Self-Organization and Adaptation of Industrial Economic Systems in Dynamics of Its Entropy-Information Processes

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Abstract. The relevance of the research paper is stipulated by the growing dynamism of economic systems, the severity and turbulence of their environment that induce nonlinear processes with inherent features. Application of views and tools of nonlinear dynamics promotes better understanding of the role and nature of the impact of disturbances and entropy on the functioning and self-organization of economic systems. Nowadays the evolving economy is nonstationary by nature that is the reason of its disequilibrium and instability in disturbed environment.

The theoretical issues of the mutual influence of entropy and information on the process of self-organization of industrial economic systems are considered. The nature and condition of self-organization in economic systems are identified from the standpoint of the entropic and information approaches. The influence of the information factor on the adaptation of the effect and stability of the activity of industrial enterprises in a non-stationary environment using V. Trapeznikov model, which formalizes the connection of indices of entropy, control information and the effect of functioning of the economic systems is discussed. In the future, due to the study of the dynamic properties of the functioning and self-organization of nonlinear industrial economic systems, it becomes possible to analyze the corresponding mathematical equations for the stability of the movements described by them.

1. Introduction

The staggering pace of change in a globalizing world generates flows of institutional and innovative disturbances that test domestic enterprises for viability and encourage development and implementation of self-organization and adaptive management concepts.

The revival of discussions and the growing number of publications on the theoretical and methodological justification, as well as development of the application-oriented apparatus to ensure stability and adaptation of the development of industrial enterprises in the face of the vicissitudes of the turbulent market environment have become the response to the increased demands of economic science and practice.

2. Relevance, scientific importance and review of references

The rapid flow of changes in the environment of economic systems invades the process of their functioning, not only making new opportunities possible, but also creating threats to their stability and progressive development.
Due to such non-stationary background, Russian industrial enterprises have to adapt to assertive disturbance, which cause mayhem of their activities and subject enterprises to quality restructuring as part of their self-organization.

In the view of historical retrospect, the entropic interpretation of the behavior of the system goes back to the pioneer studies of R. Clausius [1], L. Boltzmann [2], J. Gibbs [3], M. Smoluchowski [1] on thermodynamics and statistical physics. Having introduced the concept of entropy into scientific usage, R. Clausius established that in the event of a closed system it remains either unchanged (reversible processes) or increases (irreversible processes). Having applied the probabilistic interpretation to the entropy, L. Boltzmann proved that “every closed system of bodies tends to a definite finite state where the entropy is its maximum” [2, p. 176-177].

Henceforth, the relationship between entropy, organization and the amount of information in the system was investigated in a meticulous way by the classical cyberneticians. “As the amount of information in the system is a measure of the organization of the system, believed N. Wiener, in the same way the entropy of the system is a measure of the disorganization of the system; one is equal to another, taken with the opposite sign” [4, c. 56]. This innovative idea was picked up and successfully developed in their papers by L. von. Bertalanffy [5], S. Beer [6], L. Brillouin [7], C. Shannon [8], W. Ashby [9] and others.

From the perspective of relevance and scientific importance for the development of the concept of corporate management, it is reasonable to increase the adaptive properties of the instruments of its implementation in the space of not only destructive influences, but a powerful process of generation and mastering innovations, that has been the subject of numerous scientific conferences [10, 11, 12] and publications of scientists ([13, 14]).

3. Statement of the problem
The achievement of the objectives of the study involves the implementation of classical and modern opinions on nonlinear and self-organizing systems. Meanwhile, despite a wide range of detailed research on corporate governance, the analytical research tools to study the activities of industrial enterprises in a non-stationary environment and their management against a backdrop of an unpredictable and harsh business environment have not been conceptually developed to the full extent. In this connection, the problem of understanding the nature and argumentation of the prerequisites and nature of self-organization and adaptation of economic systems in a disturbed environment acquires urgency and theoretical significance: to interpret the chaos and order, the mathematical scenarios of self-organization and interpretation of the characteristics of nonlinear processes in industrial economic systems, based on cybernetic ideas on entropy, information and the process of self-organization of systems.

