The study of the applicability of catastrophe theory in predicting the systemic risks of managing the digital economy and Internet of things systems

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Abstract. The article discusses the applicability of the theory of disasters and nonlinear dynamics in predicting the systemic risks of managing the digital economy and Internet of things systems. One of the approaches may be modeling of nonlinear processes based on the use of the concepts of catastrophe theory. Studies have shown a key indicator of such modeling is to determine the essential features of the disaster. The study showed that the widely used models of the economic processes of the digital economy, as well as the software and technical components of the internet of things, can be transformed into the canonical equation of «assembly», which subsequently leads to the emergence of such an area in the space of phase development variables in which jumps can occur or for the better, or vice versa, such as a collapse. Currently, in the digital economy, the study of such phenomena seems to be very relevant, since an uncontrolled «spasmodic» change in the functioning parameters of such systems can lead to disastrous consequences for the functioning of all interconnected subsystems. The collapse or unstable behavior of one of the components of such systems can lead to the collapse of the entire system. Such phenomena are not allowed in the digital economy and can trigger not only economic consequences, but also social ones.

Keywords: Digital economy, Internet of things, forecasting, catastrophe theory

1. Introduction
The effective functioning of the economy has become dependent on the digital environment so research subject is topical. At the same time more and more noticeable the growing number of uncertainties inherent in the digital space. Digital threats have become wider, which often leads to significant financial, reputational, time costs [1].

As you know, during the implementation and functioning of software and hardware environments that support the work of the entire digital economy, there are three key problematic issues, the study of the behavior and reactions of which using the theory of disasters and nonlinear dynamics can be considered fundamentally significant [2]:
1. Issues related to the information security function of all of the digital economy.
2. Problems of data transmission and processing of large volumes of unsystematized information.
3. Problems of electric power safety and the stability of the functioning of technical systems of the
digital economy [3].

These issues of the functioning of the digital economy are interrelated, and failures and critical
changes that can be described, analyzed and modeled using catastrophe theory relate to the systemic
risks of the functioning of the entire digital economy.

Also, systemic risks should include both fundamentally economic changes in the rules for the
functioning of the elements of the digital economy, as well as software and technical risks, in particular
those related to both data transfer systems and the problems of protecting information and organizing
external attacks on such systems.

In any economic system, and even more so, based on software and hardware systems, which are
influenced by various factors, not only smooth, but also abrupt, spasmodic changes occur. The modern
digital economy is a complex system, the sudden changes of which are also difficult to analyze and
predict. As you know, "disasters" in mathematics are called abrupt changes that occur in the form of a
sudden response of the system to a smooth change in external conditions. If we consider the complex
elements of the digital economy as the system under study, it should be noted that its elements are not
only new economic relations between entities, but also many complex information technology
environments and realizations that, in the aggregate of multifactorial elements of such systems, may be
subject to unpredictable and drastic «catastrophic» changes.

Recent studies have shown that traditional forecasting methods are not applicable to real-life
problems of the digital economy, such as forecasting system overloads, predicting the appearance of
atypical «anomalies» in the operation of controlled systems, etc. In this connection, the study of the
applicability of catastrophe theory and methods of nonlinear dynamics in the above questions is an
urgent scientific problem of a fundamental nature. As a result of the work, algorithms and models will
be obtained that describe and predict the behavior of complex systems, in particular the digital economy.
Mechanisms have been developed for early prediction of the phenomena of the digital economy,
which can lead to "catastrophic" consequences of the entire system.

2. Informal statement of the problem

The aim of the study is to investigate the possibility of using models of catastrophe theory and
nonlinear dynamics to predict the systemic risk management of the digital economy, including systems
based on Internet of Things technologies. In particular, basic research is aimed at solving interrelated
issues that allow the entire system to function effectively. These are issues of integrated information
security and the study using catastrophe theory models of the predictability of instability as a result of
hacker attacks, system hacks, etc. The study of these issues will allow not only to assess the impact and
consequences of such attacks in time, but also during the development process, specific software and
hardware solutions based on a system of residual classes will be proposed, the construction of new
information protection systems that increase the stability of these systems to similar influences. These
are issues related to the problems of data transmission and processing of large volumes of
unsystematized information, and related problems of sharply increasing volumes of unsystematized
information. These are issues related to the problems of electric power safety and the stability of the
functioning of technical systems of the digital economy.

