UDC 368:519.2

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APPLICATIONS OF CHAOS THEORY TO STATISTICAL MODELS

Abstract. *Our research is based on the problem of substantiation of use of basic provisions of the chaos theory for local modeling of economic processes. Chaos theory represents a set of techniques for analyzing dynamical systems that are deterministic and yet very sensitive to perturbations of input. This theory is connected with mathematical catastrophe theory, when a point in a model of an input-output system, where a vanishingly small change in the input can produce a large change in the output. In this article we examine mathematical catastrophe model on the example of the industrial enterprise PrJSC "Ukrgraphite" in relation to the development model, which allows us to draw a conclusion about the stable imbalance development of the enterprise. PrJSC "Ukrgraphite" produces carbon graphite products focusing on various branches of the metallurgical industry, namely: steelmaking, ferroalloy, aluminum, titanium-magnesium and others. Based on the analysis of the economic indicators of the enterprise PrJSC "Ukrgraphite", we assessed its sustainability. If it is established that the relationship between the variables that characterize the behavior of the system is described by a polynomial of the third degree then it can be asserted that the system may exhibit instability. In the paper we obtained the coefficients of the equation of the theory of catastrophe and we may concluded that the economic condition of PrJSC "Ukrgraphite" can be characterized as sustainable development. The practical application of the model enables to assess possible changes in the sustainability of the enterprise's development under the influence of the determining evaluation criteria. The advantages of applying theory of chaos are that the ideas embedded in catastrophe theory help to understand the real experience of change management. In addition, one can see why real change is a dangerous phenomenon. The theory shows why changes cannot be "managed", but they can be influenced.*

Key words: dynamic system, chaos theory, catastrophe theory, economic system, statistical model.

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ЗАСТОСУВАННЯ ТЕОРІЇ ХАОСУ В СТАТИСТИЧНИХ МОДЕЛЯХ

Анотація. *Наше дослідження базується на проблемі обґрунтування використання основних положень теорії хаосу для локального моделювання економічних процесів. Теорія хаосу являє собою набір методів аналізу динамічних систем, які є детермінованими, але дуже чутливими до збурень вхідних даних. Ця теорія пов'язана з математичною теорією катастрофи, коли в моделі системи входу-виходу дуже мала зміна на вході може призвести до великої зміни на виході. В статті розглянуто модель математичної теорії катастрофи на прикладі промислового підприємства ПрАТ "Укрграфіт" по відношенню до моделі розвитку, що дозволяє зробити висновок про стійку нерівновагу розвитку підприємства. ПрАТ "Укрграфіт" виробляє вуглеграфітову продукцію, орієнтуючись на різні галузі металургійної промисловості, а саме: сталеплавильну, сталеливарну, феросплавну, алюмінієву, титаномагнієву та інші. На основі аналізу економічних показників підприємства ПрАТ "Укрграфіт" оцінено його стійкість. Якщо зв'язок між змінними, які характеризують поведінку системи, описується поліномом третього ступеня, то можна стверджувати, що в системі можливі прояви нестійкості. У роботі отримано коефіцієнти рівняння теорії катастроф і можна зробити висновок, що економічний стан ПрАТ "Укрграфіт" можна охарактеризувати як сталий розвиток. Практичне застосування моделі дозволяє оцінити можливі зміни стійкості розвитку підприємства під впливом визначальних критеріїв оцінки. Переваги застосування теорії хаосу полягають у тому, що ідеї, закладені в теорії катастроф, допомагають зрозуміти реальний досвід управління змінами. Крім того, можна побачити, чому реальні зміни є небезпечним явищем. Теорія показує, чому змінами не можна "керувати", але на них можна впливати.*

Ключові слова: динамічна система, теорія хаосу, теорія катастроф, економічна система, статистична модель.