Within the scope of the objectives, the following questions were the subject of research:

1. What impact do entropy and information produce on the process of self-organization of the system?
2. How do nonlinear processes occur in industrial economic systems in a non-stationary environment, what are their distinguishing features?
3. What is the impact of the information factor on the functioning and effect of industrial enterprises and their stability and adaptation in a dynamic environment?

Theoretical concepts and methods of thermodynamics, statistical physics, information and catastrophe theories, synergetics form the scientific basis for studying the behavior and self-organization of industrial economic systems in nonlinear disturbed environments.

4. Entropy, chaos and information in the economic system
It is known that according to J. Gibbs, the supply of energy to the system is the condition of a decrease in entropy in it, because it resists the growth of chaos in the system. Meanwhile Gibbs' understanding of entropy resulted as the argumentation of its influence on the structural order of the system. One of the creators of quantum mechanics, E. Schrödinger [15] noticed penetratingly that the entropy used
with a negative sign is a measure of order, so the escalating of negative entropy (called negentropy) is a mean of restraining and weakening chaos that can cause the destruction of the system.

When applying to the economic system, we know that it is possible to reduce entropy and "restore order" in the system by entering instruction data to produce a coordinating effect on its subsystems (elements) and prescribes cooperative behavior to them. Along with the increase in the volume of instruction data having been entered into the economic system, the coherence and structural order of the functioning increases due to the fact that the mismatch in the actions of personnel is eliminated, unforeseen breaks are reduced as well as the loss of resources and, as a result, the efficiency of their use increases.

In the 60s of the last century, academician V.A. Trapeznikov justified the exponential relationship between entropy and the disorder of the system that became an important step in promoting the entropy paradigm [16]. From the standpoint of statistical physics, he showed that the relationship between entropy $H$ and disorder $B$ is as follows:

$$ \frac{B}{B_0} = e^{\frac{(H_0 - H)}{a}} , $$

and taking into account that $H_0 - H = I$

Is entered into the system data $I$, we get [16, c. 6]:

$$ \frac{B}{B_0} = e^{\frac{-I}{a}} , $$

where $B_0$ – disorder of the system at the initial state,

$H_0$ – entropy of the system at the initial state,

$a$ – constant.

Random nature of system $B$ is characterized by the number of its possible microstates, and the amount of information $I$ is equivalent to the value of the captured entropy and interpreted probabilistically.

According to V.A. Trapeznikov, some of the information is embodied in the objects of labor, the other part is accumulated in the form of knowledge; at last, part is spent in the process of labor to prevent disorder, that is quite in tune with the approach we outline. In an industrial economic system, the information is not only entered in the course of management and circulates in the form of decisions and reports, but also materializes in the objects and means of labor in the form of knowledge embodied in them.

5. The entropic condition of self-organization of the industrial economic system

Cognition and interpretation of synergetic qualities in their functioning are valued not only theoretically, but also practically while understanding and designing a system to manage the stability of industry enterprises in a disturbed business environment [17].

In the search for an order measure in the system, H. Foerster logically suggested that "relative entropy" can be used, an expression for determining redundancy [18], which he borrowed from the founder of information theory C. Shannon [8]

$$ R = 1 - \frac{H}{H_m} , \quad (1) $$

where $H$ – entropy of the source of information,

$H_m$ – maximum possible entropy of the source of information.
Since self-organization of the system implies an increase in its order, the rate of change of the indicator $R$ should be positive:

$$\frac{dR}{dt} > 0$$

and, taking into account formula (1), we have the inequality

$$\frac{dR}{dt} = -\frac{H_m \frac{dH}{dt} - H \frac{dH_m}{dt}}{H^2_m} > 0$$

(2)