The proposed project of fundamental scientific research is based on the hypothesis that methods
based on the theory of disasters and nonlinear dynamics will increase the predictability of the behavior
of both individual elements of the digital economy, as well as its behavior and functioning as a whole.
The study of catastrophe models in the tasks of predicting the behavior of elements or complex systems
of the digital economy will allow us to «struggle» with the instability of such systems, as well as predict
unstable behavior and, in the event such systems transition to such a state, quickly localize the
consequences caused by such phenomena.

To achieve the goal of basic research, the following tasks are solved in the work:
• identify the main conceptual approaches to the study of the applicability of catastrophe theory and nonlinear dynamics to predict the behaviour of interconnected systems of the digital economy;
• determine the functional content of the application of catastrophe theory in economics and software and hardware systems;
• formulate the basic laws of the emergence of disasters and the predictability of their occurrences in digital economy systems;
• analyze the qualitative and quantitative certainty of the sustainability of the functioning and development of the digital economy and its elements;
• study the conditions and factors of increasing the sustainability levels of the digital economy and its system elements;
• conduct a comprehensive study of disaster models in the applicability of this theory in economic systems, in particular in digital economy systems;
• develop a methodology for interpreting disaster flags, which are indirect signs by which one can judge the possibility or presence of a disaster in the system;
• develop recommendations on the application of forecasting methods based on the theory of disasters and nonlinear dynamics;
• to ensure the stability of encryption algorithms and the security of information processes in the digital economy system, justify the use of the system of residual classes;
• study of the effectiveness of the proposed methods using simulation processes.

The solution of the tasks set in the work will make it possible in the future to obtain a scientific and technical reserve for the further implementation of the application of the theory of disasters and nonlinear dynamics in the tasks of predicting the behavior of systems in the digital economy.

The research being carried out is part of the direction of the Strategy for Scientific and Technological Development of the Russian Federation, namely, the transition to advanced digital, intelligent manufacturing technologies, robotic systems, new materials and design methods, the creation of systems for processing large amounts of data, machine learning and artificial intelligence.

3. Analysis of the current state of research in this field

The application of catastrophe theory and nonlinear dynamics in forecasting problems has not been practically studied, since for the economic and production systems the application of these theories is difficult for several reasons. One of these reasons is the difficult formalizability of factors affecting the behavior of such systems and the lack of sophistication in the theory of disasters, the definition of disaster flags.

In the 80s. there has been a leap in the development of catastrophe theory. Many different works on its study and application to various systems are published. An example is the work of such authors as A.V. Gaponova-Grekhova and M.I. Rabinovich «Nonlinear waves. Structures and bifurcations» (Gaponov-Grekhov, 1987), «Nonlinear waves. Dynamics and evolution»; G. Zaslavsky and R. Sagdeev «Introduction to nonlinear physics. From the pendulum to turbulence and chaos» (Zaslavsky, Sagdeev, 1998); R. Gilmore «Applied Theory of Disasters» (Gilmore, 1988).

In modern foreign science, economic security is studied in the context of two independent trends: catastrophe theory (I. Ziman, T. Oliva, E. Laszlo, G. Kolata, I. Casetti, etc.) and risk theory (R. Dembo, R. Keske, J. Clark, C. Arrow and others). However, there is a small number of works in which the authors directly examine the problem of interest to us (A. Westing, V. Kable, W. Albrecht) [4–7].

A fundamentally different approach to the study of the nature and specificity of the stability of economic systems, in our opinion, is possible on the methodological achievements of the natural and technical sciences in the field of self-organization (I. Prigogine, G. Haken) and the general theory of systems (R. Akoff, JI. Bertalanfi, I Blauberg, J. Clough). In this aspect, we note the evolution of methodology in economic research, the transition to interdisciplinary and system analysis in the works of domestic scientists - N. Moiseev, I. Shurgalina, V. Vasilkova, L. Evstigneeva and others.
It must be emphasized that questions on the topic under study, domestic scientists began to pay attention only in the early 90's in the face of a radical transformation of the socio-economic foundations of the country's life.