JEL Classification: C40
DOI: https://doi.org/10.36477/2522-1205-2022-70-07

Statement of the problem. The current situation in the world is characterized by the unfolding of a global systemic crisis, increased competition, increasing uncertainty, risks and instability in all spheres and at all levels of the economy. Among the new, dynamic scientific trends of the XXI century, the concept of "controlled chaos" occupies a leading place. A new interdisciplinary direction of scientific research is actively developing, which can be generally called the "science of chaos", the subject of which is the study of systems with nonlinear dynamics, unstable behavior, self-organization effects, the presence of chaotic regimes and bifurcation.

Analysis of the previous publications. Chaos theory has a lot to offer in the way of practical application. The key to unlocking the power of chaos theory regarding practical problems is its statistical side. Statistical models developed using chaos Theory are known as nonlinear statistical methods. These methods are particularly powerful because they are qualitative rather than quantitative [2, 4]. The theoretical foundations of chaos theory are outlined in [5]. Economic models which involve chaos were considered in [1, 3, 6, 7]. The issue of using elements of dynamic chaos to manage microeconomic systems is new branch in modern science.

The purpose of the research is to substantiate the expediency of using chaos theory in the process of managing industrial enterprises.

At the scientific level, mathematical models of the development of processes at the global level are created and issues related to the development of systems are studied. Any system undergoes crisis stages, which are characterized by the temporary predominance of one of the forces, which leads to chaos, which destroys the previous structures; then harmonization occurs, equilibrium is restored, but already in a new, qualitatively different state. Therefore, it is necessary to focus attention on the problem of justifying the use of the main provisions of chaos theory for global and local modeling of economic processes.

Chaos theory represents a set of techniques for analyzing dynamical systems that are deterministic (i.e., they follow apparently simple rules that lead to behaviors which depend only upon their initial conditions) and yet very sensitive to perturbations of input. This theory is connected with mathematical catastrophe theory. A mathematical catastrophe is a point in a model of an input-output system, where a vanishingly small change in the input can produce a large change in the output.

The mathematical theory of catastrophes is used not only in applied mathematics and physics, it is also applied to economic systems. The theory of catastrophes studies the changes to which this or that system is exposed in time, it records certain regularities associated with its transition from one state to another, analyzes the mechanisms that lead to the change of regimes in its dynamics, the reasons that cause an interruption in the gradualness of changes of individual parameters and the system as a whole, their jump to a new level, transition to a new qualitative state. If we do not see the differences between development and change in the dynamics of the socio-economic system, then the conclusions of the theory of catastrophes can be interpreted as universal for any social processes. After all, as you know, the content of development, which is understood as change, is a departure from the former, initial state of the system. And if the "old" state was deemed unsatisfactory for any reason, the new state must be

consciously better, because it is connected with change, that is, with the development of the system [8].

Presentation of the main part of the research. The traditional approach considers chaos exclusively as a negative category, that is, the main goal of any targeted intervention in natural, social or economic processes is to minimize chaos. However, synergy reveals the positive role of chaos. In reality, all processes occur unevenly: calm periods are replaced by tense critical states, when it is necessary to make a decision on the further development of the system. In such moments, chaos plays a decisive role, not order. Without this disordered, uncontrolled, random component, no qualitative changes, transition of the system to a qualitatively new state are possible. Chaos theory states that complex systems are extremely dependent on initial conditions and that small changes in the environment lead to unpredictable consequences. Mathematical systems with chaotic behavior are deterministic or ordered.

The concept of bifurcation is used to mathematically describe chaotic (catastrophic) states. At the bifurcation points, the trajectory of possible development of the system branches out. There is a close relationship between instability and bifurcation. A change in qualitative properties usually violates the stability of the original system, and, accordingly, in this case the system must have some other state different from the original one. The values of the parameters at which such qualitative changes occur are usually called the bifurcation characteristics of the system.

The alternatives (attractors) that appear in this case are equivalent for the system and the choice of a branch (path of further development) depends on random fluctuations, on local scale factors. Due to small fluctuations, the system spontaneously enters the area of attraction of one of the possible trajectories of further movement. Chaos first provides the possibility of the system's descent from the former trajectory when stability is lost in the crisis zone, and then helps to connect to a new attractor, causing obstacles on this path. It is in this that the constructive role of chaos is manifested.