Further, taking into account that the denominator of the fraction is always positive ($H^2_m > 0$), we come to the assumption of expression of the equation (2)

$$H \frac{dH_m}{dt} > H_m \frac{dH}{dt}$$

(3)

Thus, compliance with this formula means that, the process of self-organization occurs in the observed system, and therefore disorder of its behavior is reduced, while the order increases. First of all, we note that since the entropy in the system cannot exceed its maximum value ($H \leq H_m$), compliance with assumption (3) causes the necessity to keep inequality $dH_m > dH$. In other words, the self-organization of the system assumes that the differential of entropy $dH$ in this case is inferior to the differential of the maximum possible entropy $dH_m$ that indicates a relative increase in order in the system.

Taking into consideration the analysis of H. Foerster [18], a number of conclusions can be formulated.

First of all, we are talking about two particular cases of constancy of the quantities of this inequality.

1. Let the maximum entropy of the system remains constant ($H_m = \text{const}$). In view of this, derivative $\frac{dH_m}{dt} = 0$, therefore for the right-hand fraction of inequality (3) we obtain assumption $\frac{dH}{dt} < 0$. The result is the most understandable and expected: for a fixed value of the maximum entropy, the self-organization of the system is accompanied by a decrease in entropy, i.e. increasing order in its behavior. Being affected by the process of self-organization, the industrial economic system improves the coordination and consistency of its subsystems (elements) due to the saturation of their actions and interactions with instruction data that drives out entropy (and with it disorder) from the system and improves its adaptation.

2. Now we assume that the entropy of the system is constant ($H = \text{const}$) and that is why its derivative $\frac{dH}{dt} = 0$. In view of this, the right-hand side of the inequality (3) also become zero, and in such case we find out the assumption of the positive rate of change of the derivative $\frac{dH_m}{dt} > 0$. The resulting conclusion is less obvious, but it is quite expected for self-organization and adaptation of the system: despite the potentially possible increase in the maximum entropy $H_m$, it keeps the current value of entropy $H$ at the same level. This manifests the stabilizing effect of the regulatory function in economic systems, which, contrary to the pressure on it of assertive disturbances and their desire to strengthen chaotization in the system, preserves the entropy and order in it constant. In this sense, it is also important that developing an industrial economic system (for example, an enterprise) by adding new links to it may entail a weakening of the functions of managing an expanding system, and therefore additional measures should be taken to streamline its functioning or, in our terminology, to maintain its entropy constant, but at the same time, the adaptive abilities of the system also increase.

The general case where the variation of the quantities of both entropies is accepted in the inequality (3) is of interest.
First, this inequality establishes the universal property of self-organizing systems, not requiring marginal (threshold) entropy values, but obliging to observe inequality (3).

Secondly, the coordinated change in indicators is not excluded. Thus, for the left-hand side of the inequality, we can state the following: if the current value of entropy $H$ is sufficiently large, the growth rate $\frac{dH_m}{dt}$ can be reduced at the supplied by the assumption level (3). Such a conclusion is well explained by the conceptual view of achieving self-organization of the system: if the value of entropy is sufficiently large, the requirement to increase the potential maximum entropy $H_m$ is softened. Conversely, when the rate of change of the latter increases, the value of entropy $H$ may "not rush". For example, I would refer to the degradation of the industrial economic system, when the behavior of its subsystems becomes disorderly and threatening its adaptability and integrity, the desire to curb further chaos of the functioning of the system with the help of instruction data is obvious.

Similar arguments can be given for the right side of inequality (3). For the process of self-organization of the system, the situation is favorable when the maximum possible entropy $H_m$ does not tend to increase, and the growth rate of entropy $\frac{dH}{dt}$ also remains moderate. Along with this, if there is a decrease in one of these factors, the other "has the right" to grow within the assumption (3). For example, in a highly randomized industrial economic system, it is advisable to reduce the current entropy by entering instruction data into the system, as a result of which the orderliness of its behavior and adaptability increases.