Despite the presence of significant research and fundamental approaches to the disclosure of the scientific problems posed in the draft, there is currently no single methodology for applying the theory of disasters and nonlinear dynamics in forecasting economic systems.

Several works can be distinguished from the works that are presented in the Web of Science database on the topic of research. For example, the following [8,9]. However, these works show one of the approaches, as a rule, highly specialized is applicable to one of the economic sectors of the financial market.

An analysis of the work of other authors, both Russian and foreign, allows us to conclude that there is no single integrated methodology for using the theory of disasters in economics. The practical application of catastrophe theory is usually of a private nature and it is not possible to apply the results of research for other economic or technical systems [10,11]. In this connection, the choice of the topic of our fundamental research was justified.

4. Scientific novelty of the studied subject
A fundamental scientific problem is the creation of a system reaction model (digital economy) and the prediction of systemic risk using the methods of catastrophe theory and nonlinear systems [12]. The applicability of such systems is possible in such components of the digital economy as the development of models of interaction in the Internet of things, in decision-making tasks in the smart city or smart home system. Scientific novelty consists in the development of a comprehensive methodology for applying the theory of disasters and nonlinear dynamics for the fundamental problems indicated above.

Among the sources of the fundamental problems of the digital economy are the following:
1. «Hacking» of systems (unauthorized access to data, or specialized attacks that provoke the system to exit the established (stable) mode of operation;
2. Poorly protected IoT devices can become entry points for cyber attacks, giving attackers the opportunity to reprogram the device or fail, devices that do not work correctly also create security vulnerabilities;
3. Problems of collecting unsystematized data, inadequate processing of such Big Data;
4. Control or regulation systems built 20, 30, or even 40 years ago transmit data in different formats, and no one will change the infrastructure of industrial control systems, including sensors, as this entails high capital costs;
5. The intensive exchange and use of large data streams reduce the confidentiality of the information used and contribute to the creation of a number of digital threats.

To conduct basic scientific research, the following research methods will be applied in the work:
1. Mathematical modeling.
2. The study of models of catastrophe theory and nonlinear dynamics in the formulated problems
3. The study of the possibility of increasing the security of the system using the system of residual classes.
4. Based on the results of simulation modeling, it is supposed to verify the adequacy of the proposed models and methods and, if necessary, to adjust them.

The main task of the economic system is optimization, i.e. maximizing the profit function or minimizing the cost function [13,14]. However, as our studies have shown, for managing the components of the digital economy, in particular technical or software, standard management methods can be used, but based on neural network management and the use of residual class systems.

The key expected results that are of practical importance include the following:
1. Development of a comprehensive methodology for the application of catastrophe theory in the tasks of predicting the behavior of digital economy systems.
2. To increase the security of these systems and eliminate factors that can lead to "catastrophic" consequences, a system of residual classes will be applied.

3. Systematization of the methods obtained as a result of research for their further application in science.

4. Identification of the main conceptual approaches to the study of the applicability of catastrophe theory and nonlinear dynamics for predicting the behavior of interconnected systems of the digital economy.

5. Determination of the functional content of the application of catastrophe theory in economics and software and hardware systems [15].

6. The formulation of the basic laws of occurrence of accidents and the predictability of their appearances in the digital economy systems.

7. Analysis of the qualitative and quantitative certainty of the sustainability of the functioning and development of the digital economy and its elements.

8. The study of the conditions and factors for increasing the sustainability levels of the digital economy and its system elements [16].

5. Conclusion

In any system, including the economic one, on which various factors act, not only smooth, but also abrupt, spasmodic changes occur. For the digital economy or technology of the Internet of things, any critical impact that could lead to a sharp change in all system parameters is not acceptable. The key to sustainable development of any system, and even more so having social significance, is the control of the behaviour of such systems. Therefore, forecasting and preventing sudden changes in such systems, which can lead to uncontrolled «folding» of such systems, is an extremely urgent task. As noted above, one of the approaches to effectively forecast and predict the future behaviour of such systems is the application of catastrophe theory.

To solve the tasks set, it is necessary to perform a number of key actions or steps. To identify the main conceptual approaches to the study of the applicability of catastrophe theory and nonlinear dynamics for predicting the behavior of interconnected systems of the digital economy. Determine the functional content of the application of catastrophe theory in economics and software and hardware systems. It is necessary to clearly formulate the basic laws of occurrence of accidents and the predictability of their appearances in the digital economy systems [17].

