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Natural-Scientific Interpretation and Assessment of Orderliness, Effect and Perfection of the Industrial System Management

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Abstract: The information dynamics of the effect of the functioning of the industrial system from the standpoint of macroscopic principles is interpreted, which, in accordance with the natural scientific teachings on thermodynamics and statistical physics, introduce the concept of entropy to characterize the chaotic behavior of the system. The modernization of the model of V.A. Trapeznikov provides a substantiation of the influence of entropy and ordering on the dynamics of this effect of the functioning of the system and the level of perfection of management, taking into account the control information accumulated in the system. The conclusions of the proposed study were formulated in the context of the exponential dependence of the mentioned effect of the industrial system from the number of control information received by it..

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1 INTRODUCTION

The symbiosis of natural-scientific and economic knowledge in the arsenal of the study opens up the prospect of attracting views and principles of physical teachings for understanding and analyzing the phenomena of the functioning of the industrial system. Subject to random influences of its environment, it as a macroscopic system detects to one degree or another spontaneous, arbitrary behavior displayed according to the canons of thermodynamics and statistical physics of various means of chaotization and order. For economic structures and, in particular, industrial systems to block the growth of chaos and turn its growth as it is possible to introduce control information and establishing interactions and coordination in a system that reduces the degree of its disorders. On this basis, the conditions for targeted collective work, more complete use of resources, increase the productivity of the industrial system and thereby positive dynamics of the effect of its functioning are improved. The purpose of the study is the meaningful and formalized argumentation from the angle of view of the macroscopic theory of the features of the influence of entropy and the order of behavior of the industrial system and the control information introduced into the dynamics of the effect of work and level of perfection of management of the system. It is carried out on the basis of the proposed modernization of the V.A. Trapeznikov model of the statistical dependence of the effect of work of the system on the number of managing information received by it. It is carried out on the basis of the proposed modernization of the V.A. Trapeznikov model of the statistical dependence of the effect of work of the industrial system on the number of control information received by it.

2 MATERIALS AND METHODS

The achievement of the formulated goal of the study is based on the symbiosis of natural-scientific and economic teachings, in particular, thermodynamics and statistical physics, cybernetics, the theory of information, organization and self-organization, economics and management of enterprises. Thanks to the attraction of their classical and latest developments, it becomes possible to disclose, interpret and use to management the patterns of the behavior of chaosized industrial systems in the disturbed economic space.

3 RESULTS AND DISCUSSION

With the development and application of natural-scientific teachings on thermodynamics and statistical physics, experts gained unique theoretical and methodological tools and, through its use in economic studies, enrich their knowledge about the structure and laws of the behavior of industrial systems. It is legitimate to expect that understanding from the standpoint of fundamental postulates of a number of prevailing ideas about the order, stability and effect of the functioning of these systems significantly expands the views about them from the view of the phenomena of chaotization and information exchange of systems with their business environment.

Strictly speaking, fundamental studies in thermodynamics are devoted to the properties of macroscopic (consisting of a very large number of identical particles) physical systems that are in a state of thermodynamic equilibrium, and the processes of the transition between them, and statistical physics - the substantiation of the laws of thermodynamics and their connection with the laws of the movement of individual particles and interactions between them in such systems (Prokhorov, 1983, p. 719, 750).

A significant contribution to physical science is the classical research of R. Clausius, L. Boltzmann, J. Gibbs, M. Smoluchowski introduced the doctrine of entropy and statistical behavior of the macro-system within the framework of the thermodynamics and statistical physics created by them.

It is noteworthy that a universal entropic approach to the study of the functioning of dynamic systems has gained recognition among scientists engaged in the study of the laws of behavior of systems of different nature. In particular, the dependence between the entropy, organization and the amount of information in the system was scrupulously investigated in the writings on the theory of systems and cybernetics L. von Bertalanffy, N. Wiener, S. Beer, L. Brillouin, C. Shannon, W. Ashby, etc.

Meanwhile, the universality of these scientific postulates about the structure and behavior of multi-element systems prompted the transfer of classical ideas from the sections of physics to the sphere of economic applications. In the theory of management

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of economic systems, entropy is the disorders of their behavior, expressing the degree of information support of the system management technology.