6. Non-linearity and information factor to ensure the effect and stability of the developing industrial economic system

According to I. Prigogine's well-known concept [19], order is formed with chaos in a nonequilibrium system. In the course of this process, the energy of the system is dissipated and a so-called dissipative structure arises spontaneously in it, signifying a decrease in energy in the system and an increase in its entropy. Meanwhile, in nonequilibrium media, energy losses are compensated by inflow from outside, due to which the self-organization of the system takes place. The fundamental condition for such a process is the transfer of the system to a state of disequilibrium, which is achievable only if it exchanges material-energy or information flows with its environment and is sensitive to external disturbances. In this case, due to the nonlinearity of the proceeding processes, small external disturbances can multiply many times and generate large-scale (at times, catastrophic) rearrangements in the system.

It is obvious to us that the adaptive development of the system relies on the extraction of information from the environment and its use to adapt the system to recorded external disturbances. In the course of this information process, the system assesses the nature and level of penetrating interference and the consequences of their action on its behavior. Based on the results of the analysis, the system makes a decision aimed at neutralizing or reducing the negative impact of disturbances on the motion of the industrial system along the target trajectory.

In statistical interpretation, the dependence of the effect $\mathcal{E}$ of the functioning of the system on the volume $I$ of entered data is expressed by the suggested by V. A. Trapeznikov formula [16, p. 51]:

$$\frac{\mathcal{E}}{\mathcal{E}_{\text{max}}} = e^{-\frac{I}{I_0}},$$

where $\mathcal{E}_{\text{max}}$ – the effect of an ideally functioning system (the maximum possible effect), $I_0$ – the amount of information typical for a given object of instruction.

As a result, maintenance of stable level of economic effect $\mathcal{E}$ in the field of large values makes the enterprise increase the payback period of its management system, and within the limits of approximating its effect to the maximum $\mathcal{E}_{\text{max}}$, the payback period increases multifoldly. So, while
modernizing the management system in order to increase the effect level $\Theta$ from 0.80 to 0.90 from the maximum $\Theta_{\text{max}}$, the payback period of the improved management system will increase by a factor of 1.71 in comparison with increasing the effect from 0.70 to 0.80 from $\Theta_{\text{max}}$. By continuing increase of the effect level $\Theta$ for the enterprise from 0.90 to 0.95 payback, the period of its management will increase in 2.00 compared with the option of increasing the effect from 0.80 to 0.90 of the maximum $\Theta_{\text{max}}$.

Thus, concluding, we state that in the course of nonlinear dynamics, the behavior of industrial economic systems is characterized by stages of stable and non-stable functioning. Moreover, the synergetic interpretation [20] treats the process of development of the system as predominantly unstable, since the inherent nonlinearity causes a high instability of behavior in the system. As a result, in a turbulent flow of changes, modern industrial economic systems are "doomed" to unstable development with a typical chaotic nature, which reasonably actualizes the problem of optimal management of unstable economic systems [21].

7. Nonlinear dynamics of economic evolution and efficiency of activities of the developing industrial enterprises

In this respect, the paradigm of the theory of catastrophes interprets the evolution of the economic system in a nonstationary medium as a reflection of its motion "along the curve of trajectory." The departure from the position of low productivity to its higher level occurs with the mobilization of all resources of the industrial system and only when it passes through the "point of no return" it is attracted to a stable favorable position by itself.

Taking into account the characteristics of nonlinear processes and the nature of the economic systems' development, let's use qualitative conclusions of the mathematical perestroikas theory that V. Arnold refers to [22]. Given the fact that the restructured economic system (in our case - an enterprise) is nonlinear and is in a "bad" stable-state condition, there are notable stages of its ascending development in order to move to a better stable-state condition. A visual representation of these stages is given in Fig., which allows us to use the following notation: $P_1$ - the level of entrepreneurship and $P_2$ - the level of economic efficiency of the system.