It is necessary to analyze the qualitative and quantitative certainty of the sustainability of the functioning and development of the digital economy and its elements. Including studying the conditions and factors for increasing the sustainability levels of the digital economy and its system elements.

It is necessary to conduct a comprehensive study of models of the theory of disasters and nonlinear dynamics to predict the systemic risks of managing the digital economy. Based on the analysis, to develop methods for interpreting disaster flags, which are indirect signs by which to judge the possibility or presence of a disaster in the system. To develop recommendations on the application of forecasting methods based on the theory of disasters and nonlinear dynamics.

A completely new approach to ensure the stability of encryption algorithms and the security of information processes in the digital economy system is proposed to justify the use of the system of residual classes. Conduct a study of the effectiveness of the proposed methods using simulation processes.

The solution of the tasks set in the study will allow in the future to obtain scientific and technical groundwork for further implementation of the application of the theory of catastrophes and nonlinear dynamics in the problems of predicting the behavior of systems in the digital economy.

References

[1] Răzvan Şerbu 2019 Several Contemporary Economy Features, Consequences of Internet Expansion and I.C.T. Innovations in the World Stud. Bus. Econ. 14 pp 175–81.

[2] Scott R C and Sattler E L 1983 Catastrophe Theory in Economics J. Econ. Educ. 14 pp 48.
[3] Tikhonov E E, Chebanov K A and Burlyaeva V A 2019 Improvement of Information Protection and Data Transmission Methods in the Power Industry Using Neural Networks and a System of Residual Classes 2019 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon) 2019 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon) (Vladivostok, Russia: IEEE) pp 1–5.

[4] Zahler R S and Sussmann H J 1977 Claims and accomplishments of applied catastrophe theory Nature 269 pp 759–63.

[5] O’Donovan N 2020 From Knowledge Economy to Automation Anxiety: A Growth Regime in Crisis? New Polit. Econ. 25 pp 248–66.

[6] Zíkeš F, Baruník J and Shenai N 2017 Modeling and forecasting persistent financial durations Econom. Rev. 36 pp 1081–110.

[7] Rosser J B 2007 The rise and fall of catastrophe theory applications in economics: Was the baby thrown out with the bathwater? J. Econ. Dyn. Control 31 pp 3255–80.

[8] Pázsit I, Dykin V, Konno H and Kozłowski T 2020 A possible application of catastrophe theory to boiling water reactor instability Prog. Nucl. Energy 118 pp 103054.

[9] Lin X, Song S, Zhai H, Yuan P and Chen M 2020 Using catastrophe theory to analyze subway fire accidents Int. J. Syst. Assur. Eng. Manag. 11 pp 223–35.

[10] Cobb L and Zacks S 1985 Applications of Catastrophe Theory for Statistical Modeling in the Biosciences J. Am. Stat. Assoc. 80 pp 793–802.

[11] Cazzolli A, Misseroni D and Dal Corso F 2020 Elastica catastrophe machine: theory, design and experiments J. Mech. Phys. Solids 136 pp 103735.

[12] Oliva T A, Desarbo W S, Day D L and Jedidi K 1987 Gemcat: A general multivariate methodology for estimating catastrophe models Behav. Sci. 32 pp 121–37.

[13] Vosvrda M and Barunik J 2008 Stock market crashes modeling: stochastic cusp catastrophe application Polit. Ekon. 56 pp 759–71.

[14] Wagenmakers E-J, Molenaar P C M, Grasman R P P P, Hartelman P A I and van der Maas H L J 2005 Transformation invariant stochastic catastrophe theory Phys. Nonlinear Phenom. 211 pp 263–76.

[15] Cobb L 1981 Parameter estimation for the cusp catastrophe model Behav. Sci. 26 pp 75–8.

[16] El Hilali W, El Manouar A and Janati Idrissi M A 2020 Reaching sustainability during a digital transformation: a PLS approach Int. J. Innov. Sci. 12 pp 52–79.

[17] Kristoufek L and Vosvrda M 2014 Measuring capital market efficiency: long-term memory, fractal dimension and approximate entropy Eur. Phys. J. B 87 pp 162.