In the focus of research, a wide range of problematic issues of the entropy nature of the information processes of corporate management (Qixin, Yajing, 2024), the entropy model of assessing the degree of ordering of the system management structure (Xiang, Tie, Bing, 2013), design conditions and factors of the information quality, system quality and analysis quality in self-service business intelligence (Al-Dwairi, Daradkeh, 2017). The study of the influence of the factors is considered relevant and applicable for the management of enterprises (Nour, 2023; Kirmizi, Kocaoglu, 2022; Vargas, Comuzzi, 2019), factors affecting cloud ERP adoption decisions in organizations (Christiansen, Haddara, Langseth, 2022; Shatat, Shatat, 2021), sustainable performance (Gupta, Meissonier, Drave, Roubauda, 2019), for support the decision-making Process (Hustad, Stensholt, 2023). In relation to the theory of management of economic systems, entropy is the disorders of their behavior, expressing the degree of information support for system management technology.

The rapidly developing synergetics demonstrates the constructiveness of its analytical techniques in relation to chaotic processes in nonequilibrium economic systems with changes in their information potential. In such systems, a stable state of equilibrium when merging with an unstable equilibrium position disappears and it makes a jump, which we observe in crisis periods at domestic industrial enterprises. The spread of chaos in them in the absence of the neutralizing influence of useful information undermines the structure and resources of the enterprise and in the end can paralyze its activities. According to V.I. Arnold, with such a chaotic behavior of the enterprise, various restructuring (bifurcation) in its future activities can be expected. The further course of events at the enterprise may proceed rather rapidly, and the resolution of the crisis will have optimistic (restoration of resource potential, and with it equilibrium), or more likely pessimistic (resource depletion and bankruptcy) prospects with degradation of information and management processes (Arnold, 1990).

Another scenario of loss of a stable state of equilibrium suggests two possible options that differ in the phase portrait (state space) of the system. The first is the degeneration of the position of equilibrium in the maximum cycle, i.e. the transition of a state of equilibrium from stable to unstable. The second option consists in dying in a position of equilibrium of an unstable maximum cycle, during which the cycle disappears and after it the equilibrium becomes an unstable character.

In discussing the results of the study, let us touch upon the principles of thermodynamics and statistical physics that are valuable to it:

1. An isolated system eventually reaches a state of equilibrium;

2. The state function of a system is entropy, which in a closed system can only increase and reaches a maximum in a state of equilibrium associated with complete disorder (chaotization) of the industrial system;

3. Entropy has a statistical nature and, taking into account the influence of fluctuations on the system, the thermodynamics of nonequilibrium processes has been developed, which in the economy means the tendency of its systems to states that differ from equilibrium;

4. Information entropy takes on its greatest value when the quantities describing the messages take on the same probability and the uncertainty in the information is maximum;

5. Fluctuations transfer the system from a more probable state to a less probable one, as a result of which the entropy of the system decreases and, similarly, the disorder in economic activity decreases;

6. The dynamics of non-equilibrium processes in an industrial system with a decrease in the disorder of its behavior correlates with the growth of the information resource and organization of this system and, in a statistically expressed increase in the effect of its functioning.

Indeed, it is known that industrial systems surrounded by information space consume, accumulate, transform incoming information and transmit it to the external environment. Moreover, information is entered into the system both directly – data on the environment (demand, inflation, competitors, etc.), and in a transformed form as professional skills and abilities of personnel and embodied in the form of know-how, inventions, etc. in acquired technical means (equipment, apparatus, communications, etc.), components and other supplied resources. Similarly, information transmitted to the external environment is various types of data on the enterprise (accounting documents, advertising, business projects, etc.) and discoveries, patents and other innovations used in the products manufactured or services provided.

The absorbed information enables the industrial system to adapt to rapidly changing conditions of activity (suppliers, consumers, competitors, banks, etc.) and maintain its stability and the effect of activity in a dynamic environment. To do this, the system tends to maintain orderliness and consistency of its actions, which will allow it to resist the influence of aggravating factors and respond to innovative signals from the environment. The latter is achieved in the course of system management, due to which it is possible to localize and suppress emerging interference (interruptions in the supply and movement of materials, blanks, energy and cash flows, forced downtime, product defects, etc.), reduce the chaos of activity and strengthen the competitive position of the enterprise.

Meanwhile, the growth of chaos in the industrial system entails an increase in unpredictability in its behavior, since organizational and technological connections in the system are disrupted and their coordination and orderliness deteriorate. In the language of thermodynamics and statistical physics, an increase in entropy occurs in a system, and the greater the uncertainty of the system's behavior, the higher its entropy, and vice versa, a more certain behavior of a system is equivalent to a decrease in its entropy.

