two selected groups of regions of the Russian Federation

Table 3 (see Appendix) shows parameters used to solve the problem of identifying clusters and determining their life cycle stage for the regions from the first group and the second group, their relation to the innovation processes at the macro level being revealed. This is due to the fact that all other regions from the second group are diffuse groups.

One empty single line should be left before table and after it's title. Table headings In the regions included in the first group four economic structures are distinguished which are clusters. Latent innovative machine-building clusters are located in the Krasnoyarsk Territory, the Perm Territory, and the Lipetsk Region. They are characterized by the following symptoms:

- They are significantly different from other economic structures asked by the regions in terms of the output of innovative products in the field of mechanical engineering;
- There is an interconnection between the volume of output that is, production processes with innovative processes that are implemented at the macro level;
- There is no interrelation of the volume of output, therefore, of the production processes in the specified clusters, with the information processes being implemented in the regions in which these clusters are located;
- They influence other regions in the framework of the implementation of production processes;

- There is no positive trend in the time series which set the cluster output but there is a memory effect. An exception is the cluster located in the Krasnoyarsk Territory, for the time series of which there is no memory effect.

In the Moscow region there is a collapsing innovative machine-building cluster, which is characterized by a significant difference from other economic structures in terms of the indicator that determines the volume of manufactured products being studied; production processes are not associated with innovation processes at the macro level, but at the same time associated with information processes occurring in the region. There is no positive trend and memory effect in the time series setting the output of the cluster. This cluster has an impact on other regions in which the output of innovative products in the field of engineering.

In the remaining regions of the first group there are chimerical structures, which are determined by significant volumes of manufactured innovative products in the engineering industry, at the same time by the lack of interconnection of production processes with innovation processes implemented at the macro level and information processes. In the time series which are set in these regions, with the exception of the Republic of Bashkortostan, the release of innovative products in the field of engineering, there is no positive trend and memory effect. For the Republic of Bashkortostan a memory effect is observed in the indicated time series.

In the second group of regions listed in Table 3 revealed latent clusters. Two latent clusters located in Moscow and the Chuvash Republic are transitional to the stage of the evolving cluster. These latent clusters do not have a strong internal potential, and do not significantly differ from economic structures that are not clusters. But at the same time, they have an impact on other regions in which the output of the product under investigation is being produced. Production processes implemented in these latent clusters are associated with innovation processes implemented at the macro level. In clusters located in Moscow and the Chuvash Republic there is a characteristic relationship between production processes and information processes in these regions, in the remaining clusters of the second group of regions this relationship does not exist.

In the time series determining the release of innovative products in the field of engineering for these latent clusters there is no positive trend. For latent clusters of the Samara region, Moscow, the Chuvash Republic there is a memory effect in the indicated time series for latent clusters of the Leningrad region, Yaroslavl region, Chelyabinsk region there is no memory effect in the time series.

A map of regions which illustrates clustering processes in the Russian Federation is shown in figure 2. The darkest are Moscow Region, Moscow, Chuvash Republic, the regions with the most intensive clustering process.

On the basis our calculations the following conclusions can be made.

1. Clustering processes in Russia are characterised by low intensity in the field of innovative engineering. There are no formed engineering cluster structures in the Russian Federation yet.

2. Clustering processes in engineering run most efficiently in Moscow and the Chuvash Republic. In these regions innovative engineering clusters are in the transition state from latent to evolving cluster. This is confirmed by the fact that these regions in the sphere of innovative engineering are characterized by relation to the innovation processes, which enhance development of technologies and production in the corresponding field, including radical and disruptive ones (Clayton, 1997). A significant positive impact of information flows on innovative engineering output is revealed, which is an evidence of the enhanced clustering process in the regions and a base

for the growth of production volumes (the Hurst exponent for a period that specifies the production of innovative engineering products for these regions is equal to 0.71). These regions are likely to be the centres of innovative growth in the field of engineering in the Russian Federation in the nearest future.

Figure 2. The map of RF regions, whish illustrates clustering processes in Russia

3. Of special interest is such region as Moscow Region where, as the study has shown, there is a collapsing innovative engineering cluster. This is due to the fact that there is no relations between this region and innovation processes in Russia, in recent years a decrease in the production of innovative engineering products from 8.13 billion in 2014 to 5.87 billion in 2015 is registered. The time series characterizing output of engineering products in Moscow Region refer to the class of white noise, i.e. independent random processes similar to Brownian motion, Hurst exponent being equal to 0.5. But at the same time, there is an impact of information flows on the field under investigation. The innovative engineering has an impact on the spheres of innovative production in other regions. Development and implementation of a complex of measures to increase efficiency of clustering processes in Moscow region will allow intensifying development of the sector under study and fostering innovative engineering development.

4. Latent clusters are located in the Krasnoyarsk Territory, the Perm Territory, the Lipetsk Region, the Leningrad Region, the Yaroslavl Region, the Samara Region, and the Chelyabinsk Region. Concerning these regions an assumption can be made that clustering processes and development of mature innovative engineering clusters will intensify, but this requires special measures taken at the state level as well to provide optimal conditions for cluster structures to develop.