One of the main problems that arises when modeling economic processes is that the dynamics of microeconomic indicators can be influenced by many variables, and in most cases it is impossible to predict in advance which parameters will determine the development of the system. In general, it is accepted in economics that even if the mechanism of behavior of each system at the micro-level is uncertain and unpredictable, as well as the conduct of the system in the macroenvironment, it can be described with the help of generalized variables, which allows it to be analyzed and predicted with a sufficient degree of reliability.

Any mathematical model simplifies the real situation by assuming that some effects (variables) can be neglected. An economic model that takes into account the influence of stochastic factors must take into account the degree of influence of exogenous forces on the final results of the simulation. If the results of modeling depend decisively on exogenous stochastic forces and to a small extent feel the influence of the interaction of economic variables, then from a scientific point of view the model is not of interest.

On the other hand, if stochastic effects do not have a noticeable impact on qualitative results, then from the point of view of the traditional approach, stochastic factors can be ignored. However, synergy implies that random fluctuations can play a decisive role in the development of the enterprise, even if the development itself is determined by deterministic mechanisms. Evolution depends on reasons that cannot be predicted with absolute accuracy, so the influence of fluctuations on deterministic development cannot be neglected in any situation, especially if deterministic equations are considered near critical points.

Since the loss of stability of the microeconomic system occurs in accordance with the action of spontaneous mechanisms of development, the conclusions of the chaos theory are quite acceptable for the analysis of the conditions under which the enterprise ceases to develop evolutionarily and enters the bifurcation phase. The conclusions of the theory of chaos considered from this perspective are the most relevant for the analysis of the conditions that allow avoiding unwanted bifurcations, catastrophic loss of system stability, which is happening in modern crisis conditions.

For the phase of the cycle of qualitative change of the enterprise, associated with its transition to a new stable state, the conclusions of the theory of chaos cannot be interpreted so unambiguously and straightforwardly. A jump-like one-moment transition of the system to a new stable state, hypothetically considered by the theory of chaos, can become the basis for developing recommendations for the transition to a new stable state.

Chaos theory examines the limit states of an enterprise in terms of stability-instability, therefore, on this basis, it is possible to get a general idea of the conditions that accompany the transition of an enterprise from one state to another, including its stabilization.

The conclusions that follow from the understanding of the formulated dependence are of significant importance for the study of the mechanisms of the transition processes of the enterprise both at the stage of instability (bifurcation and crisis) and for the enterprise to acquire a new stable state. This principle can be deciphered in relation to the problem of transitional processes as follows: in order to disrupt the stability of an enterprise, it is enough to influence certain indicators of its economic development.

Close attention to the theory of bifurcations and catastrophes at the present time, in the conditions of the economic crisis, is quite natural, because it opens up various aspects of the study of qualitative changes and transitional processes; considers the transformation process from the standpoint of the organization of transitional processes in time and space [8, 9]. In addition, in our opinion, those areas of analysis that are opened with the help of this theory, which allow studying the meaningful side of qualitative transformations and transitional processes in the modern economy, are also important. Speaking about the problems of development and reform of enterprises, as socio-economic systems that are on the verge of bankruptcy in the

economic crisis, we can distinguish two directions of using the tools of catastrophe theory:

- the first is related to the analysis of the mechanisms of the loss of stability of the enterprise;
- the second is related with the possibility of the enterprise obtaining a new sustainable state.

However, it should be noted that the analytical toolkit that can be used to develop recommendations for each of the mentioned directions is different: in the first case, the analysis is based on the study of critical levels, threshold values in the dynamics of individual economic indicators of the enterprise; in the second can be used to study the properties of the attraction.

Any enterprise that carries out commercial activities, interacts with other enterprises, suppliers, consumers, banks, tax services, etc., has its own potential for development, has its own cycles of its development, which do not always coincide with the cycles of development of the economy as a whole. The natural development of an enterprise is characterized by changes in its functioning, technology, product range, personnel composition, etc.