With the advent of the era of innovative economy and its digitalization in the space of permanent global and national disturbances, there is a growing need to understand, in particular, chaotic economic processes (Davydova, Bulgakova, 2024), the essence of digitalization (Silakova, Andronik, Kiselyov, 2024) and digital instrumentalization of enterprise development management complexes (Cherepanova, 2025), etc., supported by organizational, methodological, software, algorithmic and information equipment of effective management mechanisms.

Using the thermodynamic concept of entropy, C. Shannon presented a way to measure the amount of extracted or entered information I between the maximum possible entropy H_m of the information source and its current value H (Shannon, 1948):

$$I = H_m - H, \qquad (1)$$

and the amount of information I shows the eliminated uncertainty assessed by the values of entropy H_m and H.

To analyze the influence of the number of information accumulated in the system, interest is not only a change in its absolute value I, but also relative $\frac{I}{I_0}$ in composure with its size I_0 in the system in the initial state. Assuming that in this state the entropy of the system has an initial value H_0, the use of equality (1) leads to a fraction:

$$\frac{I}{I_0} = \frac{H_m - H}{H_m - H_0},$$

and subsequently to the expression:

$$\frac{I}{I_0} = 1 - \frac{H - H_0}{H_m - H_0}.$$

Obviously, mathematical operations with them confirm logical assumptions: in the initial state of the system, when $H = H_0$, it contains the amount of information $I = I_0$, and with maximum system entropy ($H = H_m$) the information in it is completely «displaced» with total chaotization and therefore its value $I = 0$. In the intermediate case ($H_0 < H < H_m$) the increase in entropy entails a decrease in the amount of information in the system, which clearly follows from the difference (1).

At the same time, in a completely chaotic system in the starting position, when $H_m = H_0$ we get the expected $I = I_0 = 0$, however, if we manage to reduce the H_m, then two options are possible depending on the current entropy $H < H_0$ or $H > H_0$. In the first situation, the information I existing in the system exceeds I_0, in the second we state the amount of information reduced in relation to I_0 the amount of information I.

In order to describe the order in the macroscopic system, H. Förster (Förster, 1960) logically proposed to take advantage of the size of the Shannon measure of relative entropy or redundancy indicated R:

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

and taking into account equality (1) we can write down for the size:

$$R = 1 - \frac{H}{H_m} = \frac{H_m - H}{H_m} = \frac{I}{H_m}. \quad (2)$$

Similarly, this formula can evaluate the measure of order R_0 in the system at the initial point in time, when it contains the initial amount of information I_0.

With reference to the macroscopic approach acad. V.A. Trapeznikov substantiated the statistical dependence of the effect E of the work of the complex on the amount of control information I entered into it (Trapeznikov, 1983):

$$E = E_{\max}\left(1 - B_0 e^{-\frac{I}{I_0}}\right), \quad (3)$$

where $E_{\max}$ is the effect of a perfectly working complex,

B_0 - disorder of the complex in the initial state,

I_0 - the amount of information characteristic of this complex.

The visualization of exponential dependence (3) in relative values for the controlled complex illustrates Fig. 1, on which the effect of work of the industrial system is determined by the number of control information received by it (part i is introduced by the operator, and the Ic is introduced management system).

Taking into account the order assessments R and R_0 (2) in the system, we upgrade the model (3) regarding these measures:

$$E = E_{\max}\left(1 - B_0 e^{-\frac{R}{R_0}}\right), \quad (4)$$

and since the level of perfection of the management Lc of the system V.A. Trapeznikov is determined by the attitude E and $E_{\max}$ (Trapeznikov, 1983, p. 51), for (4) we get equality:

$$Lc = \frac{E}{E_{\max}} = 1 - B_0 e^{-\frac{R}{R_0}} \quad (5)$$

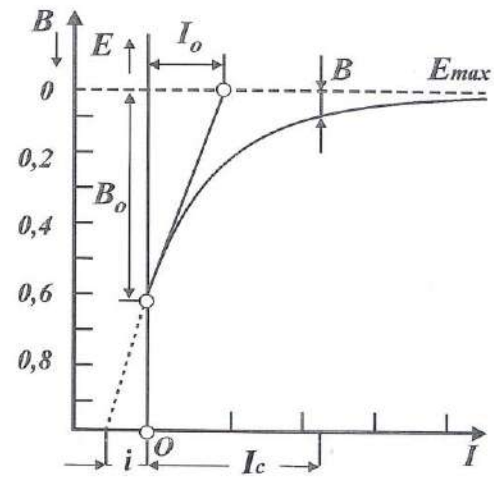

Figure 1: The effect of the functioning of industrial system, depending on the number of control information in its introduced by V.A. Trapeznikov (Trapeznikov, 1983, p. 8).