![Image](image1.png)

**Figure 1.** Restructuring of the economic system from the perestroikas theory standpoint (by V. Arnold).

We characterize the stages of restructuring of the economic system, marked in Fig. on the abscissa axis with figures 1 to 7:

- Stage 1. Being in a stable inefficient state, the enterprise has great difficulties in overcoming the resistance of the current organization of production and management, and begins to move to a higher level of economic efficiency of its operations;

- Stage 2. The enterprise's movement gathers head, but the action of conservative forces of its economic system (outdated infrastructure, lack of investments, the inertia of the company's management style, etc.) gains strength and the level of economic efficiency of the enterprise is markedly reduced;
Stage 3. The enterprise’s movement rate increases even further, but the influence of conservative forces of its economic system still affects it and even reaches its maximum; as a result, the level of economic efficiency of the enterprise continues to decrease;

Stage 4. Before the level of economic efficiency of the enterprise becomes minimal, the resistance of its economic system turns weak, and after its complete disappearance, gives way to the positive scenario (upgrading and increasing the flexibility of the equipment, the introduction of high-tech industries, etc.) of the enterprise resource development.

Stage 5. Inertia of deterioration of indices for the enterprise’s economic efficiency ceases, they are at the lowest level; the trajectory of movement is at its pivot point; and when the positive forces start prevailing, the level of the enterprise’s economic efficiency starts rising;

Stage 6. The movement ("pulling") towards a better, stable state gathers head; capital improvements ensure a rapid growth of economic efficiency and a progressive development of the enterprise;

Stage 7. The enterprise movement trajectory shows that its “climbing” to the peak of economic efficiency comes to its end; thereby the enterprise gains a stable state that differs from the initial state in its higher efficiency.

From the perestroikas theory standpoint, a less-developed industrial economic system gathers a better stable state, yielding lower losses than a developed one. The stability of the developed system runs it into additional trouble of gaining a stable efficient state. Moreover, if a jump, not a continuous transition, to a new, better stable state would be possible, then, when approaching it, the industrial system would evolve ("gravitate") to it by itself.

8. Practical relevance
In practical terms, the study is relevant because it focuses on solving the problems of studying the dynamics and properties of the functioning and self-organization of nonlinear industrial economic systems, taking into consideration the influence of a wide range of internal and external factors. Computer experiments make it possible to verify the hypotheses put forward by mathematical modeling of the behavior of systems along with the analysis of the corresponding equations for stability and the conditions for its loss and recovery, that is of interest from the point of view of crisis management of industrial enterprises. By means of these studies, it will be possible to enrich the theory and application-oriented toolkit of research on the stability and adaptation of industrial economic systems and the successful overcoming of destructive processes in a non-stationary environment to prevent bankruptcies of enterprises.

9. Conclusion
Due to the powerful influence of global and national institutional and innovation factors, the current environment of industrial economic systems is experiencing too much disturbances that affect their behavior and can frustrate their mode of functioning. In particular, the risk of chaotizing and weakening the stability and adaptability of their activities increases, the competitiveness and degradation of industrial enterprises are decreasing. Therefore, the objective to investigate the features of their functioning, which becomes nonlinear with sudden changes; slow and fast, smooth and sharp phases of motion, acquires the topicality and theoretical significance.

In the context of the entropy approach to the development of the system, a dynamic "game" of chaos and order takes place in it, the consequence of which, under certain conditions, can be defined as the self-organization of the system. In continuation of the study of its nature and features, the exponential dependence of the effect of the functioning of the industrial economic system on the amount of entered instruction data becomes obvious. Along with it, the interpretation of the evolution of the industrial economic system from the point of view of catastrophe theory makes it possible to analyze the process of its transition from a low-productivity state to a higher level in a nonstationary medium saturated with disturbances environment.
10. References

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