Changes can be both positive and negative. Positive changes are characterized by the appearance of a new quality, which increases the stability and harmony of the functioning of the enterprise, which is expressed in the increase of labor productivity, a change in its nature, the emergence of new technology, and the strengthening of the motivation of activity. Negative changes destabilize the activity of the enterprise, which is expressed in the opposition of the interests of functioning and development, imperfect management, and technological obsolescence. Negative changes reflect the entry of the enterprise into a state of crisis [11].

Catastrophe is a sudden change that occurs as a system response to a smooth change in external conditions. The marketing disaster is connected with the inadequacy of the enterprise to the market environment. There are two types of changes in the market environment : gradual change and radical change. In the first case, changes are relatively slow, and the company's management has the opportunity to predict market requirements. A change in the market environment leads to the emergence of new priorities : speed of business processes, expansion of the assortment, higher standards of quality of goods (services). Radical changes occur quickly due to significant changes in technologies, significant innovations in the market, as well as due to the crisis [14].

Since in certain situations (points of catastrophe) even minor changes can affect the development of the company, it is desirable to be able to determine how close we are to these points. Company management can often predict exactly what adjustments need to be made to the firm's strategic plan. However, even in such situations, some indirect signs that the system is near the point of catastrophe can be indicated. It is about the peculiarities of the company's work when approaching these points. Let's list some of them:

• the presence of several steady states of the firm's work;

• the existence of unstable states of the enterprise's functioning, including small changes in work;

• the ability to quickly change the company's work in case of small changes in external conditions;

• irreversibility of processes related to the company's activities.

Today, at the level of a mathematical model, it can be argued that any sufficiently large company goes through certain stages in its development. The crisis stage is characterized by extreme instability: the slightest change in the market environment forces the company to change its strategic plan. This is often not understood by the management, because sometimes only minor changes are enough to normalize the company's work.

In order to interrupt the stability of the enterprise, it is enough to influence certain indicators of its economic development. The simplest program for forecasting the financial stability of an enterprise (an elementary catastrophe in the economic system) can be built on the basis of data on the relationships of variables that characterize its behavior using the **R** package [10]. Using this program and econometric methods, we can obtaine functions describing these relationships.

It is known also that the type of elementary catastrophe defined by the relationship described by equation

$$y = \frac{x^3}{3} + ax \qquad (1)$$

is called the catastrophe of folds, since in the space of three coordinates we have two variables and a parameter *a*. The surface described by the equation (1) has the form of a fold.

If it is established that the relationship between the variables that characterize the behavior of the system is described by a polynomial of the third degree of the form

$$y = x^3 + ax + b, \qquad (2)$$

then it can be asserted that the system may exhibit instability. If the parameter a is positive, but there is a tendency to its decrease, then it can be considered that the system is approaching a catastrophe. In both cases, it is necessary to continue the study of the system and identify the conditions or possible timing of the catastrophe, assess its likely consequences. But in $a = 0$ stable and unstable extremes meet and are destroyed. This is the bifurcation point.

The nature of the function of equation (2) is determined by the value of the parameter a. If this parameter is positive, then the function has a monotonic character, its graph is a smooth monotonically increasing curve. With a negative value of the parameter a, the function described by the equation is already a non-monotonic function. It has a maximum and a minimum at values:

$$x = \pm\sqrt{a} \qquad (3)$$

Table 1

Development dynamics of PrJSC "Ukrgraphite" for 2012-2021

Years	Net income from sales of products (goods, works, services), thousand UAH	Cost of sold products (goods, works, services), thousand UAH	Net profit, thousand UAH	Value of assets, thousand UAH	Current assets, thousand UAH	Short-fixed-term liabilities, thousand UAH	Current liquidity ratio
2012	824280	691107	133173	1245117	631222	410426	1,54
2013	751075	642398	108677	1227247	565694	301813	1,87
2014	1012449	734543	277906	1161157	690329	428423	1,61
2015	1593132	1024039	569093	1270159	1060625	648160	1,64
2016	1458731	1117209	341522	1650356	1164169	587689	1,98
2017	2398514	1764216	244035	2367580	1480003	932006	1,59
2018	5851544	2167270	2766466	4349470	3262694	333638	9,78
2019	3543626	21209940	710454	4863807	3589996	141170	25,43
2020	1186693	1200802	-144408	4369162	3170720	183421	17,29
2021	1890958	1928245	-350608	4638618	2526055	225962	11,18

Source: own elaboration according to the data of annual reports of PrJSC "Ukrgraphite" [12], 2022.