Finally, with the transformation of this formula, we find a logarithmic expression for the measure of order R:

$$R = R_0 \ln \frac{B_0}{\overline{Lc}}, \quad (6)$$

where $\overline{Lc} = 1 - Lc$ call the level of imperfection of the management of the system.

Omitting mathematical transformations, we present two expressions: the first for the level :

$$\overline{Lc} = B_0 e^{-\frac{I}{I_0}}, \quad (7)$$

and then for the first derivative of the function $\overline{Lc}$ by a variable amount of information I with constant B_0 and I_0 (Chuprov, 2024):

$$\frac{d\overline{Lc}}{dI} = -\frac{B_0}{I_0} e^{-\frac{I}{I_0}} \quad (8)$$

and we point out the conclusions that follow from them:

1. In accordance with equalities (7) and (8) the level of imperfection of the management of the system $\overline{Lc}$ and its increment directly depend on the disorder of the system B_0 in its initial state.

2. According to (7), the level of imperfection of the management of the system $\overline{Lc}$ is directly proportional to the value B_0, whereas according to

(8), the increment of the level is negatively related to B_0.

3. Meanwhile, the negative sign of equality (8) postulates the inherent regularity of the system of a monotonic decrease in the increment of the level of imperfection of the management $\overline{L}c$ with an increase in the amount of control information I in the system and vice versa.

4. The amount of information to the system in its initial state I_0 plays a decreasing role in the increment of the level $\overline{L}c$.

5. Note that from the trigonometry point of view, the coefficient $\frac{B_0}{I_0}$ is the cotangent of the acute angle of a right triangle (Fig. 1): the ratio of the adjacent leg by a segment B_0 to the opposite leg by a length I_0. And as the amount of control information I increases and this angle increases, its cotangent in the analyzed interval decreases, and with it the increment in the level of imperfection of the management $\overline{L}c$ (8).

4 CONCLUSIONS

We summarize the proposed interpretation of the features of the macroscopic order in application to the analysis of the information dynamics of the effect of functioning and the level of perfection of the management of an industrial system:

1. Having the influence of external influences, such a statistical system leaves the equilibrium chaotic regime and goes to a less probable state with an increase in the order of its behavior.

2. According to the exercises on thermodynamics and statistical physics, curbing and reducing entropy with an improvement in the organization of the industrial system is achieved by the entry of control information into it.

3. As the amount of this information increases in the industrial system, the effect of its functioning increases, but it always has a certain disorders of the system behavior (Fig. 1).

4. The exponential nature of the mathematical connection between them (3) states the nonlinear dynamics of the growth of the effect of work of the industrial system: the rate of its increase changes and after the inflection point of the curve (Fig. 1) it falls, and the further it goes, the more.

5. In an effort to achieve ideal order and organization in the behavior of the industrial system, reckless extension of control information in it is turned into a decrease in the additional effect of the functioning of the system, which cannot be ignored when creating and modernizing the technology for managing it.

6. The obtained equality (5) makes it possible to deepen research on the topic of improving the management of an industrial system depending on the ratio of order measures in its initial R_0 and current R state, respectively.

7. An economic and mathematical analysis of the regular change of the latter in their connection with the disorders and level of imperfection of the industrial system is a logarithmic expression (6).

8. Effective management of the industrial system in disturbed environments presupposes skillful control and limitation of the growth of chaos in it, due to which the study of factors and modeling of chaotic systems with the analysis of indicators of perfection (5), imperfection (7), (8) of management of industrial systems acquires theoretical and applied significance.

In a word, the interpretation of the information dynamics of the effect of the functioning of industrial systems and the level of perfection of its management based on the principles of macroscopic theory allows us to build up the analytics of the evolution of these systems and develop tools for adaptive management of them in the disturbed environment of radical changes and the formation of a modern technological order (Chuprov, 2022).

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