5. Six chimerical structures were identified in the Russian Federation in the field of innovative engineering based on application of the indicators developed. To such structures refer: the Republic of Tatarstan, the Sverdlovsk Region, St. Petersburg, the Rostov Region, the Penza Region, the Republic of Bashkortostan which produce a

significant amount of goods in the sphere concerned but clustering processes do not start. In spite of the fact that there is no correspondence to innovation processes in Russia and insufficient development of information flows these regions affect the other RF regions which produce innovative engineering products.

6. Conclusion

The processes of cluster formation in the global economy play a significant role being one of the key elements of the development of modern industry and territories.

But in spite of sufficient knowledge of these processes and a large number of publications on this topic, the task of building the life cycle of clusters and their identification from a variety of economic structures is currently not sufficiently solved, which makes it difficult to manage them, and therefore the development of territories which they are located as well.

A special place in the structure of clusters is occupied by innovative machine-building clusters, which set points of growth for other economic spheres, contributing to the creation and transfer of innovative technologies. In their development, these clusters go through the following stages of the life cycle, taking into account the occurrence, intensification and extinction of cluster formation processes: a diffuse group, a latent cluster, a developing cluster, a mature cluster, and a collapsing cluster. The development of innovative machine-building clusters is associated with the implementation of information innovation processes at various levels of the economy. A key indicator of the functioning of an innovative machine-building cluster is the volume of output in it.

We realised, that the study posed and solved the problem of developing a set of indicators for identifying innovative machine-building clusters from a finite set of economic structures allowing determining the stages of the life cycle of the identified clusters. It is based on indicators determining the implementation of production processes in a cluster, their interrelations with innovation processes at the macro level, and information processes in the region in which the cluster is located.

In the process of the study based on the analysis of the functioning patterns of the studied clusters, the values of indicators for each stage of their life cycle are determined. The results of the study differ from existing approaches to the study of clusters by the ability to perform a comprehensive description of the functioning of innovative machine-building clusters, taking into account the stages of their life cycle and the bifurcation of development to identify patterns and influence on the territory in which they are located, as well as the territories with which they are interconnected. This will allow with sufficient accuracy to solve optimal control problems, including monitoring the emergence and implementation of clustering processes in the territory (region), rapid response in cases where the cluster development does not match the planned target trajectory.

The application of a set of indicators developed by the authors allows with sufficient accuracy solving image recognition problems in the study of processes and management of the formation of cluster structures in the field of innovative engineering.

Approbation of the developed set of indicators of identification of innovative machine-building clusters on the example of regions of the Russian Federation made it possible to analyze cluster processes in the Russian Federation and identify potential points of growth in the area under study. In the Russian Federation there are no developing and mature clusters in this area, which is one of the reasons for Russia's lagging in the field of innovative engineering compared to other countries. The existing clusters in the sphere under study are either latent or at the level of a diffuse group or a chimerical structure.

Moscow and the Chuvash Republic can become points of growth in the studied area. In these regions the process of cluster formation is most intense compared to other regions of the Russian Federation, they predict the transition of existing latent clusters to the next stage - the stage of developing clusters. The Moscow Region also has sufficient potential for the development of this sphere and the creation of optimal conditions in it for the intensification of clustering processes.

The results of the study can be used in providing optimal conditions for innovative engineering development, including that of Russia.

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Appendix

Table 1. Methods and algorithms of calculation of indicators of identification of innovative engineering clusters and determination the stage of their life cycle

Indicator	Type of data	Method of intellectual analysis	Algorithm of calculation
Significant difference observed economic structure economic between structures included in the test set	Logical	Algorithm of FRIS-RAING (Zagoruiko, 1999)	Using the FRIS-RATING algorithm, the set of studied economic structures is divided into two groups, and the profiles of these groups are built. The FRIS-RATING algorithm allows you to select reference - the most different economic structures from a given set, and based on this procedure, divide the studied set of structures into groups taking into account the similarity of shared economic structures with reference structures. The division of the set of economic structures into two groups is performed according to an indicator characterizing the volume of innovative products produced in the field of mechanical engineering in them. The calculation of the profile of each group is performed as an arithmetic average for each time tick, determined by the values of the indicator characterizing the output of the product under study in the economic structure. In the group in which the indicator of the volume of output of innovative products in the field of engineering is higher, they are either clusters or chimerical structures. If the studied economic structure falls into the group with high values of this indicator, then for it the indicator “Significant difference from economic structures included in the studied set” takes the value “Yes”, otherwise it means “No”.
The interconnection of production in the examined economic structure of innovation processes implemented at the macro level	Logical	Cross-correlation analysis (Svetunkov & Svetunkov, 2014).	The indicator is calculated using cross-correlation analysis for time series, which characterizes the release of innovative products in the field of engineering and the implementation of innovative processes at the macro level. The time ticks are distinguished - lags where the time series under study interact. If using a cross-correlation analysis in the study of time series, specifying the volume of innovative products produced in the field of mechanical engineering for the studied economic structure, and the volume of innovative products created, works, services created as a result of the implementation of innovative processes at the macro level, 3 to 3 revealed a significant positive relationship, then this indicator is assigned the value "Yes", otherwise, the value "No". In case with the use of cross-correlation analysis in the study of time series that specifies the volume of innovative products in the field of mechanical engineering for the study of the economic structure and creating innovative goods, works, services that are created as a result of implementation of innovative processes at the macro level, lags from 3 to 3 revealed a significant positive Association, then the indicator is set to “Yes", otherwise it is set to “No”.