The relationship between the variables in a certain part of the origin will be ambiguous. One value of the variable y will now correspond to three values of the variable x that differ in magnitude. Thus, with a monotonous smooth change of a variable y, the variable x will change in a jump-like manner. This will be a catastrophe.

To investigate the catastrophic state of the enterprise, it is necessary to conduct an analysis of the financial state of the enterprise. Liquidity is one of the key parameters for assessing the company's financial condition. In order to obtain information necessary and sufficient for making scientifically based management decisions, the criterion of which is the liquidity of the enterprise, it is necessary to evaluate liquidity indicators and conduct their factor analysis.

PrJSC "Ukrgraphite" was chosen as the object of analysis, which produces carbon graphite products focusing on various branches of the metallurgical industry, namely: steelmaking, ferroalloy, aluminum, titanium-magnesium and others. In the following table 1 is shown the financial indicators of PrJSC "Ukrgraphite" for 2012 - 2021.

Based on the analysis of the economic indicators of the enterprise PrJSC "Ukrgraphite", we will assess its sustainability.

Statistical analysis showed that the value of the coefficient of current liquidity is the most significant in assessing the sustainability of the enterprise's development. To determine the most significant indicator in the assessment of the sustainability of the enterprise, we will apply the method of calculating the integral indicator [13].

The matrix of standardized values of features is calculated by the formula

$$z_{ij} = \frac{x_{ij} - \overline{x}_j}{\sigma_j},$$

where $\overline{x}_j$ is the mean value; σ_j is root-mean-square deviation of j-th indicator [13].

In turn, these parameters are calculated according to the following formulas

$$\overline{x}_j = \frac{1}{k}\sum_{j=1}^{n} x_{ij}, \qquad \sigma_j = \sqrt{\frac{1}{k}\sum_{j=1}^{n}(x_{ij} - \overline{x}_j)^2},$$

where k is the number of initial indicators used to obtain complex indicators;

n is the number of years for which calculations are carried out.

Signs that positively affect the indicator are called stimulators in contrast to signs that negatively affect the indicator and are therefore called destimulators.

The distribution of signs into stimulators and destimulators serves as the basis for forming a reference point $P_0 = (z_{01}, z_{02}, \ldots, z_{0n})$, where the coordinates are defined as follows

$$z_{0j} = \min z_{ij}, \quad j = 1, \ldots, n;$$

z_{ij} is standardized value j-th indicator for i-th year.

The distance between individual points-units and a point P_0, representing the reference point is denoted c_{i0} and is calculated according to the formula

$$c_{i0} = \sqrt{\sum_{j=1}^{n}(z_{ij} - z_{0j})^2}.$$

The calculation of the integral indicator is presented in the following formula

$$d_i = 1 - \frac{c_{i0}}{c_0},$$

where $c_0 = \bar{c}_0 + 2S_0, \quad \bar{c}_0 = \frac{1}{k}\sum_{i=1}^{k} c_{i0},$

$$S_0 = \sqrt{\frac{1}{k}\sum_{i=1}^{k}(c_{i0} - \bar{c}_0)^2}.$$

In the table 2 is shown the calculations of the integral indicator using the MS Excel package.

We denote by y the integral indicator and x the coefficient of current liquidity. So, we calculate the next value which are presented in table 3.