Table 1. Methods and algorithms of calculation of indicators of identification of innovative engineering clusters and determination the stage of their life cycle (continued)

Indicator	Type of data	Method of intellectual analysis	Algorithm of calculation
The linkage of the production volume in the study of economic structure implemented in it information processes	Logical	Cross-correlation analysis (Svetunkov & Svetunkov, 2014).	Is defined similarly to the previous indicator. The calculations are indicators that specify the volume of innovative products in the field of mechanical engineering in the study of economic structure and the intensity of information processes implemented in it. The intensity of information flows can be determined through the costs of their implementation in the studied period of time.
The influence of the studied economic structure on other economic entities included in the test set	Logical	Cross correlation analysis (Svetunkov & Svetunkov, 2014).	The calculation is performed similarly to the two previous indicators. Time series are used determining the release of innovative products in the field of mechanical engineering in the studied economic structures. This indicator is set to "Yes" in case if in the use of cross-correlation analysis significant relationships between the indicators defining the innovative output in the field of engineering for the two studied economic structures are revealed. In the opposite case, the value is "No".
A positive trend in the time series that specifies the output in the study of economic structure	Logical	The Method of Foster-Stuart (Kobzar, 2006).	To identify a positive trend in the indicators specified by the time series of the output of innovative products in the field of mechanical engineering in the studied economic structures, the Foster-Stewart method is used. If using the method of Foster-Stuart in the time series that specifies the volume of output of innovative products for the fields of engineering in the study of economic structure is revealed the presence of a trend and the value of output of innovative product growing with time, then the investigated index is assigned the value "Yes", otherwise it is set to “No”.
The presence of memory in the time series that specifies the output in the study of economic structure	Logical	The Hurst Exponent (Hurst, 1951; Peters, 1994).	To determine the presence of memory in the time series, specifying the release of innovative products in the field of engineering used the calculation of the Hurst index. The Hurst index is one of the basic values of fractal analysis and allows you to determine whether the time series under study are random, that is, like a Brownian motion, or not. The value of the Hurst index characterizes the ratio of the trend force to the noise level in the time series under study. If the Hurst index is greater than 0.5, the time series is persistent, that is, it is characterized by long-term memory, otherwise the time series is nonresistant, which does not have long-term memory. Based on the calculation of the Hurst index value, the indicator “The presence of memory in the time series defining the output of the product in the studied economic structure” is calculated. This indicator is set to "Yes" if the calculated Hurst Exponent for a time series that specifies the output of innovative products for the fields of engineering in the study of economic structure is greater than 0.5 in the opposite case, the value is "No".

Table 3. Results of calculations for the solution of the problem of the identification of innovative engineering clusters and determining of their life cycle stage

Region	Indicators						The stage of the cluster's life cycle
	Significant difference observed economic structure economic between structures included in the test set	The interconnection of production in the examined economic structure of innovation processes implemented at the macro level	The linkage of the production volume in the study of economic structure implemented in it information processes	The influence of the studied economic structure on other economic entities included in the test set	A positive trend in the time series that specifies the output in the study of economic structure	The presence of memory in the time series that specifies the output in the study of economic structure	
Regions of the first group							
Republic of Tatarstan	Yes	No	No	Yes	No	No	Chimerical structure
Krasnoyarsk Territory	Yes	Yes	No	Yes	No	No	Latent cluster
Moscow Region	Yes	No	Yes	Yes	No	No	Collapsing cluster
Perm Territory	Yes	Yes	No	Yes	No	Yes	Latent cluster
Sverdlovsk Region	Yes	No	No	Yes	No	No	Chimerical structure
Saint-Petersburg Region	Yes	No	No	Yes	No	No	Chimerical structure
Lipetsk Region	Yes	Yes	No	Yes	No	Yes	Latent cluster
Rostov Region	Yes	No	No	Yes	No	No	Chimerical structure
Penza Region	Yes	No	No	Yes	No	No	Chimerical structure
the Republic of Bashkortostan	Yes	No	No	Yes	No	Yes	Chimerical structure
Regions of the second group							
Leningrad Region	No	Yes	No	Yes	No	No	Latent cluster
Yaroslavl Region	No	Yes	No	Yes	No	No	Latent cluster
Samara Region	No	Yes	No	Yes	No	Yes	Latent cluster
Moscow	No	Yes	Yes	Yes	No	Yes	Latent cluster, transition to the evolving cluster
Chelyabinsk Region	No	Yes	No	Yes	No	No	Latent cluster
The Chuvash republic	No	Yes	Yes	Yes	No	Yes	Latent cluster, transition to the evolving cluster