Table 2

Years	Zij net income	Zij value of asserts	Zij short fixed-term liabilites	Ci0^2	Ci0	(Ci0-C0ser)^2	Integral index
2012	-0,77765	-0,90239	-0,03627	19,66931	4,435009	0,447571052	**0,456914**
2013	-0,82406	-0,91336	-0,48163	22,11947	4,703134	0,878217227	**0,424081**
2014	-0,65838	-0,95396	0,037528	18,84504	4,341088	0,330723979	**0,468415**
2015	-0,2903	-0,88701	0,93855	13,51314	3,676022	0,008096284	**0,549855**
2016	-0,37549	-0,65348	0,690591	13,64262	3,693591	0,005243268	**0,547703**
2017	0,220218	-0,21294	2,102447	7,141674	2,672391	1,195984304	**0,672754**
2018	2,409018	1,00438	-0,35113	6,11986	2,473835	1,669694597	**0,697068**
2019	0,946079	1,320298	-1,14034	12,65585	3,557506	0,0434703	**0,564368**
2020	-0,54793	1,016476	-0,96709	18,2579	4,272927	0,256972952	**0,476761**
2021	-0,10151	1,181982	-0,79265	14,70349	3,834513	0,004693808	**0,530447**
Sum					**37,66002**	**4,840667771**	

Source: own elaboration.

Table 3

Years	Y	X	XY	X^2	X^3	X^4
2012	0,46	1,54	0,7084	2,3716	3,652264	5,62448656
2013	0,42	1,87	0,7854	3,4969	6,539203	12,22830961
2014	0,47	1,61	0,7567	2,5921	4,173281	6,71898241
2015	0,55	1,64	0,902	2,6896	4,410944	7,23394816
2016	0,55	1,98	1,089	3,9204	7,762392	15,36953616
2017	0,67	1,59	1,0653	2,5281	4,019679	6,39128961
2018	0,697	9,78	6,81666	95,6484	935,441352	9148,616423
2019	0,56	25,43	14,2408	646,6849	16445,19701	418201,3599
2020	0,477	17,29	8,24733	298,9441	5168,743489	89367,57492
2021	0,53	11,18	5,9254	124,9924	1397,415032	15623,10006
Sum	**5,384**	**73,91**	**40,53699**	**1183,8685**	**23977,35464**	**532394,2178**

Source: own elaboration

For define the coefficients a and b we solve the next system

$$\begin{cases} \sum x^3 + a\sum x + bn = \sum y \\ \sum x^4 + a\sum x^2 + b\sum x = \sum xy \end{cases}$$

$$\begin{cases} 23977 + 74a + 10b = 5 \\ 532394 + 1184a + 74b = 41 \end{cases}$$

So, $a = -558$, $b = 1732$.

According to the initial data of economic indicators for 10 years, the most deterministic model of the development of the enterprise was obtained, which has the form:

$$y = x^3 - 558x + 1732 \quad (4)$$

With a negative value of the parameter a, the function described by equation (4) is a non-monotonic function. It has a maximum and a minimum at values $x = \pm\sqrt{a} = \pm 23,62$. Due to the fact that x is the coefficient of current liquidity, its value cannot be negative. And the enterprise development function will reach the extremum point (unstable equilibrium point) at $x = 23,62$.

Since the catastrophe model of PrJSC "Ukrgraphite" is deterministic in relation to the company's development model, it is possible to draw a conclusion about the sustainability of development for the period 2012-2021. That is, the economic condition of PrJSC "Ukrgraphite" can be characterized as sustainable development.

To support sustainable development, the main tasks of PrJSC "Ukrgraphite" are:

• ensuring continuous operation of production, in order to preserve production, labor and other assets;

• maximum preservation of electrode sales markets and the company's share in them;

• providing consumers of metallurgical industries with high-quality carbon graphite products, taking into account a variety of product lines;

• development and implementation of innovative production technologies and new products taking into account prospective market needs;

• continuation of the implementation of energy-saving technologies and modernization of the enterprise with the aim of increasing competitiveness (namely, improving the quality characteristics of products and reducing specific costs);

• preservation and development of the resource base of the enterprise.

The average sales price is UAH 16,524/t and depends on the range of products in this group of goods. The increase or decrease in the price of products is dictated by the market situation, which includes: the price of raw materials, supply and demand, sometimes the political situation in the country, and other factors. Intensification of competition as a result of dumping actions by the producer of electrodes of the People's Republic of China led, starting from the second half of 2019, to a sharp decrease in electrode prices. In 2020, negative factors intensified due to the economic situation caused by the epidemic of COVID-19. The EU and USA markets remained the most significant for the company, as in the previous reporting period. The amount of sales for export during the reporting period is UAH 1,149,153,000, which is 69% of the total volume of product sales.

Prospects of production of individual goods, performance of works and provision of services. As a result of the crisis in the metallurgical industry and the pandemic due to COVID-19, there was a slowdown in global production flows, including a drop in the production and consumption of steel products in most countries of the world. The decrease in demand for metallurgical products in general and partial shutdowns of metallurgical plants led to the fact that the consumption of carbon graphite products in world markets is also falling. Graphite electrodes of various brands remain one of the main types of products produced by the enterprise. The share of sales of graphite electrodes from the total volume of sales in monetary terms is about 57%. The gradual modernization of the equipment to improve the quality characteristics of carbon graphite products made it possible to manufacture competitive products on the world market. As a result, about 69% of the sales volume was aimed at the foreign market, in the countries of the CIS, Western and Central Europe, America, the Near and Middle East, and Africa.

The years 2020 - 2022 can be characterized as a period with many risk indicators. The COVID-19 pandemic and full-scale war increased the instability of the economic and political situation, led to higher inflation rates, fluctuations of the national currency in relation to major foreign currencies, etc. There are main risks in the company's activities:

• the risk of economic and political instability;

• strong competition and instability of demand in the metallurgical industry, as well as the shutdown of many manufacturers of electrical steel;

• intensification of price competition due to a drop in demand on the carbon graphite products market.

Despite the existing uncertainty associated with the change in the economic situation and pessimistic forecasts of the development of the world and national economy during this period, the company plans to continue its activities on an uninterrupted basis. The primary issues for maintaining the competitive status of PrJSC "Ukrgraphite" on the market are:

• in production – balanced production of all types of carbon graphite products, constant work on resource conservation and reduction of specific costs per unit of production;

• in production technology – development and improvement of production technology, development of new types of products;

• in the sale of products – the stability of product quality, and ensuring the necessary level of consumer value of products;

• in the work on the market – an active marketing policy aimed at preserving each existing consumer and attracting new ones, due to a stable image and a careful attitude to each consumer enterprise.

Conclusion and perspective of future investigations. In today's world, it is of particular importance to study the possibility of managing the generation of chaos, the behavior of complex nonlinear systems, and the manifestation of instability. During the application of this theory, the system is artificially transferred to a state of chaos. Controlled chaos is the main element of building out of chaos the starting point of a new attractor, the transition to a new state of order. Thus, the implementation of the strategy of controlled chaos, which is based on chaos engineering, involves a certain "chaosification" of the system in a controlled manner, which will allow predicting possible disturbances and preparing the system for transition to a new development trajectory at the optimal time with minimal losses.

The intensification of price competition, the shutdown of many manufacturers of electrical steel in the world at the end of 2019 and in 2020, led to a reduction in the capacity of foreign sales markets for PrJSC "Ukrgraphite", put at risk the loss of a part of external suppliers of raw materials due to a reduction in the volume of its purchases, forced the management of the company to form a new sales policy in the market of graphite electrodes in the conditions of a sharp drop in demand in the market of carbon graphite products in the world. The main strategic goals of PrJSC "Ukrgraphite" are now to ensure uninterrupted production; providing consumers of metallurgical industries with high-quality carbon graphite products, taking into account various assortment product lines; development and implementation of innovative production technologies and new products taking into account prospective market needs; continuation of the implementation of energy-saving technologies and modernization of the enterprise in order to increase the competitiveness of the enterprise. Therefore, the practical application of the elements of the theory of catastrophes allows to evaluate the possible changes in the sustainability of the enterprise development under the influence of the determining evaluation criteria, as well as to identify the main positive directions of changes in indicators to increase the sustainability of the enterprise in conditions of uncertainty. But the sustainable development of the enterprise today does not guarantee the absence of catastrophes tomorrow. Any minor influence of the external environment can cause the enterprise to lose its equilibrium state.

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Стаття надійшла до редакції 01 грудня 